

**Mixed-species forest ecosystems
in the Great Lakes region:
A bibliography**

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Introduction

Most of the world's forests are dominated by mixed species stands but until recently, most forest management activities have focused on the development of single-species stands. To maximize fiber production, monoculture plantations were preferred because management and growth and yield prediction were simplified. This model of forest management developed because the primary objective of forest management was to ensure the supply of high quality timber at a minimal cost. Forestry has changed through an increased understanding of forest ecosystems and societal expectations. Mixed-species stands are generally believed to be superior to monocultures in addressing the complexity of current expectations, thus the interest in the ecology and management of mixed-species stands has increased in recent decades.

This annotated bibliography was prepared with the intent of providing researchers, students, private woodland owners, forest resource managers, and policy makers with a summary of the literature on mixed-species management in the Great Lakes region published between 1938 and late 2001. This geographic region in North America is unique in that it encompasses an area where there is an interface of the southern boreal, northern hardwood, central hardwood, and prairie ecosystems.

The bibliography contains 700 citations with abstracts, organized alphabetically by the lead author and assigned a unique reference number. The published works included are primarily refereed journal articles but include dissertations and theses, various government documents, books, proceedings papers. The scope of the works range from very applied to basic science studies.

References were obtained from one of three electronic databases: ISI Web of Science® Science Citation Index, SilverPlatter® TreeCD, and UMI® Digital Dissertations using keyword (e.g. mixed species, northern hardwood, regeneration) or author searches and limiting the scope to the Great Lakes region - roughly Minnesota, Wisconsin, Michigan, and Ontario. Additional references were identified via the "On-Line Bibliography of Northern Hardwood Literature" developed by the Lake States Forest Ecosystem Management Cooperative (LS-FOREM) and Michigan Technological University (<http://forestry.mtu.edu/research/hardwood/>). Full citation information and abstracts were then imported from the various electronic databases into reference manager software (ProCite®) as found in the electronic databases. Some abstracts contain references to a *Forestry Abstracts* volume/entry (e.g. in Alm 1974, "cf. FA 34, 2832").

Two indices have been generated to aid the user in the use of this bibliography: i) author and ii) subject keyword index. The keyword index was generated by including keywords identified by the database(s) but excluding some entries (e.g. mixed forests, Lake States, trees, forests) as they were pertinent to all references in the bibliography. The abstracts of individual articles were used to augment the subject index (e.g. biological and pathological species by Latin name, soils information, mathematical model

types/names, type of regeneration and species involved, wood/foliar chemistry information). The citation and abstract information in all references are intended to provide the reader with research summaries and direct the reader to the original work but not act as a substitute for that work.

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Bibliography

1. **Aber JD, Melillo JM, Nadelhoffer KJ, Pastor J, and Boone RD 1991. Factors controlling nitrogen cycling and nitrogen saturation in northern temperate forest ecosystems. *Ecological Applications* 1: 303-315.**

Keywords: vegetation types/light /water availability/biomass production/biological production/nitrogen cycle/nitrogen saturation /simulation /model - VEGIE

Abstract: An analysis of factors controlling rates of nitrogen cycling in northern temperate forests is presented, based on a quantitative analysis of an extensive data set for forests in Wisconsin and Massachusetts as synthesized in a computer model (VEGIE, vegetation effects on geochemistry in ecosystems) of organic matter and nutrient dynamics. The 'lumped-parameter' model deals with interactions among light, water and nutrient availability in determining transient and equilibrium rates of primary production and nutrient cycling in the ecosystem rather than stems or species.

2. **Abrams MD and Scott ML 1989. Disturbance-mediated accelerated succession in two Michigan forest types. *Forest Science* 35: 42-49.**

Keywords: Conifers /Broadleaves /Plant succession/Vegetation types/logging /ecology /Clear felling/Acer saccharum/Prunus serotina/Thuja occidentalis/Populus tremuloides/Pinus banksiana /Quercus spp. /disturbance /fire

Abstract: In northern lower Michigan, logging accelerated sugar maple (*Acer saccharum*) dominance in a northern white cedar (*Thuja occidentalis*) community, and clear felling and burning quickly converted certain sites dominated by mature jack pine (*Pinus banksiana*) to early successional broadleaves, including *Prunus serotina*, *Populus tremuloides* and *Quercus* spp. In both forest types, the succeeding broadleaves should continue to increase at the expense of the pioneer conifer species. In the cedar community, sugar maple was also increasing in an undisturbed, old-growth stand, but at a much slower rate than in the logged stand. Traditionally, disturbance was thought to set back succession to some earlier stage. These study sites and at least several other North American forest communities, however, exhibited accelerated succession following a wide range of disturbances, including logging, fire, ice storms, wind throw, disease, insect attack and herbicide spraying.

3. **Adams CM and Hutchinson TC 1992. Fine-root growth and chemical composition in declining Central Ontario sugar maple stands. *Canadian Journal of Forest Research* 22: 1489-1503.**

Keywords: broadleaves /forest decline/acid deposition/soil /roots- fine (growth, vigor) /growth /development /chemistry /plant composition/major elements/plant nutrition/fertilizers /phosphorus /soil chemistry/nutrients /Acer saccharum /calcium /magnesium /manganese /iron /aluminum /phosphorus /sulfur /potassium /zinc /root nutrients /leaching

Abstract: The condition of fine-root systems of healthy and declining sugar maples (*Acer saccharum*) was examined in 1986 at 2 sites in central Ontario, one moderately declining and the other severely declining. Roots are frequently sensitive indicators of soil nutrition, and so ingrowth cores (soil transplants) were used to assess the effect of bulk surface (F-layered Ah horizon) soils collected from beneath healthy or declining trees on fine-root chemistry and growth. Soil at each site was collected from beneath healthy and declining trees and reciprocally transplanted (buried) in mesh bags, and roots were allowed to grow into the soil cores for 8 weeks. In addition to transplants of untreated soils, transplants were made of 'healthy' and 'decline' soils treated by either (i) steam sterilization to remove pathogens or (ii) application of 120 g superphosphate/0.02 m³ of soil. Root dry weight of healthy and declining trees was reduced by 25-70% in untreated decline soils compared with healthy soils ($P \leq 0.007$). This was consistent with lower Ca, Mg, Mn, and Fe in the soil solution of declining trees at the severely declining site and a lower Mn concentration and Ca:Al and Mg:Al ratios in the soil solution at the moderately

declining site. Compared with roots of healthy trees, roots of declining trees had significantly lower Ca concentrations for both stands, and significantly lower concentrations of P, Mg, S, K, Mn, Al, Fe, and Zn in the more severely declining stand. The experimental soil transplants established that lower nutrient concentrations in soils from declining trees are reflected in the chemistry of roots growing in them. On the whole, the fertilizer treatment significantly increased root growth; the steam sterilization treatment had no effect on root growth. While this study showed that reduced nutrient availability in the rooting substrate is an important factor in decline, it is not known how recently this nutrient depletion has occurred, nor what is the cause. Although other mechanisms may be involved, reduced nutrient availability in the rooting substrate is consistent with the speculation that deposition of acidic salt solutions of sulfate and nitrate to these forest soils has caused accelerated soil base cation leaching losses that are reflected in nutritional deficiencies and growth decline.

4. **Adams DM 1975. A model of pulpwood production and trade in Wisconsin and the Lake States. *Forest Science* 21: 301-312.**

Keywords: timber trade/pulpwood production/pulp and paper industry/economics /model - econometric /wood products

Abstract: Describes an annual econometric model covering the two sub-regions, Wisconsin (importing) and Michigan/Minnesota (exporting). The model is based on one already noticed [see FA 34, 6536] and also includes explicit treatment of pulpwood flows and market interactions within the region and of inventory [stock]-holding behaviour at pulpmills. The sub-regions differed significantly in their consumption and inventory relations. Projections of regional pulpwood market activity to 1980 were developed.

5. **Adams DM 1976. A note on the interdependence of stand structure and best stocking in a selection forest. *Forest Science* 22: 180-184.**

Keywords: growing stock/stand characteristics/structure /forest management/increment /forest economics/theory

Abstract: A discussion, based on the general theory of Duerr and Bond [cf. FA 13, 3253] and using the example of hardwood stands previously studied in Wisconsin [cf. FA 36, 5066] of how to calculate the optimum economic stocking and diameter distribution. The method proposed depends on the relation of value increment to the value of growing stock. A table of 'value growth maximizing diameter distributions' is given for the example used. Calculations based on value are compared with those based on volume, basal area or number of stems.

6. **Adams DM and Ek AR 1974. Optimizing the management of uneven-aged forest stands. *Canadian Journal of Forest Research* 4: 274-287.**

Keywords: forest management/growing stock/stand characteristics/structure /age structure/ silvicultural conversion/northern hardwoods /model - non-linear

Abstract: Discusses two perennial management problems : (1) determination of the optimum sustainable distribution of trees by diameter class, i.e. stand structure, for a given initial stocking; and (2) choice of the optimum cutting schedule for converting an irregular stand to a new structure. Examples for northern hardwood stands in Wisconsin are used to show that both problems can be solved by mathematical programming techniques; these techniques involve a set of non-linear equation models for stand-table projections which take into account the interdependence of size classes within the stand. The procedures are illustrated by solutions to particular cases of (1) and (2).

7. **Adlard PG and Johnson JA 1983. Biomass estimation, nutrient cycling and organic matter relations in forest stands. Annotated bibliography. Overseas Development Administration Research Project R3738. 855 ref.**

Keywords: bibliographies /biomass production/cycling /forest management/silviculture /nutrients /review

Abstract: A working document prepared as part of the Overseas Development Administration Research Project R3738 (The effects of fast-growing tree crops on long-term site productivity). References are arranged in alphabetical order of author under the following headings: General ecosystem processes [27 ref.]; Biomass data [29 ref.]; Productivity [27 general ref.]; Energy fluxes [3 ref.]; Nutrient cycling [232 ref.]; Moisture relations [26 ref.]; Organic matter relations [56 ref.]; Productivity in relation to climate [29 ref.]; Productivity and soils [60 ref.]; Interactions, competition [27 ref.]; Evidence of site change under forest crops [25 ref.]; Effects of management on tree and stand growth [152 ref.]; and Effects of management primarily on the soil [151 ref.]. Each paper is also classified numerically by up to four subject codes out of a possible 80. An author index is provided. The reference collection is stored on floppy discs and is continually being updated.

8. **Ahlgren CE and Ahlgren IF 1981. Some effects of different forest litters on seed germination and growth. *Canadian Journal of Forest Research* 11: 710-714.**

Keywords: allelopathy /natural regeneration/succession /soil /horizons /forest litter/responses /germination /Thuja occidentalis/Populus tremuloides/Pinus strobus/Pinus banksiana/Pinus resinosa/ Abies balsamea/Picea glauca/Betula papyrifera

Abstract: Germination and growth of 12 herbs, shrubs and trees, including *Pinus banksiana*, *P. resinosa*, *P. strobus*, *Thuja occidentalis* and *Picea glauca* were investigated in soil mixed with litter of *Populus tremuloides*, *Betula papyrifera*, *P. resinosa*, *P. strobus* and *Abies balsamea* (characteristic of successional stages in NE Minnesota forests). A number of significant relationships were found between litter composition and total germination, germination rate and dry wt. Differences appeared to reflect natural habitat preferences. Germination and growth were not always similarly affected, indicating that different factors are involved.

9. **Alban DH, Host GE, Elioff JD, and Shadis D 1994. Soil and vegetation response to soil compaction and forest floor removal after aspen harvesting. U.S. For. Serv. Research Paper NC-315, 8 pp.**

Keywords: soil compaction/forest litter/logging /damage /natural regeneration/ *Populus tremuloides* /*Populus grandidentata* /soil compaction

Abstract: A 70-yr-old stand of *Populus tremuloides*/*P. grandidentata* in north central Minnesota was harvested when the ground was frozen. Two years later, litter removal and soil compaction significantly reduced biomass and height of aspen suckers.

10. **Albanese P and Middleton J 1991. Woody vegetation in a power right-of-way in Short Hills Provincial Park, Ontario. *Naturaliste Canadien* 117: 9-12.**

Keywords: nature conservation/rights of way/natural regeneration/assessment /vegetation survey

Abstract: This 688-ha conservation area in southern Ontario, which contains forests with a mixture of northern and southern species, is crossed by a cleared, high-tension electricity right of way (ROW), 2.6 km long and 100-150 m wide. A survey of every ramet of woody species within the ROW was made in September and October 1986. Some 1956 ramets of 45 species were recorded; most members of the local species pool were represented. Southern species and animal-dispersed species were significantly more common in the centre than at the edge of the ROW but,

overall, ramets were as common in the centre as near the edge. Results indicate that, under present management regimes, the ROW is not a serious conservation factor in the distribution of tree species.

11. **Alexander ME and Sando RW 1989. Fire behavior and effects in aspen-northern hardwood stands. In MacIver DC, Auld H, Whitewood R (eds.) Proceedings of the 10th Conference on Fire and Forest Meteorology, Ottawa, Ontario.**

Keywords: forest fires/fire danger/deciduous forests/Populus tremuloides/northern hardwoods

Abstract: Six experimental fires were conducted in pure trembling aspen (*Populus tremuloides*) and in mixed broadleaved stands in Minnesota and Wisconsin during both spring and late autumn (i.e. the leafless stage). Stand and fuel characteristics, fire weather, fire behaviour and initial effects on woody vegetation are described. The Canadian Forest Fire Danger Rating System indexes associated with these fires were documented.

12. **Allen DC, Barnett CJ, Millers I, and Lachance D 1992. Temporal change (1988-1990) in sugar maple health, and factors associated with crown condition. *Canadian Journal of Forest Research* 22: 1776-1784.**

Keywords: forest decline/air pollution/crown /damage /insect pests/sulfates /decline /forest trees/forest pests/sugar crops/plant pathology/agricultural entomology/*Acer saccharum*/ northern hardwoods /pear thrips /*Taeniothrips inconsequens* /crown dieback /drought effect /root damage

Abstract: Change in the health of sugar maple (*Acer saccharum*) and associated northern hardwoods was evaluated for 165 stands for 3 yr (1988-1990) in Maine, Massachusetts, Michigan, New Hampshire, New York, Vermont, Wisconsin, New Brunswick, Nova Scotia, Ontario and Quebec. Generally, levels of crown dieback and crown transparency (a measure of foliage density) in the stands decreased during this period. In 1990, less than 7% of all dominant/codominant sugar maples (n=7317) exhibited crown dieback $\geq 20\%$. Significantly ($p=0.05$) fewer of these maples were classified as having high crown transparency ($\geq 30\%$) in 1990 compared with 1988. Crowns of maples that received moderate (31-60%) or heavy ($>60\%$) pear thrips (*Taeniothrips inconsequens*) damage for 1 year recovered the following year. Crowns of maples exposed to severe drought in 1988 in Wisconsin continued to show the effects (high transparency) of this stress in 1990. A majority (69-71%) of the dominant/codominant sugar maples with high ($\geq 20\%$) crown dieback had bole and/or root damage. Of those maples with crown dieback $\geq 50\%$, some 86% had bole and/or root damage. The condition of sugar maple in operating sugar bushes and undisturbed stands was similar. The condition of sugar maple crowns was similar in locations presumed to be exposed to low, medium and high levels of sulfate deposition.

13. **Alm AA 1974. Pine tubeling survival varies with vegetative competition. *Tree Planters' Notes* 25: 33-36.**

Keywords: planting stock/weed control/plantations /container grown plants/conifers /*Pinus banksiana*/ *Pinus resinosa* /artificial regeneration

Abstract: Reports results of a further study of tubed seedlings of *Pinus resinosa* and *P. banksiana* in which the amount of vegetative competition at the time of planting was varied: (a) control; (b) shrubs clipped at ground level; (c) all vegetation clipped at ground level; and (d) all vegetation clipped and mineral soil exposed by raking [cf. FA 34, 2832]. After 5 growing seasons, mean % survivals for *P. resinosa* and *P. banksiana*, respectively, were: 13 and 16 for treatment (a); 29 and 61 for (b); 43 and 64 for (c); and 72 and 84 for (d). The mean height of *P. resinosa* was significantly higher in (d) than in the other treatments. Causes of mortality are discussed and it is concluded that most mortality was the result of 'smothering'. The usefulness of tubed seedlings in planting is discussed.

14. **Alm AA, John TJ, and Olsen DT 1978. Reforestation of clear-cut strips in a jack pine stand with plug seedlings. *Journal of Forestry* 76: 284-285.**

Keywords: browse /silvicultural systems/felling /silviculture /conifers /Pinus banksiana

Abstract: Clear-felled strips (132 or 198 by 330 ft) in a 70-yr-old stand in NE Minnesota were: (a) left to regenerate naturally from cones broken off during skidding; (b) planted with 20-wk-old seedlings in book planters (the Spencer-Lemaire or Roottrainer plug system); (c) scattered with cones (10-15/milliacre) in the autumn or spring; and (d) planted with 30-wk-old styroplug seedlings. After 4 growing seasons both (b) and (d) were successfully established with a mean tree ht. of 2.7 ft. Survival of (d) was greater (88.3%) than (b) (74.5%), probably because of age at planting. Both (a) and (c) were unsuccessful although scattering cones in the spring gave more trees than scattering in the autumn. Most mortality was due to browsing by snowshoe hares (*Lepus americanus*).

15. **Alomary A, Solouki T, Patterson HH, and Cronan CS 2000. Elucidation of Aluminum-Fulvic Acid Interactions by Gas-Phase Hydrogen/Deuterium (H/D) Exchange and Electrospray Fourier Transform Ion Cyclotron Resonance Mass Spectrometry (Esi Ft- Icr). *Environmental Science & Technology* 34: 2830-2838.**

Keywords: stability constants/laser desorption/selective electrode/humic substances/molecular weight/ionization/complexation/probe/desorption/ionization/polarization/northern hardwoods

Abstract: A gas-phase hydrogen/deuterium (H/D) exchange reaction technique using electrospray ionization Fourier transform ion cyclotron resonance (ESI FT-ICR) mass spectrometry to study the interactions between aluminum and fulvic acid (FA) species is described. The gas-phase hydrogen/deuterium exchange reactions and metal complexation (HYDERMEC) approach can be used to study both pure and impure samples. Upon metal complexation, the hydrogen atoms at the binding sites of the molecule are replaced with the metal and hence are not available for H/D exchange reactions. The HYDERMEC method provides the difference between the number of labile hydrogens that are available for H/D exchange reactions in a molecule before and after metal complexation. The HYDERMEC results for a linear oligopeptide composed of three amino acids, arginyl-glycyl-aspartic acid (Arg-Gly-Asp or RGD), and fulvic acid samples are discussed. The oligopeptide and its metal complexes were analyzed directly and without any ICR ion isolation. The electrosprayed fulvic acid ions were selectively isolated in the ICR cell by stored waveform inverse Fourier transform (SWIFT) dipolar excitation. The selected fulvic acid ions were reacted with deuterium exchange reagent molecules (e.g., CD₃OD) in the gasphase. An ESI FT-ICR mass spectrometer was used to analyze precursor and/or product ions. The number of incorporated deuterium isotopes in the product ion provides the number of active hydrogens (NOAH) for the precursor ion. The selected ions of all fulvic acid samples used in this study undergo H/D exchange with CD₃OD neutral molecules. The average maximum NOAH for northern coniferous (NCFA), northern hardwood (NHFA), and southern hardwood (SHFA) soil fulvic acid ions at mlr region 700-1000 Th is similar to 7-9 per molecule. Once aluminum ions react with the fulvic acid species, the number of observed exchangeable protons decreases. There is no significant difference at pH congruent to 2.5 between NCFA, SHFA, and NHFA in their NOAH and thus presumably in their complexation with aluminum ions. The HYDERMEC results show that not all of the functional groups with labile hydrogens participate in Al-FA complexation. Also, comparison of the results for various mlr ranges suggests that in terms of available labile hydrogens and Al complexation, species at m/z range 600-1000 Th behave similarly.

16. **Amiro BD and Courtin GM 1981. Patterns of vegetation in the vicinity of an industrially disturbed ecosystem, Sudbury, Ontario. *Canadian Journal of Botany* 59: 1623-1639.**

Keywords: pollution / vegetation types/synecology /land use /birch /maple /hemlock /white pine/ Tsuga canadensis/northern hardwoods /Populus spp. /Acer spp. /Pinus strobus

Abstract: During the past century, forests in the vicinity of Sudbury, Ontario, have been destroyed or disturbed by logging, fires and industrial pollution, producing an atypical mosaic of vegetation communities. This study investigates the patterns of plant communities that characterize this disturbed ecosystem. Nine major plant communities were recognised by classification of the tree stratum using a hierarchical cluster analysis of quantitative data gathered from 142 field sites. The communities tend to be regulated by topography, soils and distance from pollution sources. They can be grouped into two main types. The barren, birch transition and maple transition communities form a grouping that is attributed to pollution whereas the remaining six types are typical of the hemlock-white pine-northern hardwoods forest. The first three communities are restricted to the industrially disturbed region near Sudbury.

17. **Anderson RC and Katz AJ 1993. Recovery of browse-sensitive tree species following release from white-tailed deer *Odocoileus virginianus* Zimmerman browsing pressure. *Biological Conservation* 63: 203-208.**

Keywords: Browsing damage/natural regeneration/wildlife /damage /management /Acer saccharum/ Tsuga canadensis/deer /exclosure /*Odocoileus virginianus*

Abstract: Patterns of recovery of eastern hemlock (*Tsuga canadensis*) were examined at three forest sites in N. Wisconsin. In an intensively browsed forest, *T. canadensis* was the leading dominant in the tree stratum but was absent from the seedling and sapling strata where sugar maple (*Acer saccharum*) was dominant. In an area protected for 12 yr from browsing *T. canadensis* seedlings had established, but were absent from adjacent unprotected areas. In a 27-yr-old exclosure, under a canopy of shade-tolerant species, recovery of *T. canadensis* to a diameter distribution typical of all-aged forest was apparent.

18. **Anderson RC and Loucks OL 1979. White-tail deer (*Odocoileus virginianus*) influence on structure and composition of *Tsuga canadensis* forests. *Journal of Applied Ecology* 16: 855-861.**

Keywords: browse /natural regeneration/damage /browsing damage/conifers /Acer saccharum/ Tsuga canadensis/deer /*Odocoileus virginianus*

Abstract: In *T. canadensis* forests in Wisconsin, *Acer saccharum* rapidly replaced *T. canadensis* when both were heavily browsed by deer. However, regeneration of *T. canadensis* soon recovered upon removal of browsing. Heavy browsing by excessive numbers of deer appears to be a major cause of the homogeneous age-structure of these forests.

19. **Anderson RL and Mosher DG 1979. Lakeshore effect on Nectria canker of yellow birch. *Journal of Forestry* 77: 412-413.**

Keywords: fungal diseases/ plant pathology/plant pathogenic fungi/Acer saccharum/*Tilia* spp./*Betula alleghaniensis*

Abstract: In 1976, the severity of infection by *N. galligena* was significantly higher in stands of *Betula alleghaniensis* along the shores of Lakes Superior and Michigan than 5 miles or more inland. Depending on the severity of infection, recommendations include removal of cankered stems during improvement fellings, reduction in rotation length, or regeneration to less susceptible species such as sugar maple or basswood (*Tilia* spp.). From authors' summary.

20. **Anderson W and Eickmeier WG 2000. Nutrient Resorption in *Claytonia Virginica* L.: Implications for Deciduous Forest Nutrient Cycling. *Canadian Journal of Botany* 78: 832-839.**

Keywords: *Claytonia virginica*/nutrient response/resorption efficiency/nutrient cycling/spring

ephemerals/vernal dam/above-ground productivity/northern hardwoods /vernal-dam hypothesis/
use efficiency/Erythronium americanum/availability/nitrogen/gradient/dynamics/plants /fertilizers
/nitrogen /phosphorus

Abstract: According to the vernal dam hypothesis, spring ephemeral herbs temporarily sequester large nutrient pools in deciduous forests prior to canopy closure and return the nutrients to the soil following senescence of aboveground tissues. However, many species resorb nutrients from their leaves back to belowground tissues during senescence, and the degree of resorption is often associated with soil nutrient availability. Species that store large proportions of their absorbed nutrients between years are not participating in the temporary sequestering and rapid recycling of nutrients implied by the vernal dam. We investigated the extent to which *Claytonia virginica* L. sequestered and returned nutrients to the soil in response to nitrogen (N) and phosphorus (P) availability. We tested the effect of nutrient availability on nutrient use efficiency, resorption efficiency, and resorption proficiency (% nutrient in senescent leaves) of *Claytonia*. Nutrient additions significantly decreased N but not P use efficiency of *Claytonia*, particularly as the growing season progressed. Nutrient additions also significantly reduced N resorption efficiency from 80 to 47% and decreased P resorption efficiency from 86 to 56%. N and P resorption proficiencies were also significantly lower in senescent leaves of fertilized plants: N concentrations were 2.33% when unfertilized and 4.13% when fertilized, while P concentrations were 0.43% when unfertilized versus 0.57% when fertilized. When unfertilized, *Claytonia* was more efficient at resorption compared with other spring herbs, but similar to other species when fertilized. However, *Claytonia* was much less proficient in resorbing nutrients than other reported plants, because senescent tissues maintained substantially higher concentrations of N and P, particularly when fertilized. In conclusion, *Claytonia*, an important spring ephemeral species, exhibits physiological responses that emphasize its role in the vernal dam by its temporary sequestration and substantial, rapid return of nutrients in deciduous forests. Adding nutrients to the site increases the total mass and the relative proportion of nutrients that *Claytonia* returns to the soil rather than sequestering between seasons, which ultimately increases nutrient recycling rates within the entire system.

21. **Anderson WB and Eickmeier WG 1998. Physiological and Morphological Responses to Shade and Nutrient Additions of *Claytonia Virginica* (Portulacaceae): Implications for the "Vernal Dam" Hypothesis. *Canadian Journal of Botany* 76: 1340-1349.**

Keywords: *Claytonia virginica*/nutrient cycling/spring ephemerals/vernal dam/above-ground productivity/northern hardwoods /*Erythronium americanum*/ nitrogen/ ecosystem/ vegetation/ dynamics/growth/photosynthesis/availability

Abstract: Because of their unique phenology and physiology, spring ephemeral herbs are believed to play an important role in intrasystem nutrient cycling in deciduous forest ecosystems. It was hypothesized that they function as a "vernal dam" by temporarily sequestering nutrients and preventing leaching from the system during a period of high nutrient availability. However, spring ephemerals require high-irradiance growing conditions. How do their physiological and morphological responses to ambient light and shade limit their ability to sequester excess nutrients? We performed field experiments using *Claytonia virginica* L. as a model to test several responses to shade and increasing levels of nutrient additions. We also examined the biomass responses and nutrient storage capacities of other spring ephemeral herbs. In *C. virginica*, shading reduced ribulose 1,5-bisphosphate carboxylase-oxygenase (Rubisco) activity, photosynthesis rate, specific leaf weight, leaf width/length (W/L), and biomass; nutrient additions increased W/L and biomass only under unshaded conditions. Other herbs responded similarly but reached maximum biomass at lower nutrient addition levels than *C. virginica*. Shading reduced and nutrient additions increased nitrogen and phosphorus concentrations in both *C. virginica* and other herbs. Shaded herbs generally reached nutrient saturation at lower nutrient addition levels than unshaded herbs. Overall, unshaded plants sequestered larger amounts of nutrients than shaded plants. This pattern is best explained by a reduction in biomass under shaded conditions. We concluded that *C. virginica* and other spring herbs, although important components in forest nutrient cycling in the

early spring, are limited in their capacity to store excess nutrients, particularly when shaded.

22. **Arbogast C Jr. 1950. How much does felling large cull trees damage the understory (in northern hardwoods)? U.S. For. Serv. Lake St. For. Exp. Sta. Technical Note LS-337, 1 pp.**

Keywords: Logging damage/northern hardwoods /cull tree felling

Abstract: Detailed records were made of the effect of felling 17 cull trees averaging 25 in. d.b.b., 67 ft. in height, 27 ft. in crown diameter, and 36 ft. in crown length. Felling was done with a power saw by a 2-man-crew using all reasonable care. For each tree felled, 1.5 trees were damaged beyond recovery and another 3.5 severely damaged. Some damage was done to about half the trees in the impact zone of the crowns of falling trees. The use of girdling or poisoning rather than felling is recommended.

23. **Arbogast C Jr. 1957. Marking guides for northern hardwoods under the selection system. U.S. For. Serv. Lake St. For. Exp. Sta. Station Paper LS-56, 20 pp.**

Keywords: *Betula alleghaniensis*/Selection system marking/Silvicultural systems/Tree classes/northern hardwoods

Abstract: Makes recommendations on density of stocking and size of cut according to the condition of the stand. Modifications are suggested for special requirements e.g. to encourage Yellow Birch regeneration. A tree-class guide is appended as an aid in marking.

24. **Arbogast C Jr. 1951. Quality of logs and lumber obtained from an improvement cut in second-growth hardwoods in northern Wisconsin. U.S. For. Serv. Lake St. For. Exp. Sta. Station Paper LS-26, 15 pp.**

Keywords: *Acer rubrum*/*Acer saccharum* /*Betula alleghaniensis* /improvement fellings/*Betula papyrifera* /wood mill study/economics/*Fraxinus americana* /Logging costs/*Ostrya virginiana*/*Prunus serotina* /Release cuttings/*Tilia americana*/*Ulmus americana* /wood products

Abstract: A mill study was made of logs from improvement fellings in three 20-acre blocks of second-growth hardwoods in the Argonne Experimental forest. Of the 1120 hardwood logs, 88.5 % were merchantable, 7.2% were below the minimum top diameter, and 4.3% were cull logs (less than 1/3 sound). The species represented were *Fraxinus americana*, *Tilia americana*, *Betula papyrifera*, *B. alleghaniensis*, *Prunus serotina*, *Ulmus americana*, *Ostrya virginiana*, *Acer rubrum*, and *A. saccharum*. Figures showing amount and value of lumber produced from logs of different species and classes, lumber grade recovery by log classes, overrun, distribution of volume within the Madison log grades, estimates from Madison recovery tables against actual yield, and costs and returns by species for the total amount felled, are tabulated. Results show that: (1) improvement felling can yield timber justifying commercial operations; (2) Sugar Maple and Yellow Birch cull logs of comparable size and form, yield lumber of the higher grades about equal in value to that obtained from merchantable logs; (3) hardwood logs below minimum top diameter yield very poor timber and cannot be cut profitably for factory lumber; and (4) log grade rules and recovery tables developed at Madison for old-growth hardwoods apply satisfactorily to second-growth hardwoods in the area.

25. **Arbogast C Jr. and Heinselman ML 1950. Damage to natural reproduction by deer browsing. U.S. For. Serv. Lake St. For. Exp. Sta. Technical Note LS-332, 1 pp.**

Keywords: bark beetles/deer damage/forest pests/*Tsuga* spp./northern hardwoods

Abstract: A study of damage in 648 1/5-acre plots in the Hemlock and hardwood forests of the Argonne Experimental Forest, Wisconsin. Observations made in autumn and winter between December 1947 and May 1949 showed 'heavy' and 'very heavy' damage in 96-4% of plots.

26. **Arikian MJ 2001. *Soil disturbance and residual forest canopy influence tree regeneration in aspen and northern hardwood stands of Minnesota*. MS thesis, University of Minnesota, Twin Cities. 105 pp.**

Keywords: Populus spp. /aspen /northern hardwoods /harvesting impacts /soil properties /natural regeneration /soil compaction

Abstract: Impacts of clearcutting and partial harvest on aspen stands were examined at 25 sites in northern Minnesota. In each stand, residual overstory, soil compaction, and tree regeneration were determined along a disturbance gradient in the summers of 1997 and 1998, 4 to 11 years after harvest. I characterized soil disturbance as soil compaction using an Eijkelkamp soil cone penetrometer. Compaction levels on skid trails were higher on sites harvested in the summer than sites harvested in winter. After adjusting for differences in soil compaction, stands harvested in winter were associated with higher relative regeneration stem densities and height growth than on sites harvested in the summer. Relative tree regeneration stem densities and height growth decreased with increasing soil compaction and increasing residual basal area. Predictions of future stand volume at age 50 revealed moderate decreases in productivity resulting from harvest conditions investigated in this study. Impacts of clearcutting and partial harvest operation in northern hardwood stands were examined at 15 study sites in northern Minnesota. In each stand, tree regeneration and advance regeneration composition, residual overstory, and soil compaction were determined on landings, skid trails and areas off skid trails in the summers of 1997 and 1998, 4 to 8 years after harvest. Leaving more residual basal area was associated with lower soil compaction, and resulted in shade tolerant species composing a larger proportion of the regeneration. My results show the importance of understanding complex interactions between pre-harvest and post-harvest conditions, harvesting disturbance, and soil properties as they determine future stand composition and productivity.

27. **Attiwill PM 1994. *The disturbance of forest ecosystems: the ecological basis for conservative management*. *Forest Ecology and Management* 63: 247-300.**

Keywords: tropical forests/vegetation types/boreal forests/maquis /forest fires/fire ecology/wind damage/canopy gaps/climax communities/seral stages/sustainability /insect pests/forest pests/ ecosystems /plant communities/forest ecology/plant succession/natural regeneration/forest management/nature conservation/reviews /plant pests/ecology /Amazonia /biology /agricultural entomology/pines /damage

Abstract: The extensive literature - particularly recent (post-1985) work - on natural disturbance in forests is reviewed in terms of the hypotheses: (1) that disturbance is a major force moulding the development, structure and function of forests; and (2) that management of forests for all their benefits can be controlled so that the effects can be contained within those which result from natural disturbance. The causal factors of natural disturbance are explored, both endogenous and exogenous ones. There are major difficulties in the formal characterization of disturbance and of recovery after disturbance: these two processes are summarized under categories of natural disturbance agents - wind, fire, insect attack, tree fall - and ecosystem recovery dynamics - plant succession and climax. Two topics are treated in some detail: tree fall and gap dynamics as studied in the tropical forests of Central America and the Amazon, and in temperate forests of North America; and fire and its effects in the northern boreal forests, oak/pine forests, northwestern subalpine forests of North America, and in Mediterranean-type shrublands and heathlands. The conclusion from this review is that the ecological framework of natural disturbance and the knowledge of its component processes and effects provides the basis on which forests can be managed as a renewable resource which can be utilized so that forest biodiversity is retained. Forest management based on this knowledge is particularly necessary for the protection of the world's tropical forests, its peoples and their cultures.

28. **Auclair AND 1968. *Dynamics of Prunus serotina in southern Wisconsin Oak forests*. PhD dissertation, University of Wisconsin, Madison. 181 pp.**

Keywords: Prunus serotina /Quercus spp./ Cyclobalanopsis spp. /succession /vegetation types /grazing

Abstract: [Cf. F.A. 30 No. 394.] Discusses the role of P. serotina in the composition and succession of these forests, the original causes (chiefly grazing) of its establishment in the 1930s, its persistence in the understorey, and the chief factors affecting its growth rate, survival and vigour, concluding that P. serotina has only a minor effect on the compositional index of these forests, and that the changes in composition are not successional in nature but are rather fluctuations within groups of species having similar ecological adaptations.

29. **Auclair AND 1976. *Ecological factors in the development of intensive-management ecosystems in the midwestern United States*. *Ecology* 57: 431-444.**

Keywords: historical records/history /land use/agriculture /Quercus alba /Quercus macrocarpa /Quercus velutina

Abstract: Changes in the importance of 20 edaphic and 31 cover-type parameters were measured for three stages of the development of intensive agriculture: conversion of natural vegetation to pre-intensive agriculture (1833-1934), agricultural intensification associated with chemical subsidies and mechanization (1934-1948) and recent shifts in crop diversity and production (1934-1972). Of the savanna vegetation (dominant trees Quercus alba, Q. macrocarpa or Q. velutina) in 1833, 40% had been converted to cropland by 1934, 30% to permanent pasture and 20% to oak forest. Forest cover increased by 10% in the 1934-1961 period.

30. **Auclair AND and Cottam G 1971. *Dynamics of Black Cherry (Prunus serotina Ehrh. [Ehrh.] in southern Wisconsin Oak forests*. *Ecological Monographs* 41: 153-177.**

Keywords: Prunus serotina/Quercus spp. /succession/seral stages/vegetation types

Abstract: The Oak forests of S. Wisconsin are only ca. 125 years old (apart from open-grown Quercus macrocarpa and Q. alba, 300-year-old remnants of 'savanna' vegetation) and originated with the cessation of prairie and 'savanna' fires after European settlement. A detailed account is given of research on the present status and probable future role of P. serotina in these forests, in which it has become an important constituent of the understorey, comprising an average of 50% of the saplings and small trees in the stands studied. Analysis of 854 increment cores showed that 58% of all the P. serotina stems examined were established between 1931 and 1941; the widespread invasion of the forests by the species at this time is attributed primarily to extensive disturbance of the vegetation through grazing and, perhaps, cutting of foliage for cattle fodder. The subsequent growth, survival and spread of P. serotina in the understorey are explained in terms of the characteristics of the species (especially the ease of seed dispersal, the longevity of the seed and its tolerance of various seedbeds, and the capacity of the tree to coppice and to respond to release after long periods of suppression) and the complex interaction of environmental factors. The environment, composition and structure of P. serotina stands are described, and the probable effect of P. serotina on Oak-forest succession is discussed.

31. **Auclair AND and Cottam G 1968. *Dynamics of Prunus serotina in southern Wisconsin Oak forests*. *Abstr. in Bull. Ecol. Soc. Amer.* 49 (2).**

Keywords: plant ecology/Flindersia brayleyana/fungus diseases /grazing /Prunus serotina/ Quercus spp. / Cyclobalanopsis spp. / diseases and disorders/logging /disturbance

Abstract: P. serotina is a leading species in succession. Extensive disturbance of Oak woodlots, through cutting, grazing, and Oak wilt disease, is a major factor in the change.

32. **Auclair AND and Cottam G 1973. Multivariate analysis of radial growth of Black Cherry (*Prunus serotina* Erhr.) in southern Wisconsin Oak forests. *American Midland Naturalist* 89: 408-425.**

Keywords: ecology /plant succession/increment /succession /yields /*Prunus serotina* /soil moisture /temperature /growth

Abstract: After extensive disturbance of Oak forests in the 1930s, *P. serotina* became established in a wide range of habitats [cf. FA 33, 427]. The ability of *P. serotina* to reach maturity was studied in relation to soil moisture from measurements of radial growth and environmental parameters during three growing seasons. Growth rate and duration of the growth period were influenced chiefly by crown position, air temperature and soil moisture. The survival of *P. serotina* in dry mesic conditions is significantly improved by its ability to coppice and respond to release after long periods of suppression.

33. **Auclair AND, Eglinton PD, and Minnemeyer SL 1997. Principal forest dieback episodes in northern hardwoods: development of numeric indices of areal extent and severity. *Water Air and Soil Pollution* 93: 175-198.**

Keywords: dieback /patterns /temporal variation/maturity /age of trees/stress /freezing /drought /synchronization /vegetation types/deciduous forests/forest decline/*Acer saccharum*/*Betula papyrifera*/*Betula alleghaniensis*/northern hardwoods

Abstract: The incidence of forest dieback in the Northern Hardwoods biome of Canada and the USA was determined for the period from 1910 to 1990. Information from annual Forest Service pathology inventories in both countries, and other published literature, was coded to estimate yearly the severity and areal extent of dieback on white/yellow birch [*Betula papyrifera*, *B. alleghaniensis*] and sugar maple [*Acer saccharum*] from 1910 to 1990. Principal dieback episodes occurred as distinct waves coincident with maturation of the forest population in each of 6 regions. These episodes endured an average of 11 yr. It is hypothesized that, once forest populations are mature, they are susceptible to extreme stresses such as freezing and drought which serve to synchronize the onset and subsidence of major dieback episodes.

34. **Auclair AND and Goff FG 1971. Diversity relations of upland forests in the western Great Lakes area. *American Naturalist* 105: 499-528.**

Keywords: synecology /climatic factors/vegetation types/*Tsuga canadensis* /diversity /soils - xeric

Abstract: Species diversity and dominance were examined in relation to the structure and dynamics of upland forests in this area of N. America [cf. FA 29, 5346], with particular reference to three regions (northern, southern and boreal transition) that are distinguished. Pronounced correlations between tree, shrub and herb diversity were found to depend on the inherent structural and dynamic characteristics of the forests in the different regions. Shrub or herb diversity was least in climax evergreen stands of *Tsuga canadensis* and greatest in successional deciduous forests. Inter-regional comparisons of tree diversity indicated that diversity in forests on xeric sites is equally limited in northern, southern and boreal-transition forests, and that ecological specialization is greatest in the northern forests.

35. **Auclair AND and Goff FG 1974. Intraspecific diameter differentiation as a measure of species replacement potential. *Canadian Journal of Forest Research* 4: 424-434.**

Keywords: succession /stand characteristics/structure /development

Abstract: Develops a method of measuring species replacement potentials in forest vegetation

from d.b.h. records of trees taken at one particular time. Replacement potentials are based on mean d.b.h. differences within a species when it occurs with other species. The technique incorporates a correction for differences in growth rate and maximum size between species. Successional trends established for Menominee County, Wisconsin, and site/successional relations examined by cluster analysis and principal components analysis agreed closely with results of earlier studies in the Lake States. The applicability and limitations of the method are discussed.

36. **Auclair AND, Lill JT, and Revenga C 1996. The role of climate variability and global warming in the dieback of northern hardwoods. *Water Air and Soil Pollution* 91: 163-186.**

Keywords: dieback /drought injury/frost injury/damage /global warming/climatic factors/climatic change/plant succession/heat stress/vegetation types/deciduous forests/forest decline/Acer saccharum / Picea rubens/Betula papyrifera/Betula alleghaniensis/northern hardwoods

Abstract: The severity of dieback in northern hardwood forests of Canada and the USA during the 20th century (1910-90) was reconstructed from pathology records and compared with indices of extreme weather stresses in the region, and with changes in global temperatures and climatic variability over the same period. Thaw-freeze and root-freeze events in winter and early spring were key factors in triggering (and synchronizing) severe episodes of dieback. Once trees were injured by freezing, forest dieback correlated significantly with heat and drought stress. Freezing (but not drought) stresses in northern hardwoods correlated significantly with increasing global mean annual temperatures and low values of the Pacific tropical Southern Oscillation Index. Major diebacks did not occur early in the century at a time of notable freezing stress. Prior to 1940, the northern hardwoods consisted of relatively young populations of trees regrowing following extensive cutting and forest burning in the late 19th century. It appears that forest maturation is the key factor preconditioning trees to climatic injury, and dieback. A simple projection of climate and forest maturation ages suggested the recurrence of major dieback episodes on white/yellow birch [*Betula papyrifera*/B. alleghaniensis], sugar maple [*Acer saccharum*] and red spruce [*Picea rubens*] in the latter half of the 21st century.

37. **Augustine DJ and Frelich LE 1998. Effects of White-Tailed Deer on Populations of an Understory Forb in Fragmented Deciduous Forests. *Conservation Biology* 12: 995-1004.**

Keywords: Trillium grandiflorum/pellet counts/understory forb vegetation/ reproduction/ recovery/ impacts/deer /deer enclosure/browsing /*Odocoileus virginianus*

Abstract: The effects of grazing by white-tailed deer (*Odocoileus virginianus*) on populations of *Trillium* spp. were examined in remnant, old-growth patches of the highly fragmented Big Woods forest ecosystem in southeastern Minnesota. We conducted three separate studies involving an enclosure experiment, transplant experiments, and comparisons of *Trillium* populations among study sites. The highest grazing intensity was observed where deer occurred at high overwinter concentrations (similar to 25- 35/km²); significantly lower grazing intensities occurred at low overwinter density (similar to 5-10/km²). Deer focused their grazing on large, reproductive plants; at sites with high deer density, *Trillium* population structure was skewed toward small plants, and deer consistently caused over 50% reduction in reproduction during the growing season. Protection of individual plants from deer for two growing seasons resulted in dramatically increased flowering rates and significantly greater leaf area compared to control plants. No significant impact of current-year herbivory on reproduction in the following year was detected. Nevertheless, flowering rates at one site with high overwinter deer densities for at least the past 5 years suggest that the cumulative effects of grazing over several years can reduce reproduction in subsequent years. Transplant experiments with *Trillium grandiflorum* also showed that deer had significant effects on growth and reproduction where deer occur at high density. Our results suggest that changes in landscape structure and local deer abundance have altered plant-deer relationships such that grazing can lead to the local extirpation of sensitive forbs such as *Trillium* spp. As a result, active, long-term management of deer at low densities appears necessary for the conservation and restoration of fragmented forest communities in eastern North America.

38. **Baker WL 1992. Effects of settlement and fire suppression on landscape structure. *Ecology* 73: 1879-1887.**

Keywords: global warming/climate /controlled burning/simulation /land use/natural resources/resource management/geographical information systems/remote sensing/forests /landscape /forest fires/fire suppression/settlement /model - GIS

Abstract: A GIS-based spatial model and data on historical changes in fire sizes and intervals were used to simulate the effects of human settlement and fire suppression on structural elements of the landscape in the [natural forests of the] Boundary Waters Canoe Area, Minnesota. Results are discussed in terms of restoration of altered landscapes using prescribed burning, and effects of global warming.

39. **Bakken PN and Cook JE 1998. Regeneration potential of six habitat types common to north-central Wisconsin. *Northern Journal of Applied Forestry* 15: 116-123.**

Keywords: deciduous forests/natural regeneration/seedlings /regeneration surveys/site types/plant succession/silviculture /Acer rubrum/Quercus rubra/Pinus strobus/deer /Acer saccharum /Quercus rubra /Odocoileus virginianus

Abstract: Arboreal regeneration was studied in 24 mature, fully stocked forests distributed among 6 common habitat types in north-central Wisconsin. Nineteen of the stands were inventoried in 1992 and 1993; in 1993 an additional 5 stands were included. The expected overstorey climax species were *Quercus rubra* and *Acer rubrum* (habitat types QAE and AQV), *Pinus strobus* (PMV), and *A. saccharum* (AVVib, ATD and AViO). The density and composition of small (<25 cm) and large (25-150 cm) seedlings were determined, and the relationships of the understorey and overstorey were investigated. No significant ($P < 0.05$) differences were found for seedling densities of either size class among habitat types; this was caused partly by the large variation within most habitat types. The average densities per habitat type were 3125-20thin200/ha for large seedlings and 20thin208-152thin083/ha for the small seedlings. Red (*A. rubrum*) and sugar (*A. saccharum*) maple strongly dominated the regeneration. Red maple was the commonest (88-96%) species in the small seedling size class on the three driest habitat types (QAE, AQV, PMV), and sugar maple (88-99%) on the two most mesic habitat types (ATD, AViO). In the middle of the site quality gradient (AVVib), the two maples shared dominance with northern red oak (*Q. rubra*). The level of maple dominance was lower in the large seedling class, ranging from 53-93%. The small seedling size class was significantly related to the amount of maple basal area each year, but the strength of this relationship weakened from 1992 to 1993. The widespread domination by red and sugar maple is a function of their regeneration ecology, shade tolerance, fire suppression, and deer browsing. The seedling composition and densities have important implications for the management of these forests. The regeneration and overstorey characteristics suggest that it would be easiest to direct the composition one of several ways on the PMV and AVVib habitat types. Fairly heavy overstorey treatments, in conjunction with seedbed preparation, are probably necessary to regenerate significant amounts of species other than sugar maple on the two most mesic habitat types.

40. **Baldwin IT and Schultz JC 1984. Tannins lost from sugar maple (*Acer saccharum* Marsh) and yellow birch (*Betula alleghaniensis* Britt.) leaf litter. *Soil Biology and Biochemistry* 16: 421-422.**

Keywords: soil morphological features/forest litter/tannins /organic compounds/*Acer saccharum*/*Betula alleghaniensis*/northern hardwoods

Abstract: Fresh leaves were collected from sugar maple (*Acer saccharum*) and yellow birch (*Betula alleghaniensis*) at two sites in northern USA. Forest floor and F2 samples were taken beneath the trees. From late July until leaf drop in September, sugar maple leaves had higher total phenolic and condensed tannin contents and tanning capacity than yellow birch, but the two

species did not differ in hydrolyzable tannin content. Following leaf drop, tannin losses were rapid, 70-90% of the hydrolyzable tannin and total phenolic content being lost in the first four weeks. Within a year after leaf drop most of the leaf tannins were lost, and by the time the leaf litter had become part of the F2 horizon more than 80% of all tannins were lost. The effect of the high leaf tannin loss rates in the litter on nitrification rates in northern hardwood forest soils is discussed.

41. **Ball JB, Wormald TJ, and Russo L 1995. Experience with mixed and single species plantations. *Commonwealth Forestry Review* 74: 301-305.**

Keywords: biology /forest economics/sociology /silviculture /forest management/forest plantations/ literature review

Abstract: Literature is reviewed on the biological, economic and social effects of plantations of mixed or single tree species. There are relatively few reliable examples of quantified benefits of plantations consisting of several tree species compared with single species, in which the species or provenances have been correctly matched to the site and to the objectives, and which are managed according to good silvicultural practices. Nevertheless, there are instances where mixed species plantations are favoured. They include plantations established in locations where: multiple benefits are required from the plantation; the 'unnatural' appearance of a single species plantation is not acceptable; the objective is to reconstitute former natural ecosystems; the use of a mixture is required as a nurse crop or to provide shade to protect a more valuable understorey against insect attack; or an insurance is required against death or poor performance or a fall in the price obtained for a single species. While mixtures of tree species are required in such situations, their management may not be easy. The of mixed species plantations will often not be stable, and its maintenance as a mixture will require active intervention. Where the benefits of mixtures are required as a secondary environmental, social or economic benefit of plantations then the best approach may be to encourage the natural regeneration of indigenous species under the main crop. Recommendations for research are made.

42. **Balogh JC and Grigal DF 1987. Age-density distributions of tall shrubs in Minnesota. *Forest Science* 33: 846-857.**

Keywords: Understorey /Stand characteristics/age /density /vegetation types/Populus tremuloides /Populus grandidentata/Pinus banksiana/Pinus resinosa

Abstract: A total of 34 sites were sampled in 16 undisturbed stands and 8 stands that had received various silvicultural treatments at least 10 yr earlier in upland forests dominated by aspen (Populus tremuloides and P. grandidentata) or conifers (Pinus resinosa and jack pine). Age/density distributions of the entire population of shrubs and of most individual species were best described by a negative exponential model. Distributions of a few shrub species were described better by a power function. Slopes of the distributions did not differ between stands, but intercepts did differ between stands.

43. **Balogh JC and Grigal DF 1988. Tall shrub dynamics in northern Minnesota aspen and conifer forests. U.S. For. Serv. Research Paper NC-283, 15 pp.**

Keywords: broadleaves /conifers /shrubs /woody plants/understorey /synecology /layer structure/ pines /Populus tremuloides /Populus grandidentata/Pinus banksiana/Pinus resinosa /disturbance

Abstract: Dynamics of tall shrubs were examined in natural stands of aspen (Populus tremuloides and P. grandidentata), natural stands of jack pine (Pinus banksiana) and natural stands or plantations of red pine (P. resinosa). A total of 24 forests were sampled (16 were undisturbed, 8 had received silvicultural treatments at least 10 yr before sampling). Mortality rates of shrub stems were independent of stem density and age and did not differ between stands. Shrub stem regeneration did differ between stands and was related to overstorey characteristics, soil moisture

and soil nutrients. It was concluded that stem density was regulated by annual regeneration.

44. **Bare BB and Opalach D 1988. Determining investment-efficient diameter distributions for uneven-aged northern hardwoods. *Forest Science* 34: 243-249.**

Keywords: forest management/simulation /economics /Growing stock/control /northern hardwoods /Q factor

Abstract: The constant 'q' of de Liocourt is often used to model the diam. distribution of uneven-aged stands and produces 'balanced' size class distributions. Claims that such distributions are the most efficient for uneven-aged management or necessary to achieve sustained production have led to the use of the concept in a variety of management models. Using a northern broadleaved, mixed species growth model and a Weibull distribution function, it is shown that 'balanced' diam. distributions are not investment efficient and are not necessary to achieve sustained production over a fixed cutting cycle. Results are very sensitive to price per tree and max. tree size assumptions.

45. **Barnes BV, Pregitzer KS, Spies TA, and Spooner VH 1982. Ecological forest site classification. *Journal of Forestry* 80: 493-498.**

Keywords: synecology /classification /site types/site class assessment /model

Abstract: A multi-factor method of site classification used in Baden-Wurtemberg for many years [described in FA 41, 2984, pp. 324-329] was applied to the Cyrus H. McCormick Experimental Forest in the Upper Peninsula of Michigan. Physiography, soils and vegetation were closely related and used simultaneously in the field to distinguish and map ecosystem units - each unit being a collection of sites of similar silvicultural potential and risks, evaluated on the basis of growth and productivity of important commercial species. These units could form a basis for intensive, multiple-use management.

46. **Barras N 1994. *The importance of forest light and litter micro-environments of the establishment of hardwood and coniferous seedlings*. MS thesis, York University, Toronto (Canada). 150 pp.**

Keywords: deciduous forests/plant communities/boreal forests/synecology /natural regeneration/seedbeds /forest litter/light /ecotones /temperature /Acer saccharum/Abies balsamea /Picea glauca/Betula alleghaniensis/northern hardwoods

Abstract: This study examined whether tree seedling establishment patterns could account for the abrupt boundary between northern hardwood and boreal forests that exists in the Lake Superior Provincial Park area of north central Ontario. The establishment patterns of the two dominant tree species in the northern hardwood forest: sugar maple and yellow birch, and of the two dominant tree species in the boreal forest: balsam fir and white spruce, were studied. It was hypothesized that hardwood seedlings regenerated best in the micro-environments of the northern hardwood forest type, and that coniferous seedlings regenerated best in the micro-environments of the boreal forest type, so that each community remained distinct from the other. The micro-environments were interconnected; decomposed litter depth increased with increasing hardwood leaf-litter mass, and both decreased with increasing moss cover mass and increasing light levels received. Sugar maple seedlings were found growing in the deepest decomposed litter, and the greatest mass of hardwood leaf-litter. Balsam fir, yellow birch and white spruce seedlings were found growing in the greatest mass of moss cover and the highest light levels received, balsam fir being the least extreme and white spruce the most extreme of the three species. Judging from the availability of micro-environments, sugar maple seedlings could regenerate well in both pure sites, while the three other species could regenerate only in boreal sites. Sugar maple seedlings were abundant in northern hardwood stands but absent from boreal stands. It was concluded that the abrupt disappearance of sugar maple seedlings in boreal stands, was likely a result of the species reaching its physiological temperature limit, and thus the abrupt transition between northern hardwood and

boreal stands was likely a result of the removal of the dominant species in the forest stand.
(Abstract shortened by UMI.)

47. **Barras N and Kellman M 1998. The supply of regeneration micro-sites and segregation of tree species in a hardwood/boreal forest transition zone. *Journal of Biogeography* 25: 871-881.**

Keywords: plant communities/boreal forests/synecology /natural regeneration/seedbeds /forest litter/light /ecotones /temperature /Acer saccharum/Abies balsamea/Picea glauca/Betula alleghaniensis/northern hardwoods

Abstract: The role played by demand for and supply of micro-sites for seedling regeneration, in preserving segregation of species into boreal and hardwood communities, was examined in the Lake Superior region of northern Ontario, Canada. The sensitivity of tree seedlings of the two dominant species in each community (Acer saccharum with lesser quantities of Betula alleghaniensis in the northern hardwood community, and Abies balsamea and Picea glauca in the boreal forest) to micro-environmental variations was measured in transitional zones, where all species were present, and these responses compared with the availability of micro-sites in adjacent 'pure' communities. Acer saccharum seedlings exhibited the largest ecological amplitude, and were found growing on the deepest litter layers and where the greatest mass of hardwood litter had accumulated. Abies balsamea, Picea glauca and Betula alleghaniensis seedlings were found growing where hardwood litter layers were thinnest, more moss was present, and light levels were higher - all conditions most frequent in the boreal community. The results imply that Acer should regenerate well in both community types, while the other 3 species should regenerate well only in boreal communities. The abruptness of the hardwood/boreal community boundary in this area is explained by the abrupt population boundary of Acer saccharum, the potential regional dominant; this is tentatively attributed to temperature limitation on this species at its northern range limit.

48. **Barrett LR 1997. Podzolization under forest and stump prairie vegetation in northern Michigan. *Geoderma* 78: 37-58.**

Keywords: spodosols /podzolization /vegetation /deforestation /forests /iron /aluminum /horizons /soil formation/nutrients /forest soils/soil types /ortstein/second-growth

Abstract: The contrast in vegetation between the second-growth forests of northern Michigan, USA, and the nearby 'stump prairies' is striking. Prior to the logging and fires of the late nineteenth century both areas supported dense forest. Neither geomorphological surface boundaries nor soil drainage patterns explain the origin and maintenance of the contrasting vegetation types. Representative pedons of forest and stump prairie vegetation stands were sampled. Soil texture was not different between the forest and stump prairie sites, but spodic horizon development, as shown by illuvial accumulations of Fe, Al, and organic carbon was slightly stronger where forest regeneration had occurred than in the stump prairie. Ortstein content represented the primary difference between the soils in forested and stump prairie areas. The relative lack of ortstein in the nutrient-poor and droughty soils was a factor in the origin of the stump prairie. Other factors, such as pre-logging forest vegetation and logging-era wildfires, were probably also involved. The soils were examined for evidence of podzolization processes. The distribution of extractable Fe and Al in the soils indicated that organically bound sesquioxides were most common in the Bhs and ortstein portions of Bs horizons, while inorganic forms of Fe and Al became more abundant in the lower B horizon. These data are best explained as a result of two sets of processes: (1) the translocation of organically bound sesquioxides into the B horizon; and (2) the further translocation of Al (and perhaps Fe) as amorphous aluminosilicate complexes. Both sets of processes appear to be active in the soils simultaneously.

49. **Barrett LR 1995. *A stump prairie landscape in northern Michigan: soils, forest vegetation, logging, and fire.* PhD dissertation, Michigan State University, East Lansing. 206 pp.**

Keywords: spodosols /podzolization /vegetation /deforestation /iron /aluminum /horizons /soil

formation/nutrients /forest soils/soil types /Acer saccharum/Pinus strobus

Abstract: Parts of a sandy plain located in northern Michigan today are 'stump prairie,' devoid of trees, although prior to the logging and fires of the late 19th century they supported dense forest. Nearby, otherwise similar sites have regenerated to forest. The aims of this study were to determine how site and human disturbance patterns are related to patterns of long-standing changes in this ecosystem and to examine the possible impact of these forest regeneration patterns on active soil processes. Evidence from the General Land Office survey notes suggests that original forest composition has a strong relationship to forest regeneration patterns, possibly due to the manner in which early logging was accomplished. White pine (*Pinus strobus*) was especially prevalent in the pre-logging forest of current stump prairie areas, but sugar maple (*Acer saccharum*) was nearly lacking there. Land ownership and tax records suggest that stump prairie sites were acquired and logged at least as early as adjacent forested sites. Tree rings and recent stumps provide evidence that in currently forested areas loggers left more trees to provide shade and seed sources for forest recovery. Soil parent material texture is not significantly different between the forest and stump prairie sites. Spodic horizon development, as shown by degree of ortstein cementation and Fe, Al, and organic matter contents, is slightly stronger where forest regeneration has occurred than in areas that have remained stump prairie. Most of the extractable Fe and Al is present in organically-bound forms, but inorganic forms become more important in the lower B horizon. Ortstein content represents the primary difference between the soils in forested and stump prairie areas. In order to study current soil development processes, bags of cation exchange and chelating resins were buried in forested and unforested sites. Although variability within and between pedons was very high, slightly greater amounts of Fe and Al were sorbed in B horizons of soils of forested than of unforested sites, suggesting that podzolization processes are more active in the forest than in the stump prairie. These data highlight the importance of forest vegetation in maintaining the spodic (Bs) horizon.

50. **Batzer HO and Popp MP 1985. Forest succession following a spruce budworm outbreak in Minnesota. *Forestry Chronicle* 61: 75-80.**

Keywords: ecology /insect pests/*Choristoneura fumiferana* /succession /seral stages/natural regeneration/distribution /damage /food plants/trees /agricultural entomology/*Acer rubrum*/*Populus tremuloides*/*Abies balsamea*/*Picea glauca*/*Betula papyrifera*

Abstract: [See FA 34, 5912] Plots in 24 stands dominated by *Abies balsamea* and *Picea glauca*, established in 1957 or 1960 during an outbreak of *Choristoneura fumiferana*, were remeasured in 1979. Composition of the overstorey changed from an av. of 79% of b.a. in host species in 1957/60 to 31% in 1979. Only 12% of stands showed growth in non-host species that offset losses in *A. balsamea* and *P. glauca*. Min. stocking of *A. balsamea* was found in 63% of stands. *P. glauca* regeneration was sparse, occurring in 66% of stands; only 20% of quadrats were stocked with this species. Red maple [*Acer rubrum*] was the most abundant broadleaved invader. *Rubus*, *Corylus cornuta* and *A. spicatum* were the most abundant shrub species, limiting *A. balsamea* reproduction. Stands originally with a moderate mixture of non-host species had the most *A. balsamea* regeneration, resulting from seed produced by balsam firs surviving the outbreak. The net effect of the outbreak was to convert the overstorey to an earlier successional stage in which aspen (*Populus tremuloides*) and white birch (*Betula papyrifera*) predominated.

51. **Beckett PJ and Negusanti J 1990. Using land reclamation practices to improve tree condition in the Sudbury smelting area, Ontario, Canada. In Skousen J, Sencindiver J, Samuel D (eds.) *Proceedings of the 1990 Mining and Reclamation Conference and Exhibition (volume 1)*.**

Keywords: reclamation /soil pollution/air pollution/forest decline/sulfur dioxide/heavy metals/plant nutrition/soil toxicity/afforestation /chlorosis /*Acer rubrum*/*Quercus rubra* /*Robinia pseudoacacia*/*Pinus strobus*/*Pinus banksiana*/*Pinus resinosa*/*Picea glauca*/*Betula papyrifera* /artificial regeneration

Abstract: Extensive areas of mixed forest in the Sudbury area have declined over the past 100 yr through logging, fire, soil erosion, heavy metal and SO₂ pollution and frost action. Pollution controls since 1972 have not resulted in widespread tree regeneration in the barren and depauperate white birch/red maple (*Betula papyrifera*/*Acer rubrum*) communities. Birch in the toxic soils shows marginal leaf chlorosis in summer while the maple shows regressive dieback. Since 1978, approximately 3000 ha have been revegetated under a reclamation programme. Dolomitic limestone, fertilizers and a grass/legume mixture were applied in the first year, and a total of 1 million bare root and paperpot tree stock have been planted in subsequent years. Trees introduced include *Pinus resinosa*, *P. strobus*, *P. banksiana*, *Picea glauca*, *Quercus rubra* and *Robinia pseudoacacia*. Macroelements in the foliage are below normal except for N in *R. pseudoacacia*. Ni and Al concentrations are high but not toxic, while Cu is average and Zn is low. There is little evidence of foliar chlorosis in treated areas and growth rates of the conifers are typical for trees found on acid, poor sites in northern Ontario.

52. **Belli KL and Ek AR 1988. Growth and survival modeling for planted conifers in the Great Lakes region. *Forest Science* 34: 458-473.**

Keywords: artificial regeneration/simulation /conifers /*Pinus resinosa*/*Picea glauca*

Abstract: A framework of prediction equations was developed for the growth and survival of red pine (*Pinus resinosa*) and white spruce (*Picea glauca*) during the first 5 yr after planting. The model was developed using data from published reports of planting experiments in the Great Lakes region. Two compatible growth estimation functions were derived to accommodate plantation averages for annual stem height increment or total cumulative stem height. A single function was proposed for total survival. The study is considered a first step in characterizing the regeneration system.

53. **Benson CA 1981. Ontario: two trees planted for each one cut? *Forestry Chronicle* 57: 104-106.**

Keywords: natural regeneration /policy/artificial regeneration

Abstract: Forest regeneration policy in Ontario is reviewed, and tables are given summarizing areas logged and regenerated from 1968 to 1980. It is concluded that it is unlikely that natural or artificial regeneration is reaching the target of replacing two trees for each one harvested.

54. **Bergen KM, Dobson MC, Pierce LE, and Ulaby FT 1998. Characterizing Carbon in a Northern Forest by Using Sir-C/X-Sar Imagery. *Remote Sensing of Environment* 63: 24-39.**

Keywords: Land-Cover Classification/Biomass/Ecosystems/model/northern hardwoods /carbon storage /remote sensing

Abstract: A significant large-scale question in ecology and earth systems science pertains to the amount of carbon (C) stored in terrestrial vegetation. In this paper, a synthetic aperture radar (SAR)-based methodology is developed and evaluated for quantification of several key vegetative C components-both natural and human induced-of the northern forest. Specifically, the methodology provides estimates of C stored in living forest vegetation, above-ground C gain from annual growth (aboveground net primary productivity, or ANPP), and C removal due to managed forest disturbance in the form of clear-cutting. The inputs are shuttle imaging radar (SIR)-C/X-SAR-derived terrain classifications, SIR-C/X-SAR-derived biomass estimation, and allometric relations and equations developed for the northern hardwood and conifer forest in general and from local test stand data. Results are mapped quantitatively in the image domain for above-ground C storage, below-ground C storage, above- to below-ground ratios, total C in living woody vegetation, and forest absolute and relative ANPP rates. Numeric estimates also are extracted from each of these in tabular form; for example, results show that the forested parts of the sampled area contain 2.73×10^9 kg of aboveground C and 4.86×10^8 kg of below-ground C in 51,448 ha. When combined with a SAR-derived classification, similar quantifications can be extracted for

each of the several forest communities present in the region. Estimates of forest ANPP show that it ranges from 0.5 kg/m²/yr of biomass to 2.7 kg/m²/yr in the test site, with an average of 1.09 kg/m²/yr. Estimation of C removal due to clear-cutting is done by using multivariate classifications of SAR imagery and a procedure including image differencing and decision rules. Clear-cuts that were made between SIR-C/X-SAR Shuttle Radar Laboratory (SRL)-1 (April) and SRL-2 (October) are identified by differencing the classified imagery. When combined with the SAR-derived biomass image, results show that an estimated 300 ha of forest with 6.02X10⁶ kg of C were removed in this 6-month period.

55. **Berger AL and Puettmann KJ 2000. Overstorey composition and stand structure influence herbaceous plant diversity in the mixed aspen forest of northern Minnesota. *American Midland Naturalist* 143: 111-125.**

Keywords: stand structure/canopy /botanical composition/stand characteristics/ground vegetation/understorey /species diversity/basal area/climate /monoculture /shrubs /Populus tremuloides/Abies balsamea/northern hardwoods

Abstract: The relationship of herbaceous plant diversity to overstorey composition and stand structure in the mixed aspen forest of northern Minnesota was investigated on 23 study sites that contained aspen in monoculture or in mixture with boreal conifers or northern hardwood species. On each site overstorey species were placed into species groups: conifers, aspen (*Populus tremuloides*) and hardwoods other than aspen. Each site was then placed in one of three cover-type groups based on proportion of the overstorey species groups: Aspen (>0.9 basal area in aspen), Aspen-Conifer (>0.15 basal area in conifer species) and Aspen-Hardwood (>0.15 basal area in hardwood species other than aspen). The relationships between diversity of herbaceous vegetation and the following factors were tested: (1) overstorey composition, defined as the proportion of basal area by species group in the overstorey and (2) stand structure. Stand structure was described by the vertical position and horizontal arrangement of balsam fir (*Abies balsamea*) within the stand. In addition, relationships were tested with respect to other stand structural features such as shrub height and cover, average amount of plant material intercepted within the vertical profile and an index of plant occupancy within the vertical profile (modified Foliage Height Diversity Index-FDH). Understorey herbaceous diversity (*H'*) and proportion of aspen basal area were significantly positively related whereas understorey herbaceous diversity was significantly negatively related to proportion of hardwood basal area and not related to proportion of conifer basal area. Mixtures of overstorey tree species provided a range of stand structures that can be represented by shrubs, subcanopy trees or the overstorey trees. In the three cover-type groups different structural components were related to herbaceous diversity indicating that (1) overstorey composition and stand structure interactively influence understorey diversity patterns and (2) it is difficult to characterize stand structure for the range of stand conditions with a single measure. Increased diversity of structure (modified FHD) in the Aspen-Conifer group is negatively related with diversity (*H'*) of the herb layer. Composition of herbaceous species varied depending on presence or absence of conifers in the overstorey. These patterns may be influenced by the interaction of a variety of resource levels and climate conditions, which, in turn, are controlled by factors such as tree architecture or shade tolerance of overstorey trees.

56. **Berntson GM 1997. Topological Scaling and Plant Root System Architecture: Developmental and Functional Hierarchies. *New Phytologist* 135: 621-634.**

Keywords: Architecture/Fractal Geometry/Nutrient Uptake/Root Systems/Topology/Northern Hardwood Forest/Branching Patterns/Fractal Dimension/Simulation-Model/ Efficiency/ Allometry/Growth/Soil/Ecology/Length

Abstract: Topology is an important component of the architecture of whole root systems. Unfortunately, most commonly applied indices used for characterizing topology are poorly correlated with one another and thus reflect different aspects of topology. In order to understand better how different methods of characterizing topology vary, this paper presents an exploration of

several different methods for assigning order within branched root systems on the basis of (a) developmental (centrifugal) vs. functional (centripetal) ordering sequences and (b) whether orders are assigned to individual links or groups of adjacent links (segments). For each ordering system, patterns of scaling in relation to various aspects of link and segment size are explored using regression analyses. Segment-based ordering systems resulted in better fits for simple scaling relationships with size, but these patterns varied between developmental vs. functional ordering as well as the different size metrics examined. The functional (centripetal), link-based ordering system showed complex, non-linear scaling in relation to numbers of links per order. Using a simple simulation model of root growth, it is demonstrated that this method of characterizing root topology in relation to root size might be a more powerful tool for characterizing root system architecture than in the use of simple, single-index characterizations of topology.

57. **Berntson GM and Bazzaz FA 1997. Elevated CO₂ and the Magnitude and Seasonal Dynamics of Root Production and Loss in *Betula Papyrifera*. *Plant and Soil* 190: 211-216.**

Keywords: *Betula papyrifera*/elevated Co₂/Fine Root Dynamics/Image Processing/White Birch/Northern Hardwood Forest/Atmospheric carbon dioxide/Fine Roots/ Ecosystems/ Turnover/ Nitrogen/ Responses/Length/*Betula papyrifera*

Abstract: The impact of elevated atmospheric CO₂ on belowground plant growth is poorly understood relative to its effects on aboveground growth. We carried out a study of the seasonal dynamics of gross root production and death to determine how elevated CO₂ affected the dynamics of net and gross root production through a full growing season. We quantified gross root production and root loss from sequential, in situ images of fine roots of *Betula papyrifera* in ambient (375 ppm.) and elevated (700 ppm) CO₂ atmospheres from 2 weeks following germination through leaf senescence. We found that elevated CO₂ led to increases in the magnitude of cumulative gross production (Sigma P) and cumulative gross loss (Sigma L) of roots. However, the effect of elevated CO₂ on these processes was seasonally dependent. Elevated CO₂ led to greater levels of enhancement in Sigma P early in the growing season, prior to maximum standing root length (NP). In contrast, elevated CO₂ led to greater levels of enhancement in Sigma L in the last half of the growing season, after maximum NP had been reached. This difference in the timing of when elevated CO₂ affects Sigma P and Sigma L led to a transitory, early enhancement in NP. By the end of the growing season, there was no significant effect of elevated CO₂ on NP, and Sigma P was 87% greater than NP for ambient CO₂ and 117% greater in elevated CO₂. We conclude that static assessments of belowground productivity may greatly underestimate gross fine root productivity and turnover and this bias can be exaggerated with elevated CO₂.

58. **Berry AB 1982. Response of suppressed conifer seedlings to release from an aspen-pine overstorey. *Forestry Chronicle* 58: 91-92.**

Keywords: artificial regeneration /underplanting /conifers /*Populus tremuloides* /*Populus grandidentata*/*Pinus strobus*/*Pinus resinosa*/*Picea glauca*

Abstract: In 1923 a thinned natural stand of *Populus tremuloides*/*P. grandidentata*/*Pinus resinosa* in Ontario was spot-sown with *P. strobus*, *P. resinosa* and *Picea glauca*. In late 1949 the overstorey was clear felled to release the pine seedlings; aspen suckers were removed from half the site in 1951. Growth of the 3 pine species increased from 3 cm/yr before release to 30 cm/yr after release. Average ht. up to 1970 was not affected by sucker removal, but ht. growth of *P. glauca* and *P. strobus* from 1970-1980 was significantly greater on the treated site.

59. **Berry AB 1981. A study in single-tree selection for tolerant hardwoods. Petawawa Natl. For. Inst. (Canada) Info. Rep. No. PI-X-8, 1 pp.**

Keywords: thinning /management /forest management /felling /selective felling/silviculture /broadleaves /silvicultural systems/*Acer saccharum*/*Fagus grandifolia*/*Tilia americana*/*Betula*

alleghaniensis

Abstract: Interim results are presented for a large-scale experiment in managing tolerant broadleaves (*Acer saccharum*, *Betula alleghaniensis*, *Fagus grandiflora* [grandifolia?] and *Tilia americana*), commenced in 1956 in Ontario, and last examined in 1978. The effects were examined of upper diam. limits of 40 and 50 cm, stocking at 140 or 210 m³/ha and felling cycles of 5 and 10 yr. Residual vol. and upper diam. limit significantly affected survival and net vol. increment, but length of felling cycle did not. Regeneration, especially that of *A. saccharum*, was satisfactory for all treatments.

60. **Berry AB and Stiel WM 1978. Effect of rotation length on productivity of aspen sucker stands. *Forestry Chronicle* 54: 265-267.**

Keywords: suckering /natural regeneration /coppicing /aboveground biomass/*Populus tremuloides* /*Populus grandidentata*

Abstract: A 7-ha area in a mixed broadleaf forest in Ontario was clear felled in 1968 and sample plots of aspen (*Populus tremuloides* and *P. grandidentata*) laid out to represent 7 rotation ages (1, 2, 3, 5, 8, 13 and 20 yr). Living suckers were counted annually, and harvested in the year prescribed by their rotation. The number of stems and biomass data are tabulated for each rotation age every year from the initial cut. Stands with 8-, 13- and 20-yr rotations experienced heavy mortality, stem numbers declining to about 20% of the initial value after 8 yr, but dry wt./ha was still increasing by the 8th yr. Stands harvested at younger ages were unable to sustain production of new coppice shoots. A rotation age of about 15 yr is recommended.

61. **Beyerhelm CD and Sando RW 1982. Regression estimation of litter and one hour timelag fuel loading in aspen-northern hardwood stands. *Forest Science* 28: 177-180.**

Keywords: fire /fire danger/broadleaves /*Populus* spp. /aspen/northern hardwoods

Abstract: Data from 10 natural stands in Minnesota were collected in June 1978, and processed using a linear regression technique that predicts the combined loading of leaf and herbaceous litter and one hour timelag woody fuels. Observed and predicted fuel loadings ranged from 3676 and 3841 kg/ha to 6236 and 6228 kg/ha, respectively. The necessary input data (b.a., density, and importance values) are easily obtained with an angle gauge, a diam. tape and a calculator.

62. **Biltonen FE, Erickson JR, and Mattson JA 1974. A preliminary economic analysis of whole-tree chipping and bark removal. *Forest Products Journal* 24: 45-47.**

Keywords: logging /economics /barking

Abstract: Presents a brief analysis comparing costs of whole-tree chipping followed by bark removal and conventional chipping of barked roundwood in the Lake States area of the USA. In batch tests the whole-tree method was estimated to cost 12% (\$3/cord) less than the conventional method, and it is proposed to continue tests with a larger pilot plant.

63. **Biltonen FE, Hillstrom WA, Steinhilb HM, and Godman RM 1976. Mechanized thinning of northern hardwood pole stands: methods and economics. U.S. For. Serv. Research Paper NC-137, 17 pp.**

Keywords: thinning /mechanization /economics /northern hardwoods /logging costs

Abstract: Five treatments were applied to plots in a natural stand in Michigan with trees from less than 2 inches up to 28 inches d.b.h.: (a) strip thinning, mechanized felling and skidding to landing; (b) selection thinning, chain-saw felling and no skidding; (c) selection thinning, mechanized felling and skidding; (d) strip thinning with selection thinning between strips, mechanized felling

and skidding to landing; and (e) shelterwood thinning, mechanized felling and skidding to landing. Performance, operating costs, non-operating costs and damage to residual stands were determined. Felling rates were 27 trees/h in (b) and mechanized felling rates ranged from 80 to 88.8 stems/h in (c) and (a), respectively. The skidder was most productive in (c) and least productive in (a). The amount of material removed was greatest in (d) and least in (a). The greatest number of injured trees/acre occurred in (a). Production costs/ton ranged from \$7.78 in (e) to \$10.87 in (a). It is concluded that it is possible to realize a profit with mechanized thinning; treatment (d) is considered the best on the basis of a compromise between productivity, silvicultural aims and operator preferences.

64. **Biltonen FE and Steinhilb HM 1975. Mechanized thinning of northern hardwoods: early results. *Northern Logger* 23: 18-19, 59.**

Keywords: thinning /mechanization /economics /chipping /skidders /tractors /northern hardwoods

Abstract: Gives results of a study to determine the economic feasibility of recovering the felled trees in a mechanized thinning operation in a northern hardwood pole stand in Michigan. Various patterns of thinning were used, with a JD 544 feller-buncher (with accumulator), Clark Ranger 667 grapple skidder, and Trellan chipper. A few sawlogs were recovered, but most residue was chipped and sold to a pulp mill. A thinning pattern of strips 10 ft wide, with selection thinning between the cut strips, appears to be most efficient. Damage to the residual stand was not excessive.

65. **Binstock DA 1984. Potential denitrification in an acid forest soil: dependence on wetting and drying. *Soil Biology and Biochemistry* 16: 287-288.**

Keywords: Nitrogen /transformation /denitrification /soil water content/forest soils/Soil types ecological

Abstract: Soil from the H-layer of a hardwood forest floor was saturated with water, allowed to drain freely for 24 h, and sampled at intervals over 14 days as the soil dried. N₂O production was determined by the acetylene block technique, as a measure of potential denitrification. As the soil dried from saturation (80.6% moisture) to 29.1% moisture, potential denitrification increased to a maximum at 75.9% moisture (field capacity), and then decreased as drying occurred. Maximum N₂O-N production was 69.2 µg NO₂-N g⁻¹ soil. This response pattern of denitrification to soil water content differs from that in agricultural soils, where N₂O production increases with increasing soil moisture content. The difference is attributed to differing water holding capacities in the two soil types.

66. **Blake JG, Hanowski JM, Niemi GJ, and Collins PT 1994. Annual variation in bird populations of mixed conifer-northern hardwood forests. *Condor* 96: 381-399.**

Keywords: birds/habitats /wildlife /vegetation types/population dynamics/northern hardwoods

Abstract: Annual variation in breeding bird populations was studied at sites in northwestern Wisconsin and in the Upper Peninsula of Michigan from 1986 to 1992. The data were used to determine the extent to which different bird species vary in abundance over time, and whether patterns of variation differ at local and regional spatial scales. Long-distant migrants (overwintering in the tropics), short distant migrants (overwintering in temperate regions) and permanent residents were considered. Although changes in total abundance of birds were comparable between states, considerable variation existed in local versus regional patterns when changes in abundance were considered at the level of migratory group or individual species. Results illustrated the importance of considering temporal variation in abundance at more than one spatial scale.

67. **Blinn CR, Sinclair SA, and Ek AR 1983. A method for estimating the multi-product value of hardwood timber stands. *Forest Products Journal* 33: 49-54.**

Keywords: sorting /roundwood /economics /assortments/Populus spp. /aspen

Abstract: A method of appraisal of standing timber is described that can be used to select the optimum mix of products from that stand. In field trials, using this method in 6 stands in the Lake States, estimated delivered product value in each stand increased as the amount of product sorting increased. Estimated delivered product value per acre for a fully sorted roundwood harvest was 25% greater than for a pulpwood only harvest. The sorted products included pulpwood, bolts for composite panel conversion, firewood, lath bolts, pallet stock sawbolts, cooperage bolts, tie bolts, sawlogs and veneer logs. Value per acre increased 46% when the residue was chipped, though in 2 stands value per cord decreased. Sorting intensity did not have as great an effect on stands with a high aspen content as on other stands.

68. **Blinn CR, Sinclair SA, Hassler CC, and Mattson JA 1986. Comparison of productivity, capital, and labor efficiency of five timber harvesting systems for northern hardwoods. *Forest Products Journal* 36: 63-69.**

Keywords: Logging /simulation /work study/economics /northern hardwoods /model - Harvesting System Simulator /harvesting productivity

Abstract: The Harvesting System Simulator was used to estimate the productivity of 4 roundwood harvesting systems and a system that produced whole-tree chips in 13 stands from the Forest Model database at Virginia Tech. The roundwood harvesting systems were evaluated under 2 product sorting intensities: pulpwood only and fully-integrated product sorting. Av. stand d.b.h. and av. number of trees per cord were highly correlated with productivity under both sorting intensities for all roundwood systems. Productivity for the whole-tree chips system was most strongly correlated with av. number of trees per acre. The system producing whole-tree chips showed the highest productivity and labour efficiency values, while a roundwood system involving felling and bucking with a chain saw, followed by transport on a forwarder to a landing, showed the highest capital efficiency. All roundwood harvesting systems used capital and labour most efficiently when operating under the fully integrated harvest.

69. **Bockheim JG 1997. Soils in a Hemlock-Hardwood Ecosystem Mosaic in the Southern Lake Superior Uplands. *Canadian Journal of Forest Research* 27: 1147-1153.**

Keywords: Northern Hardwood/ Vegetation/Tsuga canadensis/northern hardwoods /soil properties /soil chemistry /calcium/magnesium/potassium

Abstract: One of the hypotheses explaining the complex mosaic of forest cover types in the Southern Superior Uplands is soil diversity. However, the distribution of soil taxa was comparable in 37 old-growth and managed northern hardwood and hemlock (*Tsuga canadensis* (L.) Carriere) stands. Moreover, analysis of variance revealed no significant differences in basal area, effective rooting depth, forest floor mass, and diagnostic soil horizon thicknesses between the two cover types. However, the amounts of exchangeable Ca, Mg, K, and the sum of bases were significantly greater in the upper 40 cm of mineral soil beneath hemlock than beneath northern hardwoods. These differences were accompanied by a greater amount of base cations, particularly Ca, in aboveground biomass of old-growth northern hardwoods than old-growth hemlock. A large pool of base cations exists in the lower sequum of bisequal soils composing about half of the soils of the region, but tree roots may be unable to exploit these nutrients because of a dense fragipan. There were no significant differences in soil nutrient pools in old-growth and managed stands of northern hardwoods.

70. **Books DJ and Tubbs CH 1970. Relation of light to epicormic sprouting in Sugar Maple. U.S. For. Serv. Res. Note NC-93, 2 pp.**

Keywords: Acer saccharum buds/Acer saccharum habit/Epicormics /light

Abstract: Describes an experiment showing that light is not essential for the development of epicormic shoots from dormant buds on young *Acer saccharum* stems. Decapitation stimulated the production of epicormics.

71. **Borgmann KL, Waller DM, and Rooney TP 1999. Does balsam fir (*Abies balsamea*) facilitate the recruitment of eastern hemlock (*Tsuga canadensis*)? *American Midland Naturalist* 141: 391-397.**

Keywords: browsing /browsing damage/natural regeneration/establishment /population dynamics/ boreal forests/seedlings /*Abies balsamea*/*Tsuga canadensis*/deer /*Odocoileus virginianus*

Abstract: A study was undertaken during 1997 at 11 sites in Wisconsin's Northern Highland State Forest and Chequamegon National Forest to test the hypothesis that balsam fir (*Abies balsamea*) facilitates the establishment of eastern hemlock (*Tsuga canadensis*). This region is transitional between boreal and deciduous forests, containing a mixture of conifers and hardwood species. Both species occupied mesic sites on sandy loam soils with high deer (*Odocoileus virginianus*) browsing pressure. Both species were very shade tolerant, but saplings were most abundant beneath treefall gaps. *T. canadensis* saplings were three times as dense and twice as tall when growing within patches of *A. balsamea* compared to growing outside such patches. *T. canadensis* saplings growing outside *A. balsamea* patches were also 4 times as likely to exhibit deer browsing damage as those growing inside. It is suggested that patches of *A. balsamea* may create a physical or visual barrier to deer and thus provide a refuge for *T. canadensis* saplings from browsing. Because *A. balsamea* saplings are much more abundant than *T. canadensis* in northern Wisconsin forests and establish on a wider range of sites, it is suggested that foresters could use patches to facilitate local *T. canadensis* establishment and so promote restoration of this important forest type.

72. **Borken W and Brumme R 1997. Liming Practice in Temperate Forest Ecosystems and the Effects on CO₂, N₂O and CH₄ Fluxes. *Soil Use and Management* 13: 251-257.**

Keywords: Liming/Soils/Soil pH/Carbon Dioxide/Methane/Nitrous Oxide/Emission/Northern Hardwood Forest/ *Picea abies* /Microbial Biomass/Methane Consumption/Root Respiration/ Nitrous-Oxide/ Soil Cores/Oxidation/Fertilization/Carbon

Abstract: The effect of superficial liming of acidic forest soils on CO₂ and N₂O emissions and CH₄ uptake was investigated with closed chambers in two deciduous and two spruce forests, by weekly to biweekly measurements over at least one year. The flux rates of untreated areas varied between 1.94 and 4.38 t CO₂-C/ha per y, 0.28 and 2.15 kg/N₂O-N/ha per y and between 0.15 and 1.06 kg CH₄-C/ha per y. Liming had no clear effect on CO₂ emissions which may change in the long-term with decreasing root turnover and increasing C-mineralization. Apart from one exception, liming resulted in a reduction of N₂O emissions by 9 to 62% and in an increase of CH₄ uptake by 26 to 580%. The variability in N₂O emissions between the forest sites could not be explained. In contrast, the variability of annual CH₄ uptake rates could be explained by N content ($r(2) = 0.82$), C content ($r(2) = 0.77$), bulk density ($r(2) = 0.60$), pore space ($r(2) = 0.59$) and pH ($r(2) = 0.40$) of mineral soil at a depth of 0 to 10 cm, and by the quantity of material in the organic layer ($r(2) = 0.66$). Experiments with undisturbed columns of the same soils showed that between 1 and 73% of the total N₂O emissions came from the organic layer. However, atmospheric CH₄ was not oxidized in this layer, which represents a diffusion barrier for atmospheric CH₄. When this barrier was removed, CH₄ uptake by the mineral soil increased by 25 to 171%. These results suggest that liming of acidic forest soils causes a reduction of the greenhouse gases N₂O and CH₄ in the atmosphere, due to changes in the chemical, biological, and physical condition of the soils.

73. **Botkin DB and Nisbet RA 1992. Forest response to climatic change: effects of parameter estimation and choice of weather patterns on the reliability of projections. *Climatic Change* 20: 87-111.**

Keywords: global warming/Increment /basal area/growth models/ Acer saccharum/Abies balsamea/northern hardwoods /model - JABOWA-II

Abstract: The forest growth model JABOWA-II is described. Tree growth projections made by the model were tested for sensitivity to errors in model parameter estimations and the choice of weather records used to represent 'normal' conditions. Tests were conducted with data from sites in the Superior National Forest, Minnesota, an ecological transition zone between the boreal and the northern hardwood forest in N. America, where the most rapid vegetation changes due to global warming may be expected to occur. Balsam fir (*Abies balsamea*), a common dominant of the boreal forest and sugar maple (*Acer saccharum*), a common dominant of the northern hardwood forest, were chosen for the sensitivity analyses and compared for changes in basal area in response to selected weather record input data. The sensitivity analyses suggest that projections of forest response to global warming will generally be insensitive to errors of 10% in parameter estimation. Even where projections were sensitive quantitatively (for parameters which affected temperature limits of tree growth and reproduction), there was no effect on the timing of change in species abundance or on the characteristics of the entire forest. Projections were insensitive to the choice of baseline weather records, unless the warmest or coldest decades of the 20th century were used as baselines.

74. **Bourdo EA and Willis GL 1975. Borrow pit reforestation. Ford Forestry Center (Michigan Technological University) Research Note No. 17, 8 pp.**

Keywords: plantations /mined land/artificial regeneration /*Fraxinus americana* /*Juglans nigra* /*Liriodendron tulipifera* /*Robinia pseudoacacia* /*Pinus banksiana* /*Pinus resinosa* /*Picea glauca* /*Pinus rigida* /*Platanus occidentalis*

Abstract: Two plantations were established in 1958 and 1960 on a 3-acre pit after removal of gravel and crushed rock in the Upper Peninsula, Michigan; 230 seedlings of *Pinus resinosa*, *P. banksiana*, *P. rigida*, *Picea glauca*, *Robinia pseudoacacia* and a few seedlings of *Platanus occidentalis* and *Liriodendron tulipifera* were planted on the first site; on the second site 350 seedlings were planted, which included *Juglans nigra* and *Fraxinus americana* in addition to the above list. In 1975 the conifers showed 69% survival; of the hardwoods only a few *R. pseudoacacia* trees survived. It is concluded that all coniferous species, except *Pinus rigida* are able to grow vigorously on such sites. The species recommended for planting are, in order of preference, *Picea glauca*, *Pinus resinosa* and *P. banksiana*, which may act as a 'nurse' to the other two species.

75. **Bowyer JL 1979. Faceglued blockboard from low-grade northern hardwoods. *Wood and Fiber* 11: 184-196.**

Keywords: blockboard /panels /mechanical properties/economics /physical properties /*Ulmus* spp. /elm/*Populus* spp. /aspen/northern hardwoods /wood products

Abstract: A technical and economic evaluation of prospects for manufacture of face-glued blockboard from low-grade hardwoods of the United States. Face-glued blockboard was manufactured in various configurations from aspen (core) and elm (faces) and then evaluated as a general purpose structural panel. Test data indicate that blockboard panels made with a low-density hardwood core of short-length pieces would have strength and dimensional properties very similar to softwood plywood if manufactured to slightly greater thickness. Economic projections show that these thicker panels could be delivered to midwestern markets at a price very close to that of softwood plywood panels of comparable strength.

76. **Bragg DC 1999. Multi-scalar spatial modeling of northern forest dynamics: Foundations, theories, and applications. PhD dissertation, Utah State University, Logan. 507 pp.**

Keywords: deer /forest dynamics model /model - NORTHWDS /*Odocoileus virginianus*

Abstract: This dissertation describes the development and analysis of a new forest dynamics model. The NORTHern Woodland Dynamics Simulator (NORTHWDS) was designed to spatially model forest pattern and process for the northern Lake States, and to incorporate multiple spatial scales. While ecologically detailed, this stand table-based model is sufficiently parsimonious to be able to simulate 100s to 1000s of hectares for centuries. Processes like tree regeneration, growth, and mortality, herbaceous and shrubby competition, biogeochemistry, carbon cycling, edge effects, and climatic influences are incorporated in *NORTHWDS*. Wind disturbance and white-tailed deer browsing were also included to help forecast stand and landscape dynamics under managed and unmanaged scenarios. Preliminary results suggest that *NORTHWDS* can reliably predict long-term forest ecosystem responses to succession and disturbance. *NORTHWDS* was also applied to test the effectiveness of a managing-for-old-growth strategy, with results indicating that this type of management can provide improvements over traditional even- and uneven-aged harvest systems in desirable old-growth attributes like aboveground live biomass and coarse woody debris patterns. The results of the *NORTHWDS* developmental and application chapters were then synthesized to produce a new conceptual approach to landscape simulation that incorporated space, multiple scales, and a hierarchical design. A user's guide, the source code, and model defaults complete this dissertation.

77. **Bragg DC, Mroz GD, Reed DD, Shetron SG, and Stokke DD 1997. Relationship between 'birdseye' sugar maple (*Acer saccharum*) occurrence and its environment. *Canadian Journal of Forest Research* 27: 1182-1191.**

Keywords: grain and figure/occurrence /environment /stand characteristics/models /stand density/plant competition/deciduous forests/*Acer saccharum*/*Tsuga canadensis*/northern hardwoods /birdseye

Abstract: The premise was tested that the 'birdseye' grain abnormality in sugar maple (*Acer saccharum*) develops from local environmental conditions, with special emphasis on the role of competition in birdseye formation. Data were collected in 16 pairs of stands in Wisconsin and the Upper Peninsula of Michigan. Previous experience with birdseye maple frequency and the inherent differences in stand structure between old-growth and managed northern hardwoods led to stratification by stand type. Old growth contained considerably more birdseye than managed stands, but the levels in both types exceeded previously published frequencies. This study did not find greater local density (and, presumably, greater competition) surrounding birdseye maples (versus non-birdseye) in either old-growth (31.5 and 30.9 m²/ha, respectively) or managed northern hardwoods (25.0 and 23.7 m²/ha, respectively). Except for diameter, no tree variable strongly correlated with birdseye occurrence. Two plot-level variables, stand density and percent hemlock (*Tsuga canadensis*) stems, strongly correlated with stand-level birdseye frequency primarily because of differences related to stand type, not because they represented causal factors. A logistic regression model was developed to estimate the likelihood of birdseye occurrence in an individual tree. Model performance varied, with non-birdseyes being predicted more accurately than birdseye maples. No evidence in this study explicitly supported a competition-birdseye linkage, but the frequency of birdseye in old growth suggests that prolonged suppression may influence birdseye formation from the extended exposure to a highly competitive environment. Management apparently results in decreased birdseye occurrence, a trend that might be ameliorated through retention of higher residual basal area and structure similar to old-growth stands.

78. **Brandner TA, Peterson RO, and Risenhoover KL 1990. Balsam fir on Isle Royale: effects of moose herbivory and population density. *Ecology* 71: 155-164.**

Keywords: browsing damage/Natural regeneration/wildlife /*Abies balsamea* /*Alces alces*

Abstract: Balsam fir (*Abies balsamea*) population parameters in 1985 from Isle Royale National Park, Michigan, USA, were analysed to assess moose (*Alces alces andersoni*) herbivory in relation

to both population densities. Fir population parameters were determined at 9 study sites, each representing a different combination of relative fir and moose density (from 2 500 to 126 000 stems/ha, and from 0 to 5 moose/km²). In general, results showed that moose suppression of fir ht. growth and canopy recruitment increased with increasing moose density and decreasing fir density. Where fir densities were low, sapling ht. was restricted to <1 m regardless of moose density: at such sites, suppression of sapling growth had been continuous since a peak in moose population in the 1920s. At high fir density, release from growth inhibition was common following a period of low moose numbers (from mid-1970s to early 1980s); this release should facilitate recruitment of fir, and replace canopy losses due to senescence. At other sites, however, continuing canopy losses and lack of recruitment due to intensive herbivory by moose will greatly reduce the fir component of the canopy, effectively preventing any return to the fir-dominated forests of the past.

79. **Brewer R 1980. A half-century of changes in the herb layer of a climax deciduous forest in Michigan. *Journal of Ecology* 68: 823-832.**

Keywords: ground vegetation/succession /climax communities/synecology /layer structure/ *Acer saccharum*/*Fagus grandifolia*

Abstract: (1) Recent assessments of species-abundance at Warren Woods, a climax beech-sugar maple forest in Michigan, were compared with data from 1919-21 and 1933. The results indicated that the abundance of several herbaceous species had declined over the past half-century. A few, mostly species already abundant in 1919-21, had increased in abundance. (2) Most of the declining species were among the ecologically more-generalized forest herbs, but the list of currently-abundant species included species having both narrow and broad patterns of community-occurrence in Wisconsin. (3) Seasonally-low light flux seemed to be a major factor in the changes. Over half of the currently-abundant species were spring ephemerals, but only one-tenth of the species which had decreased were spring ephemerals. Physiological adaptation to shade alone seemed rarely to be a successful strategy in the undisturbed forest. (4) It is suggested that the decreases were related to the continued maintenance of dense shade, and also to its intensification as sugar maple and beech increased their dominance. The loss of larger individuals of late-leafing, shade-intolerant trees eliminated patches where herbs other than spring ephemerals could make substantial growth before the canopy closed. (5) The study supported the view that recurrent disturbance tends to preserve diversity, but gap phase regeneration did not seem to be important in the process. (6) A decreasing rate of change suggested that the forest might be approaching a steady state in herbaceous composition, but at a lower diversity than is usual in the climax stage of such forests.

80. **Briggs GM, Jurik TW, and Gates DM 1986. Non-stomatal limitation of CO₂ assimilation in three tree species [*Quercus rubra*, *Acer rubrum* and *Populus grandidentata*] during natural drought conditions. *Physiologia Plantarum* 66: 521-526.**

Keywords: photosynthesis /transpiration /carbon dioxide/Drought /foliage /environment /Plant water relations/trees /*Acer rubrum*/*Quercus rubra*/*Populus grandidentata*

81. **Brown D 1994. The development of woody vegetation in the first 6 years following clear-cutting of a hardwood forest for a utility right-of-way. *Forest Ecology and Management* 65: 171-181.**

Keywords: power lines/suckering /plant succession/seedlings /natural regeneration/assessment /rights of way/raspberries /*Acer saccharum*/*Prunus serotina*/*Fraxinus americana*/*Populus tremuloides* / *Rubus idaeus*

Abstract: A summary is presented of a study of woody vegetation growth, which analysed stump survival, sprout survival, and the relative importance of seedlings, sprouts and suckers in canopy development. In autumn 1984, a sugar maple (*Acer saccharum*), white ash (*Fraxinus americana*), trembling aspen (*Populus tremuloides*) and black cherry (*Prunus serotina*) woodlot NE of Toronto,

Ontario, was clear-cut for the construction of a transmission right-of-way. Woody species were rapidly re-established, and increased from a density of 4.5 stems/m² (in spring 1985) to a maximum of 31.8 stems/m² (in autumn 1986). Initial re-growth was dominated by black cherry and white ash seedlings, followed by proliferation of trembling aspen suckers and growth of choke cherry (*Prunus virginiana*) and raspberry (*Rubus idaeus*) seedlings. By the sixth year, trembling aspen and choke cherry density had been reduced, white ash density had increased, and overall stem density was reduced to 22.1 stems/m². Relative densities of tree seedlings and sprouts were similar; sprouts were considerably taller, however, and represented the major source of revegetation. In a study of sprouts and suckers from the stumps of 317 trees, the most prolific sprouters, black cherry and white ash, exhibited the highest stem mortality, while the poorest sprouter (sugar maple) experienced better survival. After 6 yr, sprout numbers were converging on a range of five to seven stems per stump, irrespective of species. Height growth was greatest in the first year and was reduced thereafter. Black cherry and trembling aspen had the greatest growth rates and white ash the lowest. Growth was correlated to parent tree height and diameter for maple and aspen; the ability to predict growth from these parameters, however, was very poor.

82. **Brown SE 1999. *Production dynamics and climate in four northern hardwood stands located in Michigan*. PhD dissertation, Michigan Technological University, Houghton. 63 pp.**

Keywords: *Acer saccharum*/northern hardwoods /climate /forest productivity /aboveground productivity /canopy dynamics /belowground productivity /root respiration

Abstract: Studies have linked changes in climate to changes in forest production. To address the impact of climate on above- and belowground production, estimates of root respiration and measurements of canopy dynamics and aboveground woody production were recorded in four northern hardwood forests dominated by sugar maple (*Acer saccharum* Marsh.) over ten years (1989-1998). The stands extend along a 500 km latitudinal gradient from northern to southern Michigan and have similar soils, physiography, stand structure, and species composition. Rates of fine root respiration were estimated using climatic data collected from these stands. Over the lifetime of the root, assuming no acclimation to higher temperatures, the fine root system becomes a significant sink for carbohydrates during warm, wet periods. However, results illustrate how little is known about the environmental controls regulating root maintenance costs and mortality rates. Relationships among climate, leaf duration, litter production, and aboveground woody growth were also examined for these forests. Year-to-year differences in climate appear important in controlling shoot dynamics, especially leaf duration. However, aboveground woody production across years and sites was not strongly related to any aspect of climate or canopy dynamics, and was too variable to be predicted by any combination of these variables. This variability in aboveground woody production suggests that it is unlikely that changes in production at these sites will be predicted using models incorporating climate change scenarios.

83. **Brown SE, Pregitzer KS, Reed DD, and Burton AJ 2000. Predicting Daily Mean Soil Temperature From Daily Mean Air Temperature in Four Northern Hardwood Forest Stands. *Forest Science* 46: 297-301.**

Keywords: climate/ecosystem monitoring/sugar maple/root respiration/ climate/ ecosystems/ nitrogen/ mineralization/vegetation/gradient/decline/*Acer saccharum*/northern hardwoods /soil temperature /model - soil temperature

Abstract: Soil temperature is very important in regulating ecosystem processes, yet it is often difficult and costly to measure. Most models that have endeavored to predict soil temperature have either a long time step or several complicated independent variables. Daily mean air and soil temperatures were measured from 1989-1997 in four northern hardwood sites along a 500 km latitudinal gradient in Michigan. These data were used to derive a simple method to predict daily mean soil temperature (depth of 15 cm) using the daily mean air temperature from the previous day and a cosine function of Julian date ($R^2 = 0.93-0.96$; SEM = 0.98-1.40 degreesC). Predicted values were compared with actual recorded soil temperatures from 1997 at each of the sites, and

the average difference between the observed and predicted values ranged from 0.11 to 0.39 degreesC, Different coefficients were estimated for each of the sites; however, this general method of predicting soil temperature appears applicable to any site. Once calibrated for a given site, soil temperature may be simply estimated, thus reducing the need for extended monitoring efforts. This method also allows the reconstruction of soil temperature records beyond the monitoring period. Projecting long-term trends in soil temperature may help to further elucidate several ecosystem processes and also may provide more information on how a changing global climate will impact forest ecosystems.

84. **Brown SL, Schroeder P, and Kern JS 1999. Spatial Distribution of Biomass in Forests of the Eastern USA. *Forest Ecology and Management* 123: 81-90.**

Keywords: aboveground biomass/belowground biomass/biomass distribution/carbon cycle/disturbance/ hardwood forests/softwood forests/model/storage/cycle

Abstract: We produced a map of the biomass density and pools, at the county scale of resolution, of all forests of the eastern US using new approaches for converting inventoried wood volume to estimates of above and belowground biomass. Maps provide a visual representation of the pattern of forest biomass densities and pools over space that are useful for forest managers and decision makers, and as databases for verification of vegetation models. We estimated biomass density and pools at the county level from the USDA Forest Service, Forest Inventory and Analysis database on growing stock volume by forest type and stand size-class, and mapped the results in a geographic information system. We converted stand volume to aboveground biomass with regression equations for biomass expansion factors (BEF; ratio of aboveground biomass density of all living trees to merchantable volume) versus stand volume. Belowground biomass was estimated as a function of aboveground biomass with regression equations. Total biomass density for hardwood forests ranged from 36 to 344 Mg ha⁻¹, with an area-weighted mean of 159 Mg ha⁻¹. About 50% of all counties had hardwood forests with biomass densities between 125 and 175 Mg ha⁻¹. For softwood forests, biomass density ranged from 2 to 346 Mg ha⁻¹, with an area-weighted mean of 110 Mg ha⁻¹. Biomass densities were generally lower for softwoods than for hardwoods; ca. 40% of all counties had softwood forests with biomass densities between 75 and 125 Mg ha⁻¹. Highest amounts of forest biomass were located in the Northern Lake states, mountain areas of the Mid-Atlantic states, and parts of New England, and lowest amounts in the Midwest states. The total biomass for all eastern forests for the late 1980s was estimated at 20.5 Pg, 80% of which was in hardwood forests.

85. **Bruhn JN, Pickens JB, Richter DL, and Mihail JD 1995. Effects of litter bulking and bagging on decomposition in northern Michigan hardwoods and associated clearcuts. *Pedobiologia* 39: 264-276.**

Keywords: decomposition /fragmentation /litter /plantations/deciduous forests/forest litter/Acer rubrum/Quercus rubra/Pinus resinosa

Abstract: Effects of bulking, bagging and fragment loss on dry matter mass retention were studied with fresh-fallen pine (*Pinus resinosa*), oak (*Quercus rubra*) and maple (*Acer rubrum*) leaf litter at a site in Michigan. Samples were placed mid-December in 2-yr-old pine plantations and hardwood stands, and were retrieved monthly without replacement, from May to October in the following year. Significant mass loss occurred in June to September. Maple leaves decomposed faster than oak or pine, regardless of fragment loss. Litterbags (3 mm aperture) retained enough leaf fragments to provide results similar to non-bagged pine and oak leaves retrieved without fragment loss. Litterbags did not affect moisture content. Bulking had no effect (pine and oak) or little effect (maple) on mass loss, compared with individual leaves retrieved without fragment loss. Decomposition was faster in the plantations than in the associated hardwoods, even after greater fragmentation in the plantations was considered. Initial leaf density (as a measure of leaf quality) did not explain patterns of decomposition or fragment loss. Faster decomposition in the plantations was attributed to a moderately warmer environment. Greater fragmentation in the

plantations was attributed to greater physical wind and solar energy inputs, compared to the more protected hardwoods environment.

86. **Bruhn JN, Pickens JB, and Stanfield DB 1991. Probit analysis of oak wilt transmission through root grafts in red oak stands. *Forest Science* 37: 28-44.**

Keywords: wilts /roots /root systems/spread /models /techniques/ plant pathology/plant pathogenic fungi/*Quercus rubra*/*Quercus ellipsoidalis* /*Ceratocystis fagacearum* /soil texture

Abstract: In pure stands of red oak species (subgenus *Erythrobalanus*) in Michigan's Upper Peninsula, individual oak wilt (*Ceratocystis fagacearum*) epicenters appear to expand virtually exclusively by movement of the pathogen through root grafts between diseased and healthy trees. Containment of individual disease epicenters can be accomplished by a combination of timely separation of grafted root systems and sanitation (to prevent overland establishment of new epicenters). Disease spread models were developed by probit analysis of field data, obtained from pure stands of northern pin oak (*Quercus ellipsoidalis*) during 1987-89. These models predict the probability that the oak wilt fungus will spread across root grafts to a healthy (target) tree during the year after symptoms occur in a neighbouring diseased (source) tree. Movement of the fungus was best predicted by a logarithmic transformation of the quotient obtained by dividing the sum of the diameters for the potential source and target trees by the distance between these trees. Multiple-stemmed source or target trees were accurately represented by the sum of the diameters of their component stems. Soil type was found to influence the relationship, presumably through its effect on rooting habit. Oak root systems appear to extend over greater distances through soils of the deeper and more uniformly sandy Grayling series than through those of the loamier Pemene series. The specific models developed depend on site-related data, and therefore should not be applied in other areas. However, the modelling approach is of general applicability and can be used to predict root graft spread of oak wilt in other areas.

87. **Bruner HD and Moser JW Jr. 1973. A Markov chain approach to the prediction of diameter distributions in uneven-aged forest stands. *Canadian Journal of Forest Research* 3: 409-417.**

Keywords: stand characteristics/age structure /model - diameter distribution

Abstract: Presents a simple stochastic model to predict future diameter distributions and the numbers of trees that survive, die or are harvested, based on data collected in 19 consecutive years from a mixed hardwood stand in central Wisconsin. Results indicate that tree survival can be predicted very accurately, but that predictions of the other variables are less accurate. The length of the prediction period is limited to multiples of the remeasurement period (interval between measurements). [Cf. FA 31, 1175].

88. **Buckley DS, Sharik TL, and Isebrands JG 1998. Regeneration of northern red oak: positive and negative effects of competitor removal. *Ecology* 79: 65-78.**

Keywords: frost /regeneration /scrub control/plant competition/browsing damage/wild animals/ population dynamics/shading /soil water/stress /soil temperature/mortality /survival /seedlings /canopy / understorey /clear felling/frost injury/natural regeneration/*Quercus rubra*/*Pinus resinosa*/ deer /*Odocoileus virginianus*

Abstract: The decreased ability of northern red oak (*Quercus rubra*) to regenerate throughout its range in the eastern United States has important ecological and economic implications. Regeneration was studied of northern red oak in oak and pine stands on moderately productive sites in northern Lower Michigan, USA. Northern red oak acorns and 2-year-old nursery seedlings were sown/planted in spring 1991 in 3 natural oak stands and 3 red pine (*Pinus resinosa*) plantations on comparable, moderately productive sites. Each stand contained 4 canopy cover treatments: clear-felled, 25% cover (50% the first year), 75% cover, and uncut. Each canopy cover treatment contained 4 understorey treatments: herb-layer removal, shrub-layer removal, plant litter

removal, and control. Seedling survival, performance, and damage due to deer and late spring frosts were quantified along with vegetation characteristics, light, soil moisture, air temperature, soil temperature, and precipitation during 1991 and 1992 growing seasons. Survival of seedlings was significantly lower in pine than in oak stands: the pine stands had a higher incidence of white-tailed deer (*Odocoileus virginianus*) browsing and lower levels of belowground resources than the oak stands. Canopy cover treatments produced a gradient from high stress (low light and soil moisture) and low disturbance (slight browsing and frost damage) in uncut plots to low stress (high light and soil moisture) and high disturbance (high browsing and frost damage) in clear-felled plots. Understorey vegetation development and soil temperature were low in uncut plots, high in clear-felled plots, and intermediate in plots with partial overstorey removal. Despite poor growth, the mortality of seedlings planted in uncut plots was low. In contrast, mortality was high and surviving seedlings exhibited good growth in clear-felled plots. Understorey treatment effects were slight compared with overstorey treatment effects. The results did not support the hypothesis that regeneration success of northern red oak may be greater in pine than in oak stands and indicated that the positive effects of removing potential competitors on seedling growth and physiological status may be compromised by the simultaneous negative effects of browsing and frost damage.

89. **Buongiorno J, Dahir S, Lu HC, and Lin CR 1994. Tree size diversity and economic returns in uneven-aged forest stands. *Forest Science* 40: 83-103.**

Keywords: forest management/rotations /silvicultural systems/selective felling/stand structure/diameter / growth models/simulation /returns /forest economics/sustainability /biodiversity /northern hardwoods

Abstract: A method is presented to predict some of the effects of forest management on the tree size diversity of forest stands, measured with the Shannon-Wiener index applied to diameters. Diameter distribution is an indicator of stand structure and a determinant of biological diversity. The method, which involves linear and nonlinear programming models of managed stands, was applied to data for northern hardwood forests in Wisconsin. The attendant stand growth model was calibrated and validated with remeasured plots. The results suggest that, in this specific case, a natural, undisturbed stand would reach the greatest possible sustainable diversity of tree size. Any intervention would decrease that diversity. In particular, economic harvesting policies would reduce tree size diversity by 10 to 20%, depending on the length of the cutting cycle. However, economics and diversity did not necessarily conflict. With the data and model used here, lengthening the cutting cycle up to 30 yr led to greater tree size diversity, while it also increased the soil rent of a stand by decreasing the present value of the cost of re-entry. Similarly, for a given cutting cycle, the soil rent increased with tree size diversity up to about 90% of the sustainable maximum, but decreased sharply thereafter. Real internal rates of return of 2 to 4% could be earned with stands that had either mediocre or very good levels of diversity. Likewise, starting from the same initial stand state, proper choice of a cutting guide could lead to much greater levels of tree size diversity, without decreasing forest value.

90. **Buongiorno J and Hseu JS 1993. Volume and value growth of hardwood trees in Wisconsin. *Northern Journal of Applied Forestry* 10: 63-69.**

Keywords: volume /increment /equations /quality /prices /roundwood /wood products/hardwoods /*Acer saccharum*/*Quercus rubra*/*Ulmus americana*/*Populus tremuloides*/*Betula alleghaniensis* /*Acer saccharinum* /*Acer rubrum*

Abstract: The volume of healthy trees of commercial size in the maple-birch forest type measured during the last two Forest Inventory Analysis surveys of Wisconsin grew at 2 to 3%/yr for sawtimber, and 3 to 4% for poletimber, with substantial differences among species. However, from 1967 to 1989, the real price of logs decreased or remained constant for most grades and species. The decrease was especially large for high grade logs. The only exceptions were red oak [*Quercus rubra*] and elm [*Ulmus americana*], whose prices increased at 1 to 2%/yr, for all grades.

As a result, the average value growth rate of the trees that did not improve in grade was a modest 2%/yr, and not different from zero at a 5% significance level. Holding high grade trees led to substantial losses. Red oak and elm provided good returns because of favourable price trends, and quaking aspen [*Populus tremuloides*] because of its fast volume growth. Among the worst financial performers were hard maple [*Acer saccharum*] and soft maple [*Acer saccharinum*/*A. rubrum*], and yellow birch [*Betula alleghaniensis*], the most numerous trees in the sample. A simple equation was derived to predict volume growth rates as a function of tree diameter, site index, crown ratio, stand basal area, crown dominance, and tree species. Although these variables did influence volume growth, suggesting that silvicultural practices could be beneficial, they explained only a small part of volume growth, and less of value growth. It is concluded that the future of commercial forestry in Wisconsin depends at least as much on policies that will develop markets and obtain good prices as on improved silviculture.

91. **Buongiorno J, Kolbe AE, and Vasievich M 2000. Economic and Ecological Effects of Diameter-Limit and Bdq Management Regimes: Simulation Results for Northern Hardwoods. *Silva Fennica* 34: 223-235.**

Keywords: Uneven-Aged Management/Simulation/Economics/Diversity/Matrix Growth-Model/Tree Diversity/Forests/Vegetation/Returns/Stand/Income/northern hardwoods

Abstract: The long-term financial and ecological effects of diameter- limit regimes and basal-area-diameter-q-ratio (BDq) regimes were compared by simulation in the case of northern hardwood forests. Varying the cutting cycle between 10 and 20 years had little effect on returns or stand structure. A 28-cm diameter- limit cut gave the highest production and financial returns, and the highest species diversity, but considerably lower size diversity. A 38-cm diameter-limit cut and a heavy BDq selection harvest gave high returns, while maintaining high levels of diversity. On lands of equal site quality, Michigan's stands were more productive than Wisconsin's. The results suggest that it is possible to manage northern hardwood stands sustainably with diameter-limit cuts, combined with removal of poorly performing understory trees. Adjusting the diameter limit gave rise to stands similar in productivity and structure to those obtained by BDq cutting regimes. Given their simplicity of implementation and monitoring, more attention should be given to diameter-limit cutting regimes, with attendant stand improvement measures, as a practical means for uneven-aged management of northern hardwoods.

92. **Buongiorno J and Lu HC 1990. Economic stocking and cutting-cycle in a regulated selection forest. *Forest Ecology and Management* 32: 203-216.**

Keywords: Broadleaves /Silvicultural systems/selection /economics /forest economics/silviculture /simulation /model

Abstract: A theoretical model was developed to determine the best cutting policy (cutting cycle and residual stock) in a regulated selection or uneven-aged forest by a simple modification of the objective function in a linear-programming model of a non-regulated stand. The parallel between determination of the best rotation in an even-aged regulated forest and that of the cutting cycle in an uneven-aged regulated forest was apparent. This conceptual model could be applied to a wide variety of situations, including selective management of natural tropical forests. The model was applied to data for northern broadleaf forests in Wisconsin, USA, using 1985 prices. Results showed that regulating an uneven-aged forest for annual production had a cost, compared with cutting the entire forest at intervals equal to the cutting cycle. Cost of regulation increased with fixed cost (cost per ha of preparing and administering a harvest). Results also showed that choice of a cutting cycle in uneven-aged forests was critical only when fixed costs were low. Particular attention was given to the loss that would occur by computing best cutting cycle and residual stock of a regulated forest as if it were not regulated: this loss was small, except at extreme interest rates and fixed costs. For all practical purposes, best cutting cycle and residual stock could be computed for a regulated forest while ignoring cost of regulation.

93. **Buongiorno J and Lu HC 1989. Effects of costs, demand, and labor productivity on the prices of forest products in the United States, 1958-1984. *Forest Science* 35: 349-363.**

Keywords: forest products industries/prices /economics /wages /labour /model

Abstract: In order to study the reasons for changes in the prices of forest products, a mark-up model of price formation was proposed that linked yearly price changes to changes in variable costs and in demand. This model was estimated with annual data on prices, variable costs, and inventory/output ratios, from 1958 to 1984. Four solid wood industries and three pulp and paper industries of the United States were studied. Results showed that, depending on the industry, the theory explained 83 to 98% of the variation in annual price changes. Rises and declines of variable costs had symmetric effects on prices, except for pulp mills, the most concentrated industry, in which downward-price inflexibility was apparent. Decomposition analysis showed that during 1958-84, the rise in variable costs explained most of the rise in product prices. Further decomposition indicated that within variable costs, increases in material costs led to increases in prices that were much higher than those due to labour costs. Finally, in no industry did the increase in labour productivity compensate for the rise in the wage rate, so that increases in wages also contributed to the general inflation in forest product prices. To improve their competitiveness, the forest products industries should strive to control material costs and increase their labour productivity.

94. **Buongiorno J and Michie BR 1980. A matrix model of uneven-aged forest management. *Forest Science* 26: 609.**

Keywords: forest management /computer techniques/Acer saccharum /model

Abstract: The parameters of the model represent (a) the stochastic transition of trees between diam. classes and (b) ingrowth of new trees, and were estimated using data from broadleaved stands (mainly sugar maple) in Wisconsin and Michigan. The model was used to predict long-term growth of undisturbed and managed stands. It showed that undisturbed growth would lead to dampened oscillations of the diam. distribution tending slowly towards an equilibrium. A linear programming method was used to determine sustained-yield management regimes which would maximize the net value of periodic harvests. Opt. harvest, residual stock and felling cycle could be jointly determined; length of felling cycle depended on fixed harvesting costs/ha. Marking guides were simple, suggesting removal of all trees in specific diam. classes.

95. **Buongiorno J and Young T 1984. Statistical appraisal of timber with an application to the Chequamegon National Forest. *Northern Journal of Applied Forestry* 1: 72-76.**

Keywords: Timber trade/model /economics

Abstract: The method involves predicting the highest bid for a particular timber offering under competitive conditions and adjusting this value to reflect uncertainty and the goals of the selling agency. Using data from the Chequamegon National Forest, N. Wisconsin, a simple linear model using 14 variables explained 93% of the variance in highest bid for competitive sales during 1976-80. The model predicted well the highest bids for 1981-82. Three definitions of appraised value were investigated and the consequences of applying each definition to timber sales in 1981-82 were examined. Setting appraised value to predicted highest bid or predicted highest bid minus one standard error of estimates would have increased receipts by 28 and 5%, respectively, while decreasing the vol. sold by 5 and 3.6%. An appraised value of the predicted highest bid minus two standard errors would have led to the sale of approx. the same vol., but a decrease in receipts of 26%.

96. **Burgess D, Wetzel S, and Baldock J 2000. White/red pine stand response to partial cutting and site preparation. *Journal of Sustainable Forestry* 10: 221-227.**

Keywords: site preparation/thinning /natural regeneration/artificial regeneration / silviculture /chemical control/herbicides /glyphosate /advance growth/establishment /brush control/woody plants/survival /Pinus strobus/Pinus resinosa

Abstract: The effects of commercial thinning and site preparation treatments on pine regeneration were evaluated in a 110-year-old pine stand with 87.5% white (*Pinus strobus*) and red (*P. resinosa*) pine within the Petawawa Research Forest, Chalk River, Ontario. Main treatment plots, established in early 1994 were (1) thinning to one-crown width between trees; (2) thinning to two-crown widths; and (3) control (uncut). Four site preparation treatments were applied to subplots: (a) blade scarification (in August 1994); (b) brush control using the herbicide Vision [glyphosate] in September 1995; (c) blade scarification and brush control; and (d) untreated. Half the subplots were planted with white pine container-grown seedlings in spring 1995, and the remainder were left to regenerate naturally. Regeneration surveys were completed in autumn 1995-96. Early results show that partial cutting in mature pine stands is possible without causing damage to residual trees. Wind throw losses were small. Scarification exposed 75-81% of the surface mineral soil and increased pine (mainly white pine) regeneration and stocking, but also increased seedling numbers for some major competitors. Brush control had little effect on regeneration numbers and no effect on pine stocking. The planted white pine seedlings had a high survival rate. Scarification improved pine regeneration most in the unthinned treatment, suggesting that advance regeneration of white pine could be encouraged before thinning. Red pine has infrequent seed years and is more difficult to regenerate naturally.

97. **Burton AJ, Hart JB, and Urie DH 1990. Nitrification in sludge-amended Michigan forest soils. *Journal of Environmental Quality* 19: 609-616.**

Keywords: nitrogen /nitrification /forest soils/sewage sludge/soil types ecological/manures /soil chemistry/fertilizers /sewage /soil /pines /Populus spp. /aspen/northern hardwoods /Pinus spp.

Abstract: Net nitrification following liquid sludge application to four Michigan forest types was studied by aerobically incubating intact cores containing the forest floor and upper 10 cm of mineral soil. Significant net nitrification occurred in cores receiving surface applications of anaerobically digested municipal sludge (22.3 g N m⁻²). Core NO₃-N contents at 8 wk were 4.7, 5.3, 4.9, and 2.0 g m⁻² for aspen (*Populus* spp.), northern hardwoods, oak (*Quercus* spp.), and pine (*Pinus* spp.) forest types respectively. Net nitrification did not occur during 8-wk incubations of untreated control cores or cores receiving surface applications of sludge sterilized by freeze-drying (24.5 g N m⁻²) or liming (25.7 g N m⁻²), suggesting that the nitrifiers responsible for net nitrification in cores receiving the anaerobically digested sludge were added with the sludge. Nitrate content at 8 wk in cores from an oak field site receiving anaerobically digested sludge (43.0 g N m⁻²) 33 months prior to incubation was 72% of that in oak site soil cores treated immediately prior to incubation (22.3 kg N m⁻²), indicating that nitrifying populations introduced with sludge 33 months prior were still viable. Nitrate content at 8 wk in oak cores was 77% lower when sludge was incorporated. Nitrate contents in incubated soil cores could not be used to predict NO₃ concn directly in soil leachate and groundwater beneath sludge-treated plots at the four field sites. Results indicate that nitrification and potential for NO₃ leaching following sludge application to acid forest soils are influenced by sludge type, forest type, and history of prior sludge applications.

98. **Burton AJ, Pregitzer KS, and Hendrick RL 2000. Relationships Between Fine Root Dynamics and Nitrogen Availability in Michigan Northern Hardwood Forests. *Oecologia* 125: 389-399.**

Keywords: sugar maple/root longevity/root production/root mortality/carbon allocation/ belowground carbon allocation/deposition gradient/soil environment/organic matter/spruce stand/ Douglas fir/leaf area/life span/turnover/*Acer saccharum*/northern hardwoods /*Picea* spp. /*Pseudotsuga menziesii*

Abstract: Minirhizotrons were used to observe fine root (less than or equal to 1 mm) production,

mortality, and longevity over 2 years in four sugar-maple-dominated northern hardwood forests located along a latitudinal temperature gradient. The sites also differed in N availability, allowing us to assess the relative influences of soil temperature and N availability in controlling fine root lifespans. Root production and mortality occurred throughout the year, with most production occurring in the early portion of the growing season (by mid-July). Mortality was distributed much more evenly throughout the year. For surface fine roots (0-10 cm deep), significant differences in root longevity existed among the sites, with median root lifespans for root cohorts produced in 1994 ranging from 405 to 540 days. Estimates of fine root turnover, based on the average of annual root production and mortality as a proportion of standing crop, ranged from 0.50 to 0.68 year⁻¹ for roots in the upper 30 cm of soil. The patterns across sites in root longevity and turnover did not follow the north to south temperature gradient, but rather corresponded to site differences in N availability, with longer average root lifespans and lower root turnover occurring where N availability was greater. This suggests the possibility that roots are maintained as long as the benefit (nutrients) they provide outweighs the C cost of keeping them alive. Root N concentrations and respiration rates (at a given temperature) were also higher at sites where N availability was greater. It is proposed that greater metabolic activity for roots in nitrogen-rich zones leads to greater carbohydrate allocation to those roots, and that a reduction in root C sink strength when local nutrients are depleted provides a mechanism through which root lifespan is regulated in these forests.

99. **Burton AJ, Pregitzer KS, and MacDonald NW 1993. Foliar nutrients in sugar maple forests along a regional pollution-climate gradient. *Soil Science Society of America Journal* 57: 1619-1628.**

Keywords: vegetation types/ /nutrient deficiencies/foliage /leaves /forest litter/ soil chemistry/acid deposition/aluminum /sulfur /plant nutrition/air pollution/climate /forest decline/ *Acer saccharum*/ northern hardwoods /disturbance /nitrogen /phosphorus /sulfur/calcium /magnesium /potassium /aluminum /iron/manganese /zinc /copper /boron

Abstract: Stressing agents such as defoliation, adverse climatic conditions, and pollutant deposition have the potential to alter forest nutrition. Several recent instances of sugar maple (*Acer saccharum*) decline and dieback have been associated with foliar nutrient deficiencies. This study assessed foliar nutrient status and cycling in 5 sugar maple dominated northern hardwood forests along a Great Lakes pollution (H, SO₄ and NO₃)-climatic gradient extending from NE Minnesota to central lower Michigan. Concentrations and contents in mid-July foliage and litterfall were determined at each site for N, P, S, Ca, Mg, K, Al, Fe, Mn, B, Zn, and Cu. Where differences existed among sites in foliar nutrient concentrations, they could be predicted primarily from soil properties. Two notable exceptions were foliar S, which was strongly related to SO₄ deposition, and foliar Al, which could be predicted by a combination of soil nutrient cation availability and SO₄ deposition. Nutrient content of mid-July foliage and litterfall increased from NW to SE along the gradient for N, S, Mg, Al, Fe, B, and Cu. This was the result of an increase in foliage and litterfall biomass, combined in some cases (S, Al, Fe, and B) with increasing foliar nutrient concentrations. Reproductive effort significantly affected total litter return of all nutrients, and 43-62% of mid-July foliar N, P, K, and S were conserved through retranslocation prior to litterfall. Sugar maple foliar nutrient concentrations for the 5 sites revealed no obvious nutrient deficiencies or toxicities, and provide a regional baseline against which the effects of long-term pollutant deposition and other stresses can be assessed in the future.

100. **Burton AJ, Pregitzer KS, and Reed DD 1991. Leaf area and foliar biomass relationships in northern hardwood forests located along an 800 km acid deposition gradient. *Forest Science* 37: 1041-1059.**

Keywords: Acid deposition/increment /Foliage /leaf area index/pests //Biomass /equations /Forest litter/measurement /seed production/seed years/*Acer saccharum*/ northern hardwoods

Abstract: The canopies of northern broadleaved forests dominated by sugar maple (*Acer saccharum*) were examined at five locations spanning 800 km along an acid deposition and

climatic gradient extending from S. Michigan to NE Minnesota. Leaf area index (LAI) calculated from litterfall ranged from 6.0 to 8.0 in 1988, from 4.9 to 7.9 in 1989, and from 5.3 to 7.8 in 1990. The data suggest that maximum LAI for the sites is between 7 and 8. Insect defoliation and the allocation of assimilates to reproductive parts in large seed years reduced LAI by up to 34%. Allometric equations for leaf area and foliar biomass were not significantly different among sites; they predicted higher LAI values than were estimated from litterfall and could not account for the influences of defoliation and seed production. Canopy transmittance was a viable alternative for estimating LAI. Extinction coefficients (K) of 0.49 to 0.65 were appropriate for solar elevations of 63° to 41°. Patterns of specific leaf area (SLA) were similar for all sites. Average sugar maple SLA increased from 147 cm²/g in the upper 5 m of the canopy to 389 cm²/g in the seedling layer. Litterfall SLA averaged 196 cm²/g for all species and 192 cm²/g for sugar maple. Similarity among the sites in allometric relationships, maximum LAI, canopy transmittance, and patterns of SLA suggests that these characteristics were controlled primarily by the similar nutrient and moisture availability at the sites rather than by differences in length of growing season or levels of acid deposition. A general increase in litter production along the acid deposition gradient could not be attributed to N deposition or length of growing season, because there was so much year to year variation resulting from insect defoliation and seed production.

101. **Burton AJ, Pregitzer KS, Zogg GP, and Zak DR 1998. Drought Reduces Root Respiration in Sugar Maple Forests. *Ecological Applications* 8: 771-778.**

Keywords: Acer saccharum/carbon allocation/drought/nitrogen concentration/root respiration/soil moisture/soil temperature/stand level respiration/sugar maple/northern hardwoods/fine root/climate change/regional applications/ecosystem processes/soil temperature/carbon balance/daily patterns/general model/water status

Abstract: Soil moisture deficits can reduce root respiration, but the effects have yet to be quantified at the stand level or included in models of forest carbon budgets. We studied fine- root (less than or equal to 1.0 mm diameter) respiration in four sugar maple forests for three growing seasons in order to assess the combined effects of temperature, N concentration, and soil moisture on respiration rates. Fine-root respiration at the four sites was exponentially related to soil temperature and linearly related to root N concentration and soil moisture availability. Most of the variability in respiration rates was explained by temperature. Differences in soil moisture availability explained temporal variation within sites in respiration rate at a given temperature, whereas differences among sites in respiration rates resulted from site-specific differences in fine-root N concentration. Periodic moisture deficits during 1995 and 1996 were sufficient to cause declines of up to 17% in total growing-season root respiration at affected sites. Estimated reductions in respiration of up to 0.8 Mg C/ha during dry years were equivalent to a significant portion of annual aboveground woody biomass C increment, arguing for the inclusion of soil moisture availability as a predictor of root respiration when modeling C allocation in forest ecosystems.

102. **Burton AJ, Pregitzer KS, Zogg GP, and Zak DR 1996. Latitudinal variation in sugar maple fine root respiration. *Canadian Journal of Forest Research* 26: 1761-1768.**

Keywords: roots /soil temperature/plant composition/nitrogen /deposition /climatic change/latitude /plant physiology/climate /Acer saccharum

Abstract: A changing global climate may affect the respiration of fine roots. While many models adjust fine root respiration as temperature increases, the influence of soil nutrient availability and the possibility that root respiration may be adapted to local climate are often not addressed. Rates of fine root respiration were measured in four sugar maple (*Acer saccharum*) forests located along a latitudinal gradient in Michigan. Root respiration was measured as O₂ consumption at temperatures ranging from 6 to 24°C on excised fine root samples in early September, October, and November 1994. Root respiration increased exponentially with temperature with an average Q₁₀ of 2.7; there were no differences in Q₁₀ among sites. However, there were differences among

sites in mean respiration rate at a given temperature. This site effect did not indicate ecotypic adaptation to local climate, but rather reflected fine root N concentration. Respiration at a given temperature was consistently higher in roots with higher N concentrations, and higher root N concentrations always occurred at sites having greater N mineralization rates. Results suggest increases in soil temperature could significantly alter root respiration C flux at these sites, as could changes in site N availability associated with chronic N deposition or altered N mineralization resulting from global climate change.

103. **Butler-Fasteland MC and Alm AA 1984. Mechanical site preparation and regeneration practices in northern Minnesota. *Northern Journal of Applied Forestry* 1: 26-29.**

Keywords: site preparation/artificial regeneration/mechanical methods /survey

Abstract: A questionnaire was sent to county, state, federal and industrial forest management agencies in 1982. Results provided data on site preparation method, time of completion, logging system, species planted, type of stock used and spacing used on 12 500 acres on 330 sites in 1981.

104. **Campbell DR, Duthie HC, and Warner BG 1997. Post-glacial development of a kettle-hole peatland in southern Ontario. *Ecoscience* 4: 404-418.**

Keywords: pollen /palaeoecology /peatlands /wetlands /forest ecology/plant succession/natural regeneration/soil water/climate /climatic change/*Larix laricina* /*Fraxinus nigra*/*Pinus strobus* /*Betula papyrifera* /*Acer saccharum* /*Ilex verticillata* /*Acer saccharinum* /*Nemopanthus mucronata* /*Sphagnum*

Abstract: A kettle-hole peatland in southern Ontario was examined in a 2 core, multi-component palaeoecological study to determine the relative importance of external and internal factors in its long-term development. Dated sediment stratigraphies, loss-on-ignition, macrofossils and diatom assemblages from 2 cores were used to infer hydroseral changes within the basin, while pollen assemblages from one core were used to infer surrounding forest succession. The peatland displayed annular zones of vegetation. A lagg around the edges of the basin contained open water following spring melt and often had dried up by late summer. It had few scattered trees and tall shrubs, mostly *Acer saccharinum*, *Betula papyrifera* and *Ilex verticillata*, while a zone of forested peatland occurred between the lagg and the floating mat with the shrubs *I. verticillata* and *Nemopanthus mucronata* [*N. mucronatus*] and trees (*Larix laricina*, *Pinus strobus*, *Fraxinus nigra* and *A. saccharinum*) being characteristic. A circumneutral to slightly alkaline lake occupied the basin at 11 750 years BP after the melting of an ice block. Changes in diatom assemblages and loss-on-ignition in the early lake indicate fluctuating limnological conditions, but their exact nature was unclear. At 8200 years BP, limnological conditions in the centre of the basin stabilized to circumneutral to slightly alkaline, moderately hard waters following sediment accumulation and macrophyte growth at the edge of the basin. The water level declined 7 m by 5600 years BP, and following a return of higher water levels at around 5200 years BP, a fen mat formed around the edges of the basin, isolating the remnant lake from alkaline influences. An uncharacterized, basin-wide shift occurred at 2800 years BP, possibly as a result of a water level change. At 600 years BP, the floating fen mat advanced over the centre of the basin, and after 1830 AD, a *Sphagnum*-dominated floating mat was formed. Changes in basin infilling and vegetation succession coincided with regional vegetation succession, indicating that external forcing factors initiated these hydroseral changes. External factors included climate change at around 8200 years BP, 5600 years BP, 2800 years BP and 600 years BP and land clearance after 1830 AD. They altered hydrological characteristics in the basin, especially water level and the resultant connection to surrounding calcareous waters. It is concluded that the sensitivity of these kettle-hole peatlands with floating mats to external influences was significant.

105. **Canavan SJ and Ramm CW 2000. Accuracy and precision of 10 year predictions for Forest Vegetation Simulator -- Lake States. *Northern Journal of Applied Forestry* 17: 62-70.**

Keywords: growth models/simulation models/mortality /increment /diameter /basal area/accuracy /Acer saccharum/ Fagus grandifolia/Quercus rubra/Tilia americana /model TWIGS /Forest Vegetation Simulator (FVS)

Abstract: This study is a follow-up to the 5 year validation of the Lake States TWIGS (The Woodsman's Ideal Growth Projection System) projection system by Guertin and Ramm [Northern Journal of Applied Forestry (1996) 13 (4) 182-188]. Accuracy and precision of 10-year diameter growth, basal area growth and mortality predicted by the Lake States variant of the Forest Vegetation Simulator (FVS) were evaluated for seven upland hardwood species (northern red oak, other red oak, white oak, sugar maple, red maple, basswood and American beech) in Michigan's northern Lower Peninsula. The robustness of FVS predictions was examined by varying projection cycle length and the level of detail of stand and tree-information included in growth projections. The data used in the analysis consisted of individual tree measurements from 44 stands across 10 ecological land type phases in the Manistee National Forest. FVS-Lake States consistently overpredicted 10-year diameter growth across all seven species. Ten year diameter growth was predicted within 0.5 in. across all projections for nearly all species and size-class combinations for the seven species examined. Basal area and mortality errors were less consistent. Mean errors for trees per acre ranged from -24 for red maple to +14 for white oak. These errors led to a consistent overprediction of basal area per acre for all species combined, while prediction errors for individual species were less than ± 8 ft²/ac. Precision was variable, especially for mortality predictions. The most accurate predictions were obtained with longer cycle lengths and with projections using tree diameter, tree height, and crown ratio along with site index and individual tree past diameter growth.

106. **Canham CD, Denslow JS, Platt WJ, Runkle JR, Spies TA, and White PS 1990. Light regimes beneath closed canopies and tree-fall gaps in temperate and tropical forests. *Canadian Journal of Forest Research* 20: 620-631.**

Keywords: vegetation types/coniferous forests/temperate zones/broadleaved deciduous forests/ Light /canopy /ecology /simulation /Synecology /canopy gaps/Photography /Tropics /rain forests/ Abies balsamea /Picea rubens/Tsuga canadensis /Pseudotsuga menziesii

Abstract: Light regimes beneath closed canopies and tree-fall gaps are compared for 5 New World forests at different latitudes (between 10.4° and 44.3°N.), using fish-eye photography of intact forest canopies and a model for calculating light penetration through idealized gaps. The forest types were as follows (from N. to S.): Douglas fir (*Pseudotsuga menziesii*)/hemlock (*Tsuga heterophylla*); northern broadleaved forest; a montane red spruce (*Picea rubens*)/balsam fir (*Abies balsamea*) forest; a southern broadleaved forest; and a tropical rain forest (Costa Rica). Beneath intact canopies, analyses of canopy photographs indicate that sunflecks potentially contribute 37-68% of seasonal total photosynthetically active radiation. In all of the forests, potential sunfleck duration is brief (4-6 min), but the frequency distributions of potential sunfleck duration vary because of differences in canopy geometry and recent disturbance history. Analysis of the photographs reveals that incidence angles for photosynthetically active radiation beneath closed canopies are not generally vertical for any of the forests, but there was considerable variation both among and within sites in the contribution of overhead versus low-angle lighting. Single-tree gaps in 4 of the forest types produced significant overall increases in understorey light levels; in the Douglas fir/hemlock forest, such gaps have little effect on understorey light regimes because of the high ratio of canopy height to gap diameter. There is significant spatial variation in seasonal total radiation in and around single-tree gaps. These results demonstrate that there can be significant penetration of light into the understorey adjacent to a gap, particularly at high latitudes. As gap size increases, both the mean and the range of light levels within the gap increases, but even in large gaps (e.g. 1000 m²) the potential duration of direct sunlight is generally brief (<4 h). The major differences in gap light regimes of the 5 forests are largely a function of canopy height and latitude. The effects of latitude should also result in differences in gap light regimes across the geographic range of individual forest types.

107. **Canham CD, Kobe RK, Latty EF, and Chazdon RL 1999. Interspecific and Intraspecific Variation in Tree Seedling Survival: Effects of Allocation to Roots Versus Carbohydrate Reserves. *Oecologia* 121: 1-11.**

Keywords: Carbohydrate Reserves/Root Allocation/Tree Seedling Survival/Successional Status/Shade Tolerance/Sugar Maple/Acer saccharum /dormancy induction/Sapling Mortality/ Starch Content/ Canopy Gaps/Growth/Light/Acer rubrum/Prunus serotina/Quercus rubra

Abstract: We examined interspecific and intraspecific variation in tree seedling survival as a function of allocation to carbohydrate reserves and structural root biomass. We predicted that allocation to carbohydrate reserves would vary as a function of the phenology of shoot growth, because of a hypothesized tradeoff between aboveground growth and carbohydrate storage. Intraspecific variation in levels of carbohydrate reserves was induced through experimental defoliation of naturally occurring, 2-year-old seedlings of four northeastern tree species - Acer rubrum, A. saccharum, Quercus rubra, and Prunus serotina - with shoot growth strategies that ranged from highly determinate to indeterminate. Allocation to root structural biomass varied among species and as a function of light, but did not respond to the defoliation treatments. Allocation to carbohydrate reserves varied among species, and the two species with the most determinate shoot growth patterns had the highest total mass of carbohydrate reserves, but not the highest concentrations. Both the total mass and concentrations of carbohydrate reserves were significantly reduced by defoliation. Seedling survival during the year following the defoliation treatments did not vary among species, but did vary dramatically in response to defoliation. In general, there was an approximately linear relationship between carbohydrate reserves and subsequent survival, but no clear relationship between allocation to root structural biomass and subsequent survival. Because of the disproportionate amounts of reserves stored in roots, we would have erroneously concluded that allocation to roots was significantly and positively related to seedling survival if we had failed to distinguish between reserves and structural biomass in roots.

108. **Canham CD and Loucks OL 1984. Catastrophic windthrow in the presettlement forests of Wisconsin. *Ecology* 65: 803-809.**

Keywords: Wind damage/history /Acer saccharum/Betula alleghaniensis/Tsuga canadensis /disturbance

Abstract: The frequency, extent and probable mechanism of catastrophic windthrow was analysed for presettlement hemlock/northern broadleaved Tsuga canadensis/Acer saccharum, Betula alleghaniensis forests.

109. **Cannell MGR, Malcolm DC, and Robertson PA 1992. *The ecology of mixed-species stands of trees. British Ecological Society Special Publication 11, 312 pp.***

Keywords: growth/yield /silviculture /ecology /belowground interactions /non-timber benefits

Abstract: The 17 chapters of this book comprise the proceedings of a symposium held at Heriot-Watt University, Edinburgh, UK, 2-6 September 1990. Growth, yield and silviculture of mixed-species stands are considered from a forester's viewpoint. Interactions among tree species in mixtures are described, particularly in relation to below-ground factors affecting tree nutrition. The benefits, or otherwise, are discussed of tree species mixtures as habitats for herbaceous flora, birds, mammals and invertebrates. Reports are included from six discussion groups that identified the main issues, significant omissions, and priorities for future research arising from the published papers.

110. **Cardille JA and Ventura SJ 2001. Occurrence of Wildfire in the Northern Great Lakes Region: Effects of Land Cover and Land Ownership Assessed at Multiple Scales. *International Journal of Wildland Fire* 10: 145-154.**

Keywords: fire/wildfire/land cover/ownership/history/wildfire pattern

Abstract: Risk of wildfire has become a major concern for forest managers, particularly where humans live in close proximity to forests. To date, there has been no comprehensive analysis of contemporary wildfire patterns or the influence of landscape-level factors in the northern, largely forested parts of Minnesota, Wisconsin and Michigan, USA. Using electronic archives from the USDA Forest Service and from the Departments of Natural Resources of Minnesota, Wisconsin, and Michigan, we created and analysed a new, spatially explicit data set: the Lake States Fire Database. Most of the 18 514 fires during 1985-1995 were smaller than 4 ha, although there were 746 fires larger than 41 ha. Most fires were caused by debris burning and incendiary activity. There was considerable interannual variability in fire counts; over 80% of fires occurred in March, April, or May. We analysed the relationship of land cover and ownership to fires at two different fire size thresholds across four gridded spatial scales. Fires were more likely on non-forest than within forests; this was also true if considering only fires larger than 41 ha. An area of National or State Forest was less likely to have experienced a fire during the study period than was a forest of equal size outside National or State Forest boundaries. Large fires were less likely in State Forests, although they were neither more nor less likely to have occurred on National Forests. Fire frequency also varied significantly by forest type. All results were extremely consistent across analysis resolutions, indicating robust relationships.

111. **Carleton TJ and Arnup RW 1993. Vegetation ecology of eastern white pine and red pine forests in Ontario. Ontario Forest Research Institute, Forest Fragmentation and Biodiversity Project Report No. 11, 262 pp.**

Keywords: understorey /age /stand characteristics/natural regeneration/botanical composition/plant communities/site factors/forest ecology/species diversity/Pinus strobus/Pinus resinosa

Abstract: Changes in understorey species composition and floristic diversity in relation to site conditions (soils, topography, coarse woody debris and substrate type) and stand age were explored in eastern white pine (*Pinus strobus*) and red pine (*Pinus resinosa*) stands in Ontario, Canada. A total of 170 natural, undisturbed (no logging) stands of fire origin, ranging from 50 to 300 years old, were surveyed using quadrat sampling of fixed-area plots. White pine regeneration was significantly higher on very shallow soils than on all other site types. Little red pine regeneration was present. In order to reduce site variables and study the relationship between species composition and floristic diversity and age, stands were classified into 4 groups using a synthetic site index. In general, floristic composition was more strongly related to site features than to stand age, although old stands had more vascular species which were more abundant. Floristic diversity was strongly related to microsite heterogeneity. High specificity of non-vascular species to particular substrate types was found. It is suggested that probability of establishment is more important than either stand age or site conditions in determining species distribution in eastern white pine and red pine stands in Ontario.

112. **Carleton TJ, Maycock PF, Arnup RW, Gordon AM, Woodward FI, and Cramer W 1996. In situ regeneration of *Pinus strobus* and *P. resinosa* in the Great Lakes forest communities of Canada. *Journal of Vegetation Science* 7: 431-444.**

Keywords: synecology /plant communities/botanical composition/stand structure/recruitment /basal area/seedlings /stand density/understorey /broadleaves /shrubs /seedbeds /natural regeneration/ *Quercus alba*/*Quercus rubra*/*Pinus strobus*/*Pinus banksiana*/*Pinus resinosa*/northern hardwoods /ordination /*Polytrichum* spp.

Abstract: Two extensive forest vegetation survey datasets are explored, using ordination and classification, for evidence of in situ regeneration by *Pinus strobus* (eastern white pine) and *P. resinosa* (red pine). Ordination of tree species contributions to total basal area in 320 upland northern hardwood/conifer stands produced distinct stand groups for *P. banksiana*, *P. resinosa*, *P.*

strobis and mesic hardwoods in an ascending sequence along the first axis. *Quercus rubra* (red oak), *Q. alba* (white oak) and tolerant conifer groups formed segregates from the hardwood complex along the second axis. *P. strobus* mixes with all other forest types, but *P. resinosa* is restricted to its own group. Seedlings and trees of *P. strobus* are more abundant than saplings, which are restricted to the pine and oak forests. Therefore, seed production, dispersal and seedling establishment seem to be less of a barrier to in situ regeneration by *P. strobus* than subsequent survival and growth. Canonical correspondence analysis of 170 pine dominated stands from the Canadian Shield of Ontario, in which tree species variables are segmented into height-class pseudo-species, yielded no linear relationship between environmental features or stand structure and seedling densities of *P. strobus*. However, total tree basal area appears to impose an upper limit to seedling density on the forest floor. Strong correlations emerged between pine seedling density and understorey vegetation. Stand classification of the understorey vegetation, using constrained indicator species analysis, yielded distinct high and low seedling groups. Low pine seedling density was associated with abundant broadleaved shrubs, herbs and seedlings as well as feather mosses and tolerant conifers. High seedling density could not be ascribed to the presence of seedbed taxa, such as *Polytrichum*, but is ascribed to the absence of competition and other forms of inhibition in the understorey vegetation and down through the canopy profile. In situ regeneration of *P. strobus* does, therefore, occur but conditions over the forest landscape are largely restrictive.

113. **Carlyle-Moses DE and Price AG 1999. An Evaluation of the Gash Interception Model in a Northern Hardwood Stand. *Journal of Hydrology* 214: 103-110.**

Keywords: Interception/Throughfall/Stemflow/model Gash Analytical Interception /Rainfall Interception/ northern hardwoods

Abstract: During the growing season of 1995, canopy water fluxes were measured within a northern hardwood stand in southern Ontario, Canada. Observed canopy interception loss, throughfall, and stemflow fluxes from the stand were 19.3+/-3.5%, 76.4+/-2.9%, and 4.3+/-2.0% of incident precipitation, respectively. Both the original and revised Gash analytical rainfall interception loss models simulated these fluxes within the standard error of the observed estimates, suggesting that the analytical model may be appropriate for further applications within this forest type. The revised Gash model is recommended for further applications as it is better physically based. Both the original and revised models suggest that similar to 60% of interception loss during the study period was evaporation from the canopy once rainfall has ceased while evaporation from the saturated canopy during rainfall accounted for similar to 27%- 33% of interception loss. Additional components of interception (e.g., evaporation from trunks) were computed to be minor contributors to total canopy interception loss.

114. **Carmean WH 1979. A comparison of site index curves for northern hardwood species. U.S. For. Serv. Research Paper NC-167, 12 pp.**

Keywords: site class assessment/growth /broadleaves /northern hardwoods /site index

115. **Carmean WH 1973. Forest soils bibliography for the North-Central Region (including subject matter index through 1972). U.S. For. Serv. General Technical Report NC-GTR-5, 68 pp.**

Keywords: bibliographies /soil types ecological/forest soils/regions /review

Abstract: The report includes 793 publications dealing with forest soils in the North-Central States, the Northern Plains States, and Ohio. It includes some publications from other regions considered applicable to conditions in the North-Central Region.

116. **Carmean WH 1979. Site index comparisons among northern hardwoods in northern Wisconsin and Upper Michigan. U.S. For. Serv. Research Paper NC-169, 17 pp.**

Keywords: soil fertility/site class assessment/growth /soil water/broadleaves /northern hardwoods/ site index

Abstract: Site indices of 13 tree species found in even-aged hardwood stands of northern Wisconsin and Upper Michigan are compared. Regression equations relating site index between all possible species pairs are presented. Species differ greatly in site index when growing together, but can be grouped into four general site index classes. Regression equations relating site index between species groups are computed. Regression equations account for 38-91% of the total site index variation between species pairs or group pairs. A significant portion of the remaining variation is associated with soil drainage.

117. **Carmean WH 1978. Site index curves for northern hardwoods in northern Wisconsin and Upper Michigan. U.S. For. Serv. Res. Pap. NC-160, 16 pp.**

Keywords: increment /height /site class assessment/growth /broadleaves /yields /northern hardwoods /second growth

Abstract: [See FA 42, 2921] Tree height and age data were collected from 204 even-aged and second growth mixed plots, together with information relating to local site and soil conditions. Using the data, accurate site index curves were constructed for 13 tree species.

118. **Carmean WH, Clark FB, Williams RD, and Hannah PR 1976. Hardwoods planted in old fields favored by prior tree cover. U.S. For. Serv. Research Paper NC-134, 16 pp.**

Keywords: increment /soil /effects /site class assessment/growth /soil fertility/mycorrhizas /site types/afforestation /marginal land/yields /waste land/*Quercus rubra* /*Juglans nigra* /*Liriodendron tulipifera* /*Robinia pseudoacacia* /*Pinus echinata* /artificial regeneration

Abstract: Seedlings (1+0) of red oak (*Quercus rubra*), black walnut (*Juglans nigra*), sweetgum (*Liquidambar styraciflua*) and yellow poplar (*Liriodendron tulipifera*) were planted on 4 types of site in a field in Michigan abandoned in the mid-1930's: (a) unstocked; and after clear felling of (b) a fully stocked stand of volunteer trees and shrubs, (c) a 23-year-old *Pinus echinata* stand, and (d) a 23-year-old *Robinia pseudoacacia* stand on an eroded site. Foliar samples collected at 5, 10 and 16 yr and soil samples were analysed. After 16 years, oak and walnut had 100% mortality in (a) and had the best growth in (d). Sweetgum and yellow poplar were respectively 22.9 and 37.5 feet taller in (d) than in (a); growth was intermediate in (b) and (c). Height growth was related to foliar N content, which was greatest in (d). After 10 years, foliar N and growth of sweetgum and yellow poplar increased in (a) while foliar N and growth of all species decreased in (d). The soils of (b) and (c) had a high organic content and were similar to those of the adjacent hardwood forest. Soils of (a) and (d) had generally poor characteristics but (d) had a high N content. The correlation between growth and soil characteristics and the influence of endomycorrhizae are discussed in relation to previously reported pot culture studies [see FA 25, 4764].

119. **Carmean WH and Hahn JT 1981. Revised site index curves for balsam fir and white spruce in the Lake states. U.S. For. Serv. Research Note NC-269, 4 pp.**

Keywords: site class assessment/growth /conifers /*Abies balsamea* /*Picea glauca* /site index

120. **Carmean WH, Hahn JT, and Jacobs RD 1989. Site index curves for forest tree species in the eastern United States. U.S. For. Serv. General Technical Report NC-GTR-128, 142 pp.**

Keywords: site class assessment/site index

Abstract: A total of 127 published site curves are presented for conifers and broadleaved trees. Formulae are included for computing both total height and site index.

121. **Carmean WH and Vasilevsky A 1971. Site-index comparisons for tree species in northern Minnesota. U.S. For. Serv. Research Paper NC-65, 8 pp.**

Keywords: Pinus resinosa/site quality indices /soil-site study /site index - species pairs

Abstract: Presents regression equations and graphs comparing the site indices of ten pairs of species (comprising 9 coniferous and 4 broadleaved species) calculated from soil-site plot data. One species (Pinus resinosa) was present in three pairs of comparisons. [Cf. FA 24 No. 2554.]

122. **Chen JQ, Saunders SC, Crow TR, Naiman RJ, Brosofske KD, Mroz GD, Brookshire BL, and Franklin JF 1999. Microclimate in Forest Ecosystem and Landscape Ecology - Variations in Local Climate Can Be Used to Monitor and Compare the Effects of Different Management Regimes. *Bioscience* 49: 288-297.**

Keywords: Douglas-Fir Forest/Air-Temperature Gradients/Wavelet Analysis/Canopy Structure/Small Streams/Rain-Forest/Clear-Cut/Growth/Edge /Pseudotsuga menziesii

123. **Chimner RA and Hart JB 1996. Hydrology and microtopography effects on northern white-cedar regeneration in Michigan's Upper Peninsula. *Canadian Journal of Forest Research* 26: 389-393.**

Keywords: site factors/microrelief /groundwater level/mounds /soil water regimes/natural regeneration/ vegetation types/wetlands /Thuja occidentalis/Abies balsamea /Alnus rugosa

Abstract: Many harvested northern white-cedar (*Thuja occidentalis*) sites have not regenerated to cedar but have become dominated by other species such as balsam fir (*Abies balsamea*) and tag alder (*Alnus rugosa*). A regenerating cedar fen near Escanaba, Michigan, was used to study factors related to regeneration success and failure. Twelve plots (6.1X6.1 m) were established on the site to collect data on hydrology, microtopography, stand composition, and stem density. Abundance of cedar regeneration was positively correlated with percentage of hummocks. There were more cedar on microsites with drier conditions (numerous hummocks), while more shrubs and hardwoods were found on the wetter areas (fewer hummocks) of the fen. The shallow depth to groundwater and unsaturated soil thickness early in the growing season are suggested to be factors.

124. **Choi JK 1998. Simulation of the development and restoration of old-growth northern hardwood forest. PhD dissertation, University of Wisconsin, Madison. 147 pp.**

Keywords: Acer saccharum/Tilia americana/Fraxinus americana/northern hardwoods /model - CANOPY, growth/forest dynamics /gap dynamics /old-growth structure /restoration

Abstract: Individual-tree models for stem and crown growth were developed and evaluated for *Acer saccharum*, *Fraxinus americana*, and *Tilia americana* to simulate forest stand and gap dynamics in northern hardwoods. The use of crown variables resulted in minimal improvement in model accuracy compared to diameter-based variables except for white ash. A variety of different variables for measuring crowding or competition were all about equally useful. Crown growth equations had moderate R^2 values (0.20-0.48). Lateral growth rate of exposed branches in sugar maple was clearly greater than shaded branches as indicated by highly significant coefficients for the crown exposure variable. This feature of the crown growth equation allows for prediction of asymmetric crown development and more rapid closure of canopy gaps by lateral growth of border tree crowns. Three alternative crown-based models had similar predictive accuracy, with a root mean square error for basal area increment of 6-9 cm²/yr. Several validation measures for predicted basal area increment were evaluated and revealed good fits for all models and species. Long-term projections for individual tree growth and stand growth made over a 300-year period agreed closely with tree and stand characteristics in actual old-growth stands. A computer simulation of old-growth restoration treatments was evaluated for two different northern hardwood

stands, using several different approaches to thinning and crown release. Three heavy thinning treatments at 15-year intervals substantially reduced the time to reach threshold old-growth conditions from 74 years to 31 years in the younger stand. However, repeated heavy thinning in the older stand caused a 5-11 year delay in reaching target conditions because some relatively large trees had to be cut to provide the intended degree of crown release or stocking reduction. Surprisingly, total coarse woody debris volume showed only small differences among treatments and the control. Overall, the results suggest that old-growth structural features can be restored in many second growth stands in 30 years or less.

125. **Choi JK, Lorimer CG, Vanderwerker J, Cole WG, and Martin GL 2001. A Crown Model for Simulating Long-Term Stand and Gap Dynamics in Northern Hardwood Forests. *Forest Ecology and Management* 152: 235-258.**

Keywords: Acer saccharum/Canopy Gaps/Crown Growths/Crown Models/Ecosystem Management/ Extended Rotations/Forest Simulation/Multi-Aged Forests/Old-Growth Forests/Competition Indexes/Tree Growth/Individual Trees/Age Structure/Douglas-Fir/Pseudotsuga menziesii /management/History/Height/Site/northern hardwoods/model -CANOPY

Abstract: Evaluation of ecosystem management alternatives in forests will require new or revised models capable of simulating the development of multi-aged stands managed on long rotations and with unconventional stand structures. In this paper we describe the development and testing of an individual tree, crown-based model (CANOPY) designed to simulate canopy gap dynamics and stand structural changes in mature and old-growth northern hardwood forests dominated by *Acer saccharum*. The model was calibrated with data from 63 plots in managed and unmanaged stands, with sample trees ranging in age from 17-311 years. For *A. saccharum*, R-2 values ranged from 0.76 to 0.81 for prediction of basal area increment, 0.45-0.50 for crown radial increment, and 0.63-0.79 for height increment. Equations using field-measured crown size and crown competition variables provided only slightly better predictions than conventional mensurational variables such as DBH and plot stocking level. Use of the model for long-term (250 year) projections of cumulative DBH and crown radius provided a good match to largely independent size-age trends in the data base, but total height appeared to be moderately overestimated for trees > 100 years old. Both the field data and simulations suggest that basal area increment of individual trees does not decline with age in these species but actually increases up to the observed maximum of 300 years, which is consistent with nearly linear diameter-age trends often reported for shade-tolerant species. Lateral crown growth of trees with exposed crown margins, however, showed curvilinear decreasing trends with age. These findings suggest that the common assumption of constant radial closure of canopy gaps by border trees could potentially overestimate rates of gap closure and underestimate the probability of successful gap capture by saplings in multi-aged stands.

126. **Choi JK and Park WG 1998. A asymmetric crown growth model for predicting gap dynamics for northern hardwood forests. *Journal of Research Forests of Kangwon National University* 18: 41-53.**

Keywords: canopy gaps/crown /growth rate/increment /model - growth/virgin forests/stand characteristics/*Acer saccharum*/*Tilia americana*/*Fraxinus americana*/northern hardwoods

Abstract: Individual-tree models for annual lateral crown growth were developed and evaluated for sugar maple (*Acer saccharum*), white ash (*Fraxinus americana*), and basswood (*Tilia americana*) to simulate gap dynamics in northern hardwood in the Great Lakes Region of the USA. The data used were collected in 1987-91 from 247 trees (17-247 yr old) in 63 plots in 15 stands in Wisconsin with *A. saccharum*, *F. americana* and *T. americana* as overstorey species. Independent variables used included diameter based variables (i.e. traditional measurement variables - dbh (diameter at breast height), relative diameter, percentage stocking and competition index) and crown based variables (total and relative height, total crown projection area, live crown ratio, crown radius, exposed crown area and percentage exposed crown area); models were developed based on mixtures each type and of both types of variables. The use of crown based variables

resulted in similar R² values (0.34) to those from diameter-based variables (0.38-0.45) in sugar maple. Over all species and models R² values were moderate (0.20-0.52). The crown exposure variable was not significant for basswood and white ash, but in sugar maple the lateral crown growth rate of exposed branches was clearly greater than that of shaded branches as indicated by highly significant coefficients for the crown exposure variable. This feature of the crown growth equation allows for prediction of asymmetric crown development and more rapid closure of canopy gaps by lateral growth of border tree crowns. Long-term projections of crown radius were made over a period of 300 years for dominant-codominant sugar maple trees and compared with observed data. Given a maximum age for sugar maple of about 300 years, simulated dominant trees reached maximum dimensions of 10 m crown radius for fully exposed branches, and 6 m for partially shaded branches over time using the best crown-based model. These are similar to maximum tree dimensions observed in actual old-growth stands.

127. **Christ MJ, David MB, Mchale PJ, Mclaughlin JW, Mitchell MJ, Rustad LE, and Fernandez IJ 1997. Microclimatic Control of Microbial C, N, and P Pools in Spodosol Oa Horizons. *Canadian Journal of Forest Research* 27: 1914-1921.**

Keywords: Hardwood Forest /Biomass-C/Chloroform Fumigation/Extraction Method/Soil-Nitrogen/Carbon/Phosphorus/Spruce/Decomposition/Temperature/northern hardwoods /Picea spp. /spodosols

Abstract: We examined effects of soil moisture and temperature on CHCl₃-labile C, N, and P (fumigation-extraction method) in Oa horizons of two Spodosols. Temperature, moisture, and CHCl₃-labile pools were observed from May to November 1994 in an unmanipulated (reference) plot in a spruce forest and, except for P, in experimental plots in both spruce and northern hardwood forests, where temperature was regulated with buried heating cables and clear plastic tarps were used to exclude rain. Spruce reference plot microbial C, N, and P were 5.9, 0.49, and 0.092 g.kg⁻¹, respectively, and comprised 1.2, 4.8, and 21% of the elemental totals for the Oa horizon. Pools were positively correlated with moisture ($r = 0.38-0.49$; $p = 0.0001$), and N/C in CHCl₃-labile pools was positively correlated with temperature ($r = 0.34$; $p = 0.0007$). Neither temperature nor moisture explained a decline in P/C over time. In control plots for the hardwood soil warming study, microbial C and N were 6.4 and 0.74 g.kg⁻¹, comprising 1.5 and 3.4% of total Oa horizon pools, respectively. Excluding rain reduced variability in CHCl₃-labile C in Oa horizons of both forests ($p < 0.05$). Warming decreased CHCl₃-labile C and N in hardwood Oa horizons ($p = 0.01$) by 0.05 and 0.007 g.kg⁻¹.degrees C⁻¹, respectively. Spruce forest results suggested a net transfer of P out of microbial pools during the growing season.

128. **Church TW Jr. and Godman RM 1966. The formation and development of dormant buds in Sugar Maple. *Forest Science* 12: 301-306.**

Keywords: Acer saccharum/dormancy bud/plant ecology/physiology

Abstract: In connexion with a study of stem defects caused by epicormic shoots, the author describes and illustrates dormant buds in Acer saccharum. These originate at the terminal bud scar and the bases of lateral shoots. In the latter case they are soon transferred to the main stem, where they persist long after the shoots have died and dropped off. A minute annual elongation apparently adds one set of bud scales to a dormant bud, which is distinguishable from an axillary bud, initially by its smaller size and later by accumulation of elongations.

129. **Clark JS 1989. Ecological disturbance as a renewal process: theory and application to fire history. *Oikos* 56: 17-30.**

Keywords: Conifers /Forest fires/history /simulation /fire danger/assessment /Pinus resinosa/disturbance

Abstract: Failure time analysis and renewal theory were used to evaluate two assumptions

implicit in most studies involving calculations of disturbance frequency. These calculations assume that the disturbance process is stationary (intervals between disturbances are drawn from the same distribution) and that the probability of disturbance does not change with time since the last disturbance. Quantitative methods are presented and applied to long-term fire occurrence data (fire scars on red pine (*Pinus resinosa*) trees and stratigraphic charcoal data) and climate data from NW Minnesota, USA. Results show that past decade- and century-scale fluctuations in climate correspond to changes in the disturbance regime. Probability of fire occurrence increases with time since the last fire, albeit at different rates during the various climatic conditions that have prevailed over the last 750 yr. These results suggest two reasons to question disturbance regimes calculated from spatial dispersion of events. Firstly, expected fire intervals derived as the inverse of spatial proportion of area disturbed requires a stationary process. The space/time analogy assumed by this method is highly inaccurate when the expected interval between disturbances changes over time. Secondly, because fire hazard is an increasing function of time since the last fire, the number of disturbances predicted to occur over short time intervals will be overestimated by the usual constant hazard assumption. Probability densities of events having age-specific probabilities that increase over time (e.g. fire, windthrow) exhibit modes at time $t > 0$ compared with exponential decrease with time.

130. **Clark JS 1988. Effect of climate change on fire regimes in northwestern Minnesota. *Nature* 334: 233-235.**

Keywords: forest fires/history /ecology /climate

Abstract: Petrographic thin sections were used to determine the annual production of charcoal (as a measure of fire regimes) within a lake catchment in NW Minnesota over the past 750 yr. Max. abundance and frequency occurred in the warm, dry 15th and 16th centuries with a marked reduction with the onset of the 'little ice age' around AD 1600. Fire cycles corresponding to multiples of the 22-yr drought cycles of the area, and increased frequency at times when early successional stands were breaking up, suggest a synergistic effect of climate and fuel accumulation.

131. **Clark JS 1989. Effects of long-term water balances on fire regime, north-western Minnesota. *Journal of Ecology* 77: 989-1004.**

Keywords: Broadleaves /Conifers /Forest fires/forecasting /hydrology /climate /fire danger/ assessment /seasonality /Soil water balance/fire /forest soils/Soil types ecological/Populus tremuloides / Populus grandidentata/Pinus strobus/Pinus resinosa/Betula papyrifera

Abstract: Water balances were modelled from 150 yr data on temperature and precipitation in an area of mixed conifer and broadleaf assemblages, dominated by *Pinus resinosa*, *P. strobus*, *Betula papyrifera*, *Populus tremuloides* and *P. grandidentata*. Water balance shifted from consistently positive effective precipitation (precipitation minus potential evapotranspiration) during the 19th century to one where precipitation roughly equalled potential evapotranspiration in the 20th century. Droughts in the 1890s and 1930s had negative water balance. Fire occurrence was related to negative annual water balance or negative fire-season water balances. Fire frequency is predicted to be 10-25% greater during the 20th century than the 19th century.

132. **Clark JS 1990. Fire and climate change during the last 750 yr in northwestern Minnesota. *Ecological Monographs* 60: 135-159.**

Keywords: Forest fires/history /climate

Abstract: Spatial and temporal occurrences of fire were estimated in 1 km² of old-growth mixed conifer/broadleaved forests by analysis of charcoal in varved sediments of 3 small lakes, and by dating fire scars (150) from recent treefalls. Climate changes were estimated from sediment data, water-balance models from 150 yr of precipitation/temperature data, and published data. Fire

intervals varied from a mean of 8.6 yr during the warm/dry 15th and 16th centuries to 24.5 and 43.6 yr, respectively, for the mid-18th and mid-19th centuries (Little Ice Age). Probability of fire increased with time, probably related to fuel accumulation. S.- and W.-facing slopes burned more frequently than did N.- or E.-facing slopes.

133. **Clark JS 1991. Forest-tree growth rates and probability of gap origin - a comment. *Ecology* 72: 1166-1169.**

Keywords: plant succession/canopy gaps/growth rings/dendrochronology/gap dynamics

Abstract: A recursive method of estimating, from tree growth rings, the probability that a mature tree grew within a gap when it was a sapling is discussed. The author demonstrates a bias introduced by the recursive methodology, and presents an alternative equation which does not contain the bias.

134. **Clark JS 1990. Twentieth-century climate change, fire suppression, and forest production and decomposition in northwestern Minnesota. *Canadian Journal of Forest Research* 20: 219-232.**

Keywords: Forest fires/fire suppression/fire ecology/history /soil /simulation /Forest litter/fires /Synecology /Climate /Dendroclimatology /Vegetation types

Abstract: Long-term fire, climate and vegetation data were used together with simulation models to estimate the effects of 20th century climate change and fire suppression on fire regime and organic-matter accumulation in mixed-conifer stands of Itasca State Park, NW Minnesota. Spatial and temporal patterns of fire occurrence and forest composition over the last 150 yr determined by stratigraphic charcoal, fire-scar, tree-ring and pollen analyses in separate studies provided evidence for vegetation and fire relationships. Water balances constructed from temperature and precipitation data collected since 1840 were used to model fire probability and intensity of burn before fire suppression which began in 1910. Existing patterns of biomass accumulation in forest floor, herb, shrub and tree components were compared with fire history and topographic variability to provide a spatial perspective on fire effects. Simulation models used these relationships: (1) to estimate how accumulation of organic matter had changed through the past under the different fire regimes that prevailed on different topographic aspects; (2) to evaluate the changes brought about by fire suppression in 1910; and (3) to predict the fire regimes and their effects that would have prevailed since fire suppression with the warm-dry climate of the 20th century. Humus, litter, shrubs and herb cover were less abundant and more variable spatially and temporally before fire suppression. Spatial variability in forest floor organic matter, which resulted from different fire frequencies in different vegetation and topographic settings before fire suppression, was largely eliminated by 1920 as a result of fire suppression. Had fire suppression not been instituted in 1910, fire frequency would have increased by 20-40% in the 20th century because of warmer and drier conditions. Forest floor organic matter would have been virtually depleted by frequent and severe fires exposing mineral soils, particularly during the drought years of the 1930s. Herb biomass would have increased, shrubs would have been more variable, and tree seedling establishment would have altered substantially. The time required for buildup of fuels limits the extent to which increased moisture deficits increase fire frequency.

135. **Clark JS and Royall PD 1996. Local and regional sediment charcoal evidence for fire regimes in presettlement north-eastern North America. *Journal of Ecology* 84: 365-382.**

Keywords: deciduous forests/charcoal /sediment /settlement /forest fires/burning /history /American Indians/*Tsuga canadensis*/northern hardwoods /*Quercus* spp.

Abstract: Presettlement fire regimes in NE temperate forests in North America and their dependence on climate, fuels, and cultural patterns are poorly understood due to lack of relevant historic or palaeoecological data. Annual records of sediment charcoal accumulation were compiled from 7 sites (in Minnesota, Wisconsin, Ontario, New York, Pennsylvania, and Maine

(2)) spanning the last 2000 yr and representing important climate, vegetation, and cultural settings. Results were compared across sites and across changes in Indian cultures to determine whether fire patterns might be explained by one or more of these variables. Clearly interpretable fires were restricted to the western (most xeric) portion of the study region in the pine hardwoods of Minnesota, a single fire in the northern hardwoods of northern Wisconsin, and cultural burning near an Iroquois village in southern Ontario. Other sites in the northern hardwoods and hardwood/hemlock (*Tsuga canadensis*) forests did not show clear evidence of fire. Spectral analysis suggested instances in which local fire regimes departed from regional ones. The findings suggest substantially longer intervals between fires than reported in previous sediment charcoal studies. No evidence was found for fire in mixed oak (*Quercus*) forests, where it has been speculated that fire might be necessary for oak recruitment. A single site in northern Wisconsin was the only Algonquin site showing a clear increase in charcoal suggesting local fire. Algonquin use of fire for hunting may not have affected the sites. A single site in Sioux territory experienced such frequent fire that cultural effects were not evident, even when Sioux were replaced by Chippewa (Algonquin) in the 18th century. One of 2 Iroquois sites showed clear increases in charcoal during occupation. The second site may not have had settlements nearby.

136. **Clark JS and Royall PD 1995. Transformation of a northern hardwood forest by aboriginal (Iroquois) fire: charcoal evidence from Crawford Lake, Ontario, Canada. *Holocene* 5: 1-9.**

Keywords: forest fires/stand structure/botanical composition/charcoal /sedimentation /varves /palaeobotany /history /northern hardwoods /*Pinus* spp. /*Quercus* spp.

Abstract: Stratigraphic evidence from varves (annual laminated layers of lake sediments) for fire was obtained using charcoal analysis of lake sediments. The analysis spanned a period of Iroquois occupation when cultivation coincided with pollen evidence for transition from northern hardwood forest to white pine [*Pinus* sp.]/oak [*Quercus* sp.] forests. Charcoal data reveal that this transition was attended by increased charcoal accumulation in the varves, sufficiently high to suggest vegetation fires. Results support the suggestion that Indian burning was capable of producing dramatic changes in forest composition spanning centuries.

137. **Clausen KE and Godman RM 1969. Bark characteristics indicate age and growth rate of Yellow Birch. U.S. For. Serv. Research Note NC-75, 3 pp.**

Keywords: Bark characteristics/wood properties/*Betula alleghaniensis*/Genetics /yellow birch /growth/dendrochronology

Abstract: Annual ring measurements of 9 pairs of *Betula alleghaniensis* trees in Wisconsin showed that trees with typical smooth or peeling bark outgrew rough-barked trees at all ages. [Cf. F.A. 30 No. 214.]

138. **Coffman MS and Willis GL 1977. The use of indicator species to classify climax sugar maple and eastern hemlock forests in Upper Michigan. *Forest Ecology and Management* 1: 149-168.**

Keywords: vegetation types/synecology /broadleaves /conifers /*Acer saccharum*/*Tsuga canadensis*

Abstract: [See FA 37, 914] Ordination techniques were used to identify four climax forest types dominated by *Tsuga canadensis* and/or *Acer saccharum*. A simple key using indicator species was developed to enable land managers to identify these forest types in either climax or seral stands; its potential for the northern broadleaves region is discussed.

139. **Cole WG and Lorimer CG 1994. Predicting tree growth from crown variables in managed northern hardwood stands. *Forest Ecology and Management* 67: 159-175.**

Keywords: plant competition/basal area/plant height/height /model - growth/crown /biological

competition/growth /broadleaves /Acer saccharum/Tilia americana/Fraxinus americana/northern hardwoods

Abstract: The predictability of individual tree growth rates for *Acer saccharum*, *Fraxinus americana*, and *Tilia americana* in northern hardwood stands in Wisconsin was studied in relation to crown dimension and crown competition variables measured in the field. Data were collected from 221 destructively sampled trees in eight second-growth uneven-aged stands on above-average sites. Mean canopy tree age for all stands was 68 yr (range 22-248 yr). The single best independent variable for predicting basal area growth was the projection area of the exposed portion of the crown, which had higher correlations with observed growth than initial stem diameter, diameter-based competition indices, and other crown variables. Basal area growth equations containing total crown projection area, percentage exposed crown area, and relative height had R² values of 0.77 to 0.88, which represent increases of 13 to 47 percentage points compared to similar equations with only diameter-based competition variables. The most accurate height growth models were functions of total tree height and percentage exposed crown area, with R² values of 0.74 for the non-linear maple equation and 0.44 for the linear white ash equation. The results appear to support the hypothesis that significant competitive stress on individual trees is induced only by the ring of competitor trees immediately surrounding the subject tree crown. By using percentage exposed crown area as a crown competition variable, this competitive effect can be estimated without direct measurements of any of the competitors, potentially saving much field measurement time during the model calibration phase and eliminating the statistical lack of independence generally associated with plot competition measures.

140. **Cornett MW 1996. *Conifer regeneration in mixed deciduous-evergreen forests*. MS thesis, University of Minnesota, Twin Cities. 108 pp.**

Keywords: canopy /distribution /plant succession/natural regeneration/forest ecology/coniferous forests/reproductive behaviour/seedlings /seeds /regeneration surveys/environmental factors/soil types/population dynamics/seed dispersal/germination /establishment /site factors/forest soils/spatial distribution/*Thuja occidentalis*/*Populus tremuloides*/*Abies balsamea*/*Betula papyrifera* /*Pinus strobus* /deer exclosure /competition /microtopography

Abstract: Germination and establishment are key phases of regeneration that affect future forest composition. Objectives were to determine the influence of seedbed, seed predation, microtopography, and canopy on germination, mortality, and growth of conifer seedlings in mixed-species stands. Field studies were conducted under deciduous and evergreen canopies for paired stands at two sites: two *Abies balsamea* (L.) Miller-*Populus tremuloides* Michx. and two *Thuja occidentalis* L.-*Betula papyrifera* Marshall stands in northeastern Minnesota. Germination experiments were conducted with *A. balsamea* and *Pinus strobus* L. seeds. Experimental treatments included duff removal, caging to exclude seed predators and herbivory, and weeding to study the effects of competition. Seed rain was quantified and surveys of microtopography and regeneration (i.e. first year germinants and established seedlings) were conducted. Study species were *T. occidentalis* and *A. balsamea*, and microtopographic features included pits, mounds, stumps, logs, and level ground.

141. **Cornett MW, Frelich LE, Puettmann KJ, and Reich PB 2000. Conservation Implications of Browsing by *Odocoileus Virginianus* in Remnant Upland *Thuja Occidentalis* Forests. *Biological Conservation* 93: 359-369.**

Keywords: *Thuja occidentalis* forests/remnant forests/browsing and canopy interactions/human-altered landscapes/conservation/white-tailed deer/deciduous forests/*Tsuga canadensis*/regeneration/ herbivory/growth/cedar/*Betula papyrifera*/deer /*Odocoileus virginianus*

Abstract: Regeneration success of canopy dominants is linked to multiple factors, including the ability of their seedlings to survive browsing and to utilize available resources in the understory. In remnant upland northern white cedar *Thuja occidentalis* L. forests, effects of browsing on

recruitment of cedar seedlings were evaluated at 7 sites, including known deer yards, located on a portion of the Lake Superior Highlands in northeastern Minnesota. Experimental plantings and vegetation surveys were conducted inside and outside large deer exclosures constructed between 1937 and 1997. Objectives were to determine severity and intensity of browsing by *Odocoileus virginianus* Zimmerman, the ability of seedlings to survive browsing in environments beneath *T. occidentalis* and adjacent paper birch (*Betula papyrifera*) Marshall canopies, and potential long-term sapling recruitment under different browsing scenarios. From 1994 to 1997, 76% of unexclosed planted *T. occidentalis* seedlings had been browsed at least once, compared with 0% of exclosed seedlings. Increased browsing intensity and decreased light availability increased *T. occidentalis* mortality rates. Simulation models and vegetation surveys demonstrated that the best recruitment rates occurred for seedlings planted under *Betula* canopy and subjected to low browsing severity, but no recruitment occurred under high browsing pressure under either canopy type. The current level of browsing in these forests has the potential to alter the future composition of canopy tree species through sustained prevention of *T. occidentalis* recruitment.

142. **Cornett MW, Puettmann KJ, and Reich PB 1998. Canopy type, forest floor, predation, and competition influence conifer seedling emergence and early survival in two Minnesota conifer-deciduous forests. *Canadian Journal of Forest Research* 28: 196-205.**

Keywords: forest litter/seedling emergence/canopy /survival /plant competition/seedlings /developmental stages/effects /seed germination/predators /natural regeneration/seed predation/ seeds /understorey /*Thuja occidentalis*/*Populus tremuloides*/*Pinus strobus*/*Abies balsamea*/*Betula papyrifera*/deer exclosure

Abstract: There is concern that the conifer component of mixed forests in the Great Lakes region is declining. Limitations on conifer regeneration that occur during the first 18 months of seedling emergence and establishment were examined for *Abies balsamea* and *Pinus strobus* in two mixed conifer-deciduous forest types in northeastern Minnesota. The study was conducted under conifer and deciduous canopy types for two sites of each forest type: *Abies balsamea*/*Populus tremuloides* and *Thuja occidentalis*/*Betula papyrifera*. Germination experiments were conducted with experimental treatments including forest floor removal, caging to exclude seed predators and herbivory, and weeding to study the effects of understorey competition. *Abies balsamea* and *P. strobus* responded differently to experimental treatments at different developmental stages. The best conditions for early regeneration of both species included reduction of seed predation ($p < 0.0001$) and competition with understorey vegetation ($p \leq 0.001$). *Abies balsamea* additionally benefited from a conifer overstorey ($p < 0.0001$) and a reduction in thickness of the forest floor ($p < 0.01$).

143. **Cornett MW, Reich PB, and Puettmann KJ 1997. Canopy feedbacks and microtopography regulate conifer seedling distribution in two Minnesota conifer-deciduous forests. *Ecoscience* 4: 353-364.**

Keywords: canopy /distribution /plant succession/natural regeneration/forest ecology/coniferous forests/reproductive behaviour/seedlings /seeds /regeneration surveys/environmental factors/soil types/population dynamics/seed dispersal/germination /establishment /site factors/forest soils/spatial distribution/*Thuja occidentalis*/*Populus tremuloides*/*Abies balsamea*/*Betula papyrifera*

Abstract: The relationship between canopy feedbacks and microsite heterogeneity and their effects on conifer regeneration were studied in 2 Minnesotan mixed species forests of *Abies balsamea*-*Populus tremuloides* and *Thuja occidentalis*-*Betula papyrifera*. Microtopographic differences resulting from canopy feedbacks and conifer regeneration were studied at 3 stages (seed dispersal, germination and establishment). Seed rain was quantified and microtopography and regeneration of *T. occidentalis* and *A. balsamea* surveyed. Microtopographic features included pits, mounds, stumps, logs, and level ground. The differences in microtopography beneath deciduous and conifer canopy types were generally minor. Conifer seeds fell in larger numbers under conifer canopy types than under adjacent hardwood canopy types in both forest types, but

substantial seed rain occurred up to 20 m into hardwood canopy patches. In the Thuja-Betula stands, both germinants and seedlings of *T. occidentalis* occurred almost entirely under the Thuja canopy type, and there predominantly on decayed wood (rotting stumps and logs), which occupied only a small fraction of the forest floor. In the Abies-Populus stands, *A. balsamea* germinants and seedlings were relatively common beneath both canopy types and on all microtopographic features. The distribution of *T. occidentalis* was more restricted than that of *A. balsamea*, indicating that *A. balsamea* may be more of a generalist.

144. **Cornett MW, Reich PB, Puettmann KJ, and Frelich LE 2000. Seedbed and Moisture Availability Determine Safe Sites for Early Thuja Occidentalis (Cupressaceae) Regeneration. *American Journal of Botany* 87: 1807-1814.**

Keywords: Cupressaceae/decayed logs/leaf litter/mineral soil/moisture/safe sites/ seedbeds/northern white-cedar/conifer seedling distribution/*Picea engelmannii*/deciduous forests/*Abies lasiocarpa*/microtopography/patterns/*Thuja occidentalis*/*Abies balsamea*/*Betula papyrifera*

Abstract: Regeneration of many late-successional tree species depends on specialized safe sites. The primary objective was to investigate the roles of seedbed and moisture retention as dimensions of safe sites for the early regeneration of drought-sensitive northern white cedar (*Thuja occidentalis*). We hypothesized that rates of germination, survival, and growth of *T. occidentalis* are unlikely to differ among seedbed types under conditions of abundant water, but that differences are likely to emerge as water becomes more limited. In a 67-d greenhouse experiment, cedar seeds were sown on logs, leaf litter, and soil of cedar and paper birch (*Betula papyrifera*) canopy origin. Seedbeds were subjected to three water treatments. Among the water treatments, highest germination rates occurred within the high water treatment, although germination on cedar litter was comparable to that of the low water treatment. Higher germination and survival rates occurred on decayed logs than other natural seedbeds for medium ($P = 0.001$) and low ($P < 0.0001$) water treatments. Germination on birch logs occurred at higher rates than on cedar logs within the low water treatment ($P = 0.04$). Seedling growth for the medium water treatment was lower on leaf litter than any other type of seedbed ($P < 0.01$). Results generally demonstrated that the interplay between seedbed and moisture retention is a component of safe sites for *T. occidentalis* regeneration.

145. **Crow TR 1986. Comparing the performance of two northern hardwood growth projection systems. *Northern Journal of Applied Forestry* 3: 28-32.**

Keywords: Computer techniques/growth models/stand characteristics/development /projections /mortality /Recruitment /broadleaves /*Acer saccharum*/northern hardwoods /model STEMS, growth /model SMPS, growth

Abstract: [See FA 42, 2983; 45, 2486] The Stand and Tree Evaluation and Modeling System (STEMS) and the Sugar Maple Projection System (SMPS) are evaluated and compared for estimating growth in stands dominated by sugar maple. Based on ratios of predicted/actual net growth, both models performed equally well. Neither model gave satisfactory estimates of mortality and SMPS did not give good estimates of recruitment. STEMS does not yet have a recruitment function.

146. **Crow TR 1992. Population dynamics and growth patterns for a cohort of northern red oak (*Quercus rubra*) seedlings. *Oecologia* 91: 192-200.**

Keywords: Broadleaves /Stand characteristics/stand development/composition /Natural regeneration/ *Acer rubrum*/*Quercus rubra*/*Pinus strobus*/*Betula papyrifera*/northern hardwoods /northern red oak /red oak

Abstract: The survival and development was studied of a 1986 cohort of northern red oak (*Quercus rubra*) seedlings under a variety of overstorey and microsite conditions in a northern

hardwood forest in Wisconsin. The forest was dominated by northern red oak, red maple (*Acer rubrum*) and paper birch (*Betula papyrifera*), with scattered white pine (*Pinus strobus*). Fifty naturally regenerated seedlings of oak were selected in each of 3 canopy classes: (1) no overstorey; (2) partial overstorey; and (3) complete overstorey cover. Growth and mortality were measured from 1986 to 1991. Seedling height growth and survival decreased with overstorey density. After 6 yr, 92% of the seedlings survived in the open compared with 36% under complete overstorey cover. The open environment, in which woody and herbaceous regrowth formed a low canopy which reduced light intensities to about 50% of full sunlight, provided a favourable site for the growth of northern red oak.

147. **Crow TR, Haney A, and Waller DM 1994. Report on the scientific roundtable on biological diversity convened by the Chequamegon and Nicolet National Forests. U.S. For. Serv. General Technical Report NC-GTR-166, 55 pp.**

Keywords: biodiversity /resource management/ecosystems

148. **Crow TR, Host GE, and Mladenoff DJ 1999. Ownership and ecosystem as sources of spatial heterogeneity in a forested landscape, Wisconsin, USA. *Landscape Ecology* 14: 449-463.**

Keywords: ecosystems /land classification/forest plantations/forest ownership/ harvesting /land ownership/land use/logging /spatial variation/landscape /moraine soils/glacial soils/drainage /aerial photography/remote sensing/national forests/private forestry/upland areas/ natural regeneration/roads /environmental factors/soil types physiographic/pines /northern hardwoods

Abstract: The interaction between physical environment and land ownership in creating spatial heterogeneity was studied in largely forested landscapes in northern Wisconsin. A stratified random approach was used in which 2500-ha plots representing 2 ownerships (National Forest and private non-industrial) were located within 2 regional ecosystems (extremely well-drained outwash sands formed from collapsed and uncollapsed proglacial stream deposits, and moderately well-drained moraines). Sixteen plots were established, 4 within each combination of ownership and ecosystem, and the land cover on the plots was classified from aerial photographs using a modified form of the Anderson (US Geological Survey) land use and land cover classification system. Upland deciduous forests dominated by northern hardwoods were common on the moraines for both ownerships. On the outwash, the National Forest was dominated by pine plantations, upland deciduous forests, and upland regenerating forests (as defined by <50% canopy coverage). In contrast, a more even distribution among the classes of upland forest existed on private land/outwash. A strong interaction between ecosystem and ownership was evident for most comparisons of landscape structure. On the moraine, the National Forest ownership had a finer grain pattern with more complex patch shapes than private land. On the outwash, in contrast, the National Forest had a coarser grain pattern with less complex patch shapes than private land. When patch size and shape were compared between ecosystems within an ownership, statistically significant differences in landscape structure existed on public land but not on private land. On public land, different management practices on the moraine and outwash, primarily related to timber harvesting and road building, created very different landscape patterns. Landscape structure on different ecosystems on private land tended to be similar because ownership was fragmented in both ecosystems and because ownership boundaries often corresponded with patch boundaries on private land. The study shows that a complex relationship exists between ownership, and related differences in land use, and the physical environment that ultimately constrains land use. Studies that do not consider these interactions may misinterpret the importance of either variable in explaining variation in landscape patterns.

149. **Crow TR, Mroz GD, and Gale MR 1991. Regrowth and nutrient accumulations following whole-tree harvesting of a maple-oak forest. *Canadian Journal of Forest Research* 21: 1305-1315.**

Keywords: Broadleaves /Biomass /Clear felling/nutrients /Cycling /logging effects/Nitrogen cycle/Vegetation types/broadleaved deciduous forests/Temperate Zones /herbaceous plants

/Pteridium aquilinum /Aster macrophyllus /nitrogen /potassium /phosphorus/calcium /magnesium /herbicide /aboveground production/natural regeneration

Abstract: Rates of biomass and N, P, K, Ca and Mg accumulation were measured in a mixed (mainly) broadleaved-Haplorthod ecosystem following whole-tree harvesting and compared with preharvest conditions. Three treatments, viz. a whole-tree harvest, a whole-tree harvest with roller chopping and a whole-tree harvest with roller chopping and herbicide application, were carried out at a site near Baraga in Michigan's Upper Peninsula. Stand biomass and annual net primary production averaged 150.7 t/ha and 7.3 t/ha, respectively, in the preharvest forest. An estimated 100 t/ha of biomass was removed in a commercial whole-tree harvesting operation during the dormant season. Regrowth during the 4 years after harvest was categorized into the following floristic groups: woody plants; woodland herbaceous species that were part of the preharvest forest; early successional species that colonized the site after harvest; and graminoids. Woodland herbaceous and woody species dominated the recovery vegetation and together accounted for more than 70% of the nutrients captured by vegetation throughout the postharvest measurement period. Extensive clonal structures for many woody species and two common woodland herbaceous species, Pteridium aquilinum and Aster macrophyllus, resulted in their rapid recovery. Rapid growth along with high nutrient concentrations (especially K for woodland herbs) provided effective mechanisms for conserving nutrients following disturbance. After the first growing season following whole-tree harvesting, 44% of the total above-ground dry weight was in woody vegetation, 46% in woodland herbs, 9% in early successional species and 1% in graminoids, compared with 73, 17, 7 and 3% for the same categories by year 4. Annual rates of N, K, and Mg uptake by plants should equal or exceed their preharvest rates within 5 years after harvest; those of Ca and P take longer.

150. **Crow TR, Tubbs CH, Jacobs RD, and Oberg RR 1981. Stocking and structure for maximum growth in sugar maple selection stands [in Michigan]. U.S. For. Serv. Research Paper NC-199, 16 pp.**

Keywords: stand characteristics/growing stock/forest management/structure /planning /silviculture/ silvicultural systems/selection /broadleaves /Acer saccharum

151. **Dahir SE and Lorimer CG 1996. Variation in canopy gap formation among developmental stages of northern hardwood stands. *Canadian Journal of Forest Research* 26: 1875-1892.**

Keywords: age/stand structure/age of trees/mortality /stand development/vegetation types/ canopy gaps/stand characteristics/Acer saccharum/Tsuga canadensis/northern hardwoods /Ostrya virginiana /eastern hophornbeam/gap dynamics

Abstract: Trends in gap dynamics among pole, mature, and old-growth northern hardwood stands were investigated on eight sites in the Porcupine Mountains of western upper Michigan. Recent gaps (created between 1981 and 1992) were identified using permanent plot records of tree mortality, while older gaps (1940-81) were identified using stand reconstruction techniques. Although canopy gaps were somewhat more numerous in pole and mature stands, gaps were <25% as large as those in old-growth stands because of smaller gap-maker size, and the proportion of stand area turned over in gaps was only about half as large. Gap makers in younger stands generally had mean relative diameters (ratio of gap-maker diameter at breast height (DBH) to mean DBH of canopy trees) <1.0 and were disproportionately from minor species such as eastern hophornbeam (*Ostrya virginiana*). Gap makers in old-growth stands had mean relative diameters >1.5 and were predominantly from the dominant canopy species. Even in old-growth forests, most gaps were small (mean 44 m²) and created by single trees. Based on the identity of the tallest gap tree in each gap, nearly all shade-tolerant and mid-tolerant species have been successful in capturing gaps, but gap capture rates for some species were significantly different from their relative density in the upper canopy. The tallest gap trees of shade-tolerant species were often formerly overtopped trees, averaging more than 60% of the mean canopy height and having mean ages of 65-149 years. Canopy turnover times, based on gap formation rates over a 50-year period,

were estimated to average 128 years for old-growth stands dominated by sugar maple (*Acer saccharum*) and 192 years for old-growth stands dominated by hemlock (*Tsuga canadensis*). While these estimates of turnover time are substantially shorter than maximum tree ages observed on these sites, they agree closely with independent data on mean canopy residence time for trees that die at the average gap-maker size of 51 cm DBH. The data support previous hypothetical explanations of the apparent discrepancy between canopy turnover times of <130 years for hardwood species and the frequent occurrence of trees exceeding 250 years of age.

152. **David AJ, Zasada JC, Gilmore DW, and Landhausser SM 2001. Current Trends in the Management of Aspen and Mixed Aspen Forests for Sustainable Production. *Forestry Chronicle* 77: 525-532.**

Keywords: aspen management/retention/thinning/cut-to-length harvesting/genetic variation/genetic diversity/trembling aspen/isozyme/*Populus tremuloides*/wood products

Abstract: Quaking aspen (*Populus tremuloides* Michx.) is a remarkable species that performs several significant ecological roles throughout its range while at the same time is facing ever-increasing harvesting pressure. Although its full product potential remains untapped, aspen utilization has increased noticeably in the past 15 years as it has become a desired species for engineered wood products such as oriented strand board, and a preferred hardwood in the production of high quality pulp and paper products. Concurrent with this increase in aspen utilization has been an increase in the importance of ecological concepts in forest management. Any new silvicultural concepts in aspen management designed to address these ecological concepts must be grounded in the silvics and life history traits of the species. Here we present three trends in aspen management; aspen retention, a renewed interest in aspen thinning, and the advent of cut-to-length (CTL) harvesters that allow forest managers to address these considerations by capitalizing on aspen's unique characteristics. Finally, we discuss traditional harvesting methods and these trends in the context of their genetic implications.

153. **David MB, Gertner GZ, Grigal DF, and Ohmann LF 1989. Sulfur accumulation and atmospherically deposited sulfate in the Lake States. U.S. For. Serv. Research Paper NC-290, 7 pp.**

Keywords: forest soils/acid deposition/sulfates /soil chemistry/sulfur

Abstract: The mass of sulfur in the forest floor and mineral soil was studied in relation to atmospherically deposited sulfate along an acid precipitation gradient from Minnesota to Michigan. Contour mapping was used to show the relation graphically. Patterns of wet sulfate deposition appeared to be reflected in soil S pools.

154. **David MB, Grigal DF, Ohmann LF, and Gertner GZ 1988. Sulfur, carbon, and nitrogen relationships in forest soils across the northern Great Lake states as affected by atmospheric deposition and vegetation. *Canadian Journal of Forest Research* 18: 1386-1391.**

Keywords: Conifers /Broadleaves /Air pollution/soil chemistry/ecology /sulfates /sulfur /carbon /nitrogen /pines /*Acer saccharum*/*Populus tremuloides*/*Pinus banksiana*/*Pinus resinosa*/*Abies balsamea*

Abstract: Some 169 forested plots across Minnesota, Wisconsin and Michigan were geographically stratified into 5 zones, with annual deposition of wet sulfate increasing from 156 equiv./ha (zone 1 in the W.) to 380 equiv./ha (zone 5 in the E.). Measurements of total S, adjusted for total N, indicated higher concn. in eastern than in western zones in both the upper mineral soil (0.0152 and 0.0133% S, respectively in E. and W.) and forest floor (0.124 and 0.113% S respectively). This illustrates that forest soil S reflects geographic gradients in atmospheric sulfate deposition. Total C and N did not show any clear trends with zone, but these variables and C/N and C/S ratios were affected by vegetation type. Jack pine (*Pinus banksiana*) and red pine (*P. resinosa*) mineral soil had lower concn. of C and N than balsam fir (*Abies balsamea*), maple (*Acer*

saccharum) and aspen (*Populus tremuloides*) soil. Forest floor C and N showed no clear pattern.

155. **Davis AL 1997. *Oversotry composition and stand structure influence understory plant diversity in the mixed aspen forest in Northern Minnesota*. MS thesis, University of Minnesota, Twin Cities. 65 pp.**

Keywords: *Populus* spp. /aspen/northern hardwoods /understory plant diversity /conifer stands /overstory composition

Abstract: The relationship of understory plant diversity to overstory composition and stand structure in the mixed aspen forest of northern Minnesota was investigated on 23 study sites that contained aspen in monoculture or in mixture with boreal conifer or northern hardwood species. Each site was placed in a covertime group based on its overstory composition. Three covertime groups were used: Aspen (> 90 percent basal area in aspen), Conifer (> 15 percent basal area in conifer species) and Hardwood (> 15 percent basal area in hardwood species). The relationships between diversity of understory vegetation and the following factors were tested: (1) aspects of the overstory conditions such as proportion of basal area by species in the overstory and (2) stand structure as described by the variability of overstory species and the relative size and positioning of overstory tree species, shrub height and cover, average amount of plant material intercepted within the vertical profile and an index of the plant occupancy within the vertical profile (Foliage Height Diversity Index). Positive relationships existed between diversity and proportions of aspen basal area while diversity was negatively related to proportions of hardwood basal area and not related to proportion of conifer basal area. In the three covertime groups, different structural components are related to herbaceous diversity making it difficult to characterize vertical structure with a single measure. The interaction of overstory composition and vertical structure was useful in understanding understory diversity patterns.

156. **Davis MB, Sugita S, Calcote RR, Ferrari JB, and Frelich LE 1994. Historical development of alternate communities in a hemlock-hardwood forest in northern Michigan, USA. In Edwards PJ, May RM, Webb NR (eds.) *Large-scale ecology and conservation biology: the 35th Symposium of the British Ecological Society with the Society for Conservation Biology*, University of Southampton.**

Keywords: vegetation /history /plant colonization/plant succession/palaeoecology /stand characteristics/ stand structure/*Acer rubrum*/*Acer saccharum*/*Quercus rubra*/*Tilia americana*/*Pinus strobus*/*Tsuga canadensis*

Abstract: A spatially precise palaeoecological record from the Sylvania Wilderness, a 8500-ha reserve in northern Michigan, was used to test hypotheses on the origin of the mosaic of hemlock and hardwood forest communities, providing new information about factors affecting stand invasion and persistence of the forest mosaic through time. The mosaic comprises patches (1-20 ha) dominated either by hemlock (*Tsuga canadensis*) or by sugar maple (*Acer saccharum*) and basswood (*Tilia americana*) that began about 3200 BP when hemlock extended its geographical range into the region. Hemlock invasion of the original white pine (*Pinus strobus*)/red maple (*Acer rubrum*)/oak (*Quercus rubra*) forest was patchy. In the intervening patches sugar maple and basswood became dominant. The present hemlock and hardwood patches each have distinctive soil humus, nutrient availability, microclimate and ground flora. The mosaic is seen only in original old-growth forests, because logging has converted both stand types to hardwoods. It is concluded that restoration of the mosaic pattern would be difficult.

157. **Delcourt HR and Delcourt PA 1996. Presettlement Landscape Heterogeneity: Evaluating Grain of Resolution Using General Land Office Survey Data. *Landscape Ecology* 11: 363-381.**

Keywords: General Land Office Surveys/history/Landscape Ecology/Restoration Ecology/Hemlock-Hardwood Forests/Old-Growth/Conifer Ecosystems/northern hardwoods/Spatial Pattern/Beech Climax/Disturbance/*Fagus grandifolia*/*Tsuga canadensis*

Abstract: General Land Office Survey (GLOS) records from the A.D. 1840s provide data for quantitative characterization of presettlement vegetation across western Mackinac County, Michigan, located within the mixed conifer-northern hardwoods forest region. We analyzed data from land survey plat maps and 1958 bearing, witness, and line trees from 162 surveyed section and quarter-section corners in order to map vegetation cover types at a level of spatial resolution appropriate for characterizing landscape heterogeneity using standard landscape ecological metrics. As also demonstrated by a number of both classic and contemporary plant-ecological studies, the distribution of landforms, soils properties, hydrology, and location of fire breaks all contribute to the heterogeneity in vegetation observed at a landscape scale in the region. Through a series of spatial landscape analyses with differing grain of resolution, in this study we determine that a grid cell size of 65 ha (0.5 mi² or 0.25 mi²) to 259 ha (1 mi²) gives a conservative characterization of landscape heterogeneity using standard metrics and is therefore appropriate for use of GLOS data to study historical landscape changes.

158. **Dellasala DA 1986. *Response of three songbird species to forest disturbances in large tracts of northern hardwoods*. PhD dissertation, University of Michigan, Ann Arbor. 87 pp.**

Keywords: northern hardwoods /disturbance /birds/red-eyed vireo /Vireo olivaceus /ovenbird /Seiurus aurocapillus /least flycatcher /Empidonax minimus /forest openings

Abstract: Prior studies of forest disturbances have examined the influence of size of a forest fragment on species diversity. Frequently, this information has been used in recommendations for forest preserves. This study examined the effects of size and shape of forest disturbances on the densities and spatial distributions of three songbird species in large tracts (>100 ha) of northern hardwood forests in Michigan. Species studied included the Red-eyed Vireo (*Vireo olivaceus*), Ovenbird (*Seiurus aurocapillus*) and Least Flycatcher (*Empidonax minimus*). Distributions of Red-eyed Vireos and Ovenbirds were studied in relation to openings of different shapes and sizes, while Least Flycatchers were studied only in relation to opening size. For Red-eyed Vireos and Ovenbirds, study sites were primarily square shapes, and included small (0.02 ha), medium (0.8 ha), and large (>5 ha) openings. In addition, a petroleum pipeline-corridor represented a narrow-rectangular (15 m-wide) opening. Opening sites were compared to undisturbed plots located at least 400 m from a forest opening. For Least Flycatchers, spatial distribution was studied in relation to openings from 0.8 to 22 ha. Results for Red-eyed Vireos and Least Flycatchers indicate that the effects of forest disturbances in large continuous forests are related to opening size. Declines in Red-eyed Vireos (*Vireo olivaceus*) were more severe for large openings than medium ones, and were detected over greater distances into the forest interior. Average reductions in densities of 22 to 50% were detected over distances of 250 and 400 m for medium and large openings; respectively. However, these estimates were based on considerable variation in vireo density with distance from a forest opening. No avoidance was observed for small or narrow-rectangular openings. Declines in breeding density of Ovenbirds were not observed. Shifts in spatial distributions of Least Flycatchers (*Empidonax minimus*) were also related to forest opening size. This species forms dense aggregations that were displaced farther into the forest interior as size of openings increased. Response was detected over average distances of up to 200 m from a disturbance for openings > 10 ha. Results of this study suggest that recommendations for forest reserves that are derived solely from the response of species to size of forest fragments, may underestimate the amount of interior habitat needed by some songbirds. Data on flycatcher and vireo distributions suggest that 'buffer zones' equivalent to the distances over which these birds were displaced by an opening are also needed in estimates of reserve size.

159. **Denig J, Wengert EM, and Simpson WT 2000. *Drying Hardwood Lumber*. U.S. For. Serv. General Technical Report (Forest Products Laboratory) FPL-GTR-118, 138 pp.**

Keywords: northern hardwoods solar drying/wood defects/storage /quality /Acer saccharum/ Fraxinus spp. / Quercus spp./wood products

Abstract: This report focuses on common methods for drying lumber of different thickness, with minimal drying defects, for high quality applications. This manual also includes predrying treatments that, when part of an overall quality-oriented drying system, reduce defects and improve drying quality, especially of American oak [*Quercus* sp.] lumber. Special attention is given to drying white wood, such as hard maple [*Acer saccharum*] and ash [*Fraxinus* sp.], without sticker shadow or other discoloration. Several special drying methods, such as solar drying, are described, and proper techniques for storing dried lumber are discussed. Suggestions are provided for ways to economize on drying costs by reducing drying time and energy demands when feasible. Each chapter is accompanied by a list of references. Some references are cited in the chapter; others are listed as additional sources of information.

160. **Desanker PV, Reed DD, and Jones EA 1994. Evaluating forest stress factors using various forest growth modeling approaches. *Forest Ecology and Management* 69: 269-282.**

Keywords: stresses /growth /climate /habitats /air pollution/plant succession/biogeochemistry /ecosystems /forest ecology/vegetation types/deciduous forests/growth models/stress analysis/*Acer rubrum*/*Quercus rubra*/northern hardwoods /model STEMS, FOREST, JABOWA, FORET, FOREST-BGC/IUFRO

Abstract: This paper examines in detail the relative merits of several modelling approaches to evaluating forest site, physical, chemical and climatic stresses. The modelling approaches considered are (i) empirical growth and yield (management) models (STEMS and FOREST); (ii) successional models (JABOWA/FORET gap-phase simulation models and FORSKA); (iii) forest process models (FOREST-BGC). The models were analysed in terms of their assumptions, formulation, and predictive ability. The analysis incorporated intensive measurements of tree growth and weather conditions taken over 7 years in two stands of northern hardwoods located in Upper Michigan - dominated by *Acer rubrum* and *Quercus rubra*. The process model was very detailed and required many input variables. All models performed poorly when predictions were compared with the observed data making accurate site-specific predictions impossible without local calibrations.

161. **Deusen PC van and Lynch TB 1987. Efficient unbiased tree-volume estimation. *Forest Science* 33: 583-590.**

Keywords: volume determination/tree taper /estimation /model tree taper

Abstract: Two unbiased methods for estimating the vol. of an individual tree (based on importance sampling and critical ht. sampling) are compared using a simple model for tree taper. Importance sampling has an advantage over the critical ht. method because a smaller sample size is required. When a negative correlation was induced in the sample observations using antithetic variates, both methods became more efficient.

162. **Dey DC and Guyette RP 2000. Anthropogenic fire history and red oak forests in south-central Ontario. *Forestry Chronicle* 76: 339-347.**

Keywords: burning /forest fires/natural regeneration/stumps /recruitment /dendrochronology /history /forest ecology/fire ecology/frequency /human activity/population density/*Acer saccharum*/ *Quercus rubra*/*Pinus strobus*/*Pinus resinosa*

Abstract: The regeneration and dominance of northern red oak (*Quercus rubra*) has been associated with fire throughout eastern North America. Red oak in central Ontario grows near the northern edge of its distribution in mixed hardwood-coniferous forests under mesic conditions where it competes with more shade-tolerant species. It was hypothesized that the abundance of red oak in these stands was largely the result of anthropogenic burning and natural fires, which would favour the regeneration and recruitment of northern red oak over such shade-tolerant species as sugar maple (*Acer saccharum*). Fire histories dating from the mid-1600s were constructed by

dendrochronological methods from fire scars on stumps, trees, and natural remnants of red pine (*Pinus resinosa*), white pine (*Pinus strobus*), and red oak at six sites in south-central Ontario. Fire histories of the sites are characterized by abrupt changes in fire interval. As much or more variance in fire interval is found within sites as is found among sites. Differences in the mean fire interval among sites are related to the density and migration of historic aboriginal and European populations. The mean fire interval varied from more than 70 years to six years depending on site location and historic period. The occurrence and abundance of red oak is linked to anthropogenic fire regimes.

163. **Dey DC and Parker WC 1997. Overstorey density affects field performance of underplanted red oak (*Quercus rubra* L.) in Ontario. *Northern Journal of Applied Forestry* 14: 120-125.**

Keywords: deciduous forests/mortality /seedlings /survival /seedling growth/shelterwood system/silvicultural systems/light intensity/underplanting /artificial regeneration/*Quercus rubra*/northern hardwoods

Abstract: Red oak (*Quercus rubra*) seedlings were underplanted in spring 1993 in a closed-canopy mature northern hardwood stand and an adjacent shelterwood in central Ontario. After 2 years, seedling survival was 90% in the uncut stand and over 99% in the shelterwood. Seedlings in the uncut stand experienced negligible or negative annual increments in stem diameter and height. Seedlings in the shelterwood were about 2 mm larger in diameter and nearly twice as tall as those in the uncut stand after 2 years. Second-year stem diameter and height distributions of planted oak were significantly different in the shelterwood and the uncut stand. Root volume, area, and dry mass were substantially larger for seedlings grown in the shelterwood than those in the uncut stand. Loss of vigour, growth declines, and increased mortality of planted oak were largely a result of extremely low understorey light levels in the uncut stand. Results of this study suggest that red oak underplanted in an uncut stand 2 or more years before a shelterwood harvest will be at a competitive disadvantage once they are released. Establishment and performance of underplanted red oak is promoted by shelterwoods that provide adequate light at the forest floor and should exhibit a strong positive growth response following final overstorey removal.

164. **Dominski AS 1971. Nitrogen transformations in a northern-hardwood podzol on cutover and forested sites. PhD dissertation, Yale University, New Haven. 161 pp.**

Keywords: nitrogen cycle/clear felling/forest influences/soil /soil chemistry/nitrogen /leaching /soil types/podzols /herbicides/competition

Abstract: After clear felling and suppression of regrowth with herbicides, high NO₃-N concentrations were observed in streams leaving a northern-hardwood site with a podzol soil. A comparative study of NH₃ and NO₃ concentrations in the soil on clear-felled and forested sites indicated that considerable nitrification occurs under undisturbed forests. This finding contradicted the general belief that rates of nitrification are very slow in forest podzols. Owing to efficient vegetative uptake of NO₃ during the growing season, very little NO₃ leaks into the stream in the course of an annual cycle. Immediate increases in nitrification rates on the clear-felled site indicated that, under undisturbed conditions, nitrification was limited more by the environmental modification exerted by living vegetation than by any inherent physical or chemical properties of the soil. Vegetation limits nitrification rates primarily by modifying temperatures during the growing season, and possibly by restricting NH₃ supply to nitrifiers and/or by adding polyphenols in litter. Rapid regrowth on clear-felled sites would limit NO₃-N losses to less than half of those observed where regrowth was artificially suppressed, and it is concluded that NO₃-N losses during a normal period of regeneration would not significantly impair future productivity.

165. **Donnelly GT 1986. Forest composition as determined by canopy gap dynamics: a beech-maple forest in Michigan. PhD dissertation, Michigan State University, East Lansing. 127 pp.**

Keywords: Plant succession/Vegetation types/natural regeneration/stand characteristics/

disturbance /shade tolerance /composition/Acer saccharum/Fagus grandifolia/ Prunus serotina /Liriodendron tulipifera

Abstract: Forest regeneration was studied in Warren Woods, a mature beech-maple forest in southwestern lower Michigan to understand the role of treefall gaps in the maintenance of forest composition. Warren Woods is similar in composition to presettlement forests and to other old-growth remnant stands, and served as an excellent model of natural beech-maple forest. Gap chronosequence analysis revealed that gaps closed in 34 yr by in-growth of surrounding trees, with tree density changing via shifts in recruitment and mortality. Gap vegetation was dominated by sugar maple, but all forest tree species were represented. Average height increase of beech and maple in gaps was similar, although maximum growth in maple was greater. Seedlings and saplings were not able to grow into the canopy as a result of a single gap exposure. Suppression of small stems in closed gaps was followed by death or by re-release in subsequent gaps, as evidenced by episodic radial growth associated with recurrent gaps of successful canopy trees. Beech was more shade tolerant than sugar maple, with greater survivorship during extended suppression between gaps; relative mortality was concomitantly greater in sub-canopy maple. Superior shade tolerance is the most important mechanism by which beech maintains dominance in natural forests. Shade-intolerant yellow-poplar and black cherry were rare and non-randomly distributed in the forest, associated more with topographic, edaphic, and edge factors than with treefall gaps. Gap reconstructions around rare trees of the forest interior demonstrated that regeneration in single-treefall gaps was possible, although limited by seed dispersal and problems of germination and establishment. With a turnover time of 370-390 yr, Warren Woods incurs a lower rate of treefall disturbance than any other forest reported in the literature. This low rate of disturbance determines the dominance of shade-tolerant species and the rarity of shade-intolerant species.

166. **Dovciak M, Frelich LE, and Reich PB 2001. Discordance in Spatial Patterns of White Pine (*Pinus Strobus*) Size-Classes in a Patchy Near-Boreal Forest. *Journal of Ecology* 89: 280-291.**

Keywords: neighbourhood effects/patch dynamics/plant demography/point pattern analysis/spatial pattern/white pine/hemlock-hardwood forest/seedling recruitment/wind dispersal/ growth/seeds/autocorrelation/natural regeneration/communities/competition/Acer rubrum/Populus spp. /Pinus strobus/Tsuga canadensis

Abstract: 1 White pines (*Pinus strobus*) in a c. 1 ha near-boreal aspen- red maple stand in the western Great Lakes region, USA, were allocated to five size-classes that were tested for discordance of their spatial patterns (i.e. within-size-class spatial distribution of individuals and spatial associations among different size-classes). The size-classes were 0.5-1 m tall, 1- 2 m tall, 2-4 m tall, > 4 m tall but < 20 cm diameter at breast height (d.b.h.), and > 20 cm d.b.h. The size-classes also differed in age. Their spatial patterns were analysed using formulae for spatial autocorrelation with categorical data at neighbourhood (0-14 m) and stand (0-70 m) scales. 2 Size-classes clustered in neighbourhoods that differed in size ranging from 6 m in diameter (size-class 2) to 40 m (size-class 3), suggesting that the pattern of each size-class is due to a different set of environmental factors. Similar size-classes tended to be randomly or positively associated at neighbourhood scales, while the most dissimilar size-classes occupied different neighbourhoods. 3 Size-classes 1 and 2 were located farther away from seed trees than size-class 3, which was farther away than size-class 4. Thus periodic seedling invasion of a deciduous matrix may be followed by the gradual retraction of older size-classes into a refuge near the mature seed source where competition from shrubs and overstorey trees is lower. Although the lack of fine-scale clustering suggests density- dependent mortality within the refuge, few older individuals were found outside this area. 4 Two regeneration bottlenecks may structure white pine populations. First, recruitment into size-class 2 is restricted to small patches (possibly in understory gaps) within neighbourhoods with abundant size- class 1. Relatively unrestricted recruitment to size-class 3 follows, and after that recruitment to size-class 4 is again limited, this time to refugia with sparse canopy near adult trees.

167. **Dube P, Fortin MJ, Canham CD, and Marceau DJ 2001. Quantifying Gap Dynamics at the Patch Mosaic Level Using a Spatially-Explicit Model of a Northern Hardwood Forest Ecosystem. *Ecological Modelling* 142: 39-60.**

Keywords: Spatially-Explicit Models/model SORTIE/Individual-Based Simulations/Self-Organisation/Expanded Gaps/Gap Dynamics/Spatio-Temporal Statistics/Sensitivity Analysis/Canopy Recruitment/Sapling Mortality/Tropical Forests/Succession Model/Shade Tolerance/Growth/Patterns/northern hardwoods

Abstract: Small-scale disturbances that create canopy gaps play a key role in regulating successional pathways in temperate forests. SORTIE, a spatially-explicit, individual-based model, allows the modelling of temperate forest succession by means of gap dynamics. The aim of this paper is to evaluate, using a spatio-temporal sensitivity analysis, the spatial cohesiveness of gaps generated by SORTIE. Northern hardwood forest succession, based on local interactions of three shade tolerant and three shade intolerant species, was simulated over 1000 years. To investigate the effects of initial conditions, two seedling densities (low and high) and two spatial configurations of new seedlings (random and aggregated) were replicated five times. Statistical analyses were then performed to detect the presence of significant global spatio-temporal gap structures. These analyses were followed by a more detailed characterisation of the spatio-temporal behaviour of the model using three different spatial statistics (spatial join-count, nearest neighbour and gap size) at each time step. The cohesive temporal periodicity of these statistics was assessed using phase coherence (PC) analysis. Results exhibit consistent global spatial dynamics, with subtle differences between replicates and between initial conditions. PC analysis reveals the presence of important cyclic behaviour around 200-250 years. Finally, our results provide useful insights about the intrinsic factors regulating long-term spatial gap dynamics, as well as the effects of shade tolerance on the immediate responses of tree species to disturbance in temperate forests.

168. **Dunn CP, Guntenspergen GR, and Dorney JR 1983. Catastrophic wind disturbance in an old-growth hemlock-hardwood forest, Wisconsin. *Canadian Journal of Botany* 61: 211-217.**

Keywords: wind damage/ecology /measurement /natural regeneration/assessment /Acer saccharum/ Betula alleghaniensis/Tsuga canadensis /exclosure

Abstract: The structure and dynamics of a 61-ha fenced stand dominated by *Tsuga canadensis*, *Betula alleghaniensis* and *Acer saccharum* were studied before and after a hurricane on 4 July 1977 that reduced b.a. to 6% of that present before the storm. The study recorded the extent of canopy removal, the relative proportion of species remaining in each stratum and the potential contribution of newly germinated seedlings.

169. **Ek AR 1974. Nonlinear models for stand table projection in northern hardwood stands. *Canadian Journal of Forest Research* 4: 23-27.**

Keywords: stand tables/increment /forecasting /stand characteristics/development /northern hardwoods /model non-linear

Abstract: Presents a set of non-linear equation models for the three growth components recruitment, mortality, and growth of survivors, for individual diameter classes in these stands, and discusses their formulation, utility and limitations.

170. **Ek AR, Birdsall ET, and Spears RJ 1983. A simple model for estimating total and merchantable tree heights. U.S. For. Ser. Research Note NC-309, 5 pp.**

Keywords: model /tree height estimation

Abstract: An equation is given for estimating height of tree species from the US Lake States from d.b.h., site index and b.a. Coefficients (and originating data sets) are tabulated for 25 species

calculated from forest survey records for Minnesota (1976-78), Wisconsin (1967-68) and Michigan (1979-80).

171. **Ek AR and Monserud RA 1979. Performance and comparison of stand growth models based on individual tree and diameter-class growth. *Canadian Journal of Forest Research* 9: 231-244.**

Keywords: mathematics /increment /forecasting /theory /growth model/model FOREST,SHAF

Abstract: A distance-dependent individual tree based growth model (FOREST) was compared with a diameter-class growth model (SHAF) for describing changes in stand density and structure. Projections of Lake States' northern hardwood stand development were made by each model for 5-26 years over a range of stand conditions and harvest treatments. Results from numerous performance tests and comparisons of actual and predicted diameter distributions, basal areas, and numbers of trees, indicate the individual tree model was considerably more sensitive to harvest treatments and reproduction response than the diameter-class model. Conversely, the latter was much less expensive to operate. Prediction of species and individual tree growth with the individual tree model appeared to provide sensitivity nearly equal to that observed for predictions of the stand as a whole. Long-term projections (120 years) for reserve (no cut) and clear-cut stand conditions further suggest the potential and limitations of the models for management analyses.

172. **Ek AR, Robinson AP, Radtke PJ, and Walters DK 1997. Development and testing of regeneration imputation models for forests in Minnesota. *Forest Ecology and Management* 94: 129-140.**

Keywords: stratification /simulation models/harvesting /stand development/stand characteristics/ data analysis/statistical analysis/classification /forest inventories/increment /growth model/model tabular imputation

Abstract: Tabular imputation models were developed and tested to estimate postharvest forest stand characteristics in Minnesota. The models were based on a sorting of statewide inventory plot data into sets of tables containing estimates of number of trees and basal area per hectare by cover type, species, and diameter class for young postharvest stands. The primary bases for sorting within the sets of tables were stand age following harvest, and site index. The output tables were organized to facilitate their use as young stand input data to existing growth and yield models. Analysis of these tables indicated that basal area increased rapidly for young stands and then began to level off as stand ages approached 20 yr; furthermore, the variability within the tables decreased as forest stands matured. Implications for alternative methods of implementing the models are also discussed.

173. **Ek AR, Robinson AP, Radtke PJ, and Walters DK 1996. Regeneration imputation models and analysis for forests in Minnesota. Department of Forest Resources (University of Minnesota) Staff Paper Series No. 115, 45 pp.**

Keywords: growth models/increment /stand development/regeneration /vegetation types/basal area/stand density/forest inventories/diameter /stand tables/forests /stand characteristics/simulation /model tabular imputation

Abstract: Tabular imputation models were developed and tested for estimating post-harvest forest stand characteristics in Minnesota. The models were based on a sorting of statewide inventory plot data into sets of tables containing estimates of number of trees and basal area per acre by cover type, diameter classes, and species, for young post-harvest stands. The primary bases for sorting within the sets of tables were stand age following harvest and site index. The output tables were organized to facilitate their use as young stand input data to existing growth and yield models; summary tables are included for 13 cover types (species or groups of species). Analysis of these tables indicated that basal area increased rapidly for young stands and then began to level off as stand ages approached 20 years; furthermore, the variability within the tables decreased as forest

stands matured. Implications for alternative methods of implementing the models are also discussed.

174. **Ellsworth DS and Reich PB 1992. Leaf mass per area, nitrogen content and photosynthetic carbon gain in *Acer saccharum* seedlings in contrasting forest light environments. *Functional Ecology* 6: 423-435.**

Keywords: understorey /photosynthesis /growth /natural regeneration/canopy gaps/light /*Acer saccharum*

Abstract: Naturally regenerating seedlings of *Acer saccharum* were studied across a gradient of light environments in a stand in SW Wisconsin. Leaf structure, photosynthetic attributes, and daily net carbon gain at the leaf-level are discussed in relation to differences in light environment (understorey, gap, clearing). Best growth response was found in small gaps, which combined high photosynthetic photon flux density with amelioration of extremes of temperature and vapour pressure difference by the surrounding forest.

175. **Enebak SA and Blanchette RA 1989. Canker formation and decay in sugar maple and paper birch infected by *Cerrena unicolor*. *Canadian Journal of Forest Research* 19: 225-231.**

Keywords: Decay /biology /field tests/wood anatomy/fungal diseases/Cankers /pathogenicity /plant pathology/plant pathogenic fungi/*Acer saccharum*/*Betula papyrifera*/*Cerrena unicolor*

Abstract: One *C. unicolor* isolate from sugar maple (*Acer saccharum*) and one from paper birch (*Betula papyrifera*) were used to test the pathogenicity of the fungus by inoculation of both tree species (with their respective isolates) in field trials in Minnesota in 1984 and 1985; cankers were examined 6 months, 1.5 yr and 2.5 yr later. The 2 isolates used were found to differ in pathogenicity. Chemical and morphological barriers formed to compartmentalize the fungus. A zone of enhanced cell wall lignification and the formation of suberized impervious cells which composed the necrophylactic periderm in the host were observed. Xylem discoloration, callus formation, and periderm layers were more pronounced in maple than in birch. *C. unicolor* moved past host barriers via a mass of hyphae which annually penetrated weak points in the necrophylactic periderm and subsequently killed the adjacent cambium. Once past the necrophylactic periderm and into the xylem, *C. unicolor* was an aggressive decay organism which caused an extensive white rot. In naturally infected trees, columns of decay were two or three times longer than the cankers. Multiple zones of decayed and discolored wood were present in the xylem as a result of repeated attacks by the fungus.

176. **Erdmann GG 1967. Chemical weed control increases survival and growth in hardwood plantings. U.S. For. Serv. Research Note NC-34, 4 pp.**

Keywords: soil site preparation /*Fraxinus americana* /*Fraxinus excelsior* /*Juglans nigra* /*Liriodendron tulipifera* /*Quercus rubra* /artificial regeneration /silviculture /*Ulmus americana* /atrazine/simazine/herbicide

Abstract: A study of six weed-control treatments in plantations of (1) *Juglans nigra*, (2) *Quercus rubra*, (3) *Liriodendron tulipifera* and (4) *Fraxinus americana* in Iowa showed that 4 lb./acre of active simazine or atrazine controlled weeds effectively without injuring the trees. Better control was obtained on ploughed and disked ground. Prepared ground stimulated rapid height growth in (3) and (4), but not in (1) and (2). Guides are given for proper use of chemicals in establishing hardwood plantations.

177. **Erdmann GG, Crow TR, and Oberg RR 1982. Volume tables for second-growth northern hardwood forests in northeastern Wisconsin. U.S. For. Serv. Research Paper NC-222, 5 pp.**

Keywords: volume determination/Cordwood /equations /merchantable volume/second

growth/productivity/Acer saccharum/Tilia americana/Fraxinus americana/Betula alleghaniensis/northern hardwoods

Abstract: Cubic-ft vol. equations are presented for sugar maple, *Tilia americana*, *Betula alleghaniensis* and *Fraxinus americana*, together with conversion factors for bd ft and cordwood volumes.

178. **Erdmann GG, Godman RM, and Mattson GA 1975. Effects of crown release and fertilizer on small saw log-sized Yellow Birch. U.S. For. Serv. Research Paper NC-119, 6 pp.**

Keywords: thinning /fertilizers /increment /NPK fertilizers/responses /nutrients /broadleaves /yields /plant composition/*Betula alleghaniensis*

Abstract: In a study in Wisconsin begun in 1971 four crown release treatments of differing intensities, and one crown release and fertilizer treatment were applied to 65-year-old *Betula alleghaniensis*. Results show that diameter growth of all trees of saw-log size gradually increased during the 3-year period following crown release. The amount of growth was generally related to the degree of release. The most immediate response to release was gained by removing the two most important competitors, though it is thought that a treatment that removed all trees whose crowns were within 5-ft of the perimeter of the crown of the study tree may have greater long term benefits. Fertilizer treatment had no significant influence on diameter growth in the two year period following application.

179. **Erdmann GG, Godman RM, and Oberg RR 1975. Crown release accelerates diameter growth and crown development of Yellow Birch saplings. U.S. For. Serv. Research Paper NC-117, 9 pp.**

Keywords: silviculture /broadleaves /*Betula alleghaniensis*/crown release

Abstract: Describes a study in Ottawa to assess the effects after 3 years of five crown-release treatments of varied intensity on the diameter and height growth, crown development and stem quality of 16-year-old *Betula alleghaniensis* trees. Results (tabulated) suggest that crown release significantly increased diameter growth within each crown class, though the height growth of unreleased dominants was greater than that of released dominants. Crown response to release was generally good. These early results suggest that a single release treatment, particularly if severe, may increase the number and quality of *B. alleghaniensis* trees in mixed hardwood stands, thus enabling a considerable reduction to be made in the time required for saw- and veneer-log rotations in the Lake States.

180. **Erdmann GG, Godman RM, and Peterson RM Jr. 1982. How to release yellow birch in the Lake States. U.S. For. Serv. misc. publication, 6 pp.**

Keywords: Thinning /broadleaves /*Betula alleghaniensis*

181. **Erdmann GG, Metzger FT, and Oberg RR 1979. Macronutrient deficiency symptoms in seedlings of four northern hardwoods. U.S. For. Serv. General Technical Report NC-GTR-53, 36 pp.**

Keywords: nutrient deficiencies/nitrogen /phosphorus /potassium /calcium /magnesium /sulfur /seedlings /growth /physiology /*Acer saccharum*/*Fraxinus americana*/*Betula papyrifera*/northern hardwoods

Abstract: An illustrated description of visual deficiency symptoms for N, P, K, Ca, Mg, or S in *Acer saccharum*, *A. rubrum*, *Fraxinus americana* and *Betula papyrifera* seedlings. Effects of these deficiencies on the development and nutrient composition of seedlings are also examined. From authors' summary.

182. **Erdmann GG and Oberg RR 1973. Fifteen-year results from six cutting methods in second-growth**

northern hardwoods. U.S. For. Serv. Research Paper NC-100, 12 pp.

Keywords: improvement fellings/thinning /felling /selective felling/silvicultural systems/northern hardwoods

Abstract: Reports a study begun in 1951 in three 40-acre stands in the Argonne Experimental Forest in north-eastern Wisconsin, to compare the effects of (a) selective felling of single trees to three stocking densities (leaving a residual b.a. of 90, 75, or 60 ft²/acre); (b) selective felling (leaving 30-50 seed-trees/acre); and (c) felling all trees with stump diameters of 8 in or more (leaving an average residual b.a. of 21 ft²/acre). The control was an uncut stand with a b.a. of 94 ft²/acre. Detailed results are tabulated, showing growth in b.a., diameter, ft² volume, cordwood volume, bd ft volume, the change in stand structure, and mortality. Recommendations are made on the basis of results, but the best type of management will depend primarily on the owner's aims and then on stand condition and species composition. In general, the first felling should be an improvement felling, removing poor-quality stock in all diameter classes, and leaving the main stand of dominants and co-dominants with an average diameter below sawlog size; later treatments can be varied to suit different objects of management.

183. **Erdmann GG and Peterson RM Jr. 1972. Crown release increases diameter growth and bole sprouting of pole-size Yellow Birch. U.S. For. Serv. Research Note NC-130, 4 pp.**

Keywords: increment /epicormics /thinning /injuries /yields /Betula alleghaniensis/Sphyrapticus varius/damage

Abstract: Numerical data on the increases in diameter growth and in the number of epicormics are given on graphs and tables. Damage by *Sphyrapticus varius* was more frequent and more severe on trees that had been released.

184. **Erdmann GG and Peterson RM Jr. 1982. Estimating site index in even-aged northern hardwood stands. U.S. For. Serv. Research Paper NC-285, 4 pp.**

Keywords: site class assessment/site index/increment /height /broadleaves /Acer rubrum/Acer saccharum /northern hardwoods

Abstract: Field and office procedures are given for collecting data and developing ht./age curves for a site based on stem analyses of 3 or more felled sample trees. Sugar and red maple [*Acer rubrum*] are the recommended species for comparisons in the Lake States, and an example is given of data for red maple. A method of improving site index estimates from existing curves [see FA 43, 1462] is also given.

185. **Erdmann GG, Peterson RM Jr., and Godman RM 1981. Cleaning yellow birch seedling stands to increase survival, growth, and crown development. *Canadian Journal of Forest Research* 11: 62-68.**

Keywords: increment /2,4,5 T/usage /crops /weed control/management /yields /Betula alleghaniensis/ herbicide

Abstract: Seven-year-old even-aged regenerated stands of *Betula alleghaniensis* in Michigan were cleaned by removing all seedlings and brush with a brushcutter to a radius of 0, 1.2, 2.4, 3.7 or 4.9 m from each birch tree. Effects on diam. growth, ht. growth, survival, crown position, and stem quality were assessed over 9 yr. Growth and survival increased with cleaning radius, except in the first season when control trees grew in ht. faster than cleaned trees. Branching was greatest in the 3.7 and 4.9 m treatments, therefore a cleaning radius of 2.4 m is recommended, or a 3.7-m radius if corrective pruning is feasible.

186. **Erickson MD, Mroz GD, and Reed DD 1992. Silvicultural influence on heartwood discoloration in**

sugar maple. *Northern Journal of Applied Forestry* 9: 27-29.

Keywords: silvicultural systems/wood properties/wood defects/silviculture /logging /damage /logging effects/economics/heartwood /discoloration /selection system/Acer saccharum/northern hardwoods

Abstract: The effects of diameter limit and selection system logging on the extent of sugar maple [Acer saccharum] heartwood discoloration - thought to be triggered by injury to the stem - were evaluated by examining all stumps from five 1-acre compartments in logged second-growth northern hardwood forest in Baraga County, Michigan. The amount of discoloration was related to tree size, and it was concluded that residual damage was more likely to be the source of discoloration than harvest practice. Heartwood discoloration is more frequent in selection system stands, and thus results in a greater economic loss, because larger trees are maintained for longer periods under this forest management regime.

187. **Erickson MD, Reed DD, and Mroz GD 1990. Stand development and economic analysis of alternative cutting methods in northern hardwoods: 32-year results. *Northern Journal of Applied Forestry* 7: 153-158.**

Keywords: broadleaves /thinning /economics /selection criteria/Acer saccharum/Tilia americana/Ulmus spp./Betula alleghaniensis/northern hardwoods

Abstract: An evaluation of 8 different thinning techniques (diameter limits of 22, 16, 12 and 5 inches; single-tree selections to basal areas of 90, 70 and 50 ft²/acre, and light improvement felling) undertaken at an experimental forest in Upper Michigan. Species present were sugar maple [Acer saccharum] (dominant), with elm [Ulmus sp.], yellow birch [Betula alleghaniensis] and basswood [Tilia americana]. Stand and tree quality improved most under the improvement felling; harvest revenues were maximized by a 12-inch diameter limit (followed by 16-inch limit and improvement felling). Forest value, however, was maximized with the 16-inch felling, then the improvement felling. Tables detailing stand characteristics since 1956, harvested volumes, and financial analyses of returns (in 1988 \$) are given.

188. **Eyre FH 1939. Silvicultural management of northern hardwoods. *Journal of Forestry* 37: 719-721.**

Keywords: northern hardwoods /silviculture

189. **Eyre FH and Longwood FR 1951. Reducing mortality in old-growth northern hardwoods through partial cutting. U.S. For. Serv. Lake St. For. Exp. Sta. Station Paper LS-24, 13 pp.**

Keywords: Acer saccharum/density/Betula alleghaniensis /release cuttings/Tsuga canadensis /Fraxinus spp./Ulmus spp./northern hardwoods/selection cutting

Abstract: The study was based on data from 24 acres in permanent sample plots dating back to 1926, 12-year records of cutting units covering 175 acres, and a 6 year record of growth and mortality on 472 inventory plots, some of which were uncut. Net mortality in uncut stands was about 100 bd. ft. per acre per year, almost as much as growth. In partial cuttings mortality was only 1/5 to 1/3 that of the uncut stands and was far exceeded by growth. The very light cuttings were less successful in reducing mortality than heavier ones which allowed more scope for removing defective trees. Stands cut to an intermediate degree had especially low mortality, an average of less than 10 bd. ft./acre. Most of the data were for pure hardwoods, but some information was obtained for Hemlock, which had a mortality much higher than that of the hardwoods. Ash/Elm types showed higher mortality than well drained upland hardwoods. Sugar Maple, the most important component, suffered relatively little loss, while Yellow Birch lost more in proportion. Breakage was the most common cause of mortality, followed by trees that died standing, and those that were uprooted. Losses appeared to be proportional to the amount of defect left in the stand, and care should be taken to eliminate defective trees in partial cutting.

190. **Eyre FH and Neetzal JR 1938. Practical cutting methods for northern hardwoods. Papers of Michigan Academy of Science, Art and Letters No. 4: 197-208.**

Keywords: northern hardwoods /harvesting intensity /release response /tree growth /selective cutting

Abstract: A discussion of cutting experiments in Michigan and Wisconsin, for which a complete record is available of tree growth over a ten-year period following light, moderate, and heavy cuttings that removed 29, 62, and 90 per cent. respectively of the saw-timber volume. The results show that a selective cutting in which one-third to two-thirds of the volume is removed is good practice in northern hardwood forests, while heavy cuttings of the 'commercial' type, resulting in the removal of 90 per cent. of the volume, are disadvantageous. The advantages and disadvantages of each type of cutting are reviewed.

191. **Eyre FH and Zillgitt WM 1953. Partial cuttings in northern hardwoods of the Lake States: twenty-year experimental results. Tech. Bull. U.S. Dept. Agric. No. 1076, 124 pp.**

Keywords: ecology/release fellings/selective cutting/silvicultural systems/Tsuga canadensis /northern hardwoods/second growth

Abstract: The work is divided into 3 main parts: (1) summarizing the characteristics of the northern hardwood forest; (2) discussing the management of mature stands, with recommendations for hardwood forests based on results in the experimental area, which has been treated by clear felling, light or heavy improvement felling, felling to different diameter limits, removal of overmature and defective timber, or group selection, and with special recommendations for stands of *Tsuga canadensis*; and (3) discussing the rather different treatment needed in the younger, second-growth stands.

192. **Eyre FH and Zillgitt WM 1950. Size-class distribution in old-growth northern hardwoods twenty years after [selective] cutting. U.S. For. Serv. Lake St. For. Exp. Sta. Station Paper LS-21, 15 pp.**

Keywords: Tree classes/northern hardwoods /selective cuttings

193. **Fahey TJ, Battles JJ, and Wilson GF 1998. Responses of Early Successional Northern Hardwood Forests to Changes in Nutrient Availability. *Ecological Monographs* 68: 183-212.**

Keywords: Birch/Canopy Architecture/Co-Limitation/Competition/Leaf Area Index/northern hardwoods /Photosynthesis/Pin Cherry/aboveground productivity/*Prunus Pensylvanica*/Resorption/Specific Leaf Area/Canopy Structure/Organic-Matter/Douglas-Fir/Nitrogen /potassium /phosphorus/ Ecosystem/ Photosynthesis/ Fertilization/ Competition/ Light/ *Betula papyrifera*

Abstract: In many mesic forests the dominant trees are limited concurrently by light and soil resources, and understanding the mechanisms of competition and predicting outcomes of competition are especially difficult when co-limitation exists. We altered soil resource availability during the early stages of stand development after clearcutting of northern hardwood forests to examine the mechanism of competition. Specifically, we sought empirical evidence about the role of various physiological, morphological, allocational, and architectural responses in regulating plant competition. We expected the competitive ability of the extreme pioneer species, *Prunus pensylvanica* (pin cherry), to be enhanced by increased nutrient supply, with consequent effects at the community and ecosystem levels of organization. Nutrient availability was increased by about three-fold by monthly fertilization for 6 yr in nine even-aged northern hardwood stands dominated by pin cherry, three each of three ages (6, 12, and 18 yr at initiation of the experiment). Measurements in the control plots indicated that the interval of stand development from age 6 to 23 yr was marked by a peak in basal area and leaf area of pin cherry at about age 17 yr, followed by a steady decline in *P. pensylvanica* dominance thereafter. Fertilization increased and prolonged

the dominance of *P. pensylvanica*, indicating that nutrient limitation accelerates the demise of this species during the second and third decades of stand development. All species in the plots responded to fertilization with increased foliar nutrient (N, P, and K) concentrations and often higher specific leaf area (area:mass ratio), and these responses were most pronounced for *P. pensylvanica*. Although the light response curve for photosynthesis of *P. pensylvanica* was altered by fertilization, with higher rates at low light levels, photosynthesis of its principal competitor, *Betula papyrifera*, was not affected. The marked growth response of *P. pensylvanica* was accompanied by changes in its canopy architecture, as the trees had more leaf area per unit stem basal area, and proportionally more of this leaf area was in the upper canopy. In contrast, height and leaf area of *B. papyrifera* were similar in the control and fertilized plots. Seed deposition of *P. pensylvanica* also increased in the fertilized plots during one year of high seed production. Thus, the performance in competition of *P. pensylvanica* was improved by the removal of apparent nutrient limitations on its physiological performance, canopy growth, and ability to compete for light. Leaf area index of the fertilized plots was only slightly higher than the control plots, and the same was true for stand basal area. The removal of nutrient limitation increased the intensity of one-sided competition for light by concentrating the dominance among the largest trees; consequently, very high mortality of suppressed stems of all species occurred. The increased dominance of the fast-growing *P. pensylvanica* contributed to increases in aboveground net primary productivity (ANPP) in the fertilized plots. Some of this ANPP response was probably associated with reduced C allocation to roots in some of the fertilized plots, but this pattern was not consistent across all the stands. The results indicate that the outcome of interspecific competition in mesic forests, where co-limitation by light and soil resources prevails, depends upon the effect of site quality upon the relative intensity of one-sided competition (for light).

194. **Fassnacht KS and Gower ST 1998. Comparison of soil and vegetation characteristics of six upland forest habitat types in north central Wisconsin. *Northern Journal of Applied Forestry* 15: 69-76.**

Keywords: vegetation types/botanical composition/stand characteristics/classification /leaf area index/soil organic matter/plant communities/potassium /phosphorus /productivity /silt /silty soils/sandy soils/soil types/site factors/soil chemistry/clay soils/water holding capacity/habitats /soil physical properties

Abstract: A habitat type classification was developed for northern Wisconsin forests in 1998, but it is yet to be determined whether important soil and vegetation characteristics are similar within a habitat type, and if consistent differences are exhibited among habitat types. The soil and vegetation characteristics of 24 sites from the 6 major habitat types in north central Wisconsin, USA were compared. Total soil nitrogen and organic matter concentrations, soil available potassium, soil silt fraction, and soil water-holding capacity all generally increased in the order: *Quercus-Acer/Epigaea* (QAE) < *Acer-Quercus/Vaccinium* (AQV) < *Pinus/Maianthemum-Vaccinium* (PMV) < *Acer/Vaccinium-Viburnum* (AVVib) < *Acer-Tsuga/Dryopteris* (ATD) < *Acer/Viola-Osmorhiza* (AViO). Soil phosphorus was as low as 2 ppm for an AViO site, and as high as 99 ppm for a QAE site, but habitat type means showed less than a 2-fold difference. Soil nitrogen concentration varied from 0.03 to 0.13%, and percentages of sand, silt and clay for individual sites were 32-92%, 2-56%, and 6-11%, respectively. Water holding capacity varied very little (13-20%) despite the large ranges in silt percentage. Large differences in leaf area index and forest aboveground net primary productivity among stands were observed (1.2-8.4 ha/ha and 2.9-11.5 t/ha per year, respectively).

195. **Fassnacht KS and Gower ST 1999. Comparison of the litterfall and forest floor organic matter and nitrogen dynamics of upland forest ecosystems in north central Wisconsin. *Biogeochemistry* 45: 265-284.**

Keywords: ecosystems /forest litter/nitrogen /organic matter/composition /decomposition /hardwoods /leaf area/leaf area index/plant litter /nutrient availability/*Acer rubrum/Quercus rubra/Vaccinium angustifolium/Tsuga canadensis*/nitrogen use efficiency/carbon cycling/nitrogen

cycling

Abstract: The objectives of this study were to: (1) characterize and compare the C and N dynamics of dominant upland forest ecosystems in north central Wisconsin, USA; (2) compare the nutrient use efficiency (NUE) of these forests, and (3) examine the relationship between NUE and site characteristics. The dominant tree species were, *Quercus rubra*, *Acer rubrum*, *Vaccinium angustifolium*, *A. saccharum* and *Tsuga canadensis*. Analysing data from 24 stands spanning a moisture/nutrient gradient, resource-poor stands transferred less C and N from the vegetation to the forest floor, and N remained in the forest floor at least four times longer than in more resource-rich stands. Analysing data by leaf habit, less N was transferred to the forest floor annually via litter fall in conifer stands, and N remained in the forest floor of these stands nearly three times longer than in hardwood stands. NUE did not differ among forests with different resource availabilities, but was greater for conifers than for hardwoods. Vitousek's (1982) index of nutrient use efficiency (INUE1 = leaf litter fall biomass/leaf litter fall N) was most closely correlated to litter fall specific leaf area and percentage hardwood leaf area index, suggesting that differences in species composition were responsible for the differences in NUE among stands. NUE2, defined as ANPP/leaf litter fall N, was not closely correlated to any of the site characteristics included in this analysis.

196. **Fassnacht KS and Gower ST 1997. Interrelationships among the edaphic and stand characteristics, leaf area index, and aboveground net primary production of upland forest ecosystems in north central Wisconsin. *Canadian Journal of Forest Research* 27: 1058-1067.**

Keywords: leaf area index/stand characteristics/biological production/ecosystems /soil water/water availability/soil chemistry/nutrients /potassium /nitrogen /*Acer saccharum*/*Pinus banksiana* /northern hardwoods

Abstract: The objectives of this study were to (1) examine the relationships between site factors and both leaf area index (LAI) and aboveground net primary production (ANPP) of conifer, mixed conifer-hardwood, and hardwood forests in north central Wisconsin, and (2) determine the relationship between LAI and ANPP. Data were collected during 1992-94 from 24 stands, 4 each in 6 forest habitat types. LAI ranged from 1.2 ha/ha for a jack pine (*Pinus banksiana*) forest to 8.4 ha/ha for a sugar maple (*Acer saccharum*) dominated forest. LAI was significantly correlated with potential available water and nutrient availability, with both potassium and nitrogen identified as possibly influential elements. ANPP ranged from 2.9 (jack pine) to 11.5 t/ha per year (sugar maple). Variability in ANPP was explained primarily by changes in specific leaf area, which was highly correlated with percent broadleaved LAI. ANPP was positively correlated with LAI ($r^2=0.82$, $p<0.001$) for all stands, but the relationship was not as strong for conifer ($r^2=0.62$, $p=0.007$) and broadleaved ($r^2=0.47$, $p=0.007$) stands when analysed separately. There was evidence that production efficiency (ANPP/LAI) differed between conifer and hardwood stands, but the study design did not allow rigorous testing of this question.

197. **Ferrari JB 1999. Fine-scale patterns of leaf litterfall and nitrogen cycling in an old-growth forest. *Canadian Journal of Forest Research* 29: 291-302.**

Keywords: old growth forests/forest litter/nitrogen mineralization/nutrient availability/ soils/vegetation types/soil chemistry/lignin /nitrogen cycle/forest ecology/*Acer saccharum*/*Tilia americana*/ *Betula alleghaniensis*/*Tsuga canadensis*

Abstract: Spatial patterns of litterfall and soil nitrogen (N) mineralization were investigated in an old-growth hemlock-hardwood forest to test the hypothesis that the lignin/N ratio of litterfall is negatively correlated with soil N availability. Litterfall was measured at 50 small subplots on a 7.2 ha mapped plot in Sylvania Wilderness Area, Michigan, where pronounced patchiness of species was prominent in the canopy. *Betula alleghaniensis*, *Tsuga canadensis*, *Acer saccharum* and *Tilia americana* dominated the plot studied. Nitrogen mineralization and nitrification were measured concurrently at the subplots using buried-bag incubations of the dominant species. Total

aboveground litterfall was 3723 kg/ha per year with leaf litterfall contributing 69% of the total, and N mineralization was 68.0 kg/ha per year. The lignin/N ratios of leaf litter and total litterfall were negatively correlated with soil N mineralization and nitrification at the 50 subplots. N mineralization rates, especially percent nitrification, were higher where *T. americana* and *A. saccharum* litterfall dominated and lower where *T. canadensis* litterfall was high, demonstrating the importance of litterfall and leaf litter chemistry to soil N pattern on a fine spatial scale. It is suggested that the effect of leaf litter chemistry on soil N may be a positive feedback mechanism that maintains the landscape-scale canopy mosaic at Sylvania.

198. **Ferrari JB and Sugita S 1996. A spatially explicit model of leaf litter fall in hemlock-hardwood forests. *Canadian Journal of Forest Research* 26: 1905-1913.**

Keywords: leaf fall/vegetation types/forest litter/model litter fall /*Acer saccharum*/*Tilia americana*/*Betula alleghaniensis*/*Tsuga canadensis*

Abstract: A spatially explicit model of leaf litter fall was developed for hemlock-hardwood forests using litter-trap data from mapped forest plots and from isolated trees within the Sylvania Wilderness Area, Upper Michigan. The model assumes that litter declines exponentially with distance, as shown by the litter traps from isolated trees, and that a variable allometric equation describes the relationship of diameter at breast height to foliage biomass. Model parameters were estimated by a maximum likelihood method using field data from one mapped plot and then tested on a second plot. Predicted leaf fall of sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*), basswood (*Tilia americana*) and eastern hemlock (*Tsuga canadensis*) was consistent with the leaf fall measured in 20 traps ($r = 0.86, 0.77, 0.95, 0.92$, respectively). Data from 100 paired litter traps show the similarity of litter fall at sites 2.7 m apart; trap contents in two successive autumns were also comparable. The model results show that hemlock has the narrowest leaf-fall shadow, while basswood has the broadest. The average radius within which 90% of the leaf litter fall to a trap originates is 17.1 m. A litter fall model can be used to predict nutrient inputs to the forest floor based on a stem map, and strengthens links between population and ecosystem ecology.

199. **Flaspohler DJ, Temple SA, and Rosenfield RN 2001. Effects of Forest Edges on Ovenbird Demography in a Managed Forest Landscape. *Conservation Biology* 15: 173-183.**

Keywords: explicit population models/throated blue warblers/Douglas fir forests/neotropical migrant/nest predation/clear-cut/*Dendroica caerulescens*/habitat fragmentation/reproductive success/bird breeding success/northern hardwoods /*Seiurus aurocapillus*/birds

Abstract: We studied the reproductive ecology of Ovenbirds (*Seiurus aurocapillus*) for 3 years in a primarily forested landscape in northern Wisconsin. We searched for and monitored nests in large, closed-canopy northern hardwood forests adjacent to recent clearcuts (<6 years old) and measured the effect of proximity to edge on nest success, clutch size, and breeding pair density. Mayfield nest success was lower near the forest edge (0.44, N-nests = 42; <300 m) than in the forest interior (0.69, N-nests = 47; >300 m; $\chi^2(2) = 4.43, df = 1, p$ less than or equal to 0.04), and mean clutch size was higher (4.93) near the forest edge than in the forest interior (4.27; $t = -3.83, df = 59, p$ less than or equal to 0.0003). Edge effects on nest success and clutch size extended farther (300 m) into intact forest than has been documented previously. Using habitat-specific demographic parameters, we found that annual productivity per pair was similar in edge (3.37 fledglings) and interior (3.85 fledglings) habitat. We used our estimates of per capita annual productivity and published estimates of adult and juvenile survival to approximate the finite rate of growth (λ) for birds breeding in edge and interior locations. Based on published estimates of age-specific survival, both edge and interior habitats appear to be source habitats (where $\lambda > 1$) for Ovenbirds in the landscape we studied. Our assessment of population status however, was extremely sensitive to variation in survival estimates. We used geographic information system data from the Nicolet National Forest to estimate population size in northern and mixed- hardwood forests in this region and to quantify annual productivity in this landscape.

Ovenbirds near forest edges faced higher predation pressure but laid more eggs on average than birds in the forest interior. Our data suggest that Ovenbirds may make tradeoffs between the probability of nest success and the per-nest productivity as measured by clutch size. Our findings are consistent with the equilibrium state of the ideal free distribution model in that although individual demographic characteristics (nest success and clutch size) varied with distance from edge an important correlate of fitness, finite rate of increase (λ) remained relatively, similar.

200. Flaspohler DJ, Temple SA, and Rosenfield RN 2001. Species-Specific Edge Effects on Nest Success and Breeding Bird Density in a Forested Landscape. *Ecological Applications* 11: 32-46.

Keywords: bird reproduction/Clearcuts/Clutch Size/Ecological Trap Hypothesis/Edge Effects/ Hermit Thrush/Nest Predation/Nesting Density/Northern Hardwoods / Ovenbird/ Frequency Electromagnetic-Fields/Migratory Songbirds/Predation Rates/ *Catharus guttatus* /*Molothrus ater*/birds

Abstract: Using natural nests of eight bird species, we provide one of the first multispecies tests for edge effects on reproductive success in a forested landscape. Our primary objective was to assess whether distance to the edge of recent clearcuts was related to nesting success in intact northern hardwood forests. Estimated nest success was generally lower for the two ground-nesting species than for the six canopy-nesting species. Brood parasitism was <3% for species which typically accept eggs of the Brown-headed Cowbird (*Molothrus ater*), and nest predation was the most common cause of nest failure. Probability of nest failure was influenced by distance to forest edge for the ground-nesting Hermit Thrush (*Catharus guttatus*) and Ovenbird (*Seiurus aurocapillus*), but not for six canopy-nesting species. For the Hermit Thrush and Ovenbird, nest success relative to decreasing distance to the edge was reduced during the nestling stage, but not the incubation stage. Nest density appeared to be higher in forest zones near the clearcut edge for ground-nesting and for several canopy-nesting species. Our data suggest that the effect of proximity to edge on nest success for ground-nesting species may penetrate 300 m into intact forest, while the effect of proximity to edge on nest density may penetrate farther. These data suggest that the creation of openings in forested landscapes reduces nest success and increases nest density for some species of migratory birds in a zone adjacent to the opening. This pattern supports the notion that "ecological traps" may exist for ground-nesting birds in areas near recently created forest openings. Because areas of contiguous forest (e.g., publicly owned forest) in the Upper Great Lakes remain relatively intact, they may serve as source habitat for regional songbird metapopulations.

201. Floyd DW, Vonhof SL, and Seyfang HE 2001. Forest Sustainability - a Discussion Guide for Professional Resource Managers. *Journal of Forestry* 99: 8-28.

Keywords: history/sustainable forest management/bibliography

Abstract: The concept of sustainability is sometimes elusive, but an examination of the etymology of the word and the history of its application in forest management helps pin it down. Sustainability becomes a concern when a growing human population begins to deplete resources beyond expected rates of renewal. As used today in forest management, the term means maintaining the forest for a long time, showing concern for the well-being of future generations, making reasonable estimates of future needs, knowing current rates of resource use and regeneration, and reaching consensus on appropriate levels of resource use. Six case studies, which may or may not address all those elements, are offered as a starting point for discussion, and an annotated bibliography opens avenues for further study.

202. Foster DK 1998. *Composition, structure, and diversity of forest understories along the climatic and edaphic gradients in the Upper Great Lakes region*. PhD dissertation, University of Wisconsin, Madison. 156 pp.

Keywords: climate /edaphic gradient /herbaceous communities /forest classification /understory

community structure

Abstract: This study examined the composition, structure, and diversity of forest herb communities along climatic and edaphic gradients in western Upper Michigan. Hypotheses regarding the ecological distribution of seasonal photosynthetic guilds (spring ephemerals, early summer species, late summer species, evergreen species, and dimorphic species) were tested based on analyses of 1650 4-m² quadrats in 65 stands. A principal components analysis revealed that environmental variation across the sampled landscape was essentially unidimensional, from coarse infertile soils to finer, more fertile substrates. Non-metric multi-dimensional scaling supported this conclusion, showing that variation in growing-season length had far less correlation with ordination scores (based on species or guild abundances) than soil fertility, and that such variation was essentially orthogonal to the soil-fertility gradient. Two-factor ANOVA's (3 classes of growing-season length x 3 classes of soil fertility) showed that (1) spring ephemerals had significantly higher absolute and relative coverage on sites on sites with the highest fertility or the longest growing seasons; (2) evergreen species had significantly higher coverages on the least fertile sites; (3) dimorphic species were significantly more abundant on sites of intermediate fertility; (4) absolute coverage by early summer species increased with soil fertility; and (5) late summer species were most abundant on infertile, relatively open sites. Herb species richness varied little with soil fertility, but their modified Shannon diversity increased significantly with fertility, reflecting a dramatic and regular increase in evenness. ANOVA's restricted to morainal sites showed that (1) spring ephemerals were significantly more abundant on horizontal sites than on N- or S-facing slopes nearby; (2) dimorphic species were more abundant on N-facing slopes; and (3) graminoids were more abundant on S-facing slopes. Regression analyses suggested that a forest classification based on understory community structure would provide a much more sensitive guide to the potential productivity of sites than other present-day classifications.

203. **Foster NW, Morrison IK, Yin XW, and Arp PA 1992. Impact of soil water deficits in a mature sugar maple forest: stand biogeochemistry. *Canadian Journal of Forest Research* 22: 1753-1760.**

Keywords: Broadleaves /Plant nutrition/nitrogen /Soil chemistry/major elements/Nitrogen cycle/sulfur/calcium/magnesium/potassium/Forest decline/Plant water relations/water stress/simulation /Acid deposition/plant physiology/Air pollution/Acer saccharum /northern hardwoods

Abstract: As part of a study on the response of tolerant hardwood forests to stress, and the occurrence of decline in those forest types, the effect was examined of lack of moisture on the mobility and availability of atmospherically- and soil-derived plant nutrients (N, S, Ca, Mg and K), using data from a 10-yr study of an uneven-aged, drought tolerant hardwood forest dominated by sugar maple (*Acer saccharum*) at the Turkey Lakes Watershed, Ontario. The larger study involved investigation of atmospheric pollutant deposition, local climate and nutrient cycling and gave an opportunity to examine possible climate/nutrient/tree growth interactions. Simulation of moisture relations in this stand suggested that soil water deficits during 1982-83 and 1988-89 were among the most severe since 1952. Examination of radial growth indices for sugar maple trees suggested that reductions in growth coincided with low volumetric soil water contents and with low NO₃⁻ concentrations in soil solution. The lowest mean monthly NO₃⁻ concentrations in soil percolate were observed during severe summer droughts. Nitrate concentrations were negatively correlated ($r^2 = -0.803$) with SO₄²⁻ levels in solution and positively correlated ($r^2 = 0.761$) with Ca²⁺ levels. Nitrification, by stimulating adsorption of SO₄²⁻ by the soil, may lead to temporary retention of atmospheric SO₄²⁻ in soils that otherwise exhibit only limited capacity to retain SO₄²⁻. If warmer, drier summers become more frequent, N cycling will become more closed as the supply of N to the vegetation and leaching of N from the soil are reduced. However, sulfate-moderated leaching from the soil will increase; hence, net cation leaching is unlikely to change in response to drier summers.

204. **Frederick DJ and Coffman MS 1978. Red pine plantation biomass exceeds sugar maple on northern hardwood sites. *Journal of Forestry* 76: 13-15.**

Keywords: increment /plantations /temperate zones/volume /conifers /broadleaves /yields /Acer saccharum/Pinus resinosa/northern hardwoods

Abstract: Data are presented showing d.b.h., ht., b.a., above-ground dry wt., and estimated cordwood vol. and vol. m.a.i., for trees of d.b.h. greater than 2 inch in (a) plantations of red pine (25 and 37 yr old) and (b) adjacent naturally established stands of sugar maple (*Acer saccharum*, respectively 43 and 67, and 58 yr old) in Michigan. Greatest differences were in b.a., vol. increment, and mean annual biomass production which were 2-3 times more in (a). It is concluded that intensive management of red pine would increase vol. and fibre production on land now supporting second-growth maple.

205. **Frelich LE 1986. *Natural disturbance frequencies in the hemlock-hardwood forests of the upper Great Lakes region. PhD dissertation, University of Wisconsin, Madison. 239 pp.***

Keywords: virgin forest /*Acer saccharum*/*Tsuga canadensis* /natural disturbance /forest succession /dendrochronology

Abstract: The frequency of natural disturbances and their relationship to forest succession and character of the landscape mosaic were investigated in western Upper Michigan. Seventy randomly located 0.5 ha plots were used to sample three large (23,000 ha total area), contiguous blocks of unlogged forest dominated by *Acer saccharum* Marsh. and *Tsuga canadensis* (L.) Carr. Analysis of radial increment patterns was used to determine the decade during which each tree first entered the canopy. From these data a disturbance chronology, representing percentage canopy mortality during each decade over the last 130 years, was compiled for each plot. Mean recurrence intervals increase exponentially with increasing disturbance intensity, which is defined as %canopy removed during a disturbance episode. Best estimates of recurrence intervals are: 69 yr (>10%); 134 yr (>20%); 261 yr (>30%); 508 yr (>40%); 987 yr (>50%); 1920 yr (>60%); 3734 yr (>70%). Spatial autocorrelation analysis indicated that plots with light and medium disturbances (<40%) are randomly distributed over the landscape. Plots with heavy disturbances (>40%) are clustered with a patch radius of about 4 km, consistent with the sizes of thunderstorm downbursts. Average rates of disturbance or canopy mortality are estimated at 5.7% per decade. The corresponding average canopy residence time of a tree is 175 years. No significant differences in average disturbance rates were found among the three study areas, between plots near the coast of Lake Superior and inland plots, among several different aspects, and several different slope positions. The data indicate that light and medium disturbances dominate the disturbance regime. The majority of stands on the landscape are composed of several major and many minor age classes. A simulation of landscape dynamics suggests that multi-aged stands of all types occupy 87.2% of the landscape, while even-aged stands with one predominant age class and balanced all-aged stands with many age classes of relatively equal importance occupy the remaining 12.8%.

206. **Frelich LE 1995. *Old forest in the Lake States today and before European settlement. Natural Areas Journal 15: 157-167.***

Keywords: virgin forests/deforestation /land clearance/vegetation types/forest inventories/northern hardwoods/*Pinus resinosa*/*Pinus strobus*/*Quercus* spp./*Carya* spp.

Abstract: This paper provides estimates of the area occupied by old forests today, compares these statistics with estimated forest areas prior to European settlement of Minnesota, Wisconsin, and Michigan, and describes case studies that highlight the differences between modern commercial forests and presettlement forests. The Lake States currently have 19.8 million ha of forest, compared with approximately 32.7 million ha in presettlement times. About 5.2-8.3% of Lake States forest is old-growth or old-seral forest today, compared with an estimated 68% prior to settlement. Approximately 369 000 ha of unlogged, or primary, forest remain (1.1% of that in presettlement times), 40% of which is in the Boundary Waters Canoe Area Wilderness (BWCAN) and 50% in swamp conifer forests. The areas of unlogged red-white pine, riverbottom, northern hardwood, and oak-hickory forests remaining are extremely small ranging from 0.02 to 0.6% of

that in presettlement times. The largest area of secondary old growth is in oak-hickory and northern hardwood forest types, but this is highly fragmented. Michigan's Porcupine Mountains Wilderness State Park and Sylvania Wilderness Area are the only presettlement-like upland forest landscapes in the Lake States. The largest single block of unlogged forest in the Lake States is Minnesota's BWCAW. However, the BWCAW's spatial pattern, age structure, and species composition have been significantly altered from presettlement conditions because of lower fire frequency since 1910.

207. **Frelich LE, Bockheim JG, and Leide JE 1989. Historical trends in tree-ring growth and chemistry across an air-quality gradient in Wisconsin. *Canadian Journal of Forest Research* 19: 113-121.**

Keywords: Broadleaves /Conifers /Air pollution/heavy metals/sulfates /soil pH/wood properties/wood chemistry/inorganic compounds/growth factors/Acid rain/Acer saccharum/Pinus strobus/calcium/magnesium/potassium/manganese/zinc/phosphorus/iron/lead

Abstract: B.a. increment and chemical composition of wood were measured in 3 old-growth (approx. 75-100 yr old) white pine (*Pinus strobus*) and 3 sugar maple (*Acer saccharum*) stands across a pH and SO₄ gradient in precipitation in Wisconsin in 1986. The volume-weighted mean pH and SO₄ content of precipitation ranged from 4.5 to 5.0 and from 21 to 11 kg/ha, respectively, from SE to NW Wisconsin. With one exception (a white pine site at Point Beach in E. Wisconsin), b.a. increment increased from the 1890s until the 1950s (sugar maple) or 1970s (white pine), then levelled off. Growth efficiency, estimated as the ratio of b.a. to exposed crown area or crown vol. for the 1980-85 period, was similar for sugar maple across the gradient; however, growth efficiency of white pine was lower at Point Beach than at the two N. Wisconsin sites. Pb concn. in wood of both species increased with time, except at Crotte Creek in NW Wisconsin, and Pb concn. in wood of both species were significantly greater in SE than in NW Wisconsin. S concn. in wood of white pine increased since the 1960s at Point Beach and at one site in north-central Wisconsin; S concn. were significantly greater for both species in SE than in N. Wisconsin. Concn. of Ca, Mg, and K in wood of sugar maple decreased over the past century. Whereas wood concn. of Mn and Zn generally showed no age-related trends, Fe and P concn. increased markedly at all sites, particularly during the past decade. The age- and site-related trends in chemical composition of wood of white pine and sugar maple appear to be related to vehicular emissions (Pb), air pollution (S), migration along ray paths during conversion of sapwood into heartwood (P, Fe, Ca, K, Mg), and possibly reallocation of nutrients from the labile soil pool to perennial tree tissues during stand development (Ca, K, Mg).

208. **Frelich LE, Calcote RR, Davis MB, and Pastor J 1993. Patch formation and maintenance in an old-growth hemlock-hardwood forest. *Ecology* 74: 513-527.**

Keywords: stand characteristics/stand structure/forest ecology/autecology /model MOSAIC/plant succession/plant competition/Acer saccharum/Tsuga canadensis

Abstract: Species composition and spatial distribution were investigated on a 7.2-ha study area in Sylvania Wilderness Area, a primary forest remnant in Upper Michigan comprising a mosaic of hemlock (*Tsuga canadensis*), sugar maple (*Acer saccharum*), and mixed forest patches. Spatial autocorrelation analysis of the distribution of trees (all trees >3 cm in diameter at breast height (6160) were plotted) indicated that, although most species pairs had a neutral association between canopy trees and understorey trees of other species, hemlock and sugar maple canopy trees both had strong positive self association and negative reciprocal association with each other. No species pairs had a positive reciprocal association on regeneration with each other. MOSAIC, a simulation model, showed that the negative reciprocal association between hemlock and sugar maple could lead to spatial separation into monodominant patches over long time periods (3000 yr). Mixed forest patches occur along spatial continua of varying steepness between patches of the 2 species. Interactions between sugar maple and hemlock overstorey and understorey trees, along with the pattern of invasion of hemlock, provide a reasonable explanation for the patch structure.

Pedological, topographical, and disturbance history differences did not coincide with location of patches within upland forests in the study area.

209. **Frelich LE and Graumlich LJ 1994. Age-class distribution and spatial patterns in an old-growth hemlock-hardwood forest. *Canadian Journal of Forest Research* 24: 1939-1947.**

Keywords: distribution /patterns /stand structure/vegetation types/stand characteristics/age structure/synecology /canopy gaps/Acer saccharum/Betula alleghaniensis/Tsuga canadensis/northern hardwoods

Abstract: The frequency of canopy disturbance over the past 150 years was reconstructed on a 5-ha study area dominated by a patchy mosaic of old-growth sugar maple (*Acer saccharum*) and eastern hemlock (*Tsuga canadensis*) forest in the Sylvania Wilderness Area in western Upper Michigan. The study area was divided into a 10-m grid system and one tree was cored near the centre of each grid cell so that the spatial patterns of tree cohorts could be examined. The canopy turnover rate, averaged over all species and 150 years was 5.4% per decade, with a corresponding canopy residence time of 186 years. Canopy-residence times do not vary much between sugar maple (170 years) and hemlock (167 years), but yellow birch (*Betula alleghaniensis*) has a much longer canopy-residence time (232 years). Canopy-residence times calculated for individual decades over the last 150 years varied from 81 to 556 years. The spatial pattern of gaps of various ages is caused by disturbances in light intensity (2-12% canopy removal) that occur nearly every decade, each of which creates several to many small gaps scattered across the study area. As a result, the study area has a fine-grained random spatial mixture of age-classes at all distance classes from 5 m to >100 m. this mixture is stable throughout the mesic forest in the study area. None of the cohorts resulting from disturbance correspond spatially to patches dominated by either hemlock or sugar maple. Apparently, the dynamics of patch formation by gap-creating disturbances operate independently from the dynamics of the much larger monodominant patches. In forests such as the northern hardwood/hemlock type, where several tree lifetimes pass between any two large-scale catastrophic disturbances, spatial and temporal stability of the patch-dynamic processes (quasi equilibrium) may exist for periods of several decades in areas of 1 ha, and several thousand years for landscape 10 000 ha in size.

210. **Frelich LE and Lorimer CG 1985. Current and predicted long-term effects of deer browsing in hemlock forests in Michigan, USA. *Biological Conservation* 34: 99-120.**

Keywords: virgin forest /Browsing damage/succession /damage /conifers /Acer saccharum/Tsuga canadensis/deer /*Odocoileus virginianus*

Abstract: Remnants of virgin *Tsuga canadensis* forest in the Porcupine Mountains have experienced inadequate hemlock regeneration for several decades. Browsing by *Odocoileus virginianus* seems to be the major cause of the decline of hemlock regeneration, rather than poor seedbed conditions or changing climate. In some areas, significant changes in the size structure of the forest have already occurred, with a shift of dominance from hemlock to *Acer saccharum*. A simulation of forest development is used to predict the changes in forest structure that will occur if no action is taken to control browsing. From this simulation it is estimated that in less than 150 yr hemlock will become only a minor component of the forest over large areas where it is currently the major dominant.

211. **Frelich LE and Lorimer CG 1991. Natural disturbance regimes in hemlock-hardwood forests of the Upper Great Lakes region. *Ecological Monographs* 61: 145-164.**

Keywords: stand characteristics/age /stand development/synecology /landscape ecology/dendrochronology /Acer saccharum/Tsuga canadensis/disturbance

Abstract: The frequency of natural disturbances and their influence on the forest landscape mosaic were investigated on three large tracts of primary forest in Upper Michigan. Seventy 0.5-

ha plots were randomly distributed in a total forest area of 23 000 ha dominated by sugar maple (*Acer saccharum*) and eastern hemlock (*Tsuga canadensis*). Radial increment patterns were used to estimate canopy accession dates of each of a number of randomly selected overstorey trees on each plot. From these data a disturbance chronology, representing the percentage of stand area occupied by cohorts originating during each decade over the last 130 yr, was compiled for each plot. Average rates of disturbance or canopy mortality are estimated at 5.7 to 6.9% per decade. The corresponding average canopy residence time of a tree is 145-175 yr. No significant differences were detected in average disturbance rates among the three study areas, between plots near the coast of Lake Superior and inland plots, among different aspects, and among different slope positions. Natural rotation periods increase exponentially with increasing disturbance intensity, which is defined as the approximate percentage of the plot area converted to gaps during a disturbance episode. Estimates of rotation periods range from 69 yr for \sim 10% canopy removal to 1920 yr for \sim 60% canopy removal. Spatial autocorrelation analysis indicated that plots with light and medium disturbances (<40%) are randomly distributed over the landscape. Plots with heavy disturbances (\geq 40%) are clustered with a patch radius of about 2 km, consistent with the sizes of thunderstorm downbursts. The data indicate that light and medium disturbances dominate the disturbance regime. The majority of stands on the landscape are composed of several major and many minor age classes. Even-aged stands with one predominant age class are uncommon. The age distribution of individual patches or cohorts in the two larger study areas (14 500 and 6073 ha) follows a nearly uniform distribution. None of the three study areas had more than 15% of the forest area converted to gaps in a single decade. The two larger areas meet most of the criteria that have been proposed for equilibrium landscapes.

212. **Frelich LE and Lorimer CG 1991. A simulation of landscape-level stand dynamics in the northern hardwood region. *Journal of Ecology* 79: 223-233.**

Keywords: broadleaves /stand characteristics/age /stand structure/projections /simulation /wind damage/stand development/deciduous forests/vegetation types/landscape ecology/northern hardwoods / model STORM/disturbance

Abstract: A computer simulation model (STORM) was developed to predict the response of regional stand age structure to a given disturbance regime. The model showed that partial disturbances (e.g. wind damage) dominated the dynamics of primary forest in the study region in western upper Michigan. The majority of stands were composed of several major and many minor age classes. Multiaged stands of all types occupied 87.4% of the landscape. The application of the model to the restoration of nature reserves in the northern hardwood forest region is discussed.

213. **Frelich LE and Martin GL 1988. Effects of crown expansion into gaps on evaluation of disturbance intensity in northern hardwood forests. *Forest Science* 34: 530-536.**

Keywords: stand characteristics/development /measurement /age /broadleaves /*Acer saccharum*/ northern hardwoods

Abstract: Crown encroachment by surrounding trees reduces the size of newly formed gaps, a fact that may cause error in area-based analyses of rate of gap formation and disturbance intensity. Generally, an estimate of proportional area occupied by age classes within a stand of trees can be obtained by determining the age of a selected canopy tree nearby each of randomly or uniformly located sample points. Possible methods of selecting nearby canopy trees include: (1) the nearest-tree selection method, in which the canopy tree with its stem closest to the sample point is chosen; and (2) the overhead-crown selection method, in which the canopy tree whose crown is directly above the sample point is chosen. These two methods of selecting sample trees differ greatly in their sensitivity to crown encroachment. In sugar maple (*Acer saccharum*) stands in Michigan, the nearest-tree selection method led to better estimates of the area originally occupied by a cohort of trees. The overhead-crown selection method led to an unbiased estimate of area currently occupied by a cohort.

214. **Frelich LE and Reich PB 1995. Neighborhood effects, disturbance, and succession in forests of the western Great Lakes Region. *Ecoscience* 2: 148-158.**

Keywords: boreal forests/botanical composition/plant communities/synecology /forest fires/wind damage/stand structure/canopy gaps/plant succession/stand characteristics/stability /Thuja occidentalis/Populus tremuloides/Pinus strobus/Pinus banksiana/Abies balsamea/Picea mariana/Betula papyrifera/Tsuga canadensis

Abstract: Neighbourhood effects that enhance conspecific replacement at the time of canopy-tree death were examined in 3 cold-temperate forest types in Minnesota and Michigan, using spatial analyses and historical reconstruction on mapped plots. Important neighbourhood effects in these forests include overstorey-understorey effects whereby a species enhances likelihood of self replacement by influencing the local understorey, and disturbance-activated effects that switch on after stand-killing disturbance. Neighbourhood analyses (radius 9 m) show that understorey composition is significantly related ($p < 0.001$) to overstorey composition in a hardwood-hemlock (*Tsuga canadensis*) forest, but not in white pine (*Pinus strobus*) or near-boreal jack pine (*P. banksiana*) forests. Jack pine has strong disturbance-activated effects in the form of serotinous seedfall after fire. White pine apparently has no significant neighbourhood effects of either type. Other species are likely to replace white pine in treefall gaps, and after fire it must reinvade a given neighbourhood by means of outside seed sources. In the forest types with strong neighbourhood effects a change in the usual disturbance regime may occur that overwhelms the self-replacement mechanisms. Such events would include lack of fire in near-boreal jack pine forest, which causes succession to a spruce-fir-birch-cedar (*Picea mariana*-*Abies balsamea*-*Betula papyrifera*-*Thuja occidentalis*) mixture, and intense fire after heavy windfall in hardwood-hemlock forest, which can convert the forest to paper birch and aspen (*Populus tremuloides*). From the point of view of species compositional stability, these changes in disturbance regime are true catastrophes, unlike stand-killing fires in jack pine or complete canopy windthrow in hardwood-hemlock. These compositional catastrophes operate in a punctuated-stability context, and initiate episodes of succession, which are relatively short periods of rapid change in species composition. The neighbourhood-effect hypothesis of forest dynamics is proposed. This hypothesis predicts that forest types with weak neighbourhood effects have great temporal instability of composition, with recovery from disturbance and related successional sequences nearly always in progress, whereas species composition may be generally stable with sudden alternation between different states in forests with strong neighbourhood effects.

215. **Frelich LE and Reich PB 1999. Neighborhood Effects, Disturbance Severity, and Community Stability in Forests. *Ecosystems* 2: 151-166.**

Keywords: community stability/disturbance severity/neighborhood effects/punctuated stability/succession/hemlock-hardwood forest/age-class distribution/vegetation dynamics/accelerated succession/catastrophe theory/plant communities/spatial patterns/*Pinus banksiana*/*Tsuga canadensis*/northern hardwoods

Abstract: A theoretical framework and conceptual model for temporal stability of forest tree-species composition was developed based on a synthesis of existing studies. The model pertains primarily to time periods of several tree lifetimes (several hundred to a few thousand years) at the neighborhood and stand spatial scales (0.01-10 ha), although a few extensions to the landscape scale are also made. The cusp catastrophe was chosen to illustrate compositional dynamics at the stand level for jack pine, northern hardwood, and white pine forests in the Great Lakes Region of the United States and for tropical rainforests in the northern Amazon basin. The models feature a response surface (degree of dominance by late-successional species) that depends on two variables: type of neighborhood effects of the dominant tree species and severity of disturbances. Neighborhood effects are processes that affect the chance of a species replacing itself at the time of disturbance (they can be positive, neutral, or negative) and are of two types: overstorey-understorey effects, such as the presence of advanced reproduction; and disturbance-activated effects, such as serotinous seed rain. Disturbance severity is the proportion of trees killed during a

disturbance. Interactions between neighborhood effects and disturbance severity can lead to either punctuated stability (dramatic but infrequent change in composition, in those forests dominated by species with positive neighborhood effects) or succession (continuous change, in those forests dominated by species with neutral-negative neighborhood effects). We propose that neighborhood effects are a major organizing factor in forest dynamics that provide a link across spatial scales between individual trees and disturbance/patch dynamics at the stand and landscape scales.

216. **Frelich LE and Reich PB 1995. Spatial patterns and succession in a Minnesota southern-boreal forest. *Ecological Monographs* 65: 325-346.**

Keywords: patterns /vegetation types/boreal forests/plant succession/Thuja occidentalis/Populus tremuloides/Pinus banksiana/Pinus resinosa/Abies balsamea/Picea mariana/Betula papyrifera

Abstract: Succession was studied in a cold-temperate forest in the Boundary Waters Canoe Area Wilderness (BWCAW) of northeastern Minnesota. The 13X18 km study area comprises a complex forest mixture of jack (Pinus banksiana) and other pines, quaking aspen (Populus tremuloides), paper birch (Betula papyrifera), black spruce (Picea mariana), balsam fir (Abies balsamea), and white cedar (Thuja occidentalis) on thin soils over the Canadian Shield bedrock. Stand history reconstruction with increment cores, spatial autocorrelation, and analysis of replacement trees in canopy openings were used to study the relationships between spatial patchiness, spatial scale (0.01-16 ha), and canopy succession and to evaluate under what conditions successional direction may remain stable, converge, or diverge. Results show that the reduced fire frequency in recent years has changed the dominant successional pathways. When fire frequency was high, jack pine or aspen stands usually burned while still in the even-aged stage of development, and the new trees after the burn were the same species as before. Currently, many stands are undergoing demographic transition from even-aged stands of catastrophic fire origin to uneven-aged stands. This transition parallels a change composition from jack pine (occasionally red pine, Pinus resinosa) or aspen to an old-growth multi-aged mixture of black spruce, balsam fir, paper birch, and white cedar. The mechanism that moves this successional path forward is canopy openings, 10-30 m across on average, caused by wind, insect, and disease. At 1-16 ha spatial scales, succession leads to convergence on a mixture of species. At smaller spatial scales (e.g. 0.01-0.1 ha) successional pathways appear to diverge into four community types. The same successional pathways can be reconstructed from historical analysis of individual stands as from a chronosequence of stands; therefore, chronosequences in this area have been stable at least during the lifetime of the current generation of trees.

217. **Frelich LE, Sugita S, Reich PB, Davis MB, and Friedman SK 1998. Neighbourhood Effects in Forests: Implications for Within-Stand Patch Structure. *Journal of Ecology* 86: 149-161.**

Keywords: community assembly/neighbourhood effects/patch formation/spatial pattern/old growth/northern hardwoods /spatial patterns/boreal forest/Pinus strobus/white pine/ succession/history/disturbance/model MOSAIC

Abstract: 1 MOSAIC, a spatially referenced Markov model was used to show how interactions among trees in a neighbourhood may influence the patch structure of forests. A series of two-species simulations were conducted with neighbourhood strength ranging from neutral (chances of species replacing each other independent of neighbourhood composition) to strong (chance of replacement for each species proportional to neighbourhood composition), and with neighbourhood sizes including 1-50 neighbours. 2 Neighbourhood strength was positively correlated with the degree of patchiness. Very high neighbourhood strength is necessary to form mono-specific patches composed of hundreds of individual trees. Intermediate neighbourhood sizes (5-12 neighbours) led to the most distinct patches where individuals were arranged so that contact between species was minimized. 3 Neighbourhood effects alone are unlikely to lead to large areas (several ha) dominated by one species. However, simulations showed that neighbourhood effects can augment small differences in the environment: resulting in large mono-specific patches. 4 Simulations with 4 and 5 species indicated that groups of species can interact to

form spatially distinct communities, starting from a random mixture on a uniform environment. This implies that neighbourhood effects may be responsible for some unexplained variability in studies that attempt to relate environmental parameters to forest composition. 5 Patch structures that develop due to neighbourhood effects are usually not recognized by current vegetation classification schemes or by forest managers, and this lack of recognition could lead to the loss of certain natural spatial structures on forested landscapes.

218. **Friedman SK, Reich PB, and Frelich LE 2001. Multiple Scale Composition and Spatial Distribution Patterns of the North-Eastern Minnesota Presettlement Forest. *Journal of Ecology* 89: 538-554.**

Keywords: Bearing Trees/history/Hierarchical Structure/Landscape Ecology/Spatial Autocorrelation/Spatial Scales/ Geomorphological Heterogeneity/Seedling Recruitment/ Landscape Ecology/Fire/ Dispersal/ Autocorrelation/ Perspective/ Competition/ Disturbance/Larix laricina/Pinus banksiana/Pinus resinosa/Picea mariana /Betula papyrifera /Pinus strobus

Abstract: 1 Bearing tree data were used to characterize the composition and spatial structure of the southern boreal presettlement forest in north-eastern Minnesota, United States of America. Data collected during the General Land Office Survey (GLO) between 1853 and 1917, represents 35 324 samples (each with 1-4 trees) in a 3.2 million-hectare landscape. Nine tree species contributed at least 1% to the overall composition. Individuals of white pine and red pine were larger than all other species and represented 9% of the tree population, while accounting for 27% of the standing basal area. Black spruce, paper birch and larch, the three most abundant species, collectively accounted for 51% of the population and 38% of the basal area. 2 Eight physiographic zones were characterized by differences in glacial histories, geological surfaces, soil complexes and topographic properties, and supported different compositional mixes of the nine important species. 3 Fifty-six per cent of all four-tree plots had three or four individuals of a single species. This level of conspecific aggregation is an order of magnitude greater than would be expected based on a random distribution of the same population of trees and species. Jack pine had the greatest plot-scale aggregation, with 45% of all plots containing jack pine trees having three or four jack pine individuals. Jaccard association of similarity values of species co-occurrence ranged from less than 0.05 to 0.24, indicating limited plot-scale interspecific associations. 4 Landscape spatial patterns of the species were measured at two spatial scales, 1-10 km and from 5 to 50 km. Conspecific autocorrelation patterns were positive while interspecific autocorrelation patterns tended to be either neutral or negative. Hence, plots dominated by any given species tended to spatially aggregate near other such plots, out to substantial distances. 5 Forest tree spatial patterns reflect complex fine to landscape-scale relationships involving environmental factors, disturbance events and regeneration strategies. Management and long-term conservation of forest landscapes should consider multiscale patterns in order to re-establish forest structural properties eliminated following the disruption of natural disturbance processes.

219. **Fuller LG, Cattellino PJ, and Reed DD 1988. Correction equations for dendrometer band measurements of five hardwood species. *Northern Journal of Applied Forestry* 5: 111-113.**

Keywords: Broadleaves /Dendrometers /Diameter /measurement /Acer rubrum/Quercus rubra/Populus tremuloides /Populus grandidentata/Betula papyrifera

Abstract: A study to determine the amount of correction needed to account for first year slack on newly installed band type dendrometers is presented. In spring 1984, 472 bands were installed on northern red oak [*Quercus rubra*], red maple [*Acer rubrum*], paper birch [*Betula papyrifera*], quaking aspen [*Populus tremuloides*] and big tooth aspen [*P. grandidentata*] on 2 sites in N. Michigan, USA; one yr later a second band was installed on 6-10 samples of each species at each site, and readings from the two bands on each tree compared for the next growing season. Prediction equations to correct for first year errors are given, and their application is discussed.

220. **Gale MR, McLaughlin JW, Jurgensen MF, Trettin CC, Soelsepp T, and Lydon PO 1998. Plant**

community responses to harvesting and post-harvest manipulations in a Picea - Larix - Pinus wetland with a mineral substrate. *Wetlands* 18: 150-159.

Keywords: wetlands /vegetation types/forest ecology/harvesting /fertilizers /nitrogen fertilizers/ phosphorus fertilizers/site preparation/weed control/herbicides /glyphosate /chemical treatment/ artificial regeneration/site preparation/discing /plant succession/understorey /synecology /whole tree logging/ pines /Larix laricina /Vaccinium spp./Pinus banksiana/Picea mariana /Sphagnum/ bryophytes/Ledum groenlandicum /Chamaedaphne calyculata

Abstract: A study was conducted to examine the production changes and species diversity in the vascular plant community 4 years after a forested, mineral wetland in northern Michigan was whole-tree harvested, the site prepared (bedded/trenched with glyphosate weed control and/or discing), and fertilizer applied (N, P and NP fertilizers). The wetland had an original overstorey of Picea mariana, Larix laricina and Pinus banksiana, with a significant cover of Sphagnum and ericaceous shrubs. The ground vegetation was predominantly Vaccinium spp., Chamaedaphne calyculata and Ledum groenlandicum. Site preparation techniques were undertaken immediately after harvesting, and the site was then planted with jack pine seedlings. Fertilizer application occurred 4 years after the harvesting and site preparation. Trees in bedded areas with N fertilizer application exhibited significantly greater total seedling height, basal diameter and height increment when compared with those from harvested or trenched areas. On harvested only areas, seedling production was greater with P and NP fertilizer application than with N fertilizer alone. Fertilizer responses were attributed to which type of site preparation (bedding or trenching) was used and the degree of organic matter and Sphagnum incorporated into the mineral soil. Only site preparation treatments (not fertilizer treatments) resulted in significant effects on the number and coverage of vascular plant groups (woody, herbaceous and grass/sedge). Species diversity and total coverage of all vascular plants were significantly greater on the harvested only areas than on the trenched, bedded or uncut plots. The relative cover of the grass/sedge group increased with increasing site disturbance (bedded and trenched), mainly due to the lack of Sphagnum mat. When compared to the adjacent uncut area, the relative cover of herbaceous species was significantly reduced on treated areas. It is suggested that the resulting community may be different to the successional sequence witnessed by the original forest, but will depend on the rate of crown closure and the invasion of bryophyte species.

221. **Gates FC 1942. The bogs of northern lower Michigan. *Ecological Monographs* 12: 213-254.**

Keywords: bogs /Larix spp./Thuja spp. /Picea spp. /Carex lasiocarpa

Abstract: The region studied is in a transition zone between the northeastern coniferous forest province and the central or deciduous forest province. Approximately one-third of the area is bogland, the bogs being of the lowland type. The most common typical sere in the bogs is from aquatic associations to the Carex lasiocarpa association followed by the Chamaedaphne association, the high bog shrub association, tree associations of Larix and Picea, and climaxed by the Thuja association.

222. **Gerlach JP, Reich PB, Puettmann KJ, and Baker T 1997. Species, diversity, and density affect tree seedling mortality from Armillaria root rot. *Canadian Journal of Forest Research* 27: 1509-1512.**

Keywords: stand density/mortality /spacing /seedlings /plant diseases/plant pathogens/plant pathogenic fungi/fungal diseases/plant pathology/Acer saccharum/Larix laricina/Quercus rubra/Populus tremuloides/Pinus strobus/Pinus banksiana/Abies balsamea/Picea glauca/Picea mariana/Betula alleghaniensis/Armillaria spp.

Abstract: Field experiments were conducted in Minnesota to evaluate interspecific differential susceptibility and to assess whether density or species composition, specifically the proportion of conifers in a plot, influences seedling mortality from Armillaria spp. Seedlings of 10 tree species

(six conifers and four hardwoods) were planted at four densities in several species mixtures on recently logged sites. Species differed significantly in susceptibility; balsam fir (*Abies balsamea*), tamarack (*Larix laricina*), and black spruce (*Picea mariana*) showed the greatest infection and mortality. Hardwood species (*Populus tremuloides*, *Quercus rubra*, *Acer saccharum*, *Betula alleghaniensis*) and eastern white pine (*Pinus strobus*) showed negligible mortality. *Pinus banksiana* and *Picea glauca* were intermediate. There was a trend toward increased root infection with increasing density of the three species that showed significant mortality. Their mortality rates were 5.6, 8.7, 10.2, and 10.8% in plots with spacings of 2, 1, 0.5 and 0.25 m, respectively. Mortality increased significantly with an increase in the proportion of conifers in a plot. Mortality in the three most susceptible species was reduced by 75% when grown in aspen-rich rather than in conifer-rich plots. Thus, seedling mortality was related to species identity, planting density, and proportion of conifers, suggesting that selected diversity (mixtures of conifers with hardwoods rather than conifer monocultures) reduces disease impact.

223. **Godman RM 1958. Are water table levels an important factor in the establishment and growth of Yellow Birch? Papers of Michigan Academy of Science, Art and Letters No. 44: 183-190.**

Keywords: *Acer saccharum* /*Betula alleghaniensis* /natural regeneration/Silviculture /*Tsuga canadensis*/water table fluctuations/hydrology/dieback

Abstract: In 1954-55, wells 3-6 ft. deep were dug in 5 different stands of 3 forest cover types in the Upper Peninsula Forest, Mich., and records kept for 3 years of water-table fluctuations. Under the mixed coniferous swamp type, the water level remained near the ground surface throughout most of the growing season and showed relatively little change. Under almost pure Sugar Maple with very little Birch, the level was commonly lower than 4 1/2 ft. In Hemlock/Yellow Birch associations, groundwater levels were intermediate in depth between the above types, but varied with the degree of cutting and topographic position. In an earlier study on natural regeneration [cf. EA. 19 No. 1583], it was seen that on undisked areas Birch seedlings could only compete with the thick herbaceous cover in low-lying areas having a high water table. The influence of water-table levels on diam. growth was further shown on two plots cut by the group selection method. The mean diam. growth over 5 years was 0-2 in. higher on a plot with a water table varying from 0 to 5 ft. below surface during most of the growing season than on a plot where it averaged >15 ft., even though stocking between the openings was slightly less on the latter. The possible relationship between extended periods of high water-table levels, and top-dying of Birch is discussed briefly.

224. **Godman RM 1958. Changes in Yellow Birch top-dying Upper Michigan 1954-1957. Tech. Note Lake St. For. Exp. Sta. 527, 2 pp.**

Keywords: *Betula alleghaniensis* /dieback/forest protection/water table fluctuations

Abstract: Data after 4 years show the progress of top-dying [cf. F.A. 17 No. 3088] to be related to the intensity of cut. The % of top-dying trees reached a peak within a year after onset in virgin and moderately cut stands, and is now decreasing. In heavily cut stands, i.e. with a residual b.a. of <50 sq. ft., top-dying continued to increase till the 3rd year and then remained stable. There is a higher % of injured trees in the diam. class ≥ 15 in., but the smaller classes show the heaviest mortality, usually dying within a year of the initial injury. The top-dying may be related initially to an unusually prolonged high water-table in 1954, causing heavy rootlet mortality. Observations are being continued to determine the correlation of water-table fluctuations with tree behaviour and stand conditions.

225. **Godman RM 1957. Disking increases the number and growth of Yellow Birch seedlings. U.S. For. Serv. Lake St. For. Exp. Sta. Technical Note LS-511, 2 pp.**

Keywords: *Betula alleghaniensis* /natural regeneration/site preparation/disking/silviculture /*Tsuga canadensis*

Abstract: The survival and growth of Yellow Birch seedlings after 3 years in a heavily cut Birch/Hemlock stand in Michigan showed a definite correlation with disking intensity. Most regeneration was found on plots with 75% of the area disked, and seedlings on these plots also had the best height growth.

226. **Godman RM 1956. Progress of top-dying in Yellow Birch - Upper Michigan, 1954-55. U.S. For. Serv. Lake St. For. Exp. Sta. Technical Note LS-444, 2 pp.**

Keywords: *Betula alleghaniensis* /dieback /forest protection

Abstract: Observation plots, established in 1954 and examined in 1955, showed that top-dying in slightly injured and apparently healthy trees had developed rapidly during the year, while more severely damaged trees had tended to remain in the same injury class. Some trees (especially the smaller ones) in nearly all classes showed a trend towards recovery. Cut-over stands seemed to be more affected than virgin stands. Permanent-sample-plot records show that dieback on individual trees in the past has occurred without appreciable reduction in growth over 5-year periods. Results are tabulated.

227. **Godman RM 1958. Silvical characteristics of Northern White-Cedar [*Thuja occidentalis*]. U.S. For. Serv. Lake St. For. Exp. Sta. Station Paper LS-67, 17 pp.**

Keywords: plant ecology/Silvicultural /*Thuja occidentalis*

228. **Godman RM 1962. Sprouting of northern Oaks reduced after debarking with sodium arsenite. U.S. For. Serv. Lake St. For. Exp. Sta. Technical Note LS-617, 2 pp.**

Keywords: coppicing/logging /*Quercus* spp./herbicide/weedkillers /sodium arsenite

Abstract: All trees ≥ 5 in. d.b.h. in four 2 1/2-acre compartments in a northern Oak stand in Michigan were treated at stump height with 40% Na arsenite, in a barked zone between 2 frill girdles. Six years after treatment, the % of stumps producing coppice shoots and the number of shoots per stump were highly significantly lower in treated than in untreated trees.

229. **Godman RM 1958. Winter sunscald of Yellow Birch. *Journal of Forestry* 57: 368-369.**

Keywords: *Betula alleghaniensis* /damage /injury /forest protection/sunscald /weevils

Abstract: Describes a case in Michigan. The injury is believed to be caused by rapid re-freezing of the tissues after they have been unseasonably warmed by the sun. In this case, on 16 Feb., 1948, the air temperature rose rapidly from below freezing to 51.1°F. by 3.30 p. m. and then dropped sharply to below freezing. The injury is rare on Yellow Birch in these latitudes, but may increase as more thinnings and other stand improvement work are done. Recommendations on protection and leaving screen trees [cf. Huberman, F.A. 5 p. 273] are made.

230. **Godman RM and Books DJ 1971. Influence of stand density on stem quality in pole-size northern hardwoods. U.S. For. Serv. Research Paper NC-54, 7 pp.**

Keywords: *Acer saccharum* /log grading/thinning/grading standing timber/spacing /stand density/northern hardwoods/stem quality/epicormics

Abstract: A study in N.E. Wisconsin, in mixed stands aged ca. 60 years, of the numbers of live and dead branches, epicormics and bumps or protrusions, at heights between 1 and 33 ft on crop trees. B.a. ranged from 69 to 128 ft² on different trial plots that had been variously thinned to 20-90 ft² b.a. at ca. 45 years (some also at 55). In *Acer saccharum*, the species having the most defects, the number of live branches per tree increased markedly with decreasing density, but epicormics and also the incidence of forking were not clearly influenced by density. It is suggested

that a residual b.a. of 85 ft²/acre would give a reasonable compromise between log quality and growth rate. [Cf. FA 21 No. 485.]

231. **Godman RM and Erdmann GG 1981. How to regenerate yellow birch [*Betula alleghaniensis*] in the Lake States. U.S. For. Serv. misc. publication, 3 pp.**

Keywords: Natural regeneration/seedbeds /site preparation/broadleaves /*Betula alleghaniensis*

232. **Godman RM and Krefting LW 1960. Factors important to Yellow Birch establishment in Upper Michigan. *Ecology* 41: 18-28.**

Keywords: *Betula alleghaniensis*/natural regeneration/coppicing/site preparation /scarification/discing/*Acer rubrum*/*Tsuga canadensis*

Abstract: Reports on a study of Yellow Birch (*Betula lutea* [*alleghaniensis*]) regeneration and establishment begun in 1952 in Upper Michigan. Over a 20-acre area, all seedbearing trees except Yellow Birch and a few White Pine and Hemlock were cut during winter 1952-53; the area was disked the following autumn. Undecomposed organic matter and undisturbed hardwood litter gave the fewest seedlings and the poorest growth of those that became established. Mineral soil mixed with partially decomposed organic matter proved the best seedbed. Scarification to expose mineral soil on 50% of the seedbed yielded the best stocking and growth. Surface soil moisture was a critical factor in germination and early establishment. Competition from shrubs following the heavy cut caused much mortality. Seedlings of Red Maple and other species were not strong competitors, though Red Maple sprouts tended to become dominant. Spring frosts caused frequent injuries but killed few Yellow Birch seedlings. The amount of sunlight influenced seedling development: 50% shade resulted in the best stem, leaf and root development and the greatest amount of seasonal height growth. A further cut after 3-5 years, to increase the amount of light, is recommended to maintain growth of established reproduction.

233. **Godman RM and Mattson GA 1980. Low temperatures optimum for field germination of northern red oak. *Tree Planters' Notes* 31: 32-34.**

Keywords: seeds /germination /artificial regeneration/site preparation/scarification /soil temperature /broadleaves /*Quercus rubra*

Abstract: *Quercus rubra* acorns collected in Wisconsin in 1977 and kept in the laboratory at temp. in the range 34-81°F for 30 days, showed the greatest and fastest germination at 34°F with values decreasing at higher temp. The surface soil temp. of seedbeds were recorded in Apr.-June 1978. The av. daily temp. lay within the range 32-39°F (considered opt. for *Q. rubra* germination) for 15 days on scarified areas but for only 5 days on unscarified areas. A temp. of 32°F was reached 2-3 wk earlier (in late April) on scarified areas, at a time coinciding with earlier and more favourable moisture conditions. The results of small direct sowing trials were in general agreement with the experimental data.

234. **Godman RM and Mattson GA 1970. Periodic growth of hardwood influenced by cold weather. *Journal of Forestry* 68: 86-87.**

Keywords: increment fluctuations/air temperatures /second growth/northern hardwoods

Abstract: A study of 108 second-growth trees (d.b.h. 7-16 in.) of five species in N.E. Wisconsin, which were measured eight times during the winter 1966/67, showed that stem diameter fluctuates with air temperature so as to cause serious underestimation of periodic growth when measurements are made under freezing air temperatures. Measurement in the early dormant season, before the air temperature falls below zero, gives the best estimate of periodic growth.

235. **Godman RM and Mattson GA 1976. Seed crops and regeneration problems of 19 species in**

northeastern Wisconsin. U.S. For. Serv. Research Paper NC-123, 5 pp.

Keywords: seed production/periodicity /natural regeneration /Acer rubrum

Abstract: Seed production intervals and frequencies were recorded over a 26-year period in the Argonne Experimental Forest, each year's crop being rated in relation to a 'full' crop. The best method at present to assure adequate regeneration of preferred species is to correlate site preparation with good seed years; a method was demonstrated for predicting the seed crop of 1-year autumn-maturing species from the size of the crop of a spring maturing species, Red Maple (*Acer rubrum*).

236. **Godman RM and Mendel JJ 1977. Economic values for growth and grade changes of sugar maple in the Lake States. U.S. For. Serv. Research Paper NC-155, 16 pp.**

Keywords: economics /management /forest products industries/Acer saccharum

Abstract: A method is described for calculating the financial maturity of a tree (i.e. the point after which the rate of annual increase falls below the desired rate of return). Current and expected rates of value increase were developed over a 10-yr period for sawtimber-size trees based on variable growth rates, expected merchantable ht. changes, and butt log grade improvement. The application of this method to marketing sugar maple is outlined together with implications for silviculture and management.

237. **Godman RM and Tubbs CH 1973. Establishing even-age northern hardwood regeneration by the shelterwood method - a preliminary guide. U.S. For. Serv. Research Paper NC-99, 9 pp.**

Keywords: natural regeneration /silvicultural systems/felling /shelterwood /Acer saccharum/ *Betula alleghaniensis*/northern hardwoods/site preparation/scarification/competition

Abstract: Presents a guide for the Lake States, based on results from several studies. The method, which involves two fellings, cannot be used for natural regeneration in stands younger than 40 years or with trees of d.b.h. < 8 in. Among the topics discussed are: (a) the seeding fellings, designed to admit ca. 40% of full sunlight; (b) the response of seedlings of shadebearing species to various amounts of crown cover, in terms of their future height growth and stocking; and (c) removal of the overstorey in the final felling, when seedlings are well established. Detailed modifications are also given, to increase the proportion of less shade-tolerant species such as *Betula alleghaniensis*: these include measures such as selecting a suitable site, preparing the seedbed by scarification, and reducing competition from shadebearing species, especially *Acer saccharum*. [Cf. FA 31, 2302; 33, 2367.].

238. **Goodburn JM and Lorimer CG 1998. Cavity Trees and Coarse Woody Debris in Old-Growth and Managed Northern Hardwood Forests in Wisconsin and Michigan. *Canadian Journal of Forest Research* 28: 427-438.**

Keywords: Dynamics/Stands/Populations/Ecosystems/Sites/Birds/Moss/Tsuga canadensis/northern hardwoods/coarse wood/old growth

Abstract: The effects of uneven-aged management on the availability of coarse woody debris habitat were examined in northern hardwood forests (with and without a hemlock component) in north-central Wisconsin and adjacent western Upper Michigan. Snags, cavity trees, fallen wood, and recent tip-up mounds in 15 managed uneven-aged (selection) stands were compared with levels in 10 old-growth stands and six unmanaged even-aged second-growth stands. Amounts of coarse woody debris in selection stands were generally intermediate between old-growth and even-aged stands. Density of snags >30 cm DBH in northern hardwood selection stands averaged 12/ha, approximately double that found in even-aged northern hardwoods, but only 54% of the level in old-growth northern hardwoods. Highest densities of snags >30 cm DBH occurred in old-

growth hemlock-hardwood stands, averaging over 40 snags/ha. For combined forest types, the volume of fallen wood (>10 cm in diameter) was significantly lower in selection stands (60 m³/ha) and even-aged stands (25 m³/ha) than in old-growth stands (99 m³/ha). Volume differences were even more pronounced for large-diameter debris (>40 cm). Cavity tree density in selection stands averaged 11 trees/ha, 65% of the mean number in old-growth stands. Densities of snags (>30 cm DBH) and large-diameter cavity trees (>45 cm) present in selection stands exceeded current guidelines for wildlife tree retention on public forests.

239. **Goodburn JM and Lorimer CG 1999. Population Structure in Old-Growth and Managed Northern Hardwoods: an Examination of the Balanced Diameter Distribution Concept. *Forest Ecology and Management* 118: 11-29.**

Keywords: Diameter Distributions/Density/Growing Space Allocation/Old-Growth Forests/Q-Ratios/Stand Structure/Stand Dynamics/Sustainable Forestry/Gap Dynamics/ Simulation/ Patterns/Acer saccharum/northern hardwoods

Abstract: Silvicultural guidelines for uneven-aged management have traditionally been based on the regulation of 'balanced' stand structures that allow for periodic yields at regular intervals while providing adequate growing space for multiple cohorts. To evaluate certain assumptions behind the 'balanced' diameter distribution concept we investigated differences in the size structure, canopy recruitment, and growing space allocation among 31 old-growth, managed uneven-aged (selection), and even-aged northern hardwood stands in north-central Wisconsin and adjacent western Upper Michigan. The frequency of stands meeting criteria for balanced uneven-aged structure was substantially affected by whether diameter distributions were plotted for all crown classes combined (traditional approach) or whether the distributions included only trees with crowns exposed overhead to skylight. While all 10 old-growth stands and 11 of the 15 selection stands met the traditional criteria for balanced structure, only 50% and 27%, respectively, met the more stringent criteria for balanced structure that included evidence of substantial gap sapling recruitment. Both negative exponential and rotated sigmoid diameter distributions were found among individual old-growth and selection stands. However, all old-growth stands classified as balanced (based on exposed canopy trees) had rotated sigmoid diameter distributions for all species pooled and for sugar maple only. Negative exponential distributions were also observed in some 'balanced' stands, but only among the selection stands. Aggregate crown area distributions in old-growth and selection stands with reasonably smooth reverse-J diameter distributions provided support for a modified interpretation of the equal area allocation hypothesis. While the aggregate exposed crown area occupied by each size class tended to be lower for small trees than for medium and large trees, total crown area distribution for trees with partially or fully exposed crowns did approximate a nearly uniform distribution.

240. **Gordon AM, McBride RA, and Fisker AJ 1989. The effect of landfill leachate spraying on foliar nutrient concentrations and leaf transpiration in a northern hardwood forest, Canada. *Forestry* 62: 19-28.**

Keywords: Pollution /refuse /irrigation /sewage /irrigation water/landfill leachates/broadleaves /Acer saccharum /Fagus grandifolia/northern hardwoods /foliar chemistry/ nitrogen/ phosphorus/ magnesium/potassium/iron/boron/release

Abstract: The effect of municipal solid waste leachate spray irrigation on a mature forest in Ontario was investigated. Canopy foliar samples and stem increment cores were collected from two indicative species, sugar maple (*Acer saccharum*) and beech (*Fagus grandifolia*), within each of a heavily sprayed, lightly sprayed and control area. Foliar concn. of N and P were significantly higher in both species within sprayed areas when compared to unsprayed areas (control). Concn. of Mg and K were markedly higher in maple but not beech foliar samples within heavily sprayed areas when compared to foliage within unsprayed controls. While no significant trends were observed within maple foliage, both Fe and B increased significantly in beech foliar samples from heavily sprayed areas in comparison to foliage samples from controls. Direct porometric

measurements of transpiration rate and diffusive (stomatal) resistance of canopy and understorey leaves revealed a significant increase in diffusive resistance and a decline in transpiration rate with leachate spraying. After 4 yr of spraying a significant effect of leachate application on radial stem growth had not been observed.

241. **Gordon AM, McBride RA, Fiskén AJ, and Bates TE 1989. Effect of landfill leachate irrigation on red maple (*Acer rubrum* L.) and sugar maple (*Acer saccharum* Marsh.) seedling growth and on foliar nutrient concentrations. *Environmental Pollution* 56: 327-336.**

Keywords: irrigation /waste water/Irrigation water/broadleaves /*Acer rubrum*/*Acer saccharum*/greenhouse/ landfill leachate

Abstract: Results are presented from greenhouse experiments with red maple in Ontario, Canada, using untreated leachate (from a disposal site for municipal solid wastes) or leachate pre-treated with lime or activated carbon at irrigation rates consistent with evapotranspiration demands. Experiments were also made with sugar maple subjected to cyclic waterlogging with untreated leachate. Few undesirable side-effects were observed with red maple, but waterlogging caused 100% mortality of sugar maple within 5 cycles.

242. **Gordon AM, Simpson JA, and Williams PA 1995. Six-year response of red oak seedlings planted under a shelterwood in central Ontario. *Canadian Journal of Forest Research* 25: 603-613.**

Keywords: plant competition/weeds /seedlings /shelterwood /chemical control/controlled burning/glyphosate /browsing /silvicultural systems/shelterwood system/underplanting /weed control/interspecific competition/control /cultural control/burning /crop weed competition/snow damage/ice damage/injuries /*Quercus rubra*/deer /*Odocoileus virginianus*/damage/herbicide

Abstract: A study was made of the potential for underplanting 1+0 and 1+1 northern red oak (*Quercus rubra*) in conjunction with a two-cut shelterwood harvest of a low-quality, ridgetop, tolerant hardwood stand in central Ontario. Growth patterns were followed for 6 years; herbicide (glyphosate) application and prescribed fire (2 burns, 3 years apart) were used as competition control measures in an experimental design that tested all possible combinations of stock type, competition control, and clipping 2 years after planting. Six years after outplanting the mean height attained across all treatments was 76 cm for 1+0 stock, and 90 cm for 1+1 stock. Depending upon treatment, some individuals were almost 3 m tall. In the presence of heavy deer (*Odocoileus virginianus*) browsing, competition control of any type was not needed. Clipping also does not appear to be advantageous. It was suggested that competition control made seedlings more susceptible to browsing by deer or damage by heavy snow and ice accumulation. The competitive ability of red oak in these sites is such that it will respond well to even late release from normal competition resulting from overstorey disturbance (i.e., control treatment).

243. **Gordon AM and Williams PA 1988. Intercropping valuable hardwood tree species and agricultural crops. *Agrologist* 17: 12-14.**

Keywords: agroforestry /Economics /intercropping - Ontario pilot studies/Agrosilvopastoral systems/ broadleaves /*Juglans nigra* /maize/non-timber products

Abstract: The use of intercropping as a method of reducing regional dependence on imports of high quality hardwood logs and sawn timber in areas of high agricultural production and low wood production is discussed, with particular reference to southern Ontario. The benefits of intercropping, and the economic possibilities of using black walnut as an intercrop species, are summarized. Economic data are tabulated for a possible intercropping scenario on class 1 or 2 agricultural land in southern Ontario. These suggest that over 40 yr, black walnut grown for veneer logs and intercropped with maize would increase the value of a 40-acre farm by \$800 000 (\$114 000 in discounted or 1988 terms). Commercial nut crops, possible after 10 yr, could add an extra \$400/acre p.a. after 15 yr. Yield loss of crops is estimated as about 5% in the early years.

The possibility of allelopathy (mainly to small fruit and legume crops) caused by juglone production by black walnut is discussed. It is suggested that this would not be a problem in the first 10 yr because trees are small. After this, possible solutions are limiting intercrops to tolerant grasses and grain crops, intercropping on drier soils (as used for tobacco production), or using the land for livestock grazing. An outline is given of pilot studies already established in Ontario.

244. **Gove JH and Fairweather SE 1992. Optimizing the management of uneven-aged forest stands: a stochastic approach. *Forest Science* 38: 623-640.**

Keywords: Forest management/simulation /Stand characteristics/stand structure/northern hardwoods/model stochastic

Abstract: Mathematical programs used for management and policy decisions in natural resources normally contain at least one underlying component which is stochastic. A technique is presented that allows marginal, conditional, and empirical confidence regions to be calculated for a widely known model of optimal uneven-aged stand structure [Martin, G.L. Investment-efficient stocking guides for all-aged northern hardwood forests. Madison, Wisconsin, USA; University of Wisconsin, 1982]. The investigation also made comparisons with the original model [Adams, D.M.; Ek, A.R. Canadian Journal of Forest Research (1984) 4, 274-286] on which both Martin's and other work has been based. Multivariate normal theory was used to obtain 95% confidence statements on the decision variables and functions thereof. Results showed that the optimal steady-state investment-efficient diameter distribution for uneven-aged northern hardwood stands is an imprecise estimate given the data used for growth model calibration and the assumptions of the mathematical model. However, confidence statements found using this methodology are only approximate as they rely on an estimate of the sampling distribution for the optimum diameter distribution, not on classical statistical theory. These findings suggest a very real need for modellers, managers, and policy makers to begin considering the role of stochastic model components in mathematical programming models in natural resources.

245. **Gove JH, Patil GP, and Taillie C 1995. A mathematical programming model for maintaining structural diversity in uneven-aged forest stands with implications to other formulations. *Ecological Modelling* 79: 11-19.**

Keywords: mathematical models/diversity /programming /growing stock/forest management/stand structure/diameter /distribution /simulation /model

Abstract: A mathematical programming model is presented which yields an optimal diameter distribution that is at least as diverse as some antecedent or target distribution. At the heart of this model is a set of constraints that ensures this outcome as long as a feasible solution to the model is found. The theory of intrinsic diversity ordering, which forms the basis for the constraint set derivation, is also discussed. The set of diversity-maintaining constraints presented are completely general and may be added to other mathematical programming formulations where quantities other than horizontal structural diversity are of interest. Two examples are given which illustrate the use of the model; both use published stocking guides for the Lake States of the USA.

246. **Gower ST, Reich PB, and Son Y 1993. Canopy dynamics and aboveground production of five tree species with different leaf longevities. *Tree Physiology* 12: 327-345.**

Keywords: broadleaves /foliage /age /photosynthesis /leaf area index/increment /growth /*Quercus rubra*/*Pinus strobus*/*Pinus resinosa*/*Abies balsamea* /*Picea abies* /*Larix decidua*/aboveground productivity

Abstract: Physiological and structural characteristics of the canopy, above-ground net primary production (ANPP) and instantaneous nitrogen use efficiency were studied in species with different leaf longevities at the Coulee Experimental Forest in SW Wisconsin. In monospecific plantations, leaf longevity averaged 5, 6, 36, 46 and 66 months for *Quercus rubra*, *Larix decidua*,

Pinus strobus, *P. resinosa* and *Picea abies*, respectively. Specific leaf area, maximum net photosynthesis per unit mass (A/mass), leaf N per unit mass and maximum net photosynthesis on a leaf N basis were inversely correlated with leaf longevity ($r^2 = 0.92-0.97$, 0.91 , 0.88 and 0.80 , respectively). Maximum net photosynthesis per unit area was not correlated with leaf longevity, whereas leaf N per unit area was positively correlated with leaf longevity ($r^2 = 0.95$). For conifer trees with similar diameters, species with long-lived foliage supported a greater foliage mass than species with short-lived foliage; however, *Q. rubra* did not follow this pattern. At stand level, total foliage mass ranged from 3.3 to 30.5 t/ha and was positively correlated ($r^2 = 0.97$) with leaf longevity. Leaf area index (LAI) was also positively correlated ($r^2 = 0.82$) with leaf longevity. Production efficiency (ANPP/LAI) was inversely related to leaf longevity and positively related to A/mass. Above-ground biomass and net primary production differed significantly ($P < 0.05$) among the five species but were not correlated with leaf longevity, total foliage mass or leaf area. In monospecific plantations, stem NPP for *L. decidua* was 17% greater than for *Pinus strobus* and 14% less than for *Picea abies*, but in mixed-species plantations stem NPP for *L. decidua* was 62 and 85% greater than for *Pinus strobus* and *Picea abies*, respectively. Similar above-ground net primary production rates can be attained by tree species with different leaf longevities because of trade-offs resulting from different structural and physiological leaf and canopy characteristics that are correlated with each other and with leaf longevity.

247. Grigal DF, Bates PC, Lowe AT, and Smith CT 1997. Assessing impacts of forest harvesting - the Minnesota experience. *Biomass and Bioenergy* 13: 213-222.

Keywords: sustainability /soils/policy/forest management/planning /harvesting /logging /forest products industries/environmental impact/pulpwood production/wood products

Abstract: In late 1989, because of concerns related to a major expansion of the forest products industry, the state of Minnesota commissioned a Generic Environmental Impact Statement (GEIS) to assess the cumulative impacts of timber harvesting. Total harvest, primarily for pulpwood, was increasing from 3.5 million m³ in 1975 to an estimated 9 million m³ in 1992. The GEIS examined the direct impacts of forest management at 3 alternative levels of annual harvest, base (9 million m³), medium (11 million m³), and high (16 million m³). Ten major issues, ranging from economics to biodiversity and aesthetics, were considered. Using a 1990 forest inventory of >13 000 plots, and computer models that optimized management goals and minimized costs, harvesting scenarios were generated by 10-year increments over a 50-year planning period. The results of the scenarios were evaluated in the context of the major issues of concern. The GEIS, completed in 1994, concluded that harvesting at the base level would be sustainable if recommended mitigation strategies were implemented. The projected impacts at the medium and high levels differed in degree rather than in type compared with those occurring at the base harvest level. Harvests exceeding about 12.5 million m³ were only sustainable if substantial investments were made in forest management. Through political consensus arising via the GEIS, the 1995 Minnesota Sustainable Forest Resources Act appropriated \$1.74 million over 2 years to address site-level impacts, establish an information cooperative and a research advisory committee, develop a framework to coordinate landscape planning, encourage certification and education for forestry professionals, and provide technical assistance to private landowners. Although the GEIS did not answer all questions dealing with forest management in Minnesota, it clarified the issues, identified gaps in information, and helped bring interested parties together in setting the course for forest management in the next millennia.

248. Grigal DF and Homann PS 1994. Nitrogen mineralization, groundwater dynamics, and forest growth on a Minnesota outwash landscape. *Biogeochemistry* 27: 171-185.

Keywords: groundwater /productivity /wetlands /nitrogen mineralization /dynamics /growth /landscape /biomass production/peatlands /nutrient uptake /*Quercus* spp. /*Thuja occidentalis*

Abstract: Aboveground biomass and net primary productivity (ANPP), groundwater depth and fluctuation, and in situ nitrogen (N) mineralization were measured in 13 upland and 4 wetland

forest stands at Cedar Creek Natural History Area (CCNHA), east central Minnesota, on well-sorted glacial outwash of very uniform fine sand. Uplands were interspersed with peatlands and the area had shallow groundwater. Stands were aggregated into six ecosystem types based on overstorey composition: oak, pine-oak, mesic hardwoods, northern white-cedar, lowland hardwoods, and savanna. Aboveground overstorey biomass ranged from 35 to 250 t/ha; lowest in savanna and highest in pine-oak. ANPP ranged from about 2 to 7.5 t/ha; also lowest in savanna but highest in white-cedar. Over all types, annual aboveground uptake of N was poorly related to available N measured by in situ mineralization ($r^2=0.01$), but the relation was better ($r^2=0.88$) if N availability in wetland stands was assumed to be a fixed proportion of N in surface soil (1.5%). Over all types, in situ N mineralization was poorly related to ANPP ($r^2=0.05$) and biomass ($r^2=0.38$). Both ANPP and overstorey biomass were more closely related to groundwater fluctuation ($r^2=0.87$ and 0.28 , respectively) than to depth ($r^2=0.01$ and 0.21 , respectively). Strength of all relations varied with inclusion or exclusion of data from wetland types or savanna. Total soil N and rates of mineralization were inversely related ($r^2=0.42$) because of data from wetland stands. Results demonstrate that positive relations between aboveground productivity and measured in situ N mineralization observed in upland forests are not valid for landscape that includes wetland forests either because in situ measurements do not indicate N availability in wetlands or because of other limiting factors. North temperate landscape includes an abundance of wetland forests with potentially strong linkages to uplands. This study suggests that the commonly-used measure of N availability provides inconsistent information about controls on ecosystems processes in this diverse landscape.

249. **Grigal DF, McRoberts RE, and Ohmann LF 1991. Spatial variation in chemical properties of forest floor and surface mineral soil in the North Central United States. *Soil Science* 151: 282-290.**

Keywords: Soil chemistry/chemical properties/soil spatial variation/soil pH/soil types ecological/Variation /Broadleaves /Conifers /soil properties/soil chemistry/ nitrogen/ sulfur/calcium/magnesium/potassium/sodium/vegetation types/Acer saccharum/Populus tremuloides/Pinus banksiana/Pinus resinosa/Abies balsamea/northern hardwoods

Abstract: Samples of both forest floor and surface mineral soil (0-25 cm) were collected from plots in 171 forest stands across Minnesota, Wisconsin, and Michigan. Five forest types were represented: Abies balsamea, Pinus banksiana, Pinus resinosa, Populus tremuloides and northern hardwoods dominated by Acer saccharum. Samples were analysed for pH, total N and S, loss on ignition, and exchangeable Ca, Mg, K, Na, and acidity; the latter were summed to yield cation exchange capacity. Data for each variable included 40 pairs of laboratory duplicates; 45 samples representing three sampling points approximately 2.5 m apart within a subplot in each of 15 plots (spatial scale of 100.4 m between samples); and 830 samples from five subplots approximately 30 m apart within the 171 plots (scale of 101.5 m). Variation among samples was determined for each of those categories, as well as among the nearly 35 plots within a forest type at approximately 100 km apart (scale of 105 m), and among the five forest types. Increase in variation with spatial scale was statistically significant. Coefficients of variation were very similar to those from other studies; considering the range of locations, soils, and vegetation in the literature, reported coefficients of variation for soil properties are remarkably uniform. None of the variables was normally distributed, even after log or algebraic transformations. Determination of number of samples necessary to characterize a system adequately is fraught with uncertainty regarding assumptions of the form of the distributions and of the level of precision desired. The commonly accepted precision of 10% of the mean from a normal distribution at a defined confidence level needs re-evaluation.

250. **Grigal DF and Ohmann LF 1992. Carbon storage in upland forests of the Lake States. *Soil Science Society of America Journal* 56: 935-943.**

Keywords: Broadleaves /Conifers /Carbon cycle/Plant nutrition/carbon /Plant composition/ vegetation types/Forest litter/chemistry /Soil chemistry/soil organic matter/Cycling /Acer saccharum/ Populus tremuloides/Pinus banksiana/Pinus resinosa/Abies balsamea/northern

hardwoods

Abstract: Overstorey trees were measured and samples of forest floor and mineral soil (to 1 m) were collected from plots in 169 forest stands across Minnesota, Wisconsin and Michigan. Five forest types were represented: balsam fir (*Abies balsamea*), jack pine (*Pinus banksiana*), red pine (*Pinus resinosa*), aspen (*Populus tremuloides*) and northern hardwoods dominated by sugar maple (*Acer saccharum*). Equations were used to estimate total biomass of each tree from diameter at breast height. Biomass estimates were converted to carbon using a ratio of C : biomass of 0.5. Loss on ignition data for forest floor and mineral soil were converted to carbon using regressions. There were no strong geographic trends in carbon storage in biomass, forest floor or mineral soil across the study area. Storage differed significantly among forest types. Each major carbon pool was related to a different set of descriptors. Total carbon storage was related to forest type, stand age, available water, actual evapotranspiration and soil clay content, which explained about 65% of the variation. Use of soil and site descriptors did not completely account for the strong effects of forest type on carbon storage. Differences in the size of carbon pools, as related to time since disturbance and forest type, indicated that carbon storage in forests of the Lake States can be influenced by forest management activities. Patterns of carbon storage in these moist temperate ecosystems are not as strongly influenced by climatic variables as is carbon storage in grasslands to the west.

251. **Grigal DF and Ohmann LF 1989. Spatial patterns in elemental concentrations of the forest floor across the north central USA. *Journal of Environmental Quality* 18: 368-373.**

Keywords: Forest litter/chemistry /Humus /Air pollution/soil chemistry/ soil /nutrients /heavy metals/Soil morphology/*Acer saccharum*/*Populus tremuloides*/*Pinus banksiana*/ *Pinus resinosa*/*Abies balsamea*/northern hardwoods/heavy metals/ calcium/ magnesium/ potassium/ sodium/ phosphorus/lead /cadmium/copper/nickel/zinc/palladium

Abstract: Forest floor material was sampled in 171 forest stands, representing five forest types, in Minnesota, Wisconsin and Michigan. The five forest types were balsam fir (*Abies balsamea*), jack pine (*Pinus banksiana*), red pine (*Pinus resinosa*), aspen (*Populus tremuloides*) and northern hardwoods dominated by sugar maple (*Acer saccharum*). Elemental concentrations of forest floor material were related to forest type, and, for most elements, concentrations were also related to location defined by 5 sampling zones along a NW-SE geographic gradient. Ca, Mg, K, Na and P decreased in concentration from west to east; Pb and Cd increased. Cu and Zn did not differ among zones, and although Ni differed there was no pattern to those differences. The trends were consistent with atmospheric deposition of Ca, Mg, K, Na and P from westerly soil-derived sources and deposition of Pd and Cd from eastern anthropogenic sources.

252. **Grimm EC 1984. Fire and other factors controlling the Big Woods vegetation of Minnesota in the mid-nineteenth century. *Ecological Monographs* 54: 291-311.**

Keywords: history /vegetation /Forest fires/ecology /forest ecology/*Acer saccharum*/*Tilia americana*/*Fraxinus americana*/*Ulmus americana* /*Ulmus rubra* /*Juglans cinerea*/*Populus* spp. /aspen /oak /*Carya cordiformis* /*Populus* spp. /*Quercus* spp./soil drainage

Abstract: Data from land survey records of 1847-50 were used to reconstruct the vegetation of the Big Woods and adjacent areas along the prairie-woodland border in south-central Minnesota. The characteristic tree taxa were *Ulmus* spp., *Tilia americana*, *Acer saccharum*, *Ostrya virginiana*, *Carya cordiformis*, *Juglans cinerea* and *Fraxinus* spp. Elm (*Ulmus americana* and *U. rubra*) was the most common tree. A buffer zone of fire tolerant oaks and aspen generally lay between the Big Woods and the prairie, the width depending on topography and the presence of additional firebreaks. The prairie-woodland border was characteristically a sharp boundary along firebreaks (water bodies and physiographic breaks), in some cases occurring without an aspen-oak zone. The vegetation was strongly correlated with the fire probability pattern. Soils influenced the probability of fire and were also the major factor controlling vegetation within areas of similar fire

probability. Soil drainage was the most important factor controlling vegetation within the overall pattern. Because the location of firebreaks and the existing pattern of vegetation controlled the fire probability pattern, sites with virtually identical physical characteristics supported qualitatively different types of persistent or stable vegetation.

253. **Groffman PM 1999. Carbon Additions Increase Nitrogen Availability in Northern Hardwood Forest Soils. *Biology and Fertility of Soils* 29: 430-433.**

Keywords: carbon/nitrogen mineralization/microbial biomass/respiration/atmospheric CO₂/barley roots/ecosystems/feedback/dioxide/northern hardwoods

Abstract: The effects of acetate additions to northern hardwood forest soils on microbial biomass carbon (C) and nitrogen (N) content, soil inorganic N levels, respirable C and potential net N mineralization and nitrification were evaluated. The experiment was relevant to a potential watershed-scale calcium (Ca) addition that aims to replace Ca depleted by long-term exposure to acid rain. One option for this addition is to use calcium- magnesium (Mg) acetate, a compound that is inexpensive and much more readily soluble than the Ca carbonate that is generally used for large-scale liming. Field plots were treated with sodium (Na) acetate, Na bicarbonate or water (control) and were sampled (forest floor - Oe and Oa combined) 2, 10 and 58 days following application. It was expected that the addition of C would lead to an increase in biomass C and N and a decrease in inorganic N. Instead, we observed no effect on biomass C, a decline in biomass N and an increase in N availability. One possible explanation for our surprising results is that the C addition stimulated microbial activity but not growth. A second, and more likely, explanation for our results is that the C addition did stimulate microbial growth and activity, but there was no increase in microbial biomass due to predation of the new biomass by soil fauna. The results confirm the emerging realization that the effects of increases in the flow of C to soils, either by deliberate addition or from changes in atmospheric CO₂, are more complex than would be expected from a simple C:N ratio analysis. Evaluations of large-scale manipulations of forest soils to ameliorate effects of atmospheric deposition or to dispose of wastes should consider microbial and faunal dynamics in considerable detail.

254. **Groot A and Carlson DW 1996. Influence of shelter on night temperatures, frost damage, and bud break of white spruce seedlings. *Canadian Journal of Forest Research* 26: 1531-1538.**

Keywords: buds /air temperature/clear felling/night temperature/thermal radiation/seedlings /suckers /frost injury/canopy gaps/damage/regeneration /*Populus tremuloides*/*Picea glauca*/artificial regeneration

Abstract: Measurements of frost damage and bud-break phenology were made during the spring of 1993 and 1994 on planted white spruce (*Picea glauca*) seedlings and on trembling aspen (*Populus tremuloides*) suckers in combination with measurements of minimum air temperature and long-wave radiation in forest openings of different sizes and configurations (1.5-ha clearcut, 9 and 18 m wide strips, 9 and 18 m diameter circular openings and intact forest) near Chapleau, Ontario. The average minimum air temperature during early summer (May-June) decreased linearly as the sky view factor of the forest openings increased. The average difference in minimum air temperature between the forest and clearcut opening was nearly 3°C for the period, and during clear night sky conditions, this temperature difference approached 6°C. The difference in minimum temperature between the forest and clearcut during cloudy night sky conditions was slightly greater than 1°C. Differences in minimum air temperature between the forest and each of the openings increased with decreasing incoming long-wave radiation. The largest differences occurred between the forest and the clearcut with low incoming long-wave radiation (cloudless nights). Minimum air temperatures in the 9-m strip and 9-m circle differed little from minima in the forest under all long-wave radiation regimes. Moderation of air temperature on clear nights would be best achieved with sky view factors of less than 0.3, implying a maximum strip width of 0.6 tree heights and a maximum patch diameter of 2.2 tree heights. Damage to white spruce seedlings after a frost in the spring of 1993 increased with increasing sky view factor. Nearly 75%

of the seedlings in the clear-cut had medium or heavy frost damage, while only 2% of the seedlings in the 9-m circle and forest were frost damaged. Opening size and configuration had little influence on the timing of bud break in either the white spruce seedlings or the trembling aspen suckers.

255. **Guertin PJ 1994. *Evaluation of the Lake States TWIGS diameter growth model for upland hardwoods in the lower peninsula of Michigan*. MS thesis, Michigan State University, East Lansing. 107 pp.**

Keywords: northern hardwoods /model TWIGS /growth model /increment

Abstract: Lake States TWIGS, the primary growth and yield model available in the Lake States, was developed with regional data. Validation of the model has never been performed exclusively for Michigan. This study validates Lake States TWIGS for the Manistee National Forest, and investigates alternative distance-independent, individual-tree, diameter growth functions which may improve prediction accuracy. Diameter growth, basal area, and mortality were compared to five-year projections from Lake States TWIGS for five northern hardwood species in northern lower Michigan. Although results may have been influenced by the 1988 drought and infestations of several species of defoliating insects, Lake States TWIGS appears to accurately project five-year growth and mortality for most upland hardwoods. Development of a diameter growth function to improve prediction accuracy focused on the Chapman-Richards growth function, multivariate regression, and other established modeling methods. Results were inconclusive.

256. **Guertin PJ and Ramm CW 1996. Testing Lake States TWIGS: five-year growth projections for upland hardwoods in northern Lower Michigan. *Northern Journal of Applied Forestry* 13: 182-188.**

Keywords: testing /yields /diameter /basal area/stand density/projections /increment /growth models/model TWIGS/Acer rubrum/Acer saccharum/Quercus alba/Quercus rubra/Quercus ellipsoidalis/Quercus velutina

Abstract: Five-year diameter growth, basal area growth, and mortality for 5 upland hardwood species in northern Lower Michigan were compared with projections from Lake States TWIGS, a commonly used growth and yield model in Michigan, developed by the USDA North Central Forest Experiment Station. The species studied were northern red oak [*Quercus rubra*], white oak [*Quercus alba*], other red oak (pin oak [*Quercus ellipsoidalis*] and black oak [*Quercus velutina*] combined), sugar maple [*Acer saccharum*], and red maple [*Acer rubrum*]. The validation data consisted of individual tree measurements from 44 stands across 10 ecological land types on the Manistee National Forest. The stands were measured in 1986 and 1991; during this time interval stands experienced a drought and outbreaks of leaf defoliators. For individual diameter at breast height (d.b.h.) classes, 5-yr diameter growth was predicted within ± 0.3 inches for all species. Mean errors for basal area projections were within ± 5 ft²/acre for all species, and mean error for trees/acre ranged from -33 for other red oak to +16 for sugar maple. Although precision was variable, Lake States TWIGS provided accurate predictions of 5-yr diameter growth for the 5 species tested. Projections of mortality were less accurate.

257. **Guldin JM 1982. *Patterns of interspecific competition in even-aged northern hardwood forests in the Great Lakes region*. PhD dissertation, University of Wisconsin, Madison. 248 pp.**

Keywords: Acer saccharum/northern hardwoods /competition /stratification /stand development

Abstract: Patterns of stand development due to interspecific competition were studied in even-aged northern mesic hardwood forests of the Great Lakes region. The approach was to investigate patterns of horizontal and vertical differentiation, and to study changes in these patterns in different forest communities. The data base consisted of a single 0.4-ha study area for which historical measurements exist, and a series of 20 0.08-ha study areas for which stem analysis data

exist (site plots). All living stems larger than 2 cm were mapped; crown heights and crown radii were taken for each tree. Horizontal pattern analyses were performed with a nested-cell design using Morisita's index. Vertical pattern analyses were performed using crown-class data, crown profile analyses, paired-tree interspecific interactions, and height patterns derived from stem analysis. Multivariate ecological methods were used to classify the site plots into community types typical of some of the major forest communities in the region. The distribution of these community types was strongly related to factors representing a resource gradient of moisture supply and nutrient availability. Crown pattern deviates significantly from stem pattern for all living trees on the large study area; crowns are both more regularly distributed than stems and show regularity of pattern over a broader range of nested-cell sizes. It is hypothesized that the strength of this deviation reflects the ability of species to minimize competition in the canopy. On the site plots, eight of twenty plots show significant deviation between crowns and stems; these plots are disproportionally of the dry-mesic communities. In the stands of this study, vertical stratification of one species over another is the exception rather than the rule. Among the common mid-tolerant species, stratification is not evident. Among the common tolerant species, stratification is only apparent in the very dry-mesic communities. When stratification does occur, it is typically between the most important mid-tolerant species and the very tolerant sugar maple in the communities, although stratification does not always occur under these conditions. Observed stratification does not strictly conform to accepted tolerance rankings.

258. **Guldin JM 1996. The role of uneven-aged silviculture in the context of ecosystem management. *Western Journal of Applied Forestry* 11: 4-12.**

Keywords: silviculture /management /ecosystems /forest management/multiple use/silvicultural systems/socioeconomics

Abstract: The role of uneven-aged silviculture in an ecosystem management context in the USA is established using 3 elements: ecological science (succession and disturbance theory); economic and social constraints; and some lessons from historical application that represent adaptive management. Overall, the case is made that widespread application of uneven-aged silviculture under ecosystem management carries both potential and risk, and that trade-offs expand rather than limit future silvicultural options.

259. **Guldin JM and Lorimer CG 1985. Crown differentiation in even-aged northern hardwood forests of the Great Lakes region, USA. *Forest Ecology and Management* 10: 65-86.**

Keywords: stand characteristics/development /composition /canopy /crown /light /broadleaves /northern hardwoods

Abstract: Interspecific differences in total tree height and crown position were studied in 20 even-aged northern broadleaved stands by reconstructing historical patterns of height growth and analysing current structure of the forest canopy. Most cases of significant differences in tree height among species involve species of different shade-tolerance classes; strong crown differentiation seldom occurred among species of the same tolerance class. On some sites, height differences among species were significant but growth rates were not sufficiently different to cause trees of the slower growing species to become completely overtopped. Pronounced vertical stratification with canopy trees of one species overtopping another could be detected on only one out of six habitat types. Differences in rate of height growth among species were most pronounced in the first 40 yr of stand development and diminished rapidly after that point. The slower growth of shade-tolerant species was partly compensated in some cases by early germination in the understorey of the previous stand, but similarity of growth rates appears to be a major reason that several species are able to share dominance of the canopy layer several decades after clear felling.

260. **Gullion GW 1990. Ruffed grouse use of conifer plantations. *Wildlife Society Bulletin* 18: 183-187.**

Keywords: Conifers /Broadleaves /Plantations /wildlife /management /ecology /Populus

tremuloides /Populus grandidentata/Pinus banksiana/Pinus resinosa/Bonasa umbellus

Abstract: A 34-yr study in the Cloquet Forestry Center, Minnesota, showed that ruffed grouse (*Bonasa umbellus*) benefited if 'islands' of aspen (*Populus tremuloides*, *P. grandidentata*) regeneration, at least 0.4 ha in size, were allowed to develop within conifer (*Pinus resinosa*, *P. banksiana*) plantations. Ruffed grouse took 14-18 yr after establishment before they began to use the plantations, compared with the usual 8-10 yr between clear felling and reoccupation of aspen regeneration at Cloquet. It is recommended that aspen and associated broadleaved species should be allowed to persist in small dispersed stands on about 10% of conifer plantations.

261. **Guyette RP and Dey DC 1995. A history of fire, disturbance, and growth in a red oak stand in the Bancroft district, Ontario. Ontario Forest Research Institute, Forest Research Information Paper No. 119, 14 pp.**

Keywords: dendrochronology ARSTAN /forest fires/history /disturbance/*Quercus rubra*/*Pinus resinosa*/natural regeneration

Abstract: Stem cross sections were taken (approximately 15 to 30 cm above the ground) from 22 northern red oaks (*Quercus rubra*), and one red pine (*Pinus resinosa*), on a 2 ha site at Barry's Bay, Ontario, Canada. These were used to determine the date of fire scars, serial variation in growth, periods of regeneration, and the dates of growth release and suppression. The oldest oak sampled was 179 years old, and the youngest 68. Two ring width chronologies were constructed using ARSTAN (a standardization and chronology construction programme). The first presents a standard chronology reflecting the growth trend of the stand due to climate and tree biology, and the second shows a residual chronology. The mean fire free interval was calculated at 6 years for the time between 1875 and 1954 based on 17 dated fire scars (range 2-18 years). The probability of fires that produce scars on trees may be greater in years of low precipitation. Data on the establishment of the trees indicated that regeneration of the current forest was disturbance-based on this site. The pre-1950s fire regime, with short fire-free intervals, favoured the development of oak by limiting the development of less fire-resistant, shade-tolerant species in the understorey. There was no evidence of fire after 1955, and this has led to the dominance of shade tolerant species over red oak in the understorey. It is concluded that fire suppression and the consequent loss of oak may result in a reduction in the economic and biodiversity value of the site.

262. **Hackett RL and Dahlman RA 1997. Minnesota timber industry - an assessment of timber product output and use, 1992. U.S. For. Serv. Resource Bulletin NC-186, 60 pp.**

Keywords: forest products industries/timber trade/statistics /roundwood /sawnwood /pulpwood /production

Abstract: In 1992, volume of industrial roundwood products removed from Minnesota's forest totalled 392 million cubic feet - 14% more than in 1990. Mill byproducts generated from primary manufacturers decreased 2% to 1595 thousand tons, green weight. Almost all plant residues were used, primarily for fuel and fibre products. Pulpwood was the leading roundwood product at 203 million cubic feet, saw logs ranked second at 59 million cubic feet, and veneer logs were third with 3 million cubic feet. The number of primary processing mills increased from 572 in 1990 to 596 in 1992. Total receipts increased 13% to 264 million cubic feet.

263. **Hackett RL and Whipple JW 1997. Wisconsin timber industry - an assessment of timber product output and use, 1994. U.S. For. Serv. Resource Bulletin NC-187, 73 pp.**

Keywords: forest products industries/timber trade/statistics /production /pulpwood /roundwood /wood residues/*Populus* spp. /aspen

Abstract: Industrial roundwood production rose from 357 million cubic feet in 1992 to 378 million cubic feet in 1994. Pulpwood accounted for 65% of total roundwood production in

Wisconsin - 3.1 million cords in 1994. Aspen [*Populus* spp.] constituted 37% of the roundwood cut for pulpwood. Saw-log production rose from 588 million board feet in 1992 to 645 million board feet in 1994. Logging residue generated in 1994 was estimated to be 157 million cubic feet. Ninety-eight percent or more of each residue class (coarse, fine, bark) generated at Wisconsin primary mills was used.

264. **Hahn JT and Carmean WH 1982. Lake States site index curves formulated. U.S. For. Serv. General Technical Report NC-GTR-88, 5 pp.**

Keywords: Site class assessment/site index/increment /*Acer rubrum*/*Fagus grandifolia*/*Larix laricina*/*Prunus serotina*/*Quercus alba*/*Quercus rubra*/*Tilia americana*/*Fraxinus americana*/*Ulmus americana*/*Thuja occidentalis*/*Pinus strobus*/*Pinus banksiana*/*Pinus resinosa*/*Abies balsamea*/*Picea glauca*/*Picea mariana*/*Betula papyrifera*/*Betula alleghaniensis* /*Populus* spp. /*Fraxinus nigra* /*Acer saccharum* /site index

Abstract: Published data were used to develop functions and parameters for calculating site index and total ht. of dominant and co-dominant trees for 21 species (*Abies balsamea*, *Acer rubrum*, *A. saccharum*, *Betula alleghaniensis*, *B. papyrifera*, *Fagus grandifolia*, *Fraxinus americana*, *F. nigra*, *Larix laricina*, *Picea glauca*, *P. mariana*, *Pinus banksiana*, *P. resinosa*, *P. strobus*, *Populus*, *Prunus serotina*, *Quercus alba*, *Q. rubra*, *Thuja occidentalis*, *Tilia americana* and *Ulmus americana*).

265. **Hairston AB and Grigal DF 1994. Topographic variation in soil water and nitrogen for two forested landforms in Minnesota, USA. *Geoderma* 64: 125-138.**

Keywords: moraine soils/aspect /soil organic matter/topography /slope /soil water/ physiography/ edaphic characteristics /nitrogen /soil /soil chemistry/broadleaves /*Quercus ellipsoidalis*/*Populus tremuloides*

Abstract: Relationships between topographic position, soil water, soil nitrogen and tree growth were investigated in northern pin oak stands (*Quercus ellipsoidalis*) on an outwash plain and in aspen stands (*Populus tremuloides*) on a ground moraine complex in Minnesota, USA. Three slope positions (upper, middle, lower), four aspects (NE, SE, SW, NW) and concave and convex plan (across slope) curvature were compared. Differences in soil water were significant ($P < 0.05$) among slope positions at both locations but they differed most strongly in the subdued outwash plain due to a shallower water table. Only soil water in lower slope positions in the moraine differed significantly between concave and convex across-slope shapes ($P < 0.05$). In the outwash plain, organic matter and N of the upper soil horizon were related to slope position; organic matter and total N in the forest floor and anaerobically released N in the upper soil horizon were related more strongly to aspect. In the moraine, N variables did not differ significantly by topographic position. In the outwash plain tree growth rates differed by slope position and aspect; in the moraine, tree volume (but not growth rate) differed by slope position ($P < 0.10$).

266. **Hale CM and Pastor J 1998. Nitrogen content, decay rates, and decompositional dynamics of hollow versus solid hardwood logs in hardwood forests of Minnesota, USA. *Canadian Journal of Forest Research* 28: 1276-1285.**

Keywords: logs /dead wood/decay /decayed wood/decay fungi/forest litter/decomposition /chemical composition/nitrogen /deciduous forests/*Acer saccharum*/*Quercus rubra*/bryophytes

Abstract: This study quantified and compared the nitrogen dynamics, residence times, and decay rates of hollow and solid sugar maple (*Acer saccharum*) and red oak (*Quercus rubra*) logs in decay classes 1 (freshly fallen log with both outer and inner bark intact) to 4 (logs completely colonized by invertebrates, fungi, bryophytes, and other vegetation) in old-growth maple or oak forests in Minnesota, USA. Decay parameters were not correlated with log age but did correlate with decay class. Hollow logs generally had lower percent original density and higher percentage N than did solid logs in each decay class. The point of maximum net immobilization of N and initial net N

mineralization occurred late in decay class 1 or early in decay class 2 (logs are firm but show partial invertebrate or fungal colonization in the sapwood). Residence time of logs in each decay class was low in decay class 1 (2 years), high in decay class 2 (17 years), and low in decay classes 3 (extensive invertebrate and/or fungal colonization, and colour change in sapwood and heartwood) and 4 (3 and 4 years, respectively). Decay rates varied by decay class, being low in decay classes 1 and 2 and high in decay classes 3 and 4.

267. **Hale CM, Pastor J, and Rusterholz KA 1999. Comparison of structural and compositional characteristics in old-growth and mature, managed hardwood forests of Minnesota, U.S.A. *Canadian Journal of Forest Research* 29: 1479-1489.**

Keywords: old growth forests/basal area/logs /seedlings /botanical composition/stand structure/understorey /species diversity/species richness/deciduous forests/stand characteristics/ forest management/dead wood/Acer saccharum/Quercus rubra/Tilia americana

Abstract: A study was conducted in Minnesota, USA, during 1993-94 to compare quantitative parameters (density and volume of logs and snags, coarse woody debris volume (volume of logs + volume of snags), the proportion of hollow logs, basal area and tree, sapling, large and small seedling densities), distributional patterns (diameter class and rot class of live trees, decay class of logs), and vascular plant species composition and diversity in 11 old-growth and 11 mature, managed, Acer saccharum-Tilia americana stands and in 10 old-growth and 10 mature, managed Quercus rubra stands. Old-growth forests had higher coarse woody debris volumes and higher proportions of hollow logs, of live trees in large diameter classes, of logs in decay classes 1 and 2, and of live trees in rot classes 3-5 compared with the mature, managed forests. Old-growth and managed forests did not differ significantly in plant species composition. It is concluded that, while older extended-rotation, managed stands can be very similar compositionally to old-growth forests, they differ quantitatively in structural features.

268. **Hansen GD and Nyland RD 1987. Effects of diameter distribution on the growth of simulated uneven-aged sugar maple stands. *Canadian Journal of Forest Research* 17: 1-8.**

Keywords: yield regulation/Q ratio /Forest management/model /computer techniques/broadleaves /Acer saccharum

Abstract: A computer simulation model was used to determine the effects of q ratio (a constant ratio of numbers of trees in adjacent diam. classes over the entire range of size classes present), max. tree size and b.a. on stand response as measured by net total vol., large sawtimber vol. and value growth and compound rate of return in felling cycles of 10 and 30 yr. A q ratio of 1.2 was best for achieving max. growth of large sawtimber, but larger q ratios were needed in sapling and pole size classes to ensure sufficient trees to sustain the diam. distribution to the end of the cutting cycle. Retaining trees larger than 40 cm d.b.h. was no advantage for max. vol. production or for achieving a better compound rate of return on initial stand value. A max. d.b.h. of 50 cm was better for obtaining max. sawtimber vol. and value. Under all options, longer cutting cycles required smaller initial b.a.

269. **Harman JR and Nutter MD 1973. Soil and forest patterns in northern Lower Michigan. *East Lakes Geographer* 8: 1-12.**

Keywords: succession /soil types/vegetation types/history/General Land Office/soil-site study

Abstract: Data from the field and from the General Land Office Survey were used to investigate soil/forest patterns. Vegetational changes since pre-settlement times may reflect both intensive logging of the Pines, and the effect of fires that have favoured regeneration by the more fire-tolerant species.

270. **Harris AR and Urie DH 1983. Changes in a sandy forest soil under northern hardwoods after 5 years**

of sewage effluent irrigation. *Soil Science Society of America Journal* 47: 800-805.

Keywords: Irrigation water/sewage effluent/soils/Soil types ecological/soil types/Fagus spp. /Acer spp./northern hardwoods/leaching /humus/soil pH/soil chemistry /nitrogen /phosphorus /calcium /magnesium/sodium

Abstract: Thinned and unthinned plots in a 50-year-old beech (*Fagus sp.*)-maple (*Acer sp.*) stand in northwestern lower Michigan were irrigated with sewage lagoon effluent. After 5 years of effluent application at rates of 38 and 76 mm/week, litter weights were reduced, leaching was increased, and forest floor humus weights were increased. Irrigation also resulted in decreased organic matter in the mineral soil. Nitrogen and P were leached from the litter; Ca, Mg, and Na were retained in forest floor humus and mineral soil, greatly increasing the pH and base saturation. Nitrogen concentrations measured in leachate from the 120-cm soil depth were consistently below 10 mg L⁻¹. Sodium was the predominant cation in the leachate. Irrigation over 5 years with wastewater effluent has had such minimal effects that higher irrigation rates might be considered without posing serious environmental risks.

271. Harrison TP and Michie BR 1985. A generalized approach to the use of matrix growth models. *Forest Science* 31: 850-856.

Keywords: increment /forecasting /simulation /model

Abstract: A matrix factorization approach is used to overcome the inflexibility of matrix models for making growth projections over intervals that are not integer multiples of the remeasurement period. The techniques permit the development of approximated 1-yr transition matrices for any matrix model.

272. Hasse WD and Ek AR 1981. A simulated comparison of yield for even- versus uneven-aged management of northern hardwood stands. *Journal of Environmental Management* 12: 235-246.

Keywords: increment /management /forest management/yield regulation/broadleaves /yields /yield forecasting/*Acer saccharum*/*Betula alleghaniensis*/northern hardwoods/model FOREST

Abstract: A distance-dependent individual-tree based model FOREST [see FA 36, 7950] was used to compare m.a.i. of b.a., total stemwood, merchantable ft³ vol. and bd ft yields of Wisconsin northern hardwood stands (*Acer saccharum* and *Betula alleghaniensis*). Three uneven-aged and 5 even-aged (20-155 yr) treatments (two with thinning) were considered. Analysis of variance of predicted yields suggested that uneven-aged management could be significantly more productive for merchantable ft³ vol. and bd ft vol., but that total stemwood yields were equal for all treatments. Even-aged management produced significantly greater b.a. growth. Yields from uneven-aged management appear to be dependent on the choice of management guides or diam. distributions [see FA 36, 5066].

273. He HS, Mladenoff DJ, and Boeder J 1999. An object-oriented forest landscape model and its representation of tree species. *Ecological Modelling* 119: 1-19.

Keywords: ecosystems /landscape /model LANDIS /plant succession/population dynamics/age of trees/stand structure/botanical composition/stand characteristics/species /growth models/forest management

Abstract: LANDIS is a forest landscape model that simulates the interaction of large landscape processes and forest successional dynamics at tree species level. The integration of object-orientated design (OOD) approaches such as modularity, abstraction and encapsulation into the design of LANDIS is discussed. It is shown that using OOD approaches, model decisions (often as model assumptions) can be made at 3 levels paralleling understanding of ecological processes.

These decisions can be updated with relative efficiency because OOD components are less interdependent than those designed using traditional approaches. In order to examine object design further, an examination was made of how forest species objects - AGELIST (tree age-classes), SPECIE (single species) and SPECIES (species list) - are designed, linked and functioned. The data structure of AGELIST is discussed in detail and it is shown that different data structures can significantly affect model performance and model application scopes. Following the discussion of forest species objects, the model is applied to a real forest landscape in northern Wisconsin. It is demonstrated that the model is capable of tracking species age cohorts in a spatially explicit manner at each time step. The use of these models at large spatial and temporal scales reveals important information that is essential for the management of forested ecosystem.

274. **Heinselman ML 1954. The extent of natural conversion to other species in the Lake States Aspen-Birch type. *Journal of Forestry* 52: 737-738.**

Keywords: Abies spp./Betula papyrifera/Betula spp./plant ecology/Picea spp./Populus tremuloides/ succession /synecology/conversion/northern hardwoods

Abstract: Of the existing 19.5 million acres of Aspen/Birch, present trends indicate that, by 1990, 2.1 will have reverted to northern hardwoods, 1.43 to Spruce/Fir, 0.75 to mixed types and 0.08 to Pine. Low-value types will cover > 1.0 million acres, 2.6 are already partly converted to other types and 9.5 do not give much promise of conversion in the foreseeable future.

275. **Heinselman ML 1970. Restoring fire to the ecosystems of the Boundary Waters Canoe Area, Minnesota, and to similar wilderness areas. *Proc. Tall Timbers Fire Ecol. Conf. No. 10.***

Keywords: Fire/Synecology/plant communities/vegetation types/virgin forests

Abstract: The remaining virgin forests of this area owe their composition and structure to periodic fires over the past 400 years, and the whole ecosystem is adapted to fire. The problem of retaining the ecosystem depends on the reintroduction of fire as a key environmental factor, and methods of achieving this, and its implications for management policy, are discussed.

276. **Heitzman E and Nyland RD 1991. Cleaning and early crop-tree release in northern hardwood stands: a review. *Northern Journal of Applied Forestry* 8: 111-115.**

Keywords: literature review /silviculture /broadleaves /cleaning /thinning /northern hardwoods

Abstract: Literature is reviewed on the effects of cleaning and early thinning treatments in sapling-stage broadleaved stands on crop tree growth and future yield.

277. **Heitzman E, Pregitzer KS, and Miller RO 1997. Origin and early development of northern white-cedar stands in northern Michigan. *Canadian Journal of Forest Research* 27: 1953-1961.**

Keywords: stand development/coniferous forests/stand establishment/age structure/recruitment /natural regeneration/logging /history /Thuja occidentalis/disturbance

Abstract: Stem analysis was used to reconstruct establishment and development patterns of seven mature northern white-cedar (*Thuja occidentalis*) stands in the Upper Peninsula of Michigan. Data were collected during 1993-95 from the stands which originated after single or repeated disturbances, probably timber harvests, that occurred between 1870 and 1935. These disturbances were essential for successful cedar recruitment into the overstorey. Stands developed as single or multiple cohorts, depending upon the severity and frequency of disturbance. Duration of the establishment period following single disturbances ranged from less than 10 years to 50 years. Seedlings in some multiple cohort stands established almost continuously for 100 years. Cedar overstorey trees, saplings, and seedlings that survived disturbances exhibited highly plastic height growth responses to suppression and release. All study areas developed stand initiation and stem

exclusion stages. Only 3% of all stems ≥ 2.54 cm diameter at breast height established after 1945. Cedar germination beneath the mature canopy was abundant, but cedar seedlings taller than 30 cm were completely absent from most sites. Successful cedar establishment and recruitment following the initial wave of timber harvesting contrast with widespread regeneration failures after present-day cutting practices. Factors influencing the cedar recruitment process have apparently changed over the past century.

278. **Held ME 1983. Pattern of beech regeneration in the east-central United States. *Bulletin of the Torrey Botanical Club* 110: 55-62.**

Keywords: natural regeneration/suckering /climate /seedlings /broadleaves /*Fagus grandifolia*

Abstract: *Fagus grandifolia* regeneration from seedlings and root suckers was recorded from 8 areas in Wisconsin, Ohio, Kentucky, Indiana, Tennessee and North Carolina. Results indicated a partial shift from seedling establishment towards a dependence on vegetative reproduction in areas where climate is more severe.

279. **Hendrick RL 1992. *Fine root production, demography and turnover in northern hardwood forests.* PhD dissertation, Michigan State University, East Lansing. 171 pp.**

Keywords: *Acer saccharum*/northern hardwoods /root growth /root turnover /nitrogen allocation to roots /productivity /biomass production

Abstract: Data were collected from two sugar maple (*Acer saccharum* Marsh.) forests in 1989 and 1990. Direct observations of fine root production, development and mortality were used in conjunction with physical harvests of fine root biomass and nitrogen content to measure root growth and death, and to estimate the amount of carbon and nitrogen allocated to fine root production and subsequently returned to the soil via fine root turnover. Analyses of cumulative survival distributions of contemporaneous 1989 and 1990 cohorts revealed that roots at the northern site consistently lived longer on average than roots born during the same periods of time at the southern site. The longer lifespan of roots in the northern forest was due to significantly lower first-season mortality rates; new roots were lost 64% faster at the southern forest (0.41 vs. 0.25 % /day/sp[-1], $p < 0.01$). Overwinter and second-year mortality rates were not significantly different ($p > 0.5$; 0.14 vs. 0.12 %/day/sp[-1]) among the sites. Patterns of fine root mortality at each site were the same for roots produced at all times of the year, and our results suggest that temporal differences in biomass 'turnover' may be due to temporal variation in root production, not in root mortality. Greater than 50% of annual length production occurred before mid-summer in both ecosystems, while the period of greatest mortality was from late summer through winter. About 1/3 of annual fine root production and mortality occurred simultaneously, with little observable change in total root length. Total fine root length observable in the minirhizotrons peaked in mid-summer in both ecosystems. Annual production values of approximately 8000 and 7300 kg/ha/yr/sp[-1] were calculated at the Southern and Northern sites, respectively, representing about 60% of total NPP in both forests. Corresponding biomass mortality (i.e. turnover) values were 6700 and 4800 kg/ha/yr/sp[-1], and total nitrogen returns to the soil from fine root mortality were 72 kg/ha/yr/sp[-1] at the Southern site and 54 kg/ha/yr/sp[-1] at the Northern site. Fine roots dominated total biomass and N litter inputs to the soil in both ecosystems, accounting for over 55% of total biomass and nearly 50% of total N returns. In both ecosystems, roots < 0.5 mm comprised the bulk of fine root biomass and N pools, and the contribution of these roots to northern hardwood ecosystem carbon and nitrogen budgets has probably been underestimated in the past.

280. **Hendrick RL and Pregitzer KS 1996. Applications of Minirhizotrons to Understand Root Function in Forests and Other Natural Ecosystems. *Plant and Soil* 185: 293-304.**

Keywords: decomposition/minirhizotron/production/soil biota/turnover/northern hardwoods /*Hordeum vulgare* /fine roots/length density/nitrogen availability/simulation approach/wet

heathlands/image analysis

Abstract: Minirhizotrons have proved useful to understand the dynamics and function of fine roots. However, they have been used comparatively infrequently in forests and other natural plant communities. Several factors have contributed to this situation, including anomalous root distributions along the minirhizotron surface and the difficulty of extracting data from minirhizotron images. Technical and methodological advances have ameliorated some of these difficulties, and minirhizotrons have considerable potential to address some questions of long standing interest. These questions include more fully understanding the role of roots in carbon and nutrient cycling, rates of root decomposition, responses to resource availability and the functional significance of interactions between plant roots and soil organisms. Maximizing the potential for minirhizotrons to help us better understand the functional importance of fine roots in natural plant communities depends upon using them to answer only those questions appropriate to both their inherent strengths and limitations.

281. **Hendrick RL and Pregitzer KS 1992. The demography of fine roots in a northern hardwood forest. *Ecology* 73: 1094-1104.**

Keywords: soil /minirhizotron/second growth/production /development /mortality /roots /plant morphology/Acer saccharum/northern hardwoods

Abstract: Production, development and mortality of fine roots (<2.0 mm in diameter) was monitored for 1 yr using minirhizotrons in a second growth, Acer saccharum-dominated stand in the northern lower peninsula of Michigan.

282. **Hendrick RL and Pregitzer KS 1993. The dynamics of fine root length, biomass, and nitrogen content in two northern hardwood ecosystems. *Canadian Journal of Forest Research* 23: 2507-2520.**

Keywords: carbon cycle/nitrogen cycle/plant composition/chemical composition/ minirhizotron/ length / mortality /dynamics /vegetation types/deciduous forests/roots /biomass production/ nitrogen / Acer saccharum/northern hardwoods

Abstract: The dynamics of fine (<2.0 mm) roots were measured in two sugar maple (Acer saccharum) dominated ecosystems (northern and southern sites) in the northern lower peninsula of Michigan during 1989 and 1990 using a combination of minirhizotrons and destructive harvests of fine root biomass and N content. More than 50% of annual length production occurred before midsummer in both ecosystems, while the period of greatest mortality was from late summer through winter. About one third of annual fine root production and mortality occurred simultaneously, with little observable change in total root length pools. Using fine root length dynamics to derive biomass production and mortality, annual biomass production was estimated as 8000 and 7300 kg/ha at the southern and northern sites, respectively. Corresponding annual biomass mortality (i.e. turnover) values were 6700 and 4800 kg/ha, and annual total N returns to the soil from fine root mortality were 72 and 54 kg/ha, respectively. Fine roots dominated total biomass and N litter inputs to the soil in both ecosystems, accounting for over 55% of total biomass and nearly 50% of total N returns. In both ecosystems, roots <0.5 mm comprised the bulk of fine root biomass and N pools, and the contribution of these roots to northern hardwood ecosystem carbon and N budgets may have been underestimated in the past.

283. **Hendrick RL and Pregitzer KS 1993. Patterns of fine root mortality in two sugar maple forests. *Nature* 361: 59-61.**

Keywords: roots /mortality /soil temperature/Acer saccharum /minirhizotron

Abstract: Minirhizotrons were used to study the mortality of contemporaneous fine root cohorts in 1989-90 in two sugar maple (Acer saccharum) forests located 80 km apart in Michigan. Warmer

soil temperatures seemed to be associated with more rapid death of roots at the southern site.

284. **Hendrick RL and Pregitzer KS 1997. The Relationship Between Fine Root Demography and the Soil Environment in Northern Hardwood Forests. *Ecoscience* 4: 99-105.**

Keywords: Fine Root Length/Production/Mortality/Soil Temperature/Moisture/Water Balance/Growth/ Water/Dynamics/Nitrogen/Temperature/Ecosystem/Turnover/Minirhizotrons /northern hardwoods

Abstract: We used minirhizotrons to measure growing-season fine root dynamics at 0-30 and 50-100 cm depths in two northern hardwoods forests. Concomitant measurements of several soil and site environmental variables were also made. We then used regression models to quantify the relationships between these environmental variables and fine root demography. Generally, environmental factors had a moderate effect on broad, inherent phenological patterns of root activity and abundance. For example, both shallow fine root length density and potential evapotranspiration reached their maximum in mid-summer, but the relationship between the two was not strong at either site ($R^2=0.12$). Deep root length density was not significantly related to any measured environmental factor. Periods of high water demand during which soil moisture was also abundant (i. e., late spring and early summer) were related to increased shallow root production. Root length mortality was low at these times, but the correlation with soil moisture was statistically significant only in the shallow depth increment. Quantifying the relative importance of the environment on root growth in large field studies like ours is complicated by a number of factors. These include the difficulty of intensive sampling, interactive effects of environmental factors, and the uncertainty of encountering environmental conditions sufficiently severe to elicit a measurable root response during the study period.

285. **Hendrick RL and Pregitzer KS 1992. Spatial variation in tree root distribution and growth associated with minirhizotrons. *Plant and Soil* 143: 283-288.**

Keywords: minirhizotron/root systems/distribution /growth /roots /production /spatial variation/ *Acer saccharum*

Abstract: Four minirhizotrons were installed in each of three replicate plots in a deciduous forest dominated by *Acer saccharum* in Michigan. Length growth of tree roots along the surface of minirhizotrons was measured for a period of one year, and resulting data were analysed in nested, averaged and pooled arrangements. Analyses of nested data showed that spatial variation in root growth and abundance among minirhizotrons within plots was greater than variation among plots. Averaging data from minirhizotrons within plots prior to analysis reduced variation about plot means, but extensive intraplot variation invalidates this approach on statistical grounds. Both nested and averaged data failed to account for the contribution of individual roots to the mean, and root production rates were consequently overestimated. Pooling data from four minirhizotrons reduced variation about means, and resulted in a more representative estimate of root production rates. Analysis of composited data can be used to incorporate small-scale variation into a single replicate sample in those circumstances where activity of root systems of plant communities is the object of study.

286. **Hendrick RL and Pregitzer KS 1996. Temporal and depth-related patterns of fine root dynamics in northern hardwood forests. *Journal of Ecology* 84: 167-176.**

Keywords: mortality /phenology /production /patterns /seasonal variation/vegetation types/roots /depth /dynamics /*Acer saccharum*/northern hardwoods

Abstract: The dynamics of fine (<2.0 mm diameter) roots growing in two northern hardwood forests (dominant species *Acer saccharum*) in the northern lower peninsular of Michigan, USA, were quantified to a depth of 1 m in 10 cm increments. It was hypothesized that patterns of root production and mortality would be broadly synchronous at all depths, but that deep roots would be

comparatively less dynamic than shallow roots. The data showed that shallow roots were responsible for the majority of total annual fine root production and mortality. Nearly half of all roots growing and dying in the 1 m profile occurred in the upper 20 cm of the soil, while roots located at depths of 75 cm or more accounted for only 11% of annual production and 4% of annual mortality. Fine root production prior to, or coincident with, canopy expansion was significant at all depths. The relative importance of early fine root growth generally increased with depth, with 50-80% of annual production occurring prior to mid-June at depths exceeding 50 cm. Episodic deep root production during the growing season appeared to be related to periods of high water demand. Patterns of fine root mortality were more variable among depths. Mortality was distributed rather evenly throughout the year near the soil surface, but mid-season mortality was generally low at depths greater than 50 cm.

287. **Hendrickson OQ 1988. Biomass and nutrients in regenerating woody vegetation following whole-tree and conventional harvest in a northern mixed forest. *Canadian Journal of Forest Research* 18: 1427-1436.**

Keywords: Natural regeneration/logging /thinning /natural thinning/ ecology /whole tree logging/Stand characteristics/composition /Forest litter /litter chemistry/ measurement /nutrients /nitrogen /potassium/calcium/Plant nutrition/nutrient reserves/Cycling /biomass /Soil morphology/Populus tremuloides /Populus grandidentata/Pinus strobus/Pinus resinosa

Abstract: The composition and biomass of tree and shrub species, the density of tree species, plant nutrient contents, litter fall and litter nutrient contents were studied following whole-tree and conventional harvest in a mixed pine/aspen stand in central Ontario. Before harvest, the site was occupied by a 95-yr-old pine (*Pinus resinosa*, *P. strobus*) and aspen (*Populus tremuloides*, *P. grandidentata*) stand growing on gently rolling, gravel-free outwash sands. Four years after harvest, aspen abundance increased 100-fold in both harvested areas, with higher densities after whole-tree harvest (WTH, 4.1 stems/m²) than after conventional harvest (CH, 2.7 stems/m²). No self-thinning of aspen occurred between 2 and 4 years after harvest. Total aboveground woody biomass accumulated at annual rates of 2.0 t/ha in the WTH area and 1.5 t/ha in the CH area; the preharvest rate was 2.0 t/ha. Peak autumn litter production occurred earlier in the harvested areas than in an adjacent uncut area. Cycling of N and K in litter fall returned to preharvest rates after 4 years. Cycling of Ca in litter fall was lower after WTH than after CH. Vegetation uptake of N and K in the harvested areas in year 4 exceeded the preharvest value. Increased annual N accumulation in woody biomass (3.0 kg/ha before harvest, 10.6 kg/ha after WTH) would place a relatively greater demand on forest floor N pools in the WTH than in the CH area owing to lack of N input in logging slash. Although WTH did not reduce initial rates of biomass production, *Populus* spp. had lower concentrations of N, Ca, and Mg in the WTH area than in the CH area. There may be a danger that WTH on less fertile sites in the region will produce dense, unproductive aspen stands with low rates of self-thinning.

288. **Hendrickson OQ 1989. Implications of natural ethylene cycling processes for forest soil acetylene reduction assays. *Canadian Journal of Microbiology* 35: 713-718.**

Keywords: Biological techniques/acetylene reduction/forest soils/soil water content/ethylene /oxidation /Soil types ecological/production /plant growth regulators/northern hardwoods

Abstract: Under aerobic conditions, ethylene production and oxidation occurred simultaneously in organic and mineral horizons of a northern hardwood forest. Ethylene oxidation rates in mineral soil were high (up to 25 nmol g⁻¹ day⁻¹) relative to other forest soils, and exceeded production rates unless moisture contents were raised above saturation. Acetylene inhibits ethylene oxidation while allowing ethylene production to proceed; control samples for acetylene reduction assays should therefore contain acetylene plus a nitrogenase inhibitor such as carbon monoxide if forest soil nitrogenase activity is to be accurately quantified. A level of 7 kPa carbon monoxide gave complete nitrogenase inhibition in active forest samples in the presence of acetylene; carbon monoxide was applied 2 h in advance of acetylene to compensate for its lower solubility in water.

Use of this methodology revealed a strong inhibitory effect of saturated water contents on forest floor acetylene reduction activity, suggesting that aerobic N₂-fixing activity predominated in unamended forest soil samples.

289. **Hendrickson OQ, Burgess D, and Chatarpaul L 1987. Biomass and nutrients in Great Lakes - St. Lawrence forest species: implications for whole-tree and conventional harvest. *Canadian Journal of Forest Research* 17: 210-218.**

Keywords: biomass production/plant nutrition/phosphorus/nitrogen /potassium/ calcium/ magnesium/ nutrient reserves/Logging /whole tree logging/nutrients /*Acer rubrum*/*Populus tremuloides*/*Pinus strobus*/*Pinus resinosa*/*Abies balsamea*/*Picea glauca*/*Betula papyrifera*

Abstract: In studies in a mixed conifer/broadleaved stand at Petawawa National Forestry Institute, Ontario, plots were established from which all aboveground parts of woody plants >1.3 m tall were removed (whole-tree harvest) or on which stems <9 cm d.b.h. were left standing and crowns were left on site after felling larger trees (conventional harvest). Dry wt. of living and dead material, and nutrient contents were determined for *Pinus strobus*, *P. resinosa*, *Picea glauca*, *Abies balsamea*, *Populus tremuloides*, *Betula papyrifera* and *Acer rubrum*. Tables show stand composition and the biomass, and content and concn. of N, P, K, Ca and Mg in wood and bark, separately for stems and large branches and combined for small branches (plus foliage for conifers). Conventional harvest yielded 138 000 kg/ha. Whole-tree harvest yielded an additional 52 000 kg/ha (38%) and increased N removal by 191 kg/ha (132%). There were clear differences between species in nutrient accumulation. Among the dominants, *P. strobus* and *P. resinosa* produced the greatest amounts of biomass per unit of nutrient. Cation concn. were high in *P. tremuloides*, but its demand for N was moderate. Shade-tolerant understorey species retained relatively large amounts of nutrients in larger diam. portions of stems and branches. Larger diam. materials, however, had lower elemental concn., except for Ca. A conventional harvest often leaves small diam. stems of species (*Abies balsamea* and *Acer rubrum*) that accumulate large amounts of nutrients and that may be poorly adapted to low throughfall cation inputs and high light intensity following canopy removal. Whole-tree harvesting on these nutrient-poor sites may lead to establishment of stands of *Populus* spp. of low productivity.

290. **Hendrickson OQ, Chatarpaul L, and Burgess D 1989. Nutrient cycling following whole-tree and conventional harvest in northern mixed forest. *Canadian Journal of Forest Research* 19: 725-735.**

Keywords: forest influences/soil chemistry/soil pH/cycling /logging /hydrology /ecology /whole tree logging /potassium /magnesium /nutrients /nitrogen

Abstract: Soil and water chemistry and soil-respiration activity were studied from 1981 to 1984 in a mature, mixed conifer and broadleaf forest and in adjacent whole-tree harvest (WTH) and conventional harvest (CH) areas dominated by broadleaf sprouts at the Petawawa National Forestry Institute, Ontario. Compared with the uncut mature forest, forest floor contents of N and K were lower in the WTH area 3 yr after harvest; Ca and Mg were greater in the CH area, probably owing to inputs in logging slash. Mineral soil Ca and pH were greater in the harvested areas than in the uncut area. During the 2nd year after harvest, cation concentrations in forest floor leachate varied in the order WTH > CH > uncut area, but differences largely disappeared the next year. Soil water NO₃ concentrations were slightly greater in the CH area, but only 1.6 kg/ha N p.a. leached below the rooting zone. Bulk precipitation K and Mg concentrations were less in the WTH area than in the CH area due to the loss of canopy leaching from the residual stand. Slightly more cations were found in the snowpack under the mature forest canopy. Midwinter rains caused movement of NO₃ and H within the snowpack. Despite the greater soil-respiration rates in the harvested areas, no differences in soil organic matter pools were observed relative to the uncut area; harvest-related inputs of slash, decaying roots, and stumps may have offset respiratory carbon losses. Current high nutrient demands of rapidly growing sprouts in the WTH area greatly exceed nutrient inputs in bulk precipitation; this may lead to future growth declines.

291. **Hill JP and Dickmann DI 1988. A comparison of three methods for naturally reproducing oak in southern Michigan. *Northern Journal of Applied Forestry* 5: 113-117.**

Keywords: clearcut/shelterwood/natural regeneration/logging effects/Acer saccharum/ Acer rubrum /Prunus serotina/Quercus alba/Quercus rubra/Quercus velutina/Ulmus americana /Ulmus rubra

Abstract: Regeneration established 14 yr after clearcutting, shelterwood and group selection cutting in a 45 acre mature mixed broadleaf stand (150- to 200-yr-old red [Quercus rubra], black [Q. velutina] and white oak [Q. alba], with younger sugar maple [Acer saccharum], red maple [A. rubrum], black cherry [Prunus serotina], slippery elm [Ulmus rubra] and American elm [U. americana]) near Dowagiac in SW lower Michigan, USA, was examined. Substantial red oak regeneration was found only in clearcut and shelterwood treatments, but most was being overtopped by black cherry, elm, sugar maple and red maple. White oak reproduction was almost non-existent, even though it had been a major component of the original stand. These results suggest that natural oak reproduction could be obtained on good sites using shelterwood or clearcut systems, though subsequent competition control would be necessary to keep it dominant.

292. **Hix DM and Barnes BV 1984. Effects of clear-cutting on the vegetation and soil of an eastern hemlock dominated ecosystem, western Upper Michigan. *Canadian Journal of Forest Research* 14: 914-923.**

Keywords: clear felling/ecology /cycling /succession /logging /soil chemistry/natural regeneration/ synecology /soil /layer structure/potassium /magnesium /calcium /nutrients /forest soils/soil types/Acer rubrum/Acer saccharum/Abies balsamea/Betula alleghaniensis/Tsuga canadensis

Abstract: A study of 4 areas along the boundaries of the Sylvania Recreation Area (Ottawa National Forest) in western Upper Michigan, USA. The position of commercially clear felled areas along the boundaries of the relatively undisturbed 8500-ha tract provided the opportunity to examine the probable effects of clear-felling after an average of 46 yr. Clear-felling resulted in the virtual elimination of eastern hemlock (Tsuga canadensis) from the overstorey; it was replaced by a mixed forest of red maple (Acer rubrum), yellow birch (Betula alleghaniensis), sugar maple (Acer saccharum) and balsam fir (Abies balsamea). The ecological species groups characteristic of the ground cover of the non-felled plots were not substantially different from the groups now present on the clear-felled plots. The thickness, mass, and nutrient (K, Mg, Ca) contents of the forest floor decreased significantly, and the acidity and nutrient contents of the upper mineral soil increased slightly. The replacement of hemlock by broadleaved species has slowly decreased the acidity and apparently increased the rate of nutrient cycling. It appears that without major disturbance, such as fire, hemlock is not likely to regain dominance following clear-felling owing to failure to regenerate naturally.

293. **Hof JG, Kent BM, and Pickens JB 1992. Chance constraints and chance maximization with random yield coefficients in renewable resource optimization. *Forest Science* 38: 305-323.**

Keywords: forest management/planning /simulation /models

Abstract: Six approaches (3 'chance-constrained' and 3 'chance maximizing') presented in a previously published paper were developed to account for random yield coefficients with known means and variances in renewable resource optimization models. Model formulations are discussed. A forestry land allocation problem is presented based on data from permanent plots in Michigan. Nine types of land were available for harvest ranging from stands not harvested since 1956 to stands recently harvested such that all trees with a diameter at breast height >5 inches were removed. Each land type was stocked with different amounts of veneer, sawtimber and pulpwood. Different approaches gave different results.

294. **Holmes MJ and Reed DD 1991. Competition indices for mixed species northern hardwoods. *Forest Science* 37: 1338-1349.**

Keywords: Increment /diameter growth/model growth /Plant competition/mathematics /Acer rubrum/Quercus rubra/Populus tremuloides/Betula papyrifera/northern hardwoods

Abstract: Several competition indices were evaluated for 4 species (Quercus rubra, Acer rubrum, Betula papyrifera and Populus tremuloides) to determine their relation to annual diameter growth in mixed species northern broadleaved stands in upper Michigan. A new index which incorporates factors representing both root and crown competition is formulated and tested. In their correlation with annual diameter growth, simple size ratio indices perform as well as, or better than indices of growing space, area overlap, and root/crown indices. Hegyi's index and several forms of the new root/crown index show the most consistent performance across study species.

295. **Holmes WE and Zak DR 1994. Soil microbial biomass dynamics and net nitrogen mineralization in northern hardwood ecosystems. *Soil Science Society of America Journal* 58: 238-243.**

Keywords: climate /seasonal variation/dynamics /hardwoods /availability /microorganisms /biomass /mineralization /forest soils/nitrogen /soil chemistry/carbon /soil chemistry/soil biology/broadleaves /Acer saccharum/Quercus rubra/Tilia americana/northern hardwoods

Abstract: The temporal relationship between microbial biomass (C and N) and rates of net N mineralization was studied in two different northern hardwood ecosystems, one dominated by sugar maple (Acer saccharum) and basswood (Tilia americana) and the other by sugar maple and red oak (Quercus rubra) in Michigan, USA. In situ buried bags were used to estimate net N mineralization and nitrification at monthly intervals for 1 yr. Microbial C and N contents of the incubated soil were determined using the chloroform fumigation-incubation method. Net N mineralization displayed marked seasonal variability, ranging from 35 to 115 mg N/m² per day during the growing season. In contrast, microbial biomass C and N were relatively constant throughout the year, averaging 112 g C/m² and 17 g N/m². Neither microbial biomass (C or N) nor the change in microbial biomass between sampling dates were significantly inversely correlated with mean daily rates of net N mineralization. These results do not support the idea that N availability is controlled by large seasonal fluctuations in soil microbial biomass such that a relatively constant pool is maintained through time. In addition, mean annual rates of net N mineralization and nitrification did not differ significantly from those previously measured in the same stands, suggesting that annual rates may be consistent in climatically similar years.

296. **Holmes WE and Zak DR 1999. Soil Microbial Control of Nitrogen Loss Following Clearcut Harvest in Northern Hardwood Ecosystems. *Ecological Applications* 9: 202-215.**

Keywords: Clear-Cut/Denitrification/Harvest/Microbial Biomass/Nitrogen Immobilization/soil chemistry/Nitrogen Leaching/Nitrogen Mineralization/Nitrification/Nitrogen Cycling/Northern Hardwoods/Sugar Maple/Denitrification Rates/ Nitrification/ Dynamics/ Variability/ Gradient/ Nitrate/ Acer saccharum/Quercus rubra/Tilia americana/northern hardwoods

Abstract: Establishing the relationship among the spatial distribution of forest ecosystems, N cycling processes, and N loss following harvesting could enable land managers to anticipate and predict the potential for N loss at the scale of local and regional landscapes. In the Great Lakes region, northern hardwood forests with distinct floristic, edaphic, and physiographic characteristics vary predictably across the landscape in N cycling processes, especially in rates of nitrification. Although their landscape distribution and patterns of N cycling are well established, it is uncertain whether this type of information could be used to predict landscape-level patterns of N loss following overstory harvest or other types of disturbance. We studied the microbial processes in soil that control the retention and loss of N following clear-cutting in two northern hardwood ecosystems that are widely distributed in the upper Great Lakes states and differ floristically, edaphically, and in N cycling processes. The overstory of one hardwood ecosystem is

dominated by *Acer saccharum* and *Quercus rubra*, and the other is dominated by *A. saccharum* and *Tilia americana*. These ecosystems differ in annual rates of net nitrification (5 vs. 15 g NO₃-N.m⁻².yr⁻¹), and we studied paired intact and clear-cut plots within them to understand whether spatial patterns of nitrification could be used to predict N loss following harvest. We measured microbial biomass, NO₃- leaching, denitrification, and microbial N transformations for one year following a clear-cut harvest. Clear-cut harvest led to significant loss of N through NO₃- leaching in both ecosystems, averaging 4.9 g N.m⁻².yr⁻¹ in clear-cut plots and 0.2 g N.m⁻².yr⁻¹ in intact plots. Denitrification was low in both ecosystems (0.08-0.42 g N.m⁻².yr⁻¹) and did not increase significantly following clear-cutting (0.16-0.79 g N.m⁻².yr⁻¹). Averaged across ecosystems, annual net N mineralization increased by a factor of 2 in clear-cut plots (14.2 g N.m⁻².yr⁻¹) relative to intact plots (7.3 g N.m⁻².yr⁻¹); net nitrification similarly increased after harvest (11.4 g N.m⁻².yr⁻¹ clear-cut vs. 5.5 g N.m⁻².yr⁻¹ intact). Gross rates of N mineralization and nitrification displayed a response similar to that of net rates. Although gross rates of N immobilization increased following clear-cutting, microbial biomass did not change. Thus, increased turnover of N through microbial biomass ([biomass N]/[gross N immobilization]) resulted in the observed increase in net N mineralization rates. Our results indicate that microbial immobilization of N was not an important process of N retention following clear-cut harvest in sugar maple-dominated northern hardwood forests. Rather, increases in net N mineralization following harvest increased substrate availability to nitrifying bacteria, which eventually resulted in substantial losses of N through leaching. Regardless of initial differences in net nitrification, harvesting led to similar rates of rates NO₃- leaching from both northern hardwood ecosystems. We conclude that N loss following clear-cutting in these forests cannot be predicted by rates of nitrification prior to harvest. Rather, N loss depends on high initial rates of net N mineralization and on the effects of changes in microclimatic conditions and heterotrophic activity on NH₄⁺ availability to nitrifying bacteria following overstory removal.

297. **Host GE 1987. *Spatial patterns of forest composition, successional pathways and biomass production among landscape ecosystems of northwestern lower Michigan. PhD dissertation, Michigan State University, East Lansing. 221 pp.***

Keywords: northern hardwoods /upland forest ecosystems /productivity /edaphic gradient /ecosystems /geomorphic map /herbaceous layer /understory

Abstract: Spatial patterns of forest composition, successional pathways, and biomass production were related to glacial landforms in a regional area of northwestern Lower Michigan. There were three general objectives: (1) to develop a geomorphic map of the study area, (2) to define and describe upland forest ecosystems, and (3) to study variation in species composition, successional pattern, and biomass production among landforms and ecosystems. Glacial landforms were mapped using field observation, airphoto interpretation, and topographic profile analysis. Eighty sample stands were located in upland landscape positions using a landform-based stratified random sampling design. Detailed observations were recorded for the overstory, understory, ground flora and soils of each stand; nine ecosystems were identified. Compositional patterns detected in multivariate analysis of floristic data were used to form ecological species groups and relate vegetation pattern to environmental factors. Chi-squared analyses showed significant patterns of species distribution related to landform. The Interlobate Moraine, a predominant landform in the northwestern portion of the study area, was characterized by a northern hardwood canopy, with herbaceous annuals, perennials, and ephemerals forming the ground flora. All other morainal and glaciofluvial landforms supported oak overstories with predominately ericaceous ground flora species. Stand ordination scores were significantly correlated with a soil textural index, providing indirect evidence that soil moisture availability is an important factor influencing species composition. Potential successional pathways were studied by comparing seedling and sapling densities with current overstory composition. The results indicate that oak is not regenerating in any landscape position, and that the potential future overstory varies by ecosystem. Total aboveground biomass and biomass increment varied significantly among landforms and ecosystems. Biomass ranged from 84 to 250 t/ha; biomass increment ranged from 1.3 to 3.6 t/ha/yr). Differences in biomass increment were correlated with the ground flora ordination,

indicating that composition and production may be controlled by similar environmental factors. Variation in the composition, production, and structure of upland forests exhibits a pattern which corresponds closely to the geomorphic surface on which the forests developed. Under homogeneous climatic conditions, landform and edaphic patterns provide an ultimate constraint on both pattern and process in forest ecosystems.

298. **Host GE and Isebrands JG 1994. An interregional validation of ECOPHYS, a growth process model of juvenile poplar clones. *Tree Physiology* 14: 933-945.**

Keywords: model ECOPHYS /intensive silviculture/plant height/growth /forest plantations/hybrids / interspecific hybridization/plant morphology/diameter /increment /growth models/ photosynthesis /Populus spp.

Abstract: Field data from poplar [*Populus* sp.] plantations in Michigan, Washington, and Wisconsin were used to validate ECOPHYS, a whole-tree growth process model for juvenile poplar. Five clones - *P. eugenei*, *P. tristis*, *P. ILL-005*, *P. HY 44-136* and *P. HY 11-11* - representing a range of morphological, phenological, and physiological characteristics were planted on the same date at the three sites. Height and diameter measurements were made monthly on 20 trees per clone, and intensive morphological measurements were made every two weeks on two trees per clone. Hourly solar radiation and temperature data were recorded at each site over the growing season. The model was run for each clone X site combination with the weather data and clonal parameters as inputs. A repeated measure ANOVA indicated that there were significant differences in height growth patterns among both clones and sites, as well as significant clone X site interactions. The model generally predicted height growth within a standard deviation of the field plantation means; three of the 15 clone X site simulations were significantly different from the plantation means. The median error between predicted and observed values was 5%. Evaluation of the clonal parameters showed that differences in photosynthetic rates, morphological attributes such as specific leaf area, and timing of budset were important factors leading to differences in growth.

299. **Host GE and Isebrands JG 1997. Modeling the effects of climatic extremes on early growth of poplar under short rotation intensive culture. U.S. For. Serv. General Technical Report NC-GTR-196, 7 pp.**

Keywords: climatic factors/climate /model ECOPHYS/hybrids /growth models/intensive silviculture /Populus spp.

Abstract: A simulation model (ECOPHYS) was used to assess the growth under different climatic conditions (data of 1988 and 1992) of 2 hybrids, *Populus* 'Eugeni' [*P. canadensis*] and *P. 'Tristis'* (*P. tristis* X *P. balsamifera*), under short rotation intensive silviculture in Wisconsin, USA.

300. **Host GE, Isebrands JG, Theseira GW, Kiniry JR, and Graham RL 1996. Temporal and spatial scaling from individual trees to plantations: a modeling strategy. *Biomass and Bioenergy* 11: 233-243.**

Keywords: scaling /intensive silviculture/forest plantations/increment /growth models /model ECOPHYS/hybrid poplar

Abstract: In order to effectively deploy short-rotation woody crop plantations for energy and fibre production at regional scales, biologically sound field-level models of plant growth are required. Individual tree growth process models have proved effective at predicting growth based on environmental driving variables, but in the past these models have been too complex to use at the plantation scale. This paper describes an object-oriented strategy for scaling ECOPHYS, an individual tree growth process model for hybrid poplar, to a plantation. Included in this strategy are methods of scaling from an individual shoot to a tree, from individual trees to a patch, and from patches to a plantation. In describing interactions among trees, both above- and below-

ground processes are considered. Finally, methods are described for integrating the plantation level ECOPHYS with EPIC, a field scale model of soil productivity and erosion used in regional assessments.

301. **Host GE and Pregitzer KS 1991. Ecological species groups for upland forest ecosystems of northwestern Lower Michigan. *Forest Ecology and Management* 43: 87-102.**

Keywords: Broadleaves /synecology /site factors/layer structure /herbaceous layer /moss /*Acer saccharum*/ *Fagus grandifolia*/*Quercus alba*/*Quercus rubra*/*Quercus velutina* /*Vaccinium angustifolium*/ *Tilia americana*/model TWINSPAN/herbaceous vegetation /*Desmodium* spp./ *Osmorhiza claytonii* /*Maianthemum canadense* /*Deschampsia flexuosa* /*Vaccinium angustifolium* /*Viburnum acerifolium*

Abstract: Multivariate classification and ordination methods were used to develop ecological species groups based on similarities in ground-flora composition and abundance patterns among 76 sample stands. Nine ecological species groups were identified using 48 herbaceous, woody and moss species. TWINSPAN (two-way indicator species analysis) classification produced six classes of stands: two dominated by northern broadleaves (sugar maple - *Acer saccharum*, basswood - *Tilia americana*, American beech - *Fagus grandifolia* and northern red oak - *Quercus rubra*) and four dominated by oaks (northern red, black and white oak - *Q. rubra*, *Q. velutina*, *Q. alba*). Distribution patterns typified by *Deschampsia flexuosa*, *Vaccinium angustifolium*, *Viburnum acerifolium* and *Desmodium* spp. were important in discriminating among oak stands, whereas patterns typical of *Osmorhiza claytonii* and *Maianthemum canadense* distinguished northern broadleaf stands. Species groups exhibited a wide range of ecological amplitudes, from highly specific associations with individual ecosystems to broad distributions across a range of site conditions. Within the geographic limits imposed by macroclimate and regional physiography, ecological species groups act to integrate site attributes and can simplify the process of mapping ecological land units.

302. **Host GE and Pregitzer KS 1992. Geomorphic influences on ground-flora and overstory composition in upland forests of northwestern lower Michigan. *Canadian Journal of Forest Research* 22: 1547-1555.**

Keywords: Broadleaves /Landforms /Stand characteristics/soil moisture/composition /Ground vegetation/geology /Synecology /layer structure/site factors/soil /*Acer saccharum*/*Quercus rubra*/*Tilia americana*/northern hardwoods

Abstract: Ground-flora and overstorey composition and abundance patterns in 76 upland forest stands were related to the glacial geomorphology of a five-county area in NW lower Michigan. Nine classes of landforms were identified based on parent material and surface configuration. Chi-squared analyses of standardized residuals indicated that spatial distribution patterns of the ground flora were significantly associated with glacial landform. Detrended correspondence analyses showed that specific overstorey-ground flora assemblages recur in characteristic landscape positions. The Interlobate Moraine, a predominant landform in the NE portion of the study area, was characterized by a northern hardwood canopy, primarily sugar maple (*Acer saccharum*), basswood (*Tilia americana*), and red oak (*Quercus rubra*), with herbaceous annuals, perennials, and ephemerals forming the ground flora. Other morainal and glaciofluvial landforms supported oak (*Quercus* spp.) overstories with a woody ericaceous or graminoid ground flora. Ground-flora and overstorey composition were highly correlated, indicating that they respond similarly to variation in environmental and historical factors. Moisture availability, as evidenced by soil texture and the presence of subsurface textural discontinuities, appeared to be a predominant factor influencing species distribution patterns. Since moisture availability and related nutrient dynamics are functions of depositional and postglacial history, it is concluded that regional-scale geomorphic patterns constrain forest composition in a probabilistic manner.

303. **Host GE, Pregitzer KS, Ramm CW, Hart JB, and Cleland DT 1987. Landform-mediated differences**

in successional pathways among upland forest ecosystems in northwestern Lower Michigan. *Forest Science* 33: 445-457.

Keywords: Succession /seral stages/site types/synecology /topography /site factors/soil /edaphic characteristics/Acer saccharum /Quercus spp. /Acer rubrum

Abstract: Stratified random sampling was used to sample the overstorey, understorey, ground flora and soils of 120 plots in 30 upland forest stands in the Manistee National Forest, Michigan. The patterns of compositional change were strongly related to topographic and edaphic differences between glacial landforms. Glaciofluvial landforms, currently dominated by oak, had relatively high densities of oak seedlings (4913 stems/ha) that seldom became saplings (10 stems/ha). Oak-dominated ecosystems on hilly ice-contact stratified drift had relatively high densities of red maple saplings (48 stems/ha). On extremely well drained outwash plains, sapling regeneration of any species was sparse in oak stands; red maple was typically absent and oak saplings appeared to be in decline. Differences in sapling recruitment between these ecosystems may be attributable to differences in fire history or site-dependent effects on the competitive abilities of species. Morainal landforms, currently supporting relatively diverse northern broadleaved overstories, showed little potential recruitment of any species other than sugar maple. The differences in composition and potential recruitment between ecosystems suggest that successional pathways vary with cover type and depend on landform, soil moisture and nutrient availability.

304. **Host GE, Pregitzer KS, Ramm CW, Lusch DP, and Cleland DT 1988. Variation in overstorey biomass among glacial landforms and ecological land units in northwestern Lower Michigan. *Canadian Journal of Forest Research* 18: 659-668.**

Keywords: Biomass /Synecology /site factors/soil /species diversity/topography /Land classification/ Site class assessment/ground vegetation/Acer saccharum/Quercus alba/Quercus rubra/Quercus velutina

Abstract: Spatial variation in overstorey biomass and mean annual biomass increment (MABI) of upland forests of the Manistee National Forest was studied for landform (scale 1:250 000-1:1 000 000) and ecological land units (1:10 000-1:80 000). Ecological land units (ecosystems) were defined by the ground flora, soil and physiography. Biomass estimates were based on allometric regression equations developed in the Lake States area. Analyses of covariance were used to study the patterns of total biomass and biomass increment among landforms and among ecosystems; stand age was used as the covariate. Overstorey biomass ranged from 105 t/ha (MABI 1.5 t/ha) on glacial outwash landforms to 208 t/ha (MABI 3.2 t/ha) on morainal landforms. Landform and ecosystem accounted for 37% and 60% of the total variation in biomass, respectively. Overstorey biomass in ecosystems ranged from 85 t/ha (MABI 1.3 t/ha) for oak-dominated (*Quercus alba*, *Q. velutina*) forests on xeric sandy outwash sediments to 249 t/ha (MABI 3.6 t/ha) for sugar maple/red oak (*Acer saccharum*/*Q. rubra*) forests on mesic moraines. Variation in biomass was strongly related to variation in species composition and soil moisture availability. A relatively strong association was found between ground flora and productivity. It is concluded that mapping ecological land units gives a relatively high degree of spatial resolution in the quantification of site productivity.

305. **Host GE, Rauscher HM, Isebrands JG, and Michael DA 1990. Validation of photosynthate production in ECOPHYS, an ecophysiological growth process model of *Populus*. *Tree Physiology* 7: 283-296.**

Keywords: Broadleaves /growth models/Photosynthesis /simulation /seedlings /model ECOPHYS /growth /hybrid poplars

Abstract: A model of photosynthate production is the central component of ECOPHYS, a whole-tree, ecophysiological, first year growth process model for *Populus*. This photosynthesis model was validated by comparing predicted photosynthate production values for individual leaves and

total tree with hourly field measurements collected from P. X euramericana cv. Eugenei [P. eugenei] growing near Rhinelander, Wisconsin. Simulated trees had the same numbers of leaves and leaf areas as sample trees studied in the field, and hourly weather data collected on the plantation site were supplied as a model input. Total production for the four sample days (3, 17 July; 15, 29 August) ranged from 200 to 4900 mg CO₂ per tree per day. Model predictions of total daily photosynthate production were within 12% of observed rates for three of the four sampling days. Diurnal variations in stomatal conductance and ambient CO₂ concentrations and seasonal variations in area leaf weight were the primary sources of error. Total leaf area, proportion of sunlit leaf area, and photosynthetic efficiency were the most important factors influencing carbon dioxide exchange rates.

306. **Hseu JS and Buongiorno J 1997. Financial performance of maple-birch stands in Wisconsin: value growth rate versus equivalent annual income. *Northern Journal of Applied Forestry* 14: 59-66.**

Keywords: growth rate/income /basal area/economics/forest inventories/site class assessment/increment /valuation /economic analysis/stumpage value/returns /Prunus serotina/ Fraxinus spp./Ulmus americana/Populus spp. /aspen /birch /Acer spp. /Quercus spp. /Betula spp.

Abstract: The value growth rate and equivalent annual income per acre were computed for the maple-birch [Acer-Betula] plots measured at the last two Wisconsin forest inventories. The computations reflected stand growth as well as real price changes between the two inventories. The equivalent annual income averaged \$13/acre on industrial forests, and \$8.50/acre on public and other private lands. Stand value growth rates, in percent per year, suggested much higher returns, but they are misleading because many of the stands that grew fast were understocked and gave low returns per acre. At the other extreme, some of the best stocked stands (highest basal area) also were poor financial performers. A regression equation showed that the stands of highest equivalent annual income were on better sites, had a basal area of about 80 ft²/acre, a large number of smaller poles ready to become sawtimber, large proportions of oak [Quercus], elm [Ulmus americana], ash [Fraxinus], and cherry [Prunus serotina] trees, and few aspen [Populus] or conifers. No single variable had a major effect by itself, but within the range of the data, by changing all of them together, the annual income on land of average site index could double.

307. **Huang FM and Buongiorno J 1986. Market value of timber when some offerings are not sold: implications for appraisal and demand analysis. *Forest Science* 32: 845-854.**

Keywords: Stumpage value/Simulation /model economics

Abstract: A theoretical model is developed of the market value of stumpage that would be applicable when a significant number of the tracts of timber offered in the past were not sold. The model yields successively the probability that an offering will be sold conditional on a certain appraised value, the expected high bid if the offering is sold and the unconditional market value. The model can also be used to estimate the demand schedule for timber from a forest. Results are given of applying the model to the Chequamegon National Forest, northern Wisconsin.

308. **Hunter AF 1991. Traits that distinguish outbreaking and nonoutbreaking Macrolepidoptera feeding on northern hardwood trees. *Oikos* 60: 275-282.**

Keywords: Outbreaks /Insect pests/Forest pests/biology /review /agricultural entomology/northern hardwoods

Abstract: The life cycle traits of outbreaking and nonoutbreaking species of Macrolepidoptera feeding on hardwood trees are compared on the basis of a literature survey. Nonoutbreaking and outbreaking species differed in several ways. The majority of outbreaking species either began feeding in the spring or were gregarious summer feeders. Diet breadth and fecundity of outbreaking species were greater, and outbreaking species also appeared to be better defended

against predators. There were no differences in size or number of generations per year. Spring feeding involved a risk of asynchrony with leaf emergence. Summer feeding species that outbreak were mostly colonial, and high between-colony variance in survival may cause fluctuations in population sizes.

309. **Hutchinson JG 1985. Northern hardwood notes. U.S. For. Serv. misc. publication.**

Keywords: Forest management/Vegetation types/broadleaved deciduous forests/northern hardwoods

Abstract: A collection of 48 looseleaf, illustrated notes, each 1-4 pages long, outlining the most critical concepts for even- or uneven-aged management of broadleaved forests in the Lake States. The notes are in sections: Northern hardwood forest; Silvicultural concepts and principles; Regeneration; Managing stands; Growth and yield; Economics; Damaging agents; and Wildlife habitat. Some notes include references.

310. **Hutchinson TC, Watmough SA, Sager EPS, and Karagatzides JD 1998. Effects of excess nitrogen deposition and soil acidification on sugar maple (*Acer saccharum*) in Ontario, Canada: an experimental study. *Canadian Journal of Forest Research* 28: 299-310.**

Keywords: nitrogen /acid deposition/soil leaching/acidification /decomposition /forest decline/deciduous forests/manganese /mycorrhizas /soil pH/symptoms /growth rings/zinc /forest health/plant composition/wood chemistry/plant nutrition/forest litter/magnesium /cadmium /arsenic /cobalt /chromium /nickel /sulfate /soil chemistry/forest soils/*Acer saccharum*

Abstract: The effect of an acidifying fertilizer (used to simulate acid deposition) on litter decomposition, root mycorrhizas, and soil and tree chemistry was assessed in two hardwood forests in central Ontario, Canada. Soil beneath mature sugar maple (*Acer saccharum*) trees was treated with (NH₄)₂SO₄ granules at application rates of 0, 250, 500, and 1000 kg/ha in May of each year during 1993-94 at Dorset and 1993-95 at Loring. The fertilizer treatments did not cause visual symptoms of forest decline. At Dorset, SO₄ and cation concentrations in soil leachate increased, but no difference in soil pH between treatments was found. An increase in foliar N was recorded at Dorset in treated plots, although there were no other differences in foliar or tree ring chemistry between treatments. At Loring, a decrease in soil pH and an increase in SO₄ in soil leachate were found in treated plots. Mycorrhizal infection and litter decomposition were also reduced in plots treated with (NH₄)₂SO₄. Fertilizer application at Loring led to increases in foliar concentrations of N, Mg, Mn, and Cd, along with increases in concentrations of trace metals (As, Co, Cr, Mn, Ni, and Zn) in tree rings formed during fertilizer application. Significant positive correlations (p<0.05) were found between wood (rings formed between 1993 and 1995) and foliage (mean of 1993-1995 values) for Mg, Mn, and Al. Deliberate acidification of surface soil resulted in changes in wood and foliar chemistry, although it remains to be established whether acidification of surface soil is responsible for the reported decline in sugar maple.

311. **Hutchinson TC, Watmough SA, Sager EPS, and Karagatzides JD 1999. The impact of simulated acid rain and fertilizer application on a mature sugar maple (*Acer saccharum* Marsh.) forest in central Ontario Canada. *Water, Air, and Soil Pollution* 109: 17-39.**

Keywords: acid rain/acid deposition/chromium /decomposition /forest litter/interactions /magnesium / mycorrhizas /nickel /nutrients /soil solution/zinc /fertilizers /effects /soil water/soil biology/soil chemistry/soil pH/calcium /wood chemistry/plant composition/pollution /*Acer saccharum*

Abstract: The effects of the addition of simulated acid precipitation, with and without added fertilizer, on mycorrhizas, litter decomposition and soil and tree chemistry in a mature stand dominated by sugar maple (*Acer saccharum*) in Ontario, Canada, were investigated. The forest floor beneath the sugar maple trees (plots were selected around individual healthy-looking trees of

diameter at breast height (d.b.h.) 25 to 35 cm) was irrigated at monthly intervals between May and September with local lake water acidified to pH 3, pH 4 or untreated lake water of pH 4.9. In addition, a commercial organic slow-release fertilizer (Maple Gro) was added to the soil prior to irrigation with pH 3 spray. Trees to which no experimental spray was applied were also included as controls. Eight trees were used for each of the five treatments; the study lasted two years. Application of the acid spray alone did not acidify surface soil nor cause visible decline symptoms in trees. The pH of the soil solution and soil leachate was increased by addition of acidified lake water. An increase in the concentration of sulphate (SO₄²⁻), calcium (Ca), and magnesium (Mg) in soil leachate was only recorded in plots irrigated with water acidified to pH 3 + Maple Gro. The initial rate of litter decomposition tended to be higher following application of the acid sprays, although mycorrhizal infection of sugar maple roots was reduced in the pH 3 and pH 4 treatments. Concentrations of zinc (Zn), chromium (Cr) and nickel (Ni) were highest in wood formed during the period irrigated with water acidified to pH 3. Foliar nitrogen (N) concentrations tended to be higher in all irrigated treatments, although there were no differences between treatment in any of the other nutrients measured in foliage after two years of treatment. It is concluded that the application of simulated acid rain under field conditions results in a complex interaction of events which are not reproduced in pot trials and must be fully understood before the impact of acid rain on sugar maple forests can be evaluated.

312. Isebrands JG, Guenther AB, Harley P, Helmig D, Klinger L, Vierling L, Zimmerman P, and Geron C 1999. Volatile Organic Compound Emission Rates From Mixed Deciduous and Coniferous Forests in Northern Wisconsin, USA. *Atmospheric Environment* 33: 2527-2536.

Keywords: Tropospheric Ozone/Quercus spp./Rubus spp./Populus spp./Picea spp./Salix spp./Isoprene/Monoterpene/VOC/Isoprene Emission/Rate Variability/Ozone Pollution/ Sensitivity/Fluxes/Leaves/model VOC/Leaf/Quercus rubra/Tilia americana /hybrid poplar/Picea mariana /Alnus spp. /hybrid poplar /hybrid spruce /Rubus spp. /Populus tremuloides /Sphagnum

Abstract: Biogenic emissions of volatile organic compounds (VOC) from forests play an important role in regulating the atmospheric trace gas composition including global tropospheric ozone concentrations. However, more information is needed on VOC emission rates from different forest regions of the world to understand regional and global impacts and to implement possible mitigation strategies. The mixed deciduous and coniferous forests of northern Wisconsin, USA, were predicted to have significant VOC emission rates because they are comprised of many genera (i.e. Picea, Populus, Quercus, Salix) known to be high VOC emitters. In July 1993, a study was conducted on the Chequamegon National Forest near Rhinelander, WI, to identify and quantify VOC emitted from major trees, shrubs, and understory herbs in the mixed northern forests of this region. Emission rates were measured at various scales - at the leaf level with cuvettes, the branch level with branch enclosures, the canopy level with a tower based system, and the landscape level with a tethered balloon air sampling system. Area-average emission rates were estimated by scaling, using biomass densities and species composition along transects representative of the study site. Isoprene (C₅H₈) was the primary VOC emitted, although significant quantities of monoterpenes (C₁₀H₁₆) were also emitted. The highest emission rates of isoprene (at 30 degrees C and photosynthetically active radiation of 1000 $\mu\text{mol m}^{-2} \text{s}^{-1}$) were from northern red oak (Quercus rubra, > 110 $\mu\text{g(C)g}^{-1} \text{h}^{-1}$); aspen (Populus tremuloides, > 77); willow (Salix spp., > 54); and black spruce (Picea mariana, > 10). Emission rates of hybrid poplar clones ranged from 40 to 90 $\mu\text{g(C)g}^{-1} \text{h}^{-1}$ at 25 degrees C; those of Picea provenances were generally <10, and emission rates of a hybrid between North American and European spruces were intermediate to parental rates. More than 30 species of plants were surveyed from the sites, including several from previously unstudied genera such as Alnus, Chamaedaphne, Ledum, Tilia, Rubus, and Sphagnum. Based on the measured isoprene concentrations in the daytime atmospheric surface layer and mixed layer, area-averaged fluxes of isoprene were estimated to be about 1 $\text{mg(C)m}^{-2} \text{h}^{-1}$. This estimate agrees reasonably well with model predictions. Our results indicate that mixed forests in the Lake States region of the USA are a significant source of reactive VOC to the atmosphere. Accurate estimates of these emissions are required for determining appropriate regulatory air pollution control strategies. Future studies are needed to extrapolate these estimates

to other landscapes and to better understand the factors controlling observed variations in VOC emissions.

313. **Iseman TM, Zak DR, Holmes WE, and Merrill AG 1999. Revegetation and Nitrate Leaching From Lake States Northern Hardwood Forests Following Harvest. *Soil Science Society of America Journal* 63: 1424-1429.**

Keywords: Whole-Tree Harvest/Nitrogen Mineralization/*Rubus idaeus*/Pin Cherry/soil leaching/Nitrification/Ecosystems/Recovery/Losses/Mechanisms/*Acer saccharum*/*Quercus rubra*/*Tilia americana*/ northern hardwoods

Abstract: The sugar maple (*Acer saccharum* Marshall)-red oak (*Quercus rubra* L.) and sugar maple-basswood (*Tilia americana* L.) ecosystems are Lake States forests that differ in net nitrification (5 and 15 g N m⁻² yr⁻¹), respectively), but experience equivalent rates of NO₃⁻ leaching following clear-cut harvest (approximate to 5 g N m⁻² yr⁻¹). Our objectives were to determine whether high rates of N leaching are sustained following harvest and whether ecosystem-specific patterns of biomass accumulation influence NO₃⁻ loss. We studied two stands in each ecosystem and established four research plots in each stand; two plots were clear-cut in 1991 and two were controls. In 1996, we measured soil solution NO₃⁻ concentration (1-m depth) and calculated areal losses by a mater balance method. We used allometric equations to estimate woody biomass in clear-cut plots; herbaceous biomass was clipped. In the sugar maple-red oak ecosystem, NO₃⁻ leaching from 5-yr-old clear-cut plots (0.56 g N m⁻² yr⁻¹), significantly greater than leaching from control plots (0.05 g N m⁻² yr⁻¹). In contrast, NO₃⁻ leaching did not differ between control (0.41 g N m⁻² yr⁻¹) and 5-yr-old clear-cut (0.02 g N m⁻² yr⁻¹) in the sugar maple-basswood ecosystem; however, loss from these clear-cut plots was significantly lower than that from clear-cut sugar maple-red oak plots. Five years after harvest, 7.1 Mg ha⁻¹ of aboveground biomass accumulated in clear-cut sugar maple-basswood plots, almost twice that of clear-cut sugar maple-red oak plots (3.9 Mg ha⁻¹). Five years after harvest, the highest rates of NO₃⁻ loss occurred in the sugar maple-red oak ecosystem, in which aboveground biomass accumulation was least.

314. **Jackson RB, Mooney HA, and Schulze ED 1997. A Global Budget for Fine Root Biomass, Surface Area, and Nutrient Contents. *Proceedings of the National Academy of Sciences of the United States of America* 94: 7362-7366.**

Keywords: northern hardwoods /Net Primary Production/Nitrogen Availability/Litter Decomposition/ Spatial- Distribution/Tallgrass Prairie/Amazonian Forests/Growth Dynamics/Organic Matter/root production

Abstract: Global biogeochemical models have improved dramatically in the last decade in their representation of the biosphere. Although leaf area data are an important input to such models and are readily available globally, global root distributions for modeling water and nutrient uptake and carbon cycling have not been available. This analysis provides global distributions for fine root biomass, length, and surface area with depth in the soil, and global estimates of nutrient pools in fine roots. Calculated root surface area is almost always greater than leaf area, more than an order of magnitude so in grasslands. The average C:N:P ratio in living fine roots is 450:11:1, and global fine root carbon is more than 5% of all carbon contained in the atmosphere. Assuming conservatively that fine roots turn over once per year, they represent 33% of global annual net primary productivity.

315. **Jacobs RD 1974. Damage to northern hardwood reproduction during removal of shelterwood overstory. *Journal of Forestry* 72: 654-656.**

Keywords: natural regeneration/advance growth/felling /shelterwood /logging /damage /silvicultural systems/ *Acer saccharum*/*Tilia americana*/*Fraxinus americana*/*Betula alleghaniensis*/*Tsuga canadensis*/northern hardwoods

Abstract: Describes the effects of a two-stage shelterwood felling on advance growth in NE Wisconsin. The shelterwood comprised mainly *Acer saccharum*, *Tsuga canadensis*, *Tilia americana* and *Betula alleghaniensis*. Advance growth was enumerated in sample quadrats before, immediately after, and 3 years after the final felling; it was composed mainly of *A. saccharum* and *Fraxinus americana*. Logging disturbance and slash accumulation were light in more than one-third of the quadrats, severe in about a quarter and moderate in the remaining quadrats; ca. 35% of advance growth >0.6 ft tall was destroyed, but all quadrats were stocked (at least 26 000 stems/acre). Three years after the final felling, 93% of quadrats were stocked with stems more than or equal to 3.6 ft and 73% with stems more than or equal to 6.6 ft tall.

316. **Jacobs RD 1969. Growth and development of deer-browsed Sugar Maple seedlings. *Journal of Forestry* 67: 870-874.**

Keywords: *Acer saccharum*/Animal damage/Browsing damage/Deer browsing damage/Deer/Mammals damage/northern hardwoods/Odocoileus virginianus/competition

Abstract: In a study on a 20-acre mature hardwood stand in N.E. Wisconsin, selectively felled to b.a. of 80 sq.ft. two years before, height growth and development of *Acer saccharum* were found not to be adversely affected by severe winter browsing (clipping of terminal leaders) by deer over a critical 5-year period, provided that the environment was otherwise kept favourable to vigorous height growth, i.e. by release from overhead competition. Seedling mortality was attributed to a combination of browsing and competition. Results are compared with those of similar studies [cf. F.A. 28 No. 4107].

317. **Jacobs RD 1965. Seasonal height growth patterns of Sugar Maple, Yellow Birch, and Red Maple seedlings in Upper Michigan. U.S. For. Serv. Research Note LS-57, 4 pp.**

Keywords: *Acer rubrum* /*Acer saccharum* /*Betula alleghaniensis* /plant ecology/Phenology height growth/Reproductive behaviour/Seedlings phenology

Abstract: Presents graphed data from weekly measurements on 50 natural seedlings of each species, mostly 1-3 ft. tall, during 1959 and 1960.

318. **Jacobs RD 1966. A silvicultural evaluation of four methods of marking second-growth northern hardwood stands. U.S. For. Serv. Research Note NC-1, 4 pp.**

Keywords: Silviculture /Tending of stands and trees/Thinnings basal area control/Thinnings marking for/northern hardwoods

Abstract: Compares four methods of marking or designating trees to be felled or left in the first commercial thinning, aiming at a residual b.a. of 80 sq. ft./acre: (1) paint-marking the trees to be removed; (2) designating for cutting all trees larger than the minimum d.b.h. required to leave 80 sq. ft. of b.a.; (3) setting a d.b.h. limit as in (2) and also paint-marking good growing stock to be left; and (4) setting a d.b.h. limit from below with good growing stock marked to be left. It is concluded that (1) is the only justifiable method if the aim is production of high-quality sawlogs.

319. **Jacobs RD 1960. Top-dying of Yellow Birch, Upper Michigan 1955-59. U.S. For. Serv. Lake St. For. Exp. Sta. Technical Note LS-585, 2 pp.**

Keywords: *Betula alleghaniensis*/dieback/forest protection/Waterlogging /damage/water table/hydrology

Abstract: [Cf. F.A. 20 No. 832.] The % of top-dying trees reached a new peak in 1959 after two years of improvement. Tabulated observations support earlier conclusions that top-dying is related to stand density, the % of injured trees being greatest in heavily cut and least in uncut stands. The

cause of top-dying is still undetermined. A prolonged high water-table was again noted in spring 1959 and observation of water-table levels is being continued.

320. **Johnson JA 1959. A test of the effectiveness of sodium arsenite impregnated paper strips in killing Aspen and northern hardwoods. Ford Forestry Center (Michigan Technological University) Technical Bulletin No. 2, 3 pp.**

Keywords: *Acer saccharum* /Ploughing /Poisoning of trees/*Populus tremuloides* /Silviculture /*Tilia* spp. /*Ulmus* spp. /Weedkillers /sodium arsenite/northern hardwoods

Abstract: Experiments were made to determine the effectiveness of strips or tabs of paper impregnated with Na arsenite, inserted under the bark, in killing Sugar Maple, Aspen, Basswood, and Elm. Data are given on % crown kill and on time and cost of application. [Cf. F.A. 18 No. 2848.]

321. **Johnson JA, Arola RA, and Miyata ES 1982. Recovery of residue tops in selectively cut northern hardwood stands. U.S. For. Serv. Research Paper NC-217, 9 pp.**

Keywords: Logging /residual damage /economics /Wood chips/production /Logging machines/ feller bunchers/northern hardwoods

Abstract: A preliminary study was made in Michigan of a prototype topwood shearing device developed by the USDA Forest Service that can sever and bunch branches up to 12 inches in diam. Bunched tops were either (a) skidded directly to the landing, or (b) accumulated at intermediate points before skidding to landing; a chain saw operator was stationed at the landing to sever any remaining branches or stubs that hindered chipping. The shear was mounted on a Gafner series mini-skidder (as carrier), skidding was with a Clark Ranger 667 GS Grapple Skidder, and chipping with a Morbark 22-inch XL Chiparvestor. Production costs per green ton of chips were (for 100% utilization) \$16.41 in (a) and \$10.04 in (b); ways of reducing costs are discussed. Damage to residual trees was considered acceptable at 7%, compared with the 15% already incurred during the conventional selective logging.

322. **Johnson JA, Hillstrom WA, Miyata ES, and Shetron SG 1979. Strip selection method of mechanized thinning in northern hardwood pole size stands. Ford Forestry Center (Michigan Technological University) Research Note No. 27, 13 pp.**

Keywords: soil physics/compaction /thinning /mechanization /types /utilization /logging machines/ feller bunchers/logging /soil /damage /northern hardwoods

Abstract: Trials were made in northern Michigan of a mechanized thinning method in which a tracked 6-m-reach Drott 40 LC feller/buncher moved along 15-ft-wide clear felled strips thinning selectively and remotely within 40-ft-wide leave areas between the strips. Thinning was from 26.6 m²/ha to a residual 12.6 m²/ha b.a., yielding 193 t/ha of whole-tree chips. Harvesting costs were \$8.64/t (1978 prices), which compared well with \$8.48/t in a 1974 study in which a rubber-tyred feller/buncher moved through the leave areas [see FPA 2, 42]. Some 13% of residual trees had 'minor' damage (less than 50 square inches of sapwood exposed) and 19% had greater damage. Preliminary studies on compaction and other effects on soil indicated the need to maintain sufficient litter cover in the strips and to minimize the number of passes made during harvesting.

323. **Johnson JA and Willis GL 1975. Estimating form class in standing trees. Ford Forestry Center (Michigan Technological University) Research Note No. 14, 6 pp.**

Keywords: stems /form factors/*Acer saccharum*/*Acer rubrum* /*Tilia americana* /*Fraxinus nigra*/*Ulmus* spp./*Betula alleghaniensis*/northern hardwoods

Abstract: Reports a study of the applicability to six northern hardwood species in Michigan of

Judson's formula for estimating form class in the southern USA [see FA 27, 1019]. A single negative correction factor was found to be satisfactory for *Acer saccharum*, *A. rubrum*, *Betula alleghaniensis*, *Ulmus* sp. and *Fraxinus nigra*, and another, rather larger, negative correction factor for *Tilia americana*.

324. **Johnson JE, Haag CL, Bockheim JG, and Erdmann GG 1987. Soil-site relationships and soil characteristics associated with even-aged red maple (*Acer rubrum*) stands in Wisconsin and Michigan. *Forest Ecology and Management* 21: 75-89.**

Keywords: Site class assessment/stem form/soil moisture /equations /soil chemistry/nutrients /soil fertility/broadleaves /*Acer rubrum*

Abstract: Site productivity (measured by site index and total biomass production) for 60 sites was related to soil physical parameters through stepwise regression. Both site index and total biomass production were predicted from regression equations based on physical soil properties which were generally related to presence of a water table, presence of clay in the profile, and overall profile and spodic horizon development. Three soil productivity groups were recognized based upon soil parent material and drainage, with mean site indices, mean annual biomass increments, and total biomass production, respectively, for each group as follows: (I) 18.9 m, 3.6 t/ha, 222 t/ha, (II) 17.6 m, 3.4 t/ha, 220 t/ha; and (III) 14.9 m, 2.8 t/ha, 184 t/ha. Group I soils were generally lacustrine and moderately well-drained glacial till soils; Group II soils were glacial till and wet glacial outwash soils; and Group III soils were dry outwash and poorly drained glacial till soils. The largest forest floor nutrient pool was associated with Group I soils. While soil nutrient pools displayed greater variability, Group I soils had most N and K, Group II soils had most Ca and Mg, and Group III soils had most P.

325. **Johnson PS 1992. Oak overstory/reproduction relations in two xeric ecosystems in Michigan. *Forest Ecology and Management* 48: 233-248.**

Keywords: Broadleaves /Natural regeneration/advance growth/stand characteristics/*Quercus alba*/*Quercus rubra*/*Quercus ellipsoidalis*/*Quercus velutina* /*Vaccinium*/*Carex pensylvanica*

Abstract: Deficiency in oak regeneration potential is often a problem in the eastern USA; following clearfelling, *Carex pensylvanica* often competitively displaces advance growth and other woody plants to form *Carex* glades. In a study of oak regeneration in west central Lower Michigan, average reproduction density of oaks in the northern pin oak (*Quercus ellipsoidalis*)/black oak (*Q. velutina*)/*Deschampsia* ecosystem was approximately half that of the slightly less xeric black oak/white oak (*Q. alba*)/*Vaccinium* ecosystem. However, when variation in total overstorey basal area and basal area of large oaks (i.e. white oaks ≥ 30 cm diameter at breast height (d.b.h.) and black oaks ≥ 36 cm d.b.h.) was accounted for, reproduction density of white oak and the black oak species-group (black, northern red (*Q. rubra*), and northern pin oaks) did not differ significantly ($P > 0.05$) between ecosystems. High white oak reproduction density was associated with low stand basal area and high basal area of white oaks of ≥ 30 cm d.b.h. In contrast, high black oak reproduction density was associated with high overstorey basal area and high basal area of black oaks of ≥ 36 cm d.b.h. In both ecosystems, height of the tallest stem of oak reproduction per 5.5 m² plot increased with decreasing overstorey density for both white and black oaks. For a given overstorey density, frequency of occurrence of all size classes of oak reproduction was greater in the black oak/white oak/*Vaccinium* ecosystem than in the pin oak/black oak/*Deschampsia* ecosystem. Silvicultural prescriptions for oak regeneration include maintaining a low to moderate overstorey density (e.g. 30-60% of stocking) by frequent thinning from below, thus encouraging recruitment in the 2-4 cm diameter class, and maximizing reproduction density by retaining large-diameter seed producers, especially white oak.

326. **Johnson PS and Jacobs RD 1981. Northern red oak regeneration after preherbicide clearcutting and shelterwood removal cutting. U.S. For. Serv. Research Paper NC-202, 5 pp.**

Keywords: natural regeneration/silvicultural systems/coppice /herbicides /2,4,5 T/clear felling/
shelterwood /advance growth/broadleaves /*Quercus rubra*

Abstract: Red oak seedlings and young sprouts were inventoried in 1979 in two shelterwood stands in SW Wisconsin that had undergone final removal fellings (a) in 1968 or (b) in 1974, and (c) in a stand treated with 2,4,5-T (for understory removal) during the 2 yr prior to clear felling in 1974. Stocking in (a) and (b) was respectively 506 and 804 stems/acre (most >5 ft tall), with 316 'unit growing spaces' (of 1/735 acre) occupied per acre in both. Stocking in (c) was 2872 stems/acre (most <5 ft tall) with 617 spaces occupied per acre. Results suggest more favourable conditions for seedling establishment in (c) than in (b) felled in the same yr, but the paucity of oaks over 5 ft tall in (c) suggests that advance growth was either absent or eliminated by herbicide. Advance growth alone gave insufficient stocking in (a) and (b), though oak sprouts and other growing stock such as *Carya ovata* could compensate for this. Poor development of oak seedlings in (a) following a large acorn crop in 1973 suggests that shelterwood conditions are not ideal for oak advance growth. The large well-distributed stocking in (c) suggests better conditions for adequate regeneration, though such success probably depends on coinciding with a good acorn crop as occurred in 1973.

327. **Johnson PS, Jacobs RD, Martin AJ, and Godel ED 1989. Regenerating northern red oak: three successful case histories. *Northern Journal of Applied Forestry* 6: 174-178.**

Keywords: Natural regeneration/advance growth/*Quercus rubra* /herbicide treatments

Abstract: This report documents the histories and presents status of 3 young northern red oak [*Quercus rubra*] stands in SW Wisconsin, USA. Two of the stands, one 11 and one 17 yr old, originated from 2 variations of the shelterwood system; the third, an 11-yr-old stand, originated from a clearcut treated with herbicide before final harvest. Of the 3, the herbicide-treated clearcut had the greatest stocking of red oak (nearly 1000 stems/acre 1 inch d.b.h and larger); the 2 shelterwoods averaged less than half that number. Nevertheless, each stand is currently stocked with enough red oak to dominate the stand eventually. The abundance of red oak in the herbicide-treated clearcut suggests that the key to regenerating red oak may be competition control and not necessarily a long regeneration period.

328. **Johnson PS and Rogers RS 1985. A method for estimating the contribution of planted hardwoods to future stocking. *Forest Science* 31: 883-891.**

Keywords: Stand characteristics/simulation /spacing /mortality /artificial regeneration

Abstract: Logistic regression analysis was used to estimate success probabilities (P) in relation to site quality, competition and planting area, as a method for determining the contributions of planted trees on forest sites. Data was obtained from the 16 yr performance of six broadleaved species on 2 sites in Wisconsin. Success probability was defined as the probability that an individual planted tree, if it survives 16 yr, will equal or exceed a specified relative ht. Estimates of (P) can be used to determine the number of planted trees required to obtain one successful tree and the future % stocking.

329. **Jones EA, Reed DD, Mroz GD, Liechty HO, and Cattelino PJ 1993. Climate stress as a precursor to forest decline: paper birch in northern Michigan, 1985-1990. *Canadian Journal of Forest Research* 23: 229-233.**

Keywords: Broadleaves /Forest decline/Wood borers/damage /increment /insect pests/
Temperature /Plant water relations/water stress/climate /*Betula papyrifera* /bronze birch borer
/*Agrilus anxius*

Abstract: Widespread paper birch (*Betula papyrifera*) mortality associated with the activity of the bronze birch borer (*Agrilus anxius*) was observed across N. Michigan in 1991. This mortality

occurred at two study sites on which paper birch growth has been intensively monitored since 1985. Recent warmer than normal growing seasons and lower than normal moisture availability are statistically associated with a reduction in annual diameter growth. On one study site 62% of the paper birch study trees were dead and 13% were visibly declining; on the other study site, although no trees were dead, 25% of the trees were visibly declining. Growth reductions since 1985 suggest that the species was under climatic stress, making it more vulnerable to pest-pathogen activity. The evidence of the role of climatic conditions acting as a precursor to decline and mortality on these sites is of serious concern given recent projections of warmer temperatures and lower precipitation for this region by several global-climate models.

330. **Jurik TW 1986. Seasonal patterns of leaf photosynthetic capacity in successional northern hardwood tree species. *American Journal of Botany* 73: 131-138.**

Keywords: Photosynthesis /seasonal variation/light /gas exchange/Acer saccharum/Acer rubrum /Fagus grandifolia/Quercus rubra/Populus grandidentata/northern hardwoods

Abstract: Gas exchange of single attached leaves was monitored in natural habitats at 2 sites at the University of Michigan Biological Station, near Pellston. Leaves of *Populus grandidentata* and *Quercus rubra* at the top of the canopy had higher max. CO₂ exchange rate (CER) than leaves of *Acer saccharum*, *A. rubrum*, *Q. rubra* and *Fagus grandifolia* in the understorey. In all leaves, CER measured at light-saturation increased to max. near the completion of leaf expansion in early June, was constant until mid Sep. and then declined rapidly until leaf death. A similar pattern was seen for CER measured at low light intensity. Rate of dark respiration was highest in young leaves and decreased during leaf expansion to a constant rate for the rest of leaf lifespan. The initial slope of the light response curve (CER vs. photosynthetic photon flux density) in summer was less for species in the understorey than for species in the canopy. Leaf conductance was constant during most of leaf lifespan, with some decline in autumn. Leaves at the top of the canopy had higher conductances for water vapour than understorey leaves. All species maintained leaf intercellular CO₂ mole fractions near 200 µl/litre until autumn, when increases occurred during leaf senescence.

331. **Jurik TW 1986. Temporal and spatial patterns of specific leaf weight in successional northern hardwood tree species. *American Journal of Botany* 73: 1088-1092.**

Keywords: Foliage /measurement /seasonal behaviour/light /broadleaves /specific leaf weight/Acer rubrum/Acer saccharum /Fagus grandifolia/Quercus rubra/Populus tremuloides /Populus grandidentata/Betula papyrifera/northern hardwoods

Abstract: Diurnal and seasonal patterns of specific leaf wt. (SLW) were measured on deciduous tree species in the understorey and the canopy at 5 sites at the University of Michigan Biological Station, near Pellston. *Populus grandidentata* dominated the canopy at all sites, with *Acer rubrum* and *Quercus rubra* as important canopy species. *Betula papyrifera* and *P. tremuloides* were occasionally present in the canopy. No significant diurnal changes in SLW were found. SLW decreased during leaf expansion then increased for several wk after expansion ceased. Most species, especially those in the understorey, then had relatively constant SLW for most of the growing season until a decline in autumn. Leaves in shade had smaller SLW than leaves in sun. SLW was also negatively influenced by soil fertility. Max CO₂ exchange rate increased with SLW. *P. grandidentata*, definitely an early successional species, had the highest photosynthetic capacity, though its SLW was not as high as that of *Q. rubra*. With this exception SLW was a good indicator of photosynthetic capacity and of relative ability to adapt to shade, with *Q. rubra*, *A. rubrum*, *A. saccharum* and *Fagus grandifolia* having successively lower SLW. This order corresponds to that traditionally assigned for successional status and shade tolerance.

332. **Jurik TW, Briggs GM, and Gates DM 1985. A comparison of four methods for determining leaf area index in successional hardwood forests. *Canadian Journal of Forest Research* 15: 1154-1158.**

Keywords: Foliage /measurement /northern hardwoods/leaf area index

Abstract: In studies in three successional mixed broadleaved forests in northern lower Michigan, direct harvests gave values for leaf area index ranging from 1.4 to 3.6. Estimates of leaf area index derived from litter fall data were consistently higher and a visual method using sightings through a tube gave values consistently lower (by 27-42%) than the harvest values. Calculations of leaf area index based on regressions of leaf mass versus tree diam. gave results very close to the harvest values for each site as a whole; calculations for smaller plots were more variable. The harvest method allowed measurement of the vertical distribution of leaf area; the other methods could not do so.

333. **Jurik TW, Weber JA, and Gates DM 1988. Effects of temperature and light on photosynthesis of dominant species of a northern hardwood forest. *Botanical Gazette* 149: 203-208.**

Keywords: Photosynthesis /light /temperature /Vegetation types/broadleaved deciduous forests/temperate zones/environment /Light intensity/Quercus rubra/Populus grandidentata/Betula papyrifera/northern hardwoods

Abstract: The response of CO₂ exchange rate (CER) to temperature and light was determined for 14 dominant species at 2 sites in broadleaved forest in northern lower Michigan. Leaves at the top of the canopy had temp. optima near 25°C for CER while leaves in the understorey had optima near 20°. Opt. temp. did not change during the growing season and the overall shapes of the response curves were similar for all species. It is suggested that the lack of change in temp. optima may be a result of little change in growing conditions rather than an inability to acclimatize. Only 2 of 12 species in the understorey had significant differences in light-saturated max. CER; at the top of the canopy, Populus grandidentata had a higher max. CER than Quercus rubra and Betula papyrifera. Understorey species generally had similar light-saturation points. Species at the top of the canopy had higher values for max. CER, light-saturation point and max. leaf conductance than species in the understorey.

334. **Kamdem DP and Chow P 1999. The Effect of Pressure on Retention and Bending Properties of Copper Naphthenate and CCA Type C Treated Hardwoods. *Wood and Fiber Science* 31: 128-135.**

Keywords: CCA/Cu-N (Copper naphthenate) /Retention/wood products/Pressure Treatment/Bending/Acer saccharum/Acer rubrum /Fagus grandifolia/Quercus rubra/northern hardwoods

Abstract: The objective of this study was to investigate the effect of the pressure level on retention and bending strength of same northern hardwood species after preservative treatment. Samples of red maple, sugar maple, beech, and red oak were pressure- treated with waterborne chromated copper arsenic (CCA) type C or with oilborne copper naphthenate (Cu-N) at four pressure levels: 0.69, 1.03, 1.38, 2.07, and 2.76 MPa. At a pressure level of 0.69 MPa (200 psi) for 2 hr retentions of 4.5 kg/m³ elemental copper from copper naphthenate and 10 +/- 7 kg/m³ total oxides from chromated copper arsenate (CCA) were achieved for maples. The pressure level did not affect the retention of Cu-N in red maple, sugar maple, and red oak: the same observation was made for CCA in maples. A pressure level of 2.76 MPa was needed to obtain a 7.5 kg/m³ CCA retention and 1.08 kg/m³ copper metal in Cu-N-treated beech. Copper naphthenate treatment did not affect the bending strength. while CCA-treated samples exhibited a reduced bending strength between 0 and 33% depending on the species, pressure level, and preservative type.

335. **Kamensky SA and Erdmann GG 1973. Diaporthe outbreak in Yellow Birch seedlings. *Plant Disease Reporter* 57: 230-233.**

Keywords: plant pathology/fungi/soil drainage/Betula alleghaniensis / Diaporthe alleghaniensis

Abstract: Cankering caused by *Diaporthe alleghaniensis* on *Betula alleghaniensis* [cf. FA 29, 4137] caused considerable damage in 8-year-old seedlings in Upper Michigan between 1968 and 1971. The trees studied had been released from tree and brush competition in the spring of 1968. Infection and mortality were greater on poorly drained sites and increased significantly from dominant to codominant to intermediate seedlings regardless of site condition. Unusually wet springs followed by dry summers seem to be factors predisposing trees to infection. On poorly drained sites, release appears to increase infection and mortality; on well drained sites, however, there were indications that release improved both diameter growth and rate of healing of the cankers.

336. **Kaya I 1987. *Economic management of uneven-aged forest stands under risk*. PhD dissertation, University of Wisconsin, Madison. 270 pp.**

Keywords: northern hardwoods /economics /market price /model economic

Abstract: A method is presented to determine economic management policies for uneven-aged stands, taking into account uncertain stand growth and prices. The method used a transition matrix giving the probability of a stand and market state in five years, given the current stand and market state. Stand states were defined by the basal area of trees in three timber sizes. Market states depended on whether timber prices were high, low or average. The transition probabilities were computed by simulation, using a stochastic model of northern hardwoods, and the probability distribution of prices in Wisconsin. A method of successive approximations was used to find the harvesting policy that would maximize the expected net discounted value of returns from a stand over an infinite horizon. The solution also gave the expected stand value, including land. The best management policy prescribed a specific harvest for each possible stand and market state. The expected stand value of northern hardwoods, under the best harvest policy, varied from \$134 per acre for stands with little timber of any kind when prices were low, to \$832 per acre for stands with much large sawtimber when prices were high, in 1967 dollars and at 3 percent interest. The expected cutting cycle was about 8 years. Other things being equal, the best policy and the expected cutting cycle changed only slightly when the interest rate was changed from 3 to 5 percent. The same was true when fixed harvesting costs were changed from 0 to 25 dollars per acre. Simultaneous changes in the interest rate and fixed costs changed the optimal policy and the expected stand values considerably. With the state variables defined in this study, the optimal policy and corresponding stand values were not very sensitive to changes in the transition probability matrix. The harvest policy obtained with the Markovian model was compared by simulation to those suggested by two deterministic models for northern hardwood management. The Markovian model led to higher net present values under similar conditions.

337. **Kaya I and Buongiorno J 1987. *Economic harvesting of uneven-aged northern hardwood stands under risk: a Markovian decision model*. *Forest Science* 33: 889-907.**

Keywords: Forest management/economics /model economic /northern hardwoods

Abstract: A method of determining economic management strategies for uneven-aged stands is presented that considers the uncertainty of future stand growth and product prices. The method uses a transition matrix to give the probability of stand and market conditions 5 yr in the future, given current conditions. Stand conditions were defined by the b.a. of trees in 3 timber sizes and market conditions were defined by timber prices. The transition probabilities were computed by simulation, using a stochastic model of northern broadleaved trees and the probability distribution of prices in Wisconsin. A method of successive approximations was used to determine the best harvesting policy and the corresponding stand value. The results consisted of a table showing the best decision for each possible stand and market condition. The expected cutting cycle and growing stock for an optimum policy are derived. The effects of interest rates, fixed harvesting costs and transition probabilities on the best policy, forest value and expected cutting cycle are discussed briefly.

338. **Kaya I and Buongiorno J 1989. A harvesting guide for uneven-aged northern hardwood stands. *Northern Journal of Applied Forestry* 6: 9-14.**

Keywords: Silvicultural systems/selective felling/Felling /planning /northern hardwoods

Abstract: A description of a felling guide for North American broadleaf stands, and a discussion of applications of the guide. Potential for increasing returns from selectively felled stands is illustrated. The guide defines stand state by b.a./acre of pole timber, small sawmill timber, and large sawtimber. Each stand is considered every 5 yr: for a given stand state and price level, the guide suggests either doing nothing, or cutting the stand into another state. The guide maximizes net present value of returns over an infinite horizon. Stand values obtained by applying the guide are much higher than those yielded by the traditional Lake States marking guide, and are generally superior to those obtained with a deterministic optimization model.

339. **Kelty MJ and Cameron IR 1994. Ecological principles of production differences between monocultures and mixtures. In Pinto da Costa ME, Preuhler T (eds.) Mixed stands: research plots, measurements and results, models. Proceedings from the Symposium of the IUFRO Working Groups S4.01, Lousa-Coimbra, Portugal.**

Keywords: forest ecology/forest plantations/monoculture /experimental design

340. **Kelty MJ and Cameron IR 1995. Plot designs for the analysis of species interactions in mixed stands. *Commonwealth Forestry Review* 74: 322-332, 386, 388.**

Keywords: choice of species/silviculture /plant competition/planting /patterns /forest plantations/interactions /research /experimental design

Abstract: Interest in the silviculture of mixed-species stands has grown rapidly throughout the world in recent years, particularly in regions where mixtures serve as an alternative to the widespread use of monoculture plantations. A considerable need exists for establishing experiments that can guide the selection of species and silvicultural treatment of mixtures. The analysis of species interactions, of both the complementary and facilitative types, is one goal of such studies. Two basic experimental approaches exist for studying species interactions in mixtures: (1) post-level studies of the additive and substitutive designs, and (2) individual-tree studies of the neighbourhood design. The principles of each approach are reviewed, as are their strengths and limitations for use in forestry experiments. A planting arrangement is proposed that allows both kinds of analysis to be conducted using one set of plots.

341. **Kernik LK and Grigal DF 1985. Soil and stand characteristics and elemental concentration of tall shrub twigs. *Soil Science Society of America Journal* 49: 1023-1027.**

Keywords: Conifers /soil fertility/plant composition/responses /Indicator plants/Understorey /Soil physics/soil texture /Stand characteristics/age /composition /wood chemistry/magnesium /magnesium/potassium/zinc /calcium /iron /potassium /Soil types/management /Synecology /Pinus resinosa

Abstract: Woody twigs (≥ 3 mm diam) of tall shrubs were collected during winter in 18 forest stands in the Superior National Forest of north-eastern Minnesota. Elemental concentration of the twigs was examined with respect to variation due to site characteristics including vegetation type, soil properties, management history, and stand age. The stands ranged from young *Pinus resinosa* plantations to natural pine and hardwood stands to lowland conifer stands on organic soils. Levels of most elements in twigs were not significantly related to soil properties. Twigs from stands on organic soils were higher in Mg and Zn concentration than were twigs from the stands on mineral soils, and Ca was lower in twigs on soils with coarser texture. Although significant differences were found in elemental concentrations of Ca, Mg, Zn, Fe, and Mn among stands classified by vegetation type, these differences were small among the upland stands. There were no differences

in concentration related to differences in site preparation; K, Ca, and Zn varied with method of release of plantations. Stand age did not appear to have a major influence on elemental concentration, but twigs in younger stands had higher K and lower Fe concentrations than did twigs in older stands. Two consistent trends emerged from the analysis, those of differences in K associated with stand development. The relatively small size of the study area, 185 km², may have led to few differences.

342. **Kershaw HMH 1993. Early successional processes of eastern white pine and red pine in the Great Lakes-St. Lawrence forest. Ontario Forest Research Institute, Forest Fragmentation and Biodiversity Project Report No. 8, 50 pp.**

Keywords: natural regeneration/autecology /plant succession/reviews /stand establishment/Pinus strobus/Pinus resinosa

Abstract: This report reviews the literature relating to red pine (*Pinus resinosa*) and eastern white pine (*Pinus strobus*) succession in the Great Lakes-St. Lawrence Forest from establishment to age fifty. Research areas included (1) red and white pine autecology, (2) early red and white pine establishment and survival, (3) post-disturbance natural successional patterns and (4) the effect of past and current management practices on early red and white pine survival and establishment. Post-fire and post-harvest plant community development, seedbed requirements, and conditions that favour early growth are well documented in the literature. Early successional red pine communities develop on xeric, competition free shallow till and deep coarse sandy sites when disturbance coincides with a good seed crop. White pine forms a component of early successional communities under a broader spectrum of conditions. It successfully establishes on moderately dry to fresh coarse loamy till soils of variable depth under low to moderate competition. Detailed information for Ontario was very limited. The effectiveness of natural regeneration prescriptions for establishing red and white has not been well documented.

343. **Kershaw HMH 1993. Natural establishment and early growth of eastern white pine and red pine in the Great Lakes-St. Lawrence forest: an annotated bibliography. Ontario Forest Research Institute, Forest Fragmentation and Biodiversity Project Report No. 10, 66 pp.**

Keywords: bibliographies /natural regeneration/seedlings /establishment /forest fires/silviculture /growth /wildlife /insect pests/forest pests/plant diseases/plant pathogens/forest ecology/autecology /Pinus strobus/Pinus resinosa

Abstract: The annotated bibliography of natural establishment and early growth of eastern white pine (*Pinus strobus*) and red pine (*P. resinosa*) is arranged in 7 broad subject categories: regeneration; soils; wildlife (including insect pests and diseases); fire; ecology; management; and succession.

344. **Kim CS, Sharik TL, Jurgensen MF, Dickson RE, and Buckley DS 1996. Effects of nitrogen availability on northern red oak seedling growth in oak and pine stands in northern lower Michigan. *Canadian Journal of Forest Research* 26: 1103-1111.**

Keywords: nitrogen /use efficiency/mineralization /plant nutrition/clear felling/silviculture /understorey /natural regeneration/forest soils/seedlings /canopy /soil chemistry/*Quercus rubra*/*Pinus resinosa*

Abstract: The nitrogen status and dry weight increment of northern red oak (*Quercus rubra*) seedlings in relation to N availability were examined at various levels of canopy cover (100, 75, 25 or 0% cover) and understorey removal treatments (control, and removal of litter, shrub or herbaceous layer) under field conditions in red oak and red pine (*Pinus resinosa*) stands in Crawford and Roscommon counties, northern Lower Michigan. Net N mineralization rates over two growing seasons (1991-92) following canopy cover treatments were determined by the in situ buried bag technique. Canopy removal increased N mineralization in both oak and pine stands.

Net N mineralization rates were ~1.2-2.2 times higher in the clearcut and other partial canopy cover treatments than in the uncut stands. Net N mineralization in the same canopy cover treatments was ~2-3 times higher in red oak stands than in red pine stands. However, red oak seedlings from the same canopy cover treatments in both stand types had similar dry weight, N concentrations, N content, and N-use efficiency despite differences in soil N availability. The only exception was ~2 times greater seedling dry weight and N content in the red oak clearcuts compared with the red pine clearcuts. The similarity in seedling performance within partial canopy removal or uncut stands may have been due to limiting factors other than N in the red oak stands. Red oak seedlings from litter removal treatments within the clearcuts had significantly higher N-use efficiency than those from the herb and shrub removal treatments. These results suggest that (i) canopy manipulation increases soil N availability; (ii) increases in dry weight and N uptake by red oak seedlings when forest canopies are completely removed are due, in part, to increased available soil N; and (iii) red oak seedling response to soil N availability resulting from no or only partial canopy removal may be the same in different stand types because factors other than N, such as light, are limiting.

345. **Kobe RK 1996. Intraspecific variation in sapling mortality and growth predicts geographic variation in forest composition. *Ecological Monographs* 66: 181-201.**

Keywords: landscape ecology/mortality /variation /stand development/increment /growth /site types/simulation models/light intensity/vegetation types/deciduous forests/stand characteristics/botanical composition/geographical variation/mineralogy /rocks /calcareous rocks/gneiss /model SORTIE /minerals /soil /soil parent materials/Acer saccharum/Fagus grandifolia/Fraxinus americana/ Pinus strobus/Tsuga canadensis/northern hardwoods

Abstract: With a view toward understanding variation in species composition among different forest communities, species-specific growth and mortality of juvenile trees (2.3-78 mm diameter at 10 cm above the ground) were studied in northern hardwood forests at three contrasting sites. Two sites differing in soil mineralogy and altitude (schist/gneiss uplands vs. calcareous bedrock valley) were situated in northwestern Connecticut, while the third site was in central-western Michigan. Among the three sites, the deciduous species American beech (*Fagus grandifolia*), white ash (*Fraxinus americana*) and sugar maple (*Acer saccharum*) showed little intraspecific variation in models of relative radial growth rate as a function of light availability. Strikingly, a substantial component of the variation in radial growth at the Michigan site could be explained by sampling growth models originally calibrated for the Connecticut sites. In contrast to the deciduous species, the evergreen species white pine (*Pinus strobus*) and eastern hemlock (*Tsuga canadensis*) exhibited significant intraspecific differences in growth models between the two Connecticut sites. Community dynamics at each of the sites were simulated with a model, SORTIE, which incorporated observed differences in sapling mortality and growth functions between the sites. The model showed that among-site differences in only juvenile survivorship and growth were sufficient to predict dominant species in the adult stand, demonstrating the importance of sapling stages to community dynamics.

346. **Kobe RK 1995. *Scaling from individuals to forest communities and landscapes with models of juvenile tree growth and mortality*. PhD dissertation, University of Connecticut, Storrs. 278 pp.**

Keywords: *Fagus grandifolia*/*Fraxinus americana*/northern hardwoods /model SORTIE /forest dynamics /sapling growth

Abstract: To understand and predict forest dynamics at community and landscape scales, I calibrated individual-based, resource-dependent, species-specific models of sapling growth and mortality for temperate and tropical forests. At a whole-plant physiology scale, I found stored carbohydrates and low-light survivorship of saplings were positively correlated across four temperate tree species. A theoretical model provides an explanation: allocation to storage can enhance survivorship by buffering stresses (e.g. defoliation) while constraining plant size and associated respiratory and maintenance costs. Variation in carbon balance (reflected in growth) is

scaled to individual survivorship and community-level dynamics of Connecticut oak-transition northern hardwood forests. Mortality models as a function of recent growth show continuous interspecific variation; white ash exhibits two orders of magnitude higher mortality under suppressed growth than American beech. A spatially explicit forest dynamics model (SORTIE) demonstrates that interspecific differences substantially influence community dynamics and composition. Trade-offs among species in low-light survivorship versus high-light growth provides a simple generalization of community dynamics. Landscape-level distribution of forest communities is predicted from site- and species-specific models of sapling mortality and light-dependent growth. Models were calibrated for similar species sets for a west-central Michigan and two Connecticut sites on contrasting soil types. Intraspecific variation in performance among sites directly affects site variation in canopy composition and interactions of species (e.g. competition), causing further compositional variation. Deciduous species varied among sites in mortality but not growth, and conifers in only growth. This dichotomy may simplify scaling from individuals to larger spatial scales. To understand tropical forest dynamics and maintenance of tree species diversity, I modelled light-dependent mortality and growth for four tree species at La Selva Biological Station, Costa Rica. Significant interspecific differences in performance indicate tropical tree diversity is partly maintained by species specialization on light. These studies demonstrate that mechanistic, individual-based models of plant performance can be scaled to make community predictions about succession, distribution of vegetation, and maintenance of diversity.

347. **Kobe RK, Pacala SW, Silander JA Jr., and Canham CD 1995. Juvenile tree survivorship as a component of shade tolerance. *Ecological Applications* 5: 517-532.**

Keywords: growth /mortality /shade /tolerance /population dynamics/soil pH/soil chemistry/nutrient availability/survival /stand development/light /vegetation types/deciduous forests/Acer saccharum/Acer rubrum /Fagus grandifolia/Prunus serotina/Quercus alba/Quercus rubra/Fraxinus americana/Pinus strobus/Betula alleghaniensis/Tsuga canadensis/northern hardwoods

Abstract: Juvenile survivorship was characterized for 10 dominant tree species (Acer saccharum, A. rubrum, Betula alleghaniensis, Fagus grandifolia, Fraxinus americana, Pinus strobus, Prunus serotina, Quercus alba, Q. rubra and Tsuga canadensis) of oak transition-northern hardwood forests using species-specific mathematical models. The mortality models predict the probability of a sapling dying as a function of its recent growth history; together with growth functions, these models can then characterize shade tolerance. Descriptions are given of the statistical bases and field methods used to calibrate the mortality models. Inter- and intra-specific variation in juvenile mortality was studied on 2 sites in Connecticut and 1 site in Michigan of varying soil pH and nutrient content. The 10 tree species occupied a continuum of survivorship levels at 1% of full sun. Differences in survivorship between sites were correlated with soil pH. Growth rates in high-light and survivorship in low-light were inversely correlated across species. The results indicate that interspecific differences in sapling mortality are critical components of forest community dynamics.

348. **Kolbe AE, Buongiorno J, and Vasievich M 1999. Geographic Extension of an Uneven-Aged, Multi-Species Matrix Growth Model for Northern Hardwood Forests. *Ecological Modelling* 121: 235-253.**

Keywords: Growth/Model growth/Forest Ecosystems/Ecological Diversity/Statistics/Tree Diversity/Transition Matrix/Economic Returns/Management/Stands/Income/Land/northern hardwoods

Abstract: The objective of this study was to update and extend the geographic range of a forest growth model for northern hardwoods, developed previously with data from the fourth Wisconsin inventory (Lin et al., 1996. *Ecol. Model.*, 91: 193- 211.). To this end, Lin's model was recalibrated with data from the recent fifth inventory of Wisconsin and Michigan, and with the addition of a site variable to reflect variations in land productivity. After the introduction of site effects, there

were still statistically significant differences between the equations of ingrowth, upgrowth, and mortality for Wisconsin and Michigan. Thus, two models were maintained, one for each state. Each model predicted well the growth of trees on post- sample plots, and simulated adequately the tree distribution in old stands in its own state. Applied to stands of the same initial distribution of tree species and size, the equations predicted faster early growth and higher basal area in the steady state in Michigan than in Wisconsin, with more marked differences on good than poor sites.

349. **Krefting LW 1975. The effect of white-tailed deer and snowshoe hare browsing on trees and shrubs in northern Minnesota. Minnesota Agricultural Experiment Station Technical Bulletin No. 302, 43 pp.**

Keywords: browse /wild animals/deer /Lepus americanus /snowshoe hare /Odocoileus virginianus

Abstract: Results are reported of trials conducted in 21 exclosures in the forest zone of N. Minnesota in 1950-74 on the effects of browsing by white-tailed deer (*Odocoileus virginianus*) and snowshoe hare (*Lepus americanus*) on planted conifers, natural conifer regeneration, swamp forest vegetation, forest openings and burned-over areas. The overall effect of deer and hare browsing was generally dependent on forest cover type, site quality, species composition, age and rate of growth of vegetation, browse preference, tolerance to browsing and the ability of each plant species to respond to root competition and shade from dominant trees in the stand. Deer and hare browsing had a significant effect, however, at only 3 of the 21 sites; at 2 plantation exclosures and 1 mixed-conifer swamp exclosure, browsing produced seedling mortality and caused a reduction in diameter and height of tree species, but the effect on the vegetation was short-term.

350. **Kruger EL 1992. Survival, growth and ecophysiology of northern red oak (*Quercus rubra* L.) and competing tree regeneration in response to fire and related disturbance. PhD dissertation, University of Wisconsin, Madison. 215 pp.**

Keywords: *Acer saccharum*/*Quercus rubra*/*Fraxinus americana* /restoration /competition /growth rate /oak reestablishment /fire /population dynamics/controlled burning/increment /height /population density/fire ecology/forest ecology/relative growth rate/leaf area ratio

Abstract: I examined the potential role of fire in the reestablishment of northern red oak (*Quercus rubra* L.) on productive forest sites by monitoring the response of red oak and competing tree regeneration to repeated burning in mesic forest openings in southwestern Wisconsin. In separate experiments I also studied the response of red oak seedlings to top-kill (stem destruction), a common consequence of fire. Measures of plant response to fire and top-kill included survival, height and biomass growth, leaf gas exchange, and whole-plant water, carbohydrate and nitrogen relations. In general, fire appeared to enhance the competitive status of northern red oak regeneration on mesic sites. Repeated spring surface fires had little impact on oak survival, growth and ecophysiology in mesic forest openings. However, fire adversely affected the survival and growth of several of oak's competitors on mesic sites, including sugar maple (*Acer saccharum* Marsh.) and white ash (*Fraxinus americana* L.). There was evidence that the deleterious impact of fire on several species may have been related primarily to the action of top-kill. In contrast, oak was little affected by top-kill, and in separate studies it was found to fully compensate in terms of biomass for initial stem loss through slightly increased growth rates. The differential effects of fire on biomass growth of oak, ash and maple were attributed to fire-induced changes in two co-determinants of relative growth rate (RGR), leaf area ratio (LAR) and leaf photosynthetic rate. Fire stimulated photosynthesis but reduced LAR for maple. For ash and oak, fire increased LAR and had a modest positive influence on photosynthesis. Treatment and species differences in RGR were associated primarily with variation in leaf area ratio (LAR), as the two were significantly and positively correlated. The influences of fire on leaf photosynthesis and LAR may have been interrelated, in that fire appeared to stimulate leaf photosynthesis via an increase in root:leaf ratio. The increase in root:leaf ratio was thought to result from a fire-induced decrease in the production of leaf area. Studies on oak indicated that top-kill could in certain instances reduce subsequent canopy size, and in turn alter leaf photosynthetic performance through changes in root-leaf

balance.

351. **Kruger EL and Reich PB 1993. Coppicing alters ecophysiology of *Quercus rubra* saplings in Wisconsin forest openings. *Physiologia Plantarum* 89: 741-750.**

Keywords: coppicing /hydraulic conductivity/photosynthesis /stomatal resistance/gas exchange/ plant water relations/coppice /plant physiology/*Quercus rubra*

Abstract: In the spring of 1987, entire shoots were removed from *Quercus rubra* saplings in two forest openings in SW Wisconsin. Shoots possessed newly expanding leaves at the time of coppicing. All coppiced individuals sprouted from dormant stem buds near the root collar. Leaf gas exchange and water potential were monitored on these sprouts and on untreated (control) *Q. rubra* saplings throughout several clear warm days during the 1987 growing season. Daily maxima and averages for sprout leaf photosynthesis and stomatal conductance generally exceeded those of controls. On average, treatment differences in daily maximum photosynthetic rate were modest (11-14%) and were attributed primarily to a 30-38% enhancement of sprout leaf stomatal conductance. Relative differences in daily average photosynthetic rate (29-39%) were substantially larger than those in daily maximum photosynthesis, owing to the fact that sprouts and controls exhibited distinct diurnal gas exchange patterns. Photosynthetic rate and stomatal conductance of control leaves typically declined during the day following a mid-morning maximum. Sprout leaves tended to maintain gas exchange rates nearer to their morning maxima throughout the day. This difference in diurnal gas exchange pattern was associated with an apparent differential leaf sensitivity to leaf-to-air vapour pressure gradient (VPG). The relative decline in sprout leaf gas exchange rates with increasing VPG was less than that of controls. Treatment differences in gas exchange did not appear to be related to leaf water potential or tissue water relations, but sprouts had a higher soil-to-leaf hydraulic conductivity than controls.

352. **Kruger EL and Reich PB 1997. Responses of hardwood regeneration to fire in mesic forest openings. I. Post-fire community dynamics. *Canadian Journal of Forest Research* 27: 1822-1831.**

Keywords: responses /natural regeneration/fire /population dynamics/advance growth/controlled burning/deciduous forests/increment /height /population density/leaf area index/fire ecology/forest ecology/survival /plant competition/botanical composition/ground vegetation/*Acer saccharum*/*Quercus rubra* /*Ostrya virginiana* /*Carya cordiformis*

Abstract: The influence of fire on the regeneration ecology of northern red oak (*Quercus rubra*) and sympatric tree species was examined in mesic hardwood stands in southwestern Wisconsin. A plot in each of four openings was burned in the spring of 1989 and 1990. Density and height growth of tree regeneration, and leaf area index and percent cover of all plant growth forms were monitored on burned and unburned plots in both years. Tree height growth was also measured in 1991. Fire substantially decreased tree regeneration density, and grasses and sedges became the most abundant vegetation on burned plots. Post-fire survival varied among the commonest tree species. Densities of *Acer saccharum* and *Ostrya virginiana* decreased by more than 80%, while those of *Q. rubra* and *Carya cordiformis* increased or were unaffected. Net 2-year height growth decreased by 65% or more on burned plots for all of the common tree species except *Q. rubra* and *C. cordiformis*, which experienced losses of 25-35%. The differential effects of fire on species survival and growth enhanced the competitive status of *Q. rubra*. In the absence of fire, it was uncertain whether *Q. rubra* would maintain a dominant or codominant position in the canopy of these developing stands.

353. **Kruger EL and Reich PB 1997. Responses of hardwood regeneration to fire in mesic forest openings. II. Leaf gas exchange, nitrogen concentration, and water status. *Canadian Journal of Forest Research* 27: 1832-1840.**

Keywords: gas exchange/natural regeneration/fire /nitrogen /concentration /advance growth/ controlled burning/foliar chemistry/plant water relations/water potential/deciduous forests/

photosynthesis /stomatal movement/leaves /soil moisture/forest soils/Acer saccharum/Quercus rubra/Fraxinus americana

Abstract: Gas exchange, nitrogen concentration, and water potential were monitored on foliage of burned and unburned regeneration of northern red oak (*Quercus rubra*), white ash (*Fraxinus americana*), and sugar maple (*Acer saccharum*) following spring fires in 1989 and 1990 in a mesic hardwood forest in southwestern Wisconsin. Fire led to a stimulation of light-saturated photosynthesis in foliage of resprouting plants, but the effect varied in magnitude among species. On average, photosynthesis of post-fire maple was 42% higher than that on unburned plots, with corresponding increases occurring in stomatal conductance and leaf N concentration. In general, fire had a marginal effect on leaf properties of oak and ash. In 1990, the ratio of root area to leaf area and the water potential of sunlit foliage were significantly higher on burned than unburned plots for maple, but not for oak or ash, paralleling trends in photosynthesis. There was little evidence of a treatment difference in soil moisture or nitrogen availability, and it appeared that fire-induced stimulations in photosynthesis were mediated primarily by changes in intrinsic (e.g., root area/leaf area ratio) as opposed to extrinsic (e.g., soil moisture) factors governing resource availability to the canopy of post-fire sprouts.

354. **Kruger EL and Reich PB 1997. Responses of hardwood regeneration to fire in mesic forest openings. III. Whole-plant growth, biomass distribution, and nitrogen and carbohydrate relations. *Canadian Journal of Forest Research* 27: 1841-1850.**

Keywords: natural regeneration/fire /growth /biomass /nitrogen /carbohydrates /controlled burning/ advance growth/seedlings /leaves /plant morphology/plant composition/chemical composition/ growth rate/increment /Acer saccharum/Quercus rubra/Fraxinus americana

Abstract: The effects of fire on the carbon and nitrogen balance of northern red oak (*Quercus rubra*), white ash (*Fraxinus americana*), and sugar maple (*Acer saccharum*) regeneration were studied in mesic openings in a hardwood forest in southwestern Wisconsin. A plot in each of four openings was burned in the spring of both 1989 and 1990. Relative growth rate, leaf weight ratio, and concentrations of nonstructural carbohydrate and N were monitored on planted and extant regeneration in burned and unburned plots. In the absence of fire, extant oak grew as rapidly as ash and maple, but the relative growth rate of planted oak was the lowest of any species or regeneration type. Repeated burning had little effect on the net growth of oak, but it decreased that of ash and maple by 24-85%. Fire effects on relative growth rate were mediated primarily by changes in leaf weight ratio, but the causes underlying these changes were not fully elucidated. They were not consistent with trends in plant nonstructural carbohydrate or N concentration, which increased or remained unaffected after fire in all species. In general, oak possessed a number of characteristics, such as a high root starch concentration and an abundance of below-ground dormant buds, which appeared to contribute to its post-fire vigour.

355. **Kruger EL, Volin JC, and Lindroth RL 1998. Influences of atmospheric CO₂ enrichment on the responses of sugar maple and trembling aspen to defoliation. *New Phytologist* 140: 85-94.**

Keywords: defoliation /growth /photosynthesis /carbon dioxide enrichment/responses /atmosphere /canopy /effects /relative growth rate/specific leaf area/light penetration/plant morphology/ Acer saccharum/Populus tremuloides

Abstract: Impacts of defoliation on the growth and physiology of sugar maple (*Acer saccharum*) and trembling aspen (*Populus tremuloides*) were examined in ambient and CO₂-enriched atmospheres. Saplings were grown for 70 d in controlled environments, wherein CO₂ mole fractions averaged either 356 or 645 $\mu\text{mol mol}^{-1}$, under a PPF of 500 $\mu\text{mol m}^{-2} \text{s}^{-1}$. On day 49 of the study, 50% of the leaf area was removed from a subset of each species in both CO₂ environments. Relative growth rate (RGR) and its physiological and morphological determinants were monitored before and after defoliation. For non-defoliated saplings of both species, a slight stimulation of RGR (c. 5%) in increased CO₂ led to a modest increase (9-11%) in final sapling

weight. In the case of maple, the minimal growth response corresponded with minor CO₂ effects on specific leaf area (SLA) and leaf weight ratio (LWR), and an apparent CO₂-induced down-regulation of photosynthetic metabolism. For aspen, the CO₂ stimulation of photosynthesis was largely offset by a decrease in SLA. Responses to defoliation differed markedly between species and CO₂ environments. Defoliation decreased maple RGR in ambient CO₂, whereas the opposite occurred in increased CO₂. The latter led to complete recovery of plant weight (compensation), and was attributed to a defoliation-induced increase in carbon allocation to new leaves, along with a reversal of photosynthetic CO₂ acclimatization in that foliage. In both environments, aspen RGR increased after defoliation, facilitating almost full compensation. Defoliation increased light penetration into the aspen canopy, and it was estimated that the resultant stimulation of photosynthesis in lower leaves would have more than offset the concomitant decrease in LWR. CO₂ enrichment might substantially enhance the ability of certain tree species to recover from herbivory. Moreover, responses to increased CO₂ might be largest in the presence of stresses, such as herbivory, that decrease plant source:sink ratios.

356. **Kuuseoks E, Liechty HO, Reed DD, and Dong J 1997. Relating Site-Specific Weather Data to Regional Monitoring Networks in the Lake States. *Forest Science* 42: 447-452.**

Keywords: Ecosystem Monitoring/Climate/Ecophysiology/CO₂-Induced Climate Change

Abstract: Meteorological variables most frequently used in ecological studies include, or are derived from, daily precipitation and air temperature. In many studies, weather data from the nearest permanent weather station are used as surrogates for on-site measurements. This study discusses the problems with this approach and illustrates methods for developing regression equations for calculating site-specific daily minimum, average, and maximum temperatures, and precipitation amount from regional monitoring information. Meteorological data were collected at four sites along a 650 km climatic gradient from Houghton County (47 degrees N, 89 degrees W) to Oceana County (43 degrees N, 86 degrees W), Michigan. Data from several National Oceanic and Atmospheric Administration (NOAA) stations within 40 km of each study site were related to measurements made at each site. Predictive ability was improved by using information from more than one NOAA station to predict on-site temperature. No increase in predictive ability resulted from including information from more than a single station when predicting precipitation. For the majority of the sites and climate variables, the best relationships were not obtained by using the nearest NOAA station; variables such as the relative distance from large bodies of water or elevation appeared to be influential. Since distance between two locations is rarely the most important factor governing the relationship between their climates, the use of the nearest weather station is not the best method to describe weather conditions on specific sites of interest.

357. **Lai YZ, Sajdak RL, Mroz GD, Jurgensen MF, and Schwandt DL 1980. Wood and bark specific gravity determination as affected by water-soluble extractives loss. *Wood Science* 13: 47-49.**

Keywords: wood density/measurement /bark /wood mechanical properties/wood physical properties/ *Acer rubrum*/*Acer saccharum*/coppicing

Abstract: The loss of cold water extractives during density determination was measured for 3- to 6-yr-old coppice shoots and 35- to 50-yr-old trees of sugar maple (*Acer saccharum*) and red maple (*Acer rubrum*). Av. loss of soluble extractives from bark was 12.14 and 21.56% for young sugar maple and red maple respectively, and could cause significant errors in density measurements. Losses from wood, of both species, were negligible.

358. **Lai YZ, Sajdak RL, Mroz GD, Jurgensen MF, Schwandt DL, and Steinhilb HM 1979. Properties of hardwood sprouts and seedlings. *Tappi* 62: 84-85.**

Keywords: silvicultural systems/coppice /artificial regeneration/energy resources/wood properties/growth factors/broadleaves /*Acer saccharum*/*Fraxinus americana*

Abstract: Sprouts [coppice shoots] and seedlings of sugar maple (*Acer saccharum*) and white ash (*Fraxinus americana*) were compared for m.c., density, and calorific value. Calorific values were about the same but sprouts were lower in density and higher in m.c. than seedlings, so that the apparent value for energy plantations of rapid sprout growth may be largely negated. Prepared by IPC.

359. Lane CJ, Reed DD, Mroz GD, and Liechty HO 1993. Width of sugar maple (*Acer saccharum*) tree rings as affected by climate. *Canadian Journal of Forest Research* 23: 2370-2375.

Keywords: climate /temperature /precipitation /growth rings/forest decline/acid deposition/increment /diameter /dendroclimatology /*Acer saccharum*

Abstract: The effects of climate on the growth of sugar maple (*Acer saccharum*) were studied at 5 sites along an 800-km acidic deposition gradient from Cook County, Minnesota to Oceana County, Michigan. Fifty increment cores were taken from 25 dominant and codominant individuals at each site in spring 1990. Annual ring widths (1940-1989) were measured to 0.01 mm, standardized by taking the first logarithmic differences, and averaged into chronologies using the biweight mean. The 5 resulting chronologies were then related to climate using least squares regression techniques. The analyses indicated that temperature is associated with sugar maple growth to a greater degree than precipitation, though there were differences in the relations among the 5 study sites. Growth was also significantly affected by conditions in the previous growing season. No evidence of an overall decline or increase in sugar maple growth rates was observed over the 50-year study period.

360. Lantagne DO, Ramm CW, and Dickmann DI 1990. Tree shelters increase heights of planted oaks in a Michigan clearcut. *Northern Journal of Applied Forestry* 7: 24-26.

Keywords: Tree guards/planting stock/protection /*Acer rubrum*/*Prunus serotina*/ *Quercus rubra* /*Cornus* spp./competition/site preparation /prescribed burning/herbicide /natural regeneration

Abstract: A shelterwood felling in 1954 failed to provide adequate oak regeneration on an upland site in southern Michigan. The resultant mixed broadleaf stand dominated by dogwood [*Cornus* sp.], red maple [*Acer rubrum*], black cherry [*Prunus serotina*] etc. was clear-felled in 1986 and northern red oak [*Quercus rubra*] 2+0 seedlings planted in April 1987. Treatments included: control; woody brush control (herbicide pre- and post-planting, and prescribed fire before planting); plastic tree guards (20X48X0.25 inches corrugated plastic sheets stapled to stakes); and brush control plus tree guards. Measurements of regeneration were made during 1988 and the height of planted oaks was recorded in autumn 1987 and 1988. Oaks in tree guards were 42% taller after 2 growing seasons than unsheltered seedlings; competition from woody weeds was not significant during this period.

361. LaRoque G 1985. Regeneration in a tolerant hardwood stand managed under single-tree selection. *Petawawa Natl. For. Inst. (Canada) Info. Rep. No. PI-X-50*, 16 pp.

Keywords: Silvicultural systems/selection cut /Natural regeneration/logging /assessment /broadleaves /*Acer rubrum*/*Fagus grandifolia*/*Tilia americana*

Abstract: Regeneration was assessed to determine whether different treatments within the single tree selection method (residual vol.: 140 and 210 m³/ha; max. diam.: 40 and 50 cm; cutting cycle: 5 and 10 yr) carried out in a stand at the Petawawa Forestry Institute, Ontario have an effect on seedling density and distribution. Analysis showed that interactions of treatments are more important than each individually. It was found that the highest number of established seedlings can be obtained with the combination of: residual vol. 140 m³/ha, max. diam. 40 cm, and cutting cycle 5 yr. The distribution of seedlings was found to be influenced only by the residual vol.; best results were with 140 m³/ha. The regeneration was mainly of sugar maple. Beech (*Fagus grandifolia*), red maple (*Acer rubrum*) and basswood (*Tilia americana*) were found at lower densities and 10 other

species sparsely.

362. **Leacock PR 1997. *Diversity of ectomycorrhizal fungi in Minnesota's ancient and younger stands of red pine and northern hardwood-conifer forests.* PhD dissertation, University of Minnesota, Twin Cities. 96 pp.**

Keywords: Pinus resinosa/northern hardwoods /ectomycorrhizae /Russula silvicola /Lactarius thejogalus /Laccaria laccata /Cortinarius spp. /forest age /soil pH /soil organic matter /productivity /old growth

Abstract: Remnant ancient forests were investigated to examine the magnitude of the ectomycorrhizal fungal communities, integral components of forest ecosystems. Quantitative data were obtained for these fungi in red pine and northern hardwood-conifer forests in northern Minnesota, using dispersed, circular, 4-m² sampling areas along permanent transects in half hectare plots. Basal areas of woody plants were measured for the plots, and soil organic matter and pH were determined. Diversity, species frequencies, and fruitbody densities were examined in ancient and younger stands. The red pine forest, with a major conifer component, harbored a larger community of ectomycorrhizal fungi with two to three times more species, and abundance an order of magnitude greater than that observed for northern hardwood-conifer forest. Differences were found in species composition between the two age classes. Some species characterized old-growth and others, mature red pine forest. Russulaceae were major components in, and included the most abundant taxon of each forest: Russula silvicola for red pine forest, and Lactarius thejogalus for northern hardwood-conifer forest. Laccaria laccata, the second most frequent species, had higher densities in old-growth stands of both forest types. Cortinarius was a dominant genus in the red pine forest with an unknown number of species. By comparison all but a few northern hardwood-conifer forest species were infrequent or rare, and a smaller percentage of species were shared among plots. Even though frequency and diversity were similar or less than in younger forest, old-growth stands of both forest types had greater total fruitbody density: 1.1 times greater for red pine and a significant 1.8 times greater for northern hardwood-conifer forest. Greater productivity in these two old-growth forests may be an important factor in ecosystem function. The hypothesis that fungal diversity declines with advanced forest age is not supported by the findings of this study where species diversity and abundance are maintained in these old-growth stands.

363. **Lederle KA and Mroz GD 1991. Nutrient status of bracken (*Pteridium aquilinum*) following whole-tree harvesting in Upper Michigan. *Forest Ecology and Management* 40: 119-130.**

Keywords: Cycling /logging effects/Soil fertility/Clear felling/ecology /nutrients /potassium/ phosphorus/magnesium/Populus tremuloides/Betula papyrifera /bracken /Pteridium aquilinum

Abstract: Mineral nutrient status and biomass production of bracken fronds and rhizomes were quantified immediately following whole-tree harvest of aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera*) in Upper Michigan. Sampling monitored mineral translocation from fronds to rhizomes, as well as differences in bracken mineral content between harvested and unharvested control sites. Bracken rhizomes on the harvested site had significantly higher concentrations of phosphorus, potassium and magnesium than the control site. Frond biomass production was lower on the harvested site, while rhizome biomass production showed no differences between sites. Translocation of mineral elements from the fronds to the rhizomes during senescence was monitored : nitrogen, P, and K were readily translocated, while Mg and calcium were not. The larger amounts of nutrients present in the rhizomes on the harvested site suggest increased nutrient uptake and, therefore, that nutrient conservation by bracken may occur on a harvested site. For nutrient-poor sites where bracken is present, spring harvesting (rather than late summer) is recommended, which would limit damage to bracken and thus encourage nutrient conservation.

364. **Lessard VC, Reed DD, and Monkevich N 1994. Comparing N-tree distance sampling with point and**

plot sampling in northern Michigan forest types. *Northern Journal of Applied Forestry* 11: 12-16.

Keywords: forest plantations/sample plot technique/volume determination/basal area/volume /stand characteristics/merchantable volume/forest economics/costs /techniques /forest inventories/sampling methodology /*Acer saccharum*/*Populus tremuloides*/*Pinus resinosa*/northern hardwoods

Abstract: N-tree distance sampling (NDS) is carried out by measuring characteristics of interest - such as volume and basal area - on a specified number of trees (n) closest to each sampling position. Distance from the sampling point to the centre of the nth nearest tree is also recorded, and forms the radius of the circular plot at that sampling position. The use of NDS as an alternative to the more common point and plot sampling is demonstrated, using data from sampling in Michigan's Upper Peninsula in three forest types, viz. (i) northern hardwood stands, with sugar maple [*Acer saccharum*] the dominant species, (ii) red pine [*Pinus resinosa*] plantations, and (iii) clumped, mixed hardwood stands, mainly of aspen [*Populus tremuloides*] and red maple [*A. rubrum*]. Seven sampling techniques were compared: one-fifth and one-tenth of an acre fixed radius plot sampling; BAF [basal area factors] 10 and BAF 20 variable radius point sampling; and NDS of 3, 5, and 7 trees. Estimates of mean board foot volumes, cords, basal area and number of trees per acre produced by the NDS method were biased, but when a correction factor was applied to the northern hardwood estimates, the results were equivalent to those from point and plot sampling. The costs of NDS were competitive compared with the other sampling methods.

365. **Lewis PJ 1990. *The impact of cutting method on northern hardwood stumpage prices*. MS thesis, Michigan State University, East Lansing. 163 pp.**

Keywords: northern hardwoods /economics /stumpage /silviculture /harvesting methods

Abstract: The impact of silvicultural cut method on northern hardwood stumpage prices was investigated. Timber sales from four National Forests in Michigan and Wisconsin were used to create a data base for the study. Using multiple regression techniques, a model of northern hardwood stumpage prices was developed for each National Forest. The results of the study indicate that stumpage prices are more sensitive to the species mix than to the harvesting method employed.

366. **Li HB, Franklin JF, Swanson FJ, and Spies TA 1993. *Developing alternative forest cutting patterns: a simulation approach*. *Landscape Ecology* 8: 63-75.**

Keywords: simulation models/felling /forest management/habitats /fragmentation /landscape /planning /patterns /computer simulation/model cutting impacts

Abstract: This study examines the effects of different forest cutting patterns on habitat fragmentation in managed forest landscapes. Computer simulation was used to conduct experiments in which the effects of different cutting patterns, cutting-unit size, and special constraints (e.g. a forest reserve, a stream system, or a road system) on landscape patterns were examined. Fragmentation indices are used to quantify structural changes over the cutting cycle and among different treatments. The degree of fragmentation varies greatly among the five cutting patterns used; aggregation of cutting units results in a low degree and gradual change of fragmentation. Cutting patterns with larger cutting units and additional landscape constraints also lead to a lower degree of fragmentation. Moreover, differences in fragmentation among the treatments are not observed until 30 or 50% of the landscape is cut.

367. **Liechty HO 1994. *An evaluation of throughfall chemistry in northern hardwoods along an air pollution gradient*. PhD dissertation, Michigan Technological University, Houghton. 131 pp.**

Keywords: northern hardwoods /throughfall chemistry /air pollution /canopy nutrient cycling /dissolved organic compounds /DOC

Abstract: The chemical content of precipitation, throughfall, and forest floor solutions were monitored in five northern hardwood stands located across the latitudinal range of this ecosystem and a corresponding acidic deposition gradient (increasing deposition from north to south) in the Great Lakes Region to (1) measure the spatial variation in fluxes of important elements and oxides to the soils of this ecosystem across the region (2) determine the effects of acidic deposition on canopy exchange of these elements, (3) estimate potential fluxes and spatial variation of elements in throughfall attributed to dry deposition, and (4) assess the effects of acidic deposition and temperature on levels of dissolved organic carbon (DOC) in throughfall and forest floor solutions. Precipitation fluxes of H^+ , SO_4^{2-} , and NO_3^- increased as much as 340, 69, and 83% respectively from the northern to southern study sites. Throughfall fluxes of H^+ , SO_4^{2-} , NO_3^- , Ca^{2+} , and Mg^{2+} significantly increased ($p < 0.05$) from the northern to the southern stands and were correlated with fluxes of acidic ions (H^+ , SO_4^{2-} , NO_3^-) in precipitation. Throughfall fluxes of SO_4^{2-} , NO_3^- , H^+ were respectively 87%, 142%, and 153% greater at the most southern compared to the most northern sites while fluxes of Ca^{2+} and Mg^{2+} increased between 30 and 60%. Increased levels of H^+ , SO_4^{2-} , and NO_3^- were a direct result of the increased atmospheric inputs of these ions corresponding to the acidic deposition gradient. The higher throughfall levels of Ca^{2+} and Mg^{2+} in areas receiving higher acidic deposition were primarily related to the increased leaching of base cations from the canopies resulting from the buffering of anthropogenic H^+ by foliage. Levels of DOC in both throughfall and forest floor solutions were not found to be altered by the acidic deposition levels. Thus the anionic composition of throughfall is increasingly dominated by strong acid anions (SO_4^{2-} , and NO_3^-) with increased acidic deposition. Although precipitation acidity had little effect on DOC levels, DOC in forest floor solutions was positively related to temporal and spatial variation in soil temperatures.

368. Liechty HO, Holmes MJ, Reed DD, and Mroz GD 1992. Changes in microclimate after stand conversion in two northern hardwood stands. *Forest Ecology and Management* 50: 253-264.

Keywords: Forest influences/microclimate /Clear felling/Soil water/Soil temperature/Acer saccharum/Quercus rubra/Pinus resinosa/northern hardwoods/artificial regeneration/ second growth

Abstract: Changes in air temperature, soil temperature, and soil moisture were monitored for 5 years in two second growth northern hardwood stands - dominated by red maple (*Acer saccharum*) and northern red oak (*Quercus rubra*) - located in the Central Upper Peninsula of Michigan following whole tree harvesting and planting of 3-0 bare rooted red pine (*Pinus resinosa*) seedlings. Soil temperatures at a depth of 5 cm and maximum air temperatures 2 m above the soil surface increased 5-25% after stand conversion. Soil moisture content at a depth of 5 cm increased by 10-20% in one stand but not in the other. Differences in stand, soil and topographical characteristics between the two stands had no apparent effect on the magnitude of air or soil temperature changes after stand conversion. However, higher initial stand density and soil water holding capacity appeared to be related to increased soil moisture content at one of the sites. The increased soil temperatures after conversion were not only a result of the removal of the northern hardwood canopy but also the removal and redistribution of the forest floor due to harvesting. Five years after stand conversion air temperature, soil temperature, and soil moisture showed no evidence of recovering from initial post-harvest levels.

369. Liechty HO, Jurgensen MF, Mroz GD, and Gale MR 1997. Pit and Mound Topography and Its Influence on Storage of Carbon, Nitrogen, and Organic Matter Within an Old-Growth Forest. *Canadian Journal of Forest Research* 27: 1992-1997.

Keywords: Cellulose Decomposition/Microtopography/Microrelief/Patterns/soil chemistry/ carbon/nitrogen/organic matter

Abstract: Pit and mound microtopography created by tree windthrow is a dominant feature in many old-growth forests in the Great Lakes Region. This study investigated whether stand-level quantities, or processes which control quantities, of carbon, nitrogen, and organic matter in forest floor and mineral soil have been altered by changes in microtopography caused by windthrow. Comparison of flat or relatively undisturbed surfaces with the areas that contained mounds, pits, and flat features combined indicated no changes in the amounts of carbon, nitrogen, or organic matter in the forest floor or mineral soil as a result of pit and mound microtopography. However, there was an increased mixing of forest floor organic matter within mineral soils of mounds as compared with pits. Decomposition potential after 10 weeks, as indicated by cotton strip assay method, was 116% greater within the mineral soils of mounds than in pits. The decomposition rates in the mineral soil in the mounds were related to greater amounts of organic matter, temperatures, and moisture contents within this feature. Changes in sink sizes related to organic matter mixing or alteration in decomposition were minimal. Thus long-term stand-level storage of carbon, nitrogen, or organic matter in forest floor or mineral soil pools was not found to be significantly altered by changes in microtopography resulting from windthrow disturbance levels found within this study area.

370. Liechty HO, Kuuseoks E, and Mroz GD 1995. Dissolved organic carbon in northern hardwood stands with differing acidic inputs and temperature regimes. *Journal of Environmental Quality* 24: 927-933.

Keywords: carbon /meteorology /temperature /pollution /acid deposition/throughfall /vegetation types/soil temperature /air temperature/soil organic matter/northern hardwoods/dissolved organic compounds /DOC

Abstract: Concentrations and fluxes of dissolved organic carbon (DOC) in throughfall and forest floor solutions were monitored in two northern hardwood stands located at the northern and southern end of a latitudinal acidic deposition and air temperature gradient in the Great Lakes Region of North America to determine if DOC levels are altered by regional and temporal variation in acidic inputs and temperature. Amounts of precipitation received at the two sites were similar, but precipitation pH and air temp., resp., averaged 4.83 and 13.9 °C at the northern gradient site and 4.29 and 15.1 °C at the southern gradient site. Volume weighted DOC concn in throughfall were significantly greater at the northern (20.5 mg/litre) than the southern (15.9 mg/litre) site, but these differences in DOC levels were caused by the differing amounts of throughfall passing through the canopy of the two sites rather than levels of precipitation acidity or air temp. Temporal variation in the levels of DOC in throughfall was not related to the variation in either precipitation acidity or air temp. Like throughfall, levels of DOC in forest floor solutions were not altered by acidic inputs. However, DOC in these solutions increased with seasonal increases in soil temp. A regression equation relating seasonal variation in soil temp. and forest floor concentrations of DOC estimated that an observed 2.1 °C difference in soil temp. at the 2 sites during the growing season could represent as much as 3.7 mg/litre difference in forest floor solution concn of DOC.

371. Liechty HO, Mroz GD, and Reed DD 1993. Cation and anion fluxes in northern hardwood throughfall along an acidic deposition gradient. *Canadian Journal of Forest Research* 23: 457-467.

Keywords: Air pollution/Acid deposition/Precipitation /throughfall chemistry /hydrology /nitrates /deposition /sulfates /Acer saccharum/northern hardwoods

Abstract: This paper is one of a series of studies investigating the effects of acid deposition along an acid deposition gradient extending from N. Minnesota (lowest deposition) to SE Michigan (highest deposition). Ion concentrations and fluxes were measured for 2 years (from 1 October 1987 to 30 September 1989) in five northern broadleaved stands [dominated by *Acer saccharum*]. Precipitation fluxes of H⁺, SO₄²⁻, and NO₃⁻ were, respectively, 340, 69, and 83% greater at the site with the highest deposition than at the site with the lowest deposition. No significant

differences among sites were evident for precipitation fluxes of cations along the gradient. Fluxes of H⁺, SO₄²⁻, NO₃⁻, Ca²⁺, and Mg²⁺ in throughfall increased along the gradient and were positively correlated with increased atmospheric inputs of H⁺, SO₄²⁻, and NO₃⁻ measured at the sites. Fluxes of SO₄²⁻ and NO₃⁻ in throughfall were greater than precipitation fluxes, indicating dry deposition in excess of any assimilation of these anions from precipitation. Dry deposition inputs of SO₄²⁻ increased from the northwestern to southeastern sites and were estimated to range from 23 to 49% of precipitation inputs. Precipitation acidity was neutralized by the canopy in all stands, but the amount of H⁺ retained by the canopy was significantly greater at sites with the greatest precipitation acidity. Throughfall fluxes of Ca²⁺ and Mg²⁺ in excess of precipitation fluxes were positively correlated with the canopy retention and deposition of H⁺ along the gradient. Increased throughfall fluxes of these cations were consistent with hypothesized increases in canopy leaching of cations with increased acidic deposition. Increased canopy leaching of Ca²⁺ and Mg²⁺, resulting from increased acidic deposition, was estimated to represent as much as 6.2 and 12.9% of foliar contents of these cations, respectively. Although HCO₃⁻ and organic anions were involved in maintaining electroneutrality in throughfall along the gradient, strong acid anions increasingly dominated anionic composition of throughfall with increasing acidic deposition.

372. **Lin CR 1995. *Economics and diversity of trees and landscape in northern hardwood forests: implications of deterministic and stochastic models*. PhD dissertation, University of Wisconsin, Madison. 168 pp.**

Keywords: northern hardwoods /model economic/management /simulation /model growth/shade tolerance

Abstract: A density-dependent matrix model of stand growth is presented. The model was calibrated with re-measured plots in the northern hardwood forests in Wisconsin. Trees were divided into shade-tolerant, intermediate, and shade-intolerant species in twelve diameter classes. Model predictions were tested against post-sample observations for short-term (15-year) and long-term (steady-state) accuracy. The growth model (in deterministic form) was first applied to study stand growth dynamics with and without management. Starting with the current average stand state, the predicted stand basal area of an unmanaged stand rose steadily to a maximum, dropped gradually, and finally reached a steady state. The time paths of basal area and tree size diversity were highly and positively correlated. In contrast, tree species diversity decreased when tree size diversity and basal area increased, and vice-versa. When harvesting was introduced, it was found that more intensive harvest increased the diversity of tree species, while decreasing the diversity of tree size. A 20-year cutting cycle could produce higher economic returns than a 10-year cutting cycle, with similar size and species diversity. In the second part, a Markov decision process (MDP) model was formulated to investigate the economic and ecological consequences of alternative management regimes, under an uncertain environment. Simulation based on the Markovian model showed that old growth stands with the highest tree size diversity would dominate the whole forest after a long time period. Major natural disturbances, as well as management, tended to increase the steady-state landscape diversity of the maple-birch forests in Wisconsin. Compared with the observed current cutting regimes, the economic harvesting policy could produce much more income, while keeping landscape and tree diversity at about the same level. The economic returns decreased as the desired level of tree diversity increased (especially for size diversity). Maximization of tree diversity would have a high opportunity cost compared with economic management alternatives. The MDP model is attractive for its simplicity in practice. Its drawback is the coarseness of the system state definition.

373. **Lin CR and Buongiorno J 1997. Fixed Versus Variable-Parameter Matrix Models of Forest Growth: the Case of Maple-Birch Forests. *Ecological Modelling* 99: 263-274.**

Keywords: Economics/Forest Ecosystems/Forest Management/Growth/model non-linear/Population/Economic Returns/Management/Diversity

Abstract: A matrix growth model with constant parameters has been modified, by making

survivor growth and mortality of trees functions of stand basal area. The functions, estimated from re-measured plots in Wisconsin maple-birch forests, showed that basal area affected mostly the growth of small trees. However, even when the effects were statistically significant, they were small. Fifteen-year forecasts with the variable-parameter model were almost identical to those of the fixed-parameter model for a set of 37 random plots. Long-term, steady-state predictions gave similar diameter distributions for both models, but a 20% lower basal area for the variable-parameter model. Steady-state management regimes that maximized soil rent were identical for both models in terms of intensity of harvest and length of cutting cycle. The basal area, harvests, and net present values predicted by both models, in the long run and during conversion, were also nearly the same. For managed maple-birch forests, the matrix model with constant parameters has the advantage of simplicity of form, estimation, and application, especially in optimization mode.

374. **Lin CR and Buongiorno J 1998. Tree Diversity, Landscape Diversity, and Economics of Maple-Birch Forests: Implications of Markovian Models. *Management Science* 44: 1351-1366.**

Keywords: Ecosystem Management/Optimization/Risk/Simulation/Northern Hardwood Stands/Size Diversity/Growth-Model/Biodiversity/Management/Returns

Abstract: Markov decision process (MDP) models were effective in analyzing forest management policies. Even the simplest standard results gave useful insights into forest ecology, such as how landscape diversity is shaped by natural catastrophes, and how forests mature through successional phases. The methods were also useful to predict the effects of different management policies on ecological and economic criteria. Optimization augmented the usefulness of the approach, suggesting that income from Wisconsin's maple-birch forests could be increased without ruining their diversity of landscape, tree size, and tree species. It showed that maximizing species diversity, defined by the distribution of trees in shade-tolerance classes, would require some harvest. Instead, maximum tree size diversity occurred in unmanaged forests, but this gave a less diverse landscape and no income. The MDP method allowed for the design of compromise policies that would maximize income while keeping diversity above specified limits. The opportunity cost of increasing tree size diversity was found to be much higher than for species diversity. Comparing the maximum timber income owners could have got with what they actually cut suggested that the amenity value of forests was four times that of timber. Advantages of the methods reside in the ability to model complex ecosystem processes with simple probability matrices, and in the rich MDP theory and algorithms. Limitations include the difficulty of defining a space set large enough for accurate discretization, but small enough for practical application.

375. **Lindroth RL, Roth S, Kruger EL, Volin JC, and Koss PA 1997. CO₂-mediated changes in aspen chemistry: effects on gypsy moth performance and susceptibility to virus. *Global Change Biology* 3: 279-289.**

Keywords: plant pests/pest resistance/nitrogen /starch /tannins /growth stages/natural enemies/foilage /phenolic compounds/glycosides /climatic change/insect pests/carbon dioxide enrichment/plant composition/agricultural entomology/*Populus tremuloides* /gypsy moth /*Lymantria dispar*/nucleopolyhedrosis virus/bioassay

Abstract: The effects were investigated of long-term CO₂ enrichment on the foliar chemistry of quaking aspen (*Populus tremuloides*) and the consequences of chemical changes for performance of the gypsy moth (*Lymantria dispar*), and susceptibility of the gypsy moth to a nucleopolyhedrosis virus (NPV). Foliage was collected from trees grown for 2 seasons under ambient or enriched CO₂ (average 357 and 640 $\mu\text{mol/mol}$, respectively) in outdoor open-top chambers at the University of Wisconsin Experimental Farm at Madison, and fed to insects in a quarantine rearing facility. Under enriched CO₂, levels of leaf nitrogen declined marginally, levels of starch and phenolic glycosides did not change, and levels of condensed tannins increased. Long-term bioassays revealed reduced insect growth (especially in females), prolonged development and increased consumption in larvae fed high-CO₂ foliage but no significant differences in final pupal weights or female fecundity. Short-term bioassays showed weaker, and

sex-specific, effects of CO₂ treatment on larval performance. Correlation analyses revealed strong, negative associations between insect performance and foliar phenolic glycoside concentrations, independent of CO₂ treatment. Larval susceptibility to NPV did not differ between CO₂ treatments, suggesting that the effects of this natural enemy on gypsy moths are buffered from CO₂-induced changes in foliar chemistry. The results emphasize that the impact of enriched CO₂ on plant-insect interactions will be determined not only by how concentrations of plant compounds are altered, but also by the relevance of particular compounds for insect fitness. This work also underscores the need for studies of genetic variation in plant responses to enriched CO₂ and long-term population-level responses of insects to CO₂-induced changes in host quality.

376. **Lorimer CG 1983. Eighty-year development of northern red oak after partial cutting in a mixed-species Wisconsin forest. *Forest Science* 29: 371-383.**

Keywords: stand characteristics/development /composition /natural regeneration/Vegetation /history /broadleaves /*Acer saccharum*/*Quercus rubra*

Abstract: Diameter and age distributions were recorded in summer, 1979 in a 0.6-ha plot in a mixed, old growth stand dominated by *Acer saccharum* and *Quercus rubra* and heavily felled in 1979 to salvage dead oak and open up the stand. Results indicated that the *Q. rubra* component was even aged and 60-100 yr younger than many of the overstorey maples, which were uneven aged. Of the stumps examined, 63% showed release from suppression at about 1897, which suggests a heavy partial felling at that time. The oaks did not germinate following the disturbance but were present as advance regeneration before the event. This advance regeneration averaged 2.9 cm in stem diam. 50 cm above ground, compared with a diam. of 18.9 cm for maple at the same height. Most of the ultimately successful oaks developed under small gaps less than 150 m². Despite the initial disadvantage in stem size and the small size of the gaps, 28 red oaks/ha survived to become overstorey trees, reaching an av. d.b.h. of 38 cm in 1975. From author's summary.

377. **Lorimer CG 2001. Historical and Ecological Roles of Disturbance in Eastern North American Forests: 9,000 Years of Change. *Wildlife Society Bulletin* 29: 425-439.**

Keywords: Anthropogenic Fires/Early Successional Habitat/Historic Disturbance Frequency/Hemlock-Hardwood Forests/Land-Use History/Presettlement Forests/Catastrophic Wind/Accelerated Succession/History/Disturbance

Abstract: Recent declines in habitat suitable for early successional wildlife species are interpreted in a broad historical context, using several types of scientific and historical evidence to estimate changes in amount of young forest habitat in presettlement and post-settlement eras. A major contrast in disturbance regimes between northern mesophytic hardwood forests and the oak-pine forests of the central and southern United States is evident for several thousand years before European contact. Catastrophic wind disturbance is a dominant feature in northern hardwood forests, but frequency is fairly low except in areas affected by Atlantic hurricanes. Most northern hardwood regions were dominated by old-growth forest in presettlement times, with young forest habitat (up to 15 years old) occupying <1% to 13% of the landscape in different states. In contrast, fire was a dominant force in shaping species composition and structure of oak-hickory and oak-pine forests, with savanna and grassland habitat occupying up to 65% of the landscape in some midwestern regions. Numerical estimates of the presettlement extent of young forest and savanna habitat are not possible for the Atlantic slope and Gulf regions, but the composition and structure of the vegetation seemed to bear the imprint of frequent fires in most areas where evidence is available. Comparison of historic fire frequency with modern lightning fire data suggests that humans caused most of these fires. Young forest habitat reached a peak of up to 55-60% of the forest cover in most states in the late nineteenth century because of logging, wildfires, fuelwood cutting, and farm abandonment, but has since declined to 20% or less in many regions.

378. **Lorimer CG 1989. Relative effects of small and large disturbances on temperate hardwood forest**

structure. *Ecology* 70: 565-567.

Keywords: disturbance/northern hardwoods

379. Lorimer CG, Chapman JW, and Lambert WD 1994. Tall understorey vegetation as a factor in the poor development of oak seedlings beneath mature stands. *Journal of Ecology* 82: 227-237.

Keywords: plant succession/seedlings /herbicides /plant height/natural regeneration/understorey /canopy /woody weeds/weeds /competition/fire effects/crop weed competition/disturbed land/ growth rate/Acer rubrum/Quercus alba/Quercus rubra/Tilia spp. /Ostrya spp.

Abstract: Replacement of oaks (*Quercus* spp.) by other species after natural and human-caused disturbance is recognized as a common problem on average and productive sites in many parts of eastern North America. Oak seedlings are often numerous beneath mature stands, but seedlings are usually too small to compete effectively with tall saplings of other species. Reasons for the poor development of oak seedlings are not well understood. An experiment was designed to evaluate the impact of tall and low understorey vegetation on oak seedling development beneath mature stands on two sites in southwestern Wisconsin with dominant canopy species *Quercus rubra* (30% basal area), *Acer rubrum* (16%), *Q. alba* (15%) and *Carya cordiformis* (14%). Understorey stems taller than 1.5 m and scattered small canopy trees were removed on half of the main plots, with the other plots retained as controls. Half of the nested subplots within each main plot were also sprayed with foliar herbicide to reduce the density of vegetation shorter than 1.5 m. The development of planted *Q. rubra* and natural *Q. rubra* and *Q. alba* seedlings was monitored for 5 years. On undisturbed control plots, more than 70% of the planted oak seedlings died within 5 years, and survivors showed a net decrease in height. On plots with the tall understorey vegetation removed, more than 90% of the planted seedlings survived and average total height increased by 50-96%. Understorey removal plots had 10-140 times as many natural oak seedlings after 5 years as undisturbed plots. Height growth of natural oak seedlings under heavy partial shade (87% crown cover) was slow, however, averaging 4-6 cm/year. The results suggest that tall understorey trees of *Acer*, *Ostrya*, *Tilia* and other species are a major obstacle to the development of oak seedlings. Disturbances such as fire that reduce this understorey layer can probably improve the prospects that oak will be self-perpetuating, but development of competitive natural oak seedlings is a slow process that may take several decades.

380. Lorimer CG, Dahir SE, and Nordheim EV 2001. Tree Mortality Rates and Longevity in Mature and Old-Growth Hemlock-Hardwood Forests. *Journal of Ecology* 89: 960-971.

Keywords: Forest Dynamics/Old-Growth Definitions/Population Sustainability/Tree Life Tables/Self-Thinning Rule/*Acer saccharum*/northern hardwoods/ Dynamics/ Disturbance/ Frequency/Model/*Tsuga canadensis*

Abstract: 1 Efforts to understand and forecast long-term forest dynamics are often hindered by limited data on mortality rates and longevity of trees in older stands. In this study, mortality data were analysed from 11-year permanent plot records in 10 tracts of hemlock-hardwood forest with little past human disturbance in the upper Great Lakes region, USA. 2 We compared tree size-mortality trends in mature stands (canopy trees mostly 100-170 years old) with those in true old-growth stands (canopy trees mostly 200-350 years old). Stem sections were also cut from 71 recently fallen trees to determine average and maximum longevity for canopy trees of each species. 3 All five mature stands had descending monotonic size-mortality trends for shade-tolerant species, with low rates of mortality (generally much less than 1% per year) for trees > 18 cm d.b.h. In contrast, all five old-growth stands had U-shaped mortality functions, with annual mortality rates of 1.5-2.9% for trees > 66 cm d.b.h. These size-mortality trends are biologically consistent with 'rotated sigmoid' size distributions observed for major species, although mortality rates were nearly size-invariant for trees between 18 and 66 cm d.b.h. 4 Both late-successional and gap-phase species had fairly high mortality rates for saplings (2-10 cm d.b.h.) of 25-34% over the 11-year period, which suggests that size distributions with moderately steep negative slopes

are needed to compensate for mortality and ensure population sustainability. 5 Average age at time of death for canopy trees was 216 years for sugar maple (*Acer saccharum*) and 301 years for hemlock (*Tsuga canadensis*), suggesting that the biological transition from mature to old-growth forest probably doesn't occur on these sites until a stand age of about 180-250 years.

381. **Lorimer CG and Frelich LE 1989. A methodology for estimating canopy disturbance frequency and intensity in dense temperate forests. *Canadian Journal of Forest Research* 19: 651-663.**

Keywords: Dendrochronology /Synecology /Stand characteristics/stability /Vegetation types/broadleaved deciduous forests/temperate zones/canopy gaps

Abstract: Analysis of the frequency of past moderate and high-intensity disturbances has been hindered in forests of complex age structure by methodological problems. A methodology is proposed for developing a disturbance chronology in such stands by identifying the probable date of canopy accession for each sample tree. Canopy accession dates are based on an evaluation of radial growth pattern and early growth rates of existing canopy trees. Canopy disturbance intensity is defined as the percentage of sample trees with canopy accession events in each decade. Rotation periods for disturbances of various intensities are calculated from the chronology. Problems in radial increment analysis and possible solutions are discussed. The method was evaluated using 893 increment cores from 70 plots in N. broadleaved stands of W. Upper Michigan. The estimated average disturbance rate for all plots and decades was 5.7-6.9% of land area per decade, with an implied average canopy tree residence time of 145-175 years. These estimates are similar to those obtained by on-site estimates of canopy tree residence time and studies in the literature on the rate of gap formation.

382. **Lorimer CG and Frelich LE 1994. Natural disturbance regimes in old-growth northern hardwoods: implications for restoration efforts. *Journal of Forestry* 92: 33-38.**

Keywords: afforestation /nature conservation/restoration/stand characteristics/stability /population dynamics/virgin forests/silviculture /deciduous forests/*Tsuga canadensis*/northern hardwoods

Abstract: A summary is given of what is known about natural disturbance, stand structure and landscape age-class mosaics in northern hardwood and hemlock/hardwood forests as a basis for guiding possible efforts to restore the old-growth characteristics to these forests. The geographic boundaries of the region under discussion, which corresponds approximately to the range of eastern hemlock (*Tsuga canadensis*), extend from northern Wisconsin to northern Maine, south to Pennsylvania and New York, and continue in a narrow belt along the Appalachian Mountains.

383. **Lorimer CG and Frelich LE 1984. A simulation of equilibrium diameter distributions of sugar maple (*Acer saccharum*). *Bulletin of the Torrey Botanical Club* 111: 193-199.**

Keywords: Diameter /variation /simulation /broadleaves /*Acer saccharum*

384. **Lorimer CG and Frelich LE 1998. A structural alternative to chronosequence analysis for uneven-aged northern hardwood forests. *Journal of Sustainable Forestry* 6: 347-366.**

Keywords: stand characteristics/stand structure/age structure/stand development/methodology /*Acer saccharum*/*Betula alleghaniensis*/*Tsuga canadensis*/northern hardwoods

Abstract: Diameter distributions from 70 primary northern hardwood stands in western upper Michigan, USA, were analysed to determine whether certain structural indices might allow placement of stands in a developmental sequence. Modal stand diameter and the fraction of total overstorey crown area in large trees (>46 cm diameter at breast height, dbh) were among the most useful measures for distinguishing stages of development. Modal diameter ranged from 10 to 62 cm for stands on good sites. Correlations between diameter and age were highly significant ($P < 0.0001$) for the three principal species (*Acer saccharum*, *Tsuga canadensis*, *Betula alleghaniensis*)

on all three site quality classes, suggesting that stands with a greater proportion of large trees are generally in a later stage of development. Stands with <45% of the crown area in large trees have predominantly unimodal size distributions. As modal stand diameter increases, the shape of the size distribution changes from positively skewed to nearly symmetric. As the proportion of crown area in large trees exceeds 45% and the ratio of crown area in large to mature (26-45 cm dbh) trees exceeds 1.5, the form of the size distribution changes to multimodal, irregular, or descending monotonic.

385. **Lorimer CG, Frelich LE, and Nordheim EV 1988. Estimating gap origin probabilities for canopy trees. *Ecology* 69: 778-785.**

Keywords: Conifers /Broadleaves /gap dynamics/Plant succession/seral stages/Natural regeneration/advance growth/Acer saccharum/Tsuga canadensis/northern hardwoods

Abstract: A method is presented for estimating the probability that existing canopy trees were growing in gaps during the sapling stage, given observed mean 5-yr radial growth rates starting when the trees were 4 cm d.b.h. Required calibration data are frequency distributions of radial growth rate for existing saplings that are currently suppressed in the forest understorey vs. those of saplings growing in gaps. Threshold growth rates for high confidence of gap origin are calculated in an iterative fashion using growth rate data and interpretation of radial increment patterns. The method is illustrated with data from sugar maple (*Acer saccharum*) and eastern hemlock (*Tsuga canadensis*) in mature and old northern hardwood forests of western Upper Michigan. The proportion of canopy trees that had been growing in gaps during the sapling stage ranged from 35 to 67% in different stands. This wide range suggests the adaptability of these two late-successional, shade-tolerant species to a variety of stand microenvironments.

386. **Lorimer CG, Frelich LE, and Nordheim EV 1992. Forest-tree growth rates and probability of gap origin - a reply to Clark. *Ecology* 73: 1124-1128.**

Keywords: plant succession/growth rings/growth /mathematics /canopy gaps/equations /methodology /Acer saccharum/Tsuga canadensis/northern hardwoods

Abstract: A recursive procedure for estimating the probability that a mature tree grew within a gap is further discussed. The procedure uses stand-specific growth ring data and early growth patterns of canopy trees, and is illustrated with data from northern hardwood forests (*Acer saccharum*, *Tsuga canadensis*) in Michigan.

387. **Lu HC 1992. *Economic management of Wisconsin's northern hardwood forest stands: a mixed-species model*. PhD dissertation, University of Wisconsin, Madison. 176 pp.**

Keywords: northern hardwoods /stocking guides /economics /model growth/Q-factor /Arbogast stocking guide /logging /forest ecology /valuation

Abstract: The primary objective of this study was to investigate economically sustainable stocking guides for the management of Wisconsin's northern hardwood stands. Seven stocking guides were studied both in a deterministic environment and in a stochastic environment. As a first step, a mixed-species growth model was developed for northern hardwoods species aggregated by species, quality, and commercial value of trees. Based on this model, an economic guide was developed to maximize land expectation value. This guide was compared with Arbogast's, q-factor, diameter-limit, and high-grading guides in terms of their economic returns and their long-term effects on stand structure and species composition. The study revealed that, in a steady state, long-term equilibrium situation, the economic guide yielded substantially higher land expectation value than the other guides and led the stand to a good condition. The Arbogast and q-factor guides gave the lowest land expectation values. The high-grading guide led to a very poor stand condition. The influence of initial stand state on the forest value was investigated by deterministic simulation. The results of the simulations showed very small difference in forest

values obtained from the economic guide and those obtained from the diameter-limit guides or high-grading guide. This is because forest value is largely dependent on the early harvests and very little on the long-term stand structure (due to discounting). In the real world, uncertainty exists everywhere. By adding a random vector into the growth model, a Markov decision process (MDP) guide was formulated to take this uncertainty into account. This guide then was compared with the economic (deterministic) and other guides, in a stochastic environment. As in the deterministic case, the difference in forest values obtained from the economic policy and those obtained from the diameter-limit policies or high-grading policy was small. This confirms the problem inherent in the forest value criterion in judging forest management policies. The advantage of linear programming models is that these models could contain more detailed information than the MDP model. However, the model ignores the uncertain nature of stand growth and price fluctuations as well as the initial stand conditions. The advantage of an MDP model is that risk factors can be introduced and managers can work with different initial stand conditions. However, the 'curse of dimensionality' limits detailed study of forest management. Therefore, the recommendation of this study is to use the MDP guide when making the cutting decisions, while respecting the residual stand structure recommendations in the economic guide.

388. **Lu HC and Buongiorno J 1993. Long- and short-term effects of alternative cutting regimes on economic returns and ecological diversity in mixed-species forests. *Forest Ecology and Management* 58: 173-192.**

Keywords: Increment /Valuation /Forest ecology/model growth /economics/logging /northern hardwoods

Abstract: A growth model is presented, which recognizes differences in tree species, quality and size. The model was calibrated with data from permanent sample plots in northern hardwood forests in Wisconsin, classifying trees in twelve sizes, each divided into high-value, low-value and non-commercial trees. The model predicted well the short- and long-term (steady states) growth of stands, in terms of number, size and value of trees. This growth model was incorporated into a linear program in order to compare six logging guides in terms of the soil rent and ecological diversity that they would obtain in a steady state. A simple guide, felling all trees of at least 41 cm diameter at breast height every 15 years, resulted in species diversity that was nearly 95% of that of a natural stand, and a soil rent that was about 70% of the maximum achievable. High-grading the stand led to a negative soil rent and the lowest species diversity of the six alternatives. These long-term, steady-state differences between cutting guides would be missed by analyses that relied on the forest value criterion, because forest value is determined largely by the initial stand state.

389. **Luley CJ, Mielke ME, Castello JD, Cummings Carlson J, Appleby J, and Hatcher R 1992. Ash crown condition and the incidence of ash yellows and other insects and diseases in Illinois, Iowa, Missouri, and Wisconsin. *Plant Disease* 76: 1209-1212.**

Keywords: Forest pests/insect pests/Broadleaves /Mycoplasmal diseases/Dieback /geographical distribution/plant pathology/agricultural entomology/*Fraxinus americana*

Abstract: A total of 79 plots in Illinois, Iowa, Missouri and Wisconsin, USA, were surveyed in 1990 for ash yellows (AshY) and other diseases and insects. Twenty one of 38 white ash (*Fraxinus americana*) and 20 of 41 green ash (*F. pennsylvanica*) plots had trees with AshY, based on the 4'-6-diamidino-2-phenylindole (DAPI) DNA-staining technique or the presence of witches' brooms. AshY was widely distributed in all states except Wisconsin, where trees in only 2 of 20 plots were affected. Other than witches' brooms, symptoms previously associated with AshY were present on trees in plots that tested both positive and negative for mycoplasma-like organisms. Approximately 50% of the ash trees had >10% crown dieback and 5% of the trees were dead. Overall, trees representing about 12% (6-7 m³/ha) of the total ash volume had ~50% crown dieback. There was no significant difference in mean crown condition rating of the ash trees in AshY-positive and AshY-negative plots. Other disease and insect problems were common but were not considered to be major causes of crown dieback. The primary cause of crown dieback of

ash in the Midwest is unknown.

390. **Lynch AM and Bassett JR 1987. Oak stump sprouting on dry sites in northern Lower Michigan. *Northern Journal of Applied Forestry* 4: 142-145.**

Keywords: Natural regeneration/sprouting/vegetative propagation/broadleaves /*Quercus alba*/*Quercus rubra*/*Quercus ellipsoidalis*

Abstract: In clear-felled areas of 37 stands, stumps of northern red, northern pin and white oak trees [respectively, *Quercus rubra*, *Q. ellipsoidalis* and *Q. alba*] were measured to relate sprouting to stump diam., estimated d.b.h., slope position, aspect, site index and age of parent tree. At least one vigorous sprout was produced by 80, 77 and 54% of northern red, northern pin and white oak stumps, respectively. Sprouting was related to stump diam. and aspect only in white oak. All species sprouted most frequently on upper slopes. Sprouting in northern pin and white oaks was weakly related to site index. In all species, sprouting was related to tree age, but only white oak showed a consistent trend of decreased sprouting with increased tree age.

391. **Lynch TB 1982. *Diameter distribution growth and yield models for mixed species forest stands*. PhD dissertation, Purdue University, West Lafayette. 231 pp.**

Keywords: model growth/yield prediction /Upper Peninsula

Abstract: A general method for modeling growth and yield in mixed species, uneven-aged forest stands by using systems of differential equations was proposed. Recovery of diameter distribution parameters for each species from values of forest yields at any particular time was discussed. Equations for diameter distribution change rates were derived by using moment relationships together with systems of differential equations in forest yields. The utility of the modeling technique proposed was demonstrated by an application to mixed species uneven-aged permanent plot data from the upper peninsula of Michigan. Hardwood and softwood were the two species groups used. For each species group, equations which predicted change rates in basal area per acre, sum of diameters per acre, and number of trees per acre were developed by using the first two measurements taken on the permanent plots. These equations were taken to be a system of first order ordinary differential equations. Given a set of initial conditions (that is, initial values of number of trees per acre, sum of diameters per acre, and basal area per acre), yield predictions for future times may be obtained by numerical integration of the system. Future values of diameter distribution parameters may then be obtained by solving the system of equations formed by equating each yield type to the product of number of trees and the expected value of the yield per tree with respect to the diameter distribution parameters. Alternatively, the relationship mentioned above may be used to obtain differential equations for the diameter distribution parameters. When these equations are included with the system of differential equations in forest yields, predictions for diameter distribution parameters may be obtained as solutions to the resulting system of differential equations. The yield projection technique was tested by using the differential equation system to predict conditions at the third measurement period for those permanent plots on which a third measurement was taken.

392. **Lynch TB and Moser JW Jr. 1986. A growth model for mixed species stands. *Forest Science* 32: 697-706.**

Keywords: Stand tables/Yield forecasting/simulation

Abstract: A technique was developed for predicting stand tables for each of two species groups (coniferous or broadleaved) in a mixed species stand. Future stand conditions for each species group are determined by integrating a system of differential equations that relate rates of change in per acre values of b.a., sum of diam. and number of stems to current values of those variables.

393. **Lynch TB, Wiant HV Jr., and Patterson DW 1994. Comparison of log volume estimates using**

formulae for log center of gravity and center of volume. *Canadian Journal of Forest Research* 24: 133-138.

Keywords: volume determination /model/logs /broadleaves /measurement /roundwood /equations /*Quercus rubra* /*Liriodendron tulipifera*/*Pinus resinosa* /wood products

Abstract: Formulae are presented for estimating log centre of gravity for logs shaped as cones, paraboloids, paracones and neiloids, and logs having intermediate shapes of uniform density. The formulae are based on frusta of simple solids of revolution. Data for 60 logs of a variety of species (mixed broadleaved species and *Quercus rubra*, *Liriodendron tulipifera* and *Pinus resinosa*) and additional data for 15 logs of mixed broadleaved species were used to compare log volume estimates calculated using the centre of (i) gravity or (ii) volume locations as interlog positions for diameter measurements. Accurate measurements of the volume of each log were obtained from diameter measurements at 10 cm intervals. The centre of volume was better than the centre of gravity for log volume estimation. However, formulae for log centre of gravity should be useful for engineering applications with logs of uniform density.

394. **Lynham TJ and Curran TR 1998. Vegetation recovery after wildfire in old-growth red and white pine. Great Lakes Forestry Centre (Canadian Forestry Service) Frontline Technical Note No. 100, 4 pp.**

Keywords: forest fires/seedlings /natural regeneration/fire ecology/virgin forests/*Pinus strobus*/*Pinus banksiana*/*Pinus resinosa*/*Abies balsamea*

Abstract: A total of 5 vegetation plots were established to assess the recovery of red and white pine (*Pinus resinosa* and *P. strobus*, respectively) on burned stands in the summer of 1996, following a wildfire at the Quetico Provincial Park, Ontario, Canada, August 1995. One year after the fire many areas had little or no organic soil remaining due to fuel consumption by the fire or water runoff. Mature 100-300 year old red and white pine trees were left standing on bare rock. Only one sample site in the high intensity fire had any white pine regeneration in 1996. Some red pine seedlings were found throughout the study area, and jack pine (*Pinus banksiana*) was common because parent trees were often found adjacent to the transects. Very little pine regeneration was observed in 1996. It is suggested that white pine seedlings were absent due to pine trees being killed before they produced a mature cone crop. Therefore, white pine will not be a major component of the stands in the future, unless other mechanisms which favour white pine regeneration occur. Regrowth of red pine and jack pine seedlings were favoured over white pine on sites which had been intensely burned. There was abundant jack pine regeneration in all parts of the 34-yr-old stand, and seeds were probably released some time after early October 1995. Regeneration of red pine, white pine, balsam fir (*Abies balsamea*), and white pine stands was observed on sites which had burned with a low intensity.

395. **MacDonald GB and Weingartner DH 1994. A prospectus for the Mixedwood Silviculture Program at the Ontario Forest Research Institute. Ontario Forest Research Institute, Forest Research Information Paper No. 116, 16 pp.**

Keywords: silviculture /reviews/forest management/research /biodiversity /boreal forests/projects

Abstract: Management to actively promote mixedwood forests is becoming accepted practice in many parts of the world. The Boreal Mixedwood Forest of Ontario, Canada, is one component of the northern landscape that is ideally suited to holistic, integrated resource management and to the maintenance of biological diversity. The Mixedwood Silviculture Program at the Ontario Forest Research Institute is mandated to develop and transfer knowledge to advance mixedwood management in Ontario. This prospectus describes the importance of the boreal mixedwood resource and outlines the scope and goals of the Mixedwood Silviculture Program for the next 20 years. The methods used to identify research and development needs are presented and the priorities of the program for the next five years are summarized. Proposed approaches for

research, knowledge transfer, silviculture policy support and provincial program development are discussed. The relationship of the program to clients and partners and the process for reviewing and updating the program plan are also addressed.

396. **MacDonald NW, Burton AJ, Jurgensen MF, McLaughlin JW, and Mroz GD 1991. Variation in forest soil properties along a Great Lakes air pollution gradient. *Soil Science Society of America Journal* 55: 1709-1715.**

Keywords: soil podzols /soil types ecological/soil chemistry/soil physical properties /variation /acid deposition/pollution /air pollution/northern hardwoods

Abstract: A pronounced air-pollution gradient exists across the Great Lakes region with deposition of SO₄, NO₃, and H increasing from northern Minnesota to southern lower Michigan. Soils at six northern hardwood sites along this gradient were examined to characterize soil physical and chemical properties relevant to retention of pollutants, and to investigate the impact of differences in pollutant loading on soil chemical properties. Three randomly located pedons at each site were described and sampled. Soils at all sites were classified in closely related subgroups within the Spodosol order. CEC and SO₄-adsorption potential decreased from north to south along the gradient, and were related to trends in inherent soil properties. In upper B horizons, additional significant positive deposition effects on water-soluble and adsorbed SO₄, and negative deposition effects on SO₄-adsorbing potentials were consistent with hypothesized pollutant impacts on soil SO₄ pools and soil capacities to retain additional atmospheric SO₄. Exchangeable nutrient-cation contents (Ca, Mg, K) in upper B horizons decreased as pollutant deposition increased. Regression analyses showed that trends in nutrient-cation contents were primarily related to inherent soil properties such as clay, organic matter, and cation-exchange capacity.

397. **Macdonald NW, Burton AJ, Liechty HO, Witter JA, Pregitzer KS, Mroz GD, and Richter DD 1992. Ion leaching in forest ecosystems along a Great Lakes air pollution gradient. *Journal of Environmental Quality* 21: 614-623.**

Keywords: soil chemistry/soil solution/acid deposition gradient/pollution /air pollution/cations /losses from soil/sulfate /nitrate /hydrogen /calcium /magnesium /Acer saccharum/Quercus alba/Quercus rubra/Quercus velutina/northern hardwoods

Abstract: A gradient of H⁺, SO₄²⁻, and NO₃⁻ deposition across the Great Lakes region of the USA raised concerns over impacts on soil solution chemistry and ion leaching in regional forest ecosystems. Ten study sites representing northern hardwood (*Acer saccharum*) and oak (*Quercus velutina*, *Q. rubra*, *Q. alba*) ecosystems were established across the gradient of increasing deposition from Minnesota to Ohio. Lysimeters were installed at lower E and lower B horizon boundaries at each site and sampled over a 2-yr period. In soil solutions collected at lower E horizon boundaries, H⁺ and SO₄²⁻ wet deposition were correlated with solution concentrations of SO₄²⁻ (r= 0.82** and 0.92**) and Mg²⁺ (r = 0.75** and 0.85**), and with the SO₄²⁻/inorganic anion ratio (r = 0.71 and 0.70**). In soil solutions collected at lower B horizon boundaries, SO₄²⁻ deposition was correlated with solution SO₄²⁻ concn (r = 0.92**). Greater ionic outputs from B horizons than atmospheric inputs indicated that net losses of Ca²⁺ and Mg²⁺ were occurring from all sites. Sulfate outputs above background levels contributed 33 to 2367 molc SO₄²⁻/ha per yr from north to south along the gradient, equal to 3.7 to 71.7% of annual cation outputs. Excess H⁺ deposition accounted for 8 to 34% of annual cation outputs from north to south, and as much as 72% at one site with coarse-textured soils. Elevated cation losses related to H⁺ and SO₄²⁻ deposition indicate that cation depletion remains a plausible consequence of pollutant deposition to forest ecosystems with poorly buffered soils.

398. **MacDonald NW, Burton AJ, Witter JA, and Richter DD 1994. Sulfate adsorption in forest soils of the Great Lakes Region. *Soil Science Society of America Journal* 58: 1546-1555.**

Keywords: adsorption /spatial variation/model/sorption /sulfur /sulfates /soil types ecological/soil

variability

Abstract: Relationships among SO₂-24 adsorption, soil properties and seasonal variation in soil solution chemistry were examined at 13 deciduous forest sites in the Great Lakes region, USA. Mineral soils were sampled by horizon and soil solutions sampled at lower E and lower B horizon boundaries at 10 sites. Previously proposed SO₂-24 indices overpredicted sulfate adsorption in some SO₂-24 releasing horizons, limiting the applicability of published regression equations. Improved regression equations were derived using the sum of initial extractable and additional SO₂-24 adsorbed under laboratory conditions as the dependent variable. Sulfate retention indices predicted by the improved equations were independent of existing levels of extractable SO₂-24 and past history of atmospheric SO₂-24 deposition. Examination of within- and among-site variability in SO₂-24 adsorption potentials suggested that soils must be grouped tightly on a taxonomic basis for modelling purposes. Seasonal variations in soil solution SO₂-24 concn and fluxes were consistent with an annual cycle of SO₂-24 retention and release. Although seasonal variations in concn and fluxes appeared to be controlled by hydrological and S-cycling processes, the magnitude of SO₂-24 fluxes was primarily related to atmospheric SO₂-24 depositional rates.

399. MacDonald NW, Witter JA, Burton AJ, Pregitzer KS, and Richter DD 1993. Relationships among atmospheric deposition, throughfall, and soil properties in oak forest ecosystems. *Canadian Journal of Forest Research* 23: 2348-2357.

Keywords: sulfates /nitrates /soil pH/soil organic matter/throughfall /precipitation /vegetation types/acid deposition/air pollution/hydrology /soil chemistry/pollution /meteorology /Quercus alba/Quercus rubra/Quercus velutina

Abstract: Relations among pollutant (H⁺, SO₄²⁻, NO₃⁻) deposition, throughfall, ionic fluxes, and soil properties (pH, extractable SO₄²⁻, cations and Al, and organic matter) were examined at 5 oak forest sites in Michigan and one oak forest site in Ohio. The overstorey of all sites was dominated by Quercus velutina, Q. rubra and/or Q. alba. At each site, precipitation, throughfall, and soil samples were collected and chemically analysed. Sulfate and NO₃⁻ deposition increased from S. Michigan to N. Ohio in both precipitation and throughfall. Throughfall H⁺ fluxes also increased between these two areas. Throughfall fluxes of H⁺, SO₄²⁻, NO₃⁻ and Ca²⁺ were significantly related to wet pollutant deposition. Throughfall Ca²⁺ and Mg²⁺ fluxes also tended to reflect soil cation abundance, but H⁺ consumption in the canopy was a major contributor to cation fluxes at certain sites. After accounting for differences in inherent soil properties, additional variation in both surface and subsurface soil properties was statistically related to atmospheric deposition. While topographic position and impeded drainage also may be implicated, increased extractable SO₄²⁻, decreased potential to adsorb SO₄²⁻ and lower nutrient cation saturation in the solum of the most polluted site were consistent with pollutant deposition impacts. Results suggest that certain oak ecosystems in the southern Great Lakes region have experienced alteration in throughfall chemistry and soil properties as a result of increased pollutant deposition.

400. MacDonald NW, Zak DR, and Pregitzer KS 1995. Temperature effects on kinetics of microbial respiration and net nitrogen and sulfur mineralization. *Soil Science Society of America Journal* 59: 233-240.

Keywords: temperature /kinetics /transformation /cycling /climatic change/respiration /soil microorganisms /soil temperature/carbon/sulfur/nitrogen /sulfur /nitrogen mineralization/sulfur mineralization /northern hardwoods

Abstract: Global climate change may impact the cycling of C, N, and S in forest ecosystems because increased soil temperatures could alter rates of microbially mediated processes. The effects of temperature on microbial respiration and net N and S mineralization were studied in surface soils from four northern hardwood forests in the Great Lakes region, USA. Soil samples were incubated in the laboratory at five temperatures (5, 10, 15, 20, and 25 °C) for 32 wk. Headspace gas was analysed for CO₂-C at 2-wk intervals, and soils were extracted to determine

inorganic N and S. Cumulative respired C and mineralized N and S increased with temperature at all sites and were strongly related ($r^2 = 0.67$ to 0.90 , significant at $P = 0.001$) to an interaction between temperature and soil organic C. Production of respired C and mineralized N was closely fit by first-order kinetic models ($r^2 = 0.94$, $P = 0.001$), whereas mineralized S was best described by zero-order kinetics. Contrary to common assumptions, rate constants estimated from the first-order models were not consistently related to temperature, but apparent pool sizes of C and N were highly temperature dependent. Temperature effects on microbial respiration could not be accurately predicted using temperature-adjusted rate constants combined with a constant pool size of labile C. Results suggest that rates of microbial respiration and the mineralization of N and S may be related to a temperature-dependent constraint on microbial access to substrate pools. Simulation models should rely on a thorough understanding of the biological basis underlying microbially mediated C, N, and S transformations in soil.

401. **Maclean AL, Reed DD, Mroz GD, Lyon GW, and Edison T 1992. Using GIS to estimate forest resource changes. *Journal of Forestry* 90: 22-25.**

Keywords: Conifers /Remote sensing/forest inventories/thematic mapper/logging rates/Deforestation /Geographical information systems/Pinus banksiana/Pinus resinosa

Abstract: A case study is presented in which computer-assisted interpretation of Landsat Thematic Mapper imagery and GIS (geographic information systems) technology were used to assess logging rates in jack pine (*Pinus banksiana*) and red pine (*P. resinosa*) during 1986-89 in the Huron Pines Resource Conservation and Development District, Michigan. This study of removal patterns on both public and private lands confirmed that the long-term resource base in this region may be in jeopardy.

402. **Magill AH and Aber JD 2000. Dissolved Organic Carbon and Nitrogen Relationships in Forest Litter as Affected by Nitrogen Deposition. *Soil Biology & Biochemistry* 32: 603-613.**

Keywords: Decomposition/Forest Floor/Nitrogen Inputs/soil chemistry/northern hardwoods /Leaf-Litter/soil microorganisms/DOC/Soil Solution/ Decomposition/ Ecosystems/ Dynamics/ Saturation

Abstract: Dissolved forms of carbon and nitrogen have become recognized for their importance in forest nutrient cycling. The role of dissolved organic carbon (DOC) as an energy source for microbial metabolism is of particular interest. A laboratory decomposition experiment was conducted to examine the relationship between potential increased N inputs (via acid deposition) and DOC production in the forest litter layer and subsequent effects on DOC availability in the forest floor. Air-dried leaf litter (seven species) was treated with nitrogen (nitrate or ammonium) or deionized (DI) water at weekly intervals throughout 15 weeks and leached with DI water at 1 or 2 week intervals. Leachate was analyzed for DOC, inorganic nitrogen ($\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$) and dissolved organic nitrogen (DON). Litter was analyzed for percent C, percent N, weight loss and percent cellulose and lignin. Nitrogen treatments did not greatly affect DOC concentrations in litter leachate. Differences in DOC concentrations were primarily due to a wide range of initial litter chemistries, where species with high extractives and low lignin had the highest DOC leachate concentrations. Nitrogen treated samples showed greater weight loss than controls although nitrate and ammonium treatments were not significantly different. Between 6 and 39% of total carbon loss was leached as DOC. These findings suggest that different forest types could vary greatly in the quantity of carbon consumed or released and that nitrogen inputs appear to affect this overall cycle by increasing respiration (as measured by weight loss), rather than increasing DOC release into the soil solution. Further examination of the fate of DOC as it moves down in the soil profile and measurements of CO_2 evolution during laboratory decomposition, are necessary to better understand these processes.

403. **Mallik AU, Gong YL, and Bell FW 1997. Regeneration behaviour of competing plants after clear-cutting. Great Lakes Forestry Centre (Canadian Forestry Service) NODA-NFP Notes No.**

29, 5 pp.

Keywords: natural regeneration/competition/weeds /clear felling/*Prunus serotina*/*Populus tremuloides*/*Pinus banksiana* /*Alnus viridis*

Abstract: Competition by undesirable trembling aspen (*Populus tremuloides*), pin cherry (*Prunus virginiana*), green alder (*Alnus viridis*) and beaked hazel (*Corylus cornuta*) was studied in a 7-yr-old jack pine (*Pinus banksiana*) plantation in the Seine River Forest Management area, 58 km north of the Atikokan, Ontario.

404. **Mallik AU, Peterson GW, and Bell FW 1996. Vegetative and seedling regeneration of pin cherry (*Prunus pensylvanica*): efficacy of herbicide treatment. Great Lakes Forestry Centre (Canadian Forestry Service) NODA-NFP Notes No. 21, 4 pp.**

Keywords: weed control/woody weeds/chemical control/herbicide/glyphosate /natural regeneration/suckering /seeds /forest plantations/*Prunus pensylvanica*/*Pinus banksiana*

Abstract: Studies were conducted in a 7-year-old jack pine (*Pinus banksiana*) plantation near Atikokan, Ontario to determine, for pin cherry (*Prunus pensylvanica*), the ratio of the current year's seedling recruitment to the previous year's stem density, seed production, the soil seed bank (in summer 1993 and 1994) and the efficacy of Vision (glyphosate) applied aerially in August 1992 to control this woody weed. Vegetative regeneration by suckering was more common than seed regeneration for pin cherry. Glyphosate effectively controlled the shrub's vegetative growth, although seedlings regenerated after treatment.

405. **Manolis JC, Andersen DE, and Cuthbert FJ 2000. Patterns in Clearcut Edge and Fragmentation Effect Studies in Northern Hardwood-Conifer Landscapes: Retrospective Power Analysis and Minnesota Results. *Wildlife Society Bulletin* 28: 1088-1101.**

Keywords: Clearcutting/Edge Effects/Forest Fragmentation/Nesting Success/Power Analysis/Forest-Dominated Landscape/Predation Rates/Reproductive Success/ Birds/ Depredation/ Scale/Communities/Management/northern hardwoods

Abstract: The effects of edge and fragmentation on avian nesting success are well documented in agricultural landscapes. However, it is unclear whether these effects are common in predominantly forested landscapes. In particular, edge and fragmentation effects caused by clearcutting are poorly understood. To better understand this problem, we examined the relation of nesting success to clearcut edges in north-central Minnesota. We found elevated predation rates near clearcut edges using artificial and natural ground nests. To aid interpretation of studies conducted in the Northern Hardwood-Conifer Forest Region (NHCF) of North America, we estimated statistical power for 26 analyses (subsets of 11 papers and our own analyses) and, where possible, we reanalyzed the data and estimated effect size (with associated confidence intervals). In addition, we examined design issues such as presence of pseudoreplication. Statistical power was low for many of the studies and pseudoreplication was evident in several. Without considering power or design issues, 13 of the analyses found edge effects, 12 showed no effects, and one yielded greater predation rates in unfragmented versus fragmented areas ($\alpha = 0.05$). When we excluded studies with low statistical power (< 0.80) and pseudoreplication from analysis, 10 of the remaining studies reported edge effects, 3 showed no effects, and one showed greater predation rates in unfragmented versus fragmented areas. Variability in edge-effect results may be due in part to variability in strength of study design. Previous evaluations have suggested that edge effects are found mainly in agricultural landscapes, but our results suggest that these effects also may be common in extensively forested NHCF landscapes. Within extensive but managed forests of this region, relatively large, contiguous patches of mature forest, unfragmented by clearcutting, may be required to conserve some forest interior bird species.

406. **Martin AJ and Hix DM 1988. Regeneration development in an upland hardwood stand following a**

shelterwood harvest. *Northern Journal of Applied Forestry* 5: 46-49.

Keywords: Silvicultural systems/shelterwood /natural regeneration/*Quercus rubra*/*Tilia americana*/ *Fraxinus americana* /*Ostrya virginiana* /competition

Abstract: A total of 85 permanent mil-acre plots was established in 1958 in a 3-felling shelterwood, 3.5 acres, in E.-central Wisconsin. The stand was predominantly northern red oak [*Quercus rubra*] before the first cut in 1957. The plots were remeasured before and after the second felling in 1962 and in spring 1985. After 26 growing seasons, the proportion of red oak in the stand was small (7.8% of b.a., 3.6% of stems); all the red oak now present regenerated after the plots were established. The predominant species was eastern hophornbeam [*Ostrya virginiana*], although other species such as white ash [*Fraxinus americana*] and basswood [*Tilia americana*] were common. Ht. growth and survival rates were significantly greater for those stems taller than the mean seedling ht. in 1959. It is concluded that a shelterwood harvest alone may not be sufficient to regenerate northern red oak and that additional cultural practices, e.g. weeding, will be necessary.

407. **Martin AJ and Hix DM 1986. Upland hardwood regeneration following clearcut and shelterwood harvests. Department of Forestry (University of Wisconsin) Forestry Research Notes No. 264, 6 pp.**

Keywords: Natural regeneration/stand characteristics/logging /competition/composition /Clear felling/ecology /Silvicultural systems/shelterwood /broadleaves /*Acer saccharum*/*Quercus rubra*

Abstract: An account is given of 2 case studies that examined regeneration of northern red oak [*Quercus rubra*] in E.-central Wisconsin. By autumn 1984, red oak comprised 20-25% of the basal area and number of trees per acre in a stand clear felled in 1949. The distribution of oak within the stand was quite variable. Although the red oak is presently well established, the proportion of sugar maple [*Acer saccharum*] is increasing so that the oak component may be smaller in the next rotation. Oak regeneration by 1985 after 3 shelterwood fellings in 1957, 1962 and 1972 (final felling) was unsatisfactory, comprising only 4% of the stems and 8% of the basal area.

408. **Martin CW, Smith CT, and Tritton LM 1989. New perspectives on silvicultural management of northern hardwoods. U.S. For. Serv. General Technical Report NE-GTR-124, 107 pp.**

Keywords: silvicultural systems/Vegetation types/management /northern hardwoods/site characteristics/pathology

Abstract: Including 8 invited papers (peer reviewed) and 4 contributed posters. The objective of the symposium was to discuss the combined influences of sites, nutrients, pathology, entomology, equipment technology and economics on the choice of a silvicultural system for the management of northern broadleaved forests in the northeastern and Lake States of the USA. The final chapter summarizes the panel discussion.

409. **Martin ME and Aber JD 1997. High spectral resolution remote sensing of forest canopy lignin, nitrogen, and ecosystem processes. *Ecological Applications* 7: 431-443.**

Keywords: lignin /nitrogen /remote sensing/resolution /canopy /foliar chemistry /forest litter/imagery /infrared photography/aerial photography/carbon cycle/nitrogen cycle/cycling /*Acer rubrum*/*Acer saccharum*/*Larix laricina*/*Quercus rubra*/*Quercus velutina*/*Tilia americana*/*Pinus strobus*/*Pinus resinosa*/*Abies balsamea*/*Tsuga canadensis*

Abstract: Remote sensing of foliar chemistry has been recognized as an important element in producing large-scale, spatially explicit estimates of forest ecosystem function. This study was designed to determine whether data from NASA's Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) could be used to determine forest canopy chemistry at a spatial resolution

of 20 m, and if so, to use that information to drive an ecosystem productivity model. Foliage and leaf litter were sampled to determine canopy-level nitrogen and lignin concentrations on 40 plots at Blackhawk Island, Wisconsin, where the forest trees were predominantly *Acer saccharum*, *Tilia americana*, *Quercus velutina*, *Pinus resinosa*, *Pinus strobus* and *Tsuga canadensis*, and Harvard Forest, Massachusetts, where the stands comprised either mixed-hardwood species (primarily *Quercus rubra* and *Acer rubrum*) or conifers (*Pinus resinosa*, *Pinus strobus*, *Abies balsamea*, *Larix laricina* and *Tsuga canadensis*). At the time of the field sampling, AVIRIS data were acquired for both study areas. Calibration equations were developed, relating nitrogen and lignin to selected first-difference spectral bands ($R^2 = 0.87$ and 0.77 , respectively). Calibration equations were evaluated on the basis of inter- and intrasite statistics. These equations were applied to all image pixels to make spatially explicit estimates of canopy nitrogen and lignin for both study sites. These estimates of nitrogen and lignin concentrations were then used with existing models to predict net ecosystem productivity at Harvard Forest and nitrogen mineralization rates at Blackhawk Island.

410. **Mattson JA 1993. Tree-section harvesting of northern hardwood thinnings. U.S. For. Serv. Research Paper NC-312, 16 pp.**

Keywords: thinning /logging /whole tree logging/hardwoods /shortwood logging/northern hardwoods

411. **Mauldin TE and Plantinga AJ 1999. Land Use in the Lake States Region: an Analysis of Past Trends and Projections of Future Changes. U.S. For. Serv. Research Paper PNW-519, 24 pp.**

Keywords: Land Use Change/Urban Development/Land Rents/Timberland Area Projections/Cropping Patterns/Quality/Policies/Impact

Abstract: This paper presents the historic trends and future projections of forest, farm, and urban land uses for the Lake States of Michigan, Minnesota, and Wisconsin. Since the 1950s, forest and farm land have been decreasing, and urban and other land uses have been increasing throughout the Lake States. Forest, crop, and pasture land have decreased in the region by 3.2, 5.4, and 4.0 million acres, respectively, whereas urban and other land uses have increased by 2.1 and 10.3 million acres, respectively. These decreases and increases were most pronounced during the 1950s and 1980s. Land rents and land quality were used to make projections of the distribution of Wisconsin's future land uses. In Michigan and Minnesota, forest and farm land use projections were based on the extrapolation of historic trends, and urban land use projections were adopted from Wisconsin's econometric projections; land rents and land quality were not used for all projections because of insufficient data. The projections of land uses through 2050 are consistent with historic trends—forest and agricultural lands will decline, and urban and other land uses will increase. Timberland is projected to be reduced by 13 percent in Wisconsin, 11 percent in Michigan, and 10 percent in Minnesota.

412. **May DM and Pilon J 1995. Michigan timber industry - an assessment of timber product output and use, 1992. U.S. For. Serv. Resource Bulletin NC-162, 64 pp.**

Keywords: forest products industries/roundwood /pulpwood /logs /logging /wood residues/resources

Abstract: Statistics are presented on industrial roundwood, pulpwood, saw logs, veneer logs, other products, timber removals, harvest residues and primary mill residues.

413. **McClain KM, Morris DM, Hills SC, and Buse LJ 1994. The effects of initial spacing on growth and crown development for planted northern conifers: 37-year results. *Forestry Chronicle* 70: 174-182.**

Keywords: cost benefit analysis/economics/volume /planting /increment /plant morphology/forest plantations/spacing /crown /growth /*Pinus resinosa*/*Picea glauca*/*Picea mariana*

Abstract: A spacing trial was established near Thunder Bay, Ontario in 1950. This trial consisted of black spruce (*Picea mariana*), white spruce (*Picea glauca*), and red pine (*Pinus resinosa*), each established at three different spacings: 1.8 m, 2.7 m, and 3.6 m. This study examines the differences in growth and crown development attributed to initial spacing. In addition, a benefit/cost analysis was performed to evaluate the economic efficiency of the various species/spacing combinations. Diameter at breast height, live crown length, and crown width, all exhibited significant ($P < 0.001$) increases as initial spacing increased, irrespective of species, but height demonstrated a decreasing trend ($P < 0.020$). Gross total and merchantable stem volume per tree increased for all species as initial spacing increased; however, volume production per unit area decreased significantly for all species as spacing increased. The shift to higher-valued products from the wider-spaced plantations appeared to provide the best economic return. As a result of both greater merchantable volumes and greater percentages of these volumes available as higher-valued products, benefit/cost ratios for red pine (0.995 to 1.337) were greater than those for the spruces (0.595 to 0.866). Although red pine currently represents less than 4% of Ontario's total regeneration effort, the results from this study suggest it deserves further consideration on some boreal sites.

414. **McCune B and Cottam G 1985. The successional status of a southern Wisconsin oak woods. *Ecology* 66: 1270-1278.**

Keywords: Wilt /Plant succession/theory /Synecology /Vegetation types/Natural regeneration/stand characteristics/broadleaves /*Quercus alba*/*Quercus velutina*/*Ceratocystis fagacearum*

Abstract: The applicability of concepts of succession was examined using tree growth and demographic data for 1956-83 from Noe Woods, dominated by *Quercus alba* and *Q. velutina*. Oak populations were heavily influenced by wilt disease (*Ceratocystis fagacearum*), with large trees of *Q. velutina* suffering 15-20% mortality in each 5-yr period. *Q. alba* increased in b.a. but declined in numbers. Regeneration was dominated by species that are short-lived and small-statured or threatened by disease and that are unlikely to form a new canopy. None of the species in the woods appears capable of forming a self-replacing climax. It is suggested that the absence of a climax species in Noe Woods and other areas of the prairie-forest transition is the result of changed disturbance regimes.

415. **McLaren BE and Janke RA 1996. Seedbed and canopy cover effects on balsam fir seedling establishment in Isle Royale National Park. *Canadian Journal of Forest Research* 26: 782-793.**

Keywords: seeds /seed germination/seedlings /mortality /canopy /recruitment /seedbeds /natural regeneration/*Abies balsamea*/browse /damage/*Alces alces*

Abstract: While balsam fir (*Abies balsamea*) dominated forests are vanishing from the southwest end of Isle Royale National Park, Michigan, renewal of fir stands and recruitment into the canopy is occurring on the northeast end. It was speculated that the difference is related both to severe browsing by moose (*Alces alces*), and to the frequency of disturbances like fire and windthrow. A survey of 24 stands in 1992 and in situ experimentation on Isle Royale show that balsam fir seedling survival is optimum under 40-79% canopy cover. Late-season and overwinter mortality in 1-year-old seedlings is highest under >80% canopy cover, while germination is lowest under <40% cover. Germination substrates were ranked by 'preference ratios', and by comparing the overwinter survival of young fir seedlings on five natural media. The ranking showed best performance on moss, variable survival success on rotten wood, and highest mortality on broadleaf litter. However, ample seedling densities occur on the southwest end of the island, and the failure of fir to reach the overstorey in this area is apparently not related to poor seedling establishment.

416. **McLaughlin JW, Reed DD, Bagley ST, Jurgensen MF, and Mroz GD 1994. Foliar amino acid**

accumulation as an indicator of ecosystem stress for first-year sugar maple seedlings. *Journal of Environmental Quality* 23: 154-161.

Keywords: growth /plant nutrition/nitrogen /phosphorus /soil chemistry/stress /plant composition/seedlings /amino acids/air pollution/nutrient deficiencies/*Acer saccharum*

Abstract: First-year growth, N and P nutrition, soluble foliar and root total amino acid concentrations, and foliar concentrations of arginine, glutamine and proline were determined for sugar maple (*Acer saccharum*) seedlings in 2 sugar maple stands in Michigan. Seedling growth was greater at the southern site (Wellston), which was exposed to high atmospheric deposition, and had high available soil P and seedling foliar P. Foliar glutamine, arginine and proline were greater at the northern site (Alberta), which received less atmospheric deposition but also had lower available soil P and seedling foliar P, less seedling growth and greater canopy closure. It is concluded that differences in amino acid concentrations reflect differences in ecological (e.g. P deficiencies) rather than anthropogenic (e.g. air pollution) stresses.

417. **McLaughlin JW, Reed DD, Jurgensen MF, Mroz GD, and Bagley ST 1996. Relationships between soluble sugar concentrations in roots and ecosystem stress for first-year sugar maple seedlings. *Water, Air, and Soil Pollution* 88: 1-19.**

Keywords: seedlings /fructose /glucose /sucrose /reducing sugars/stress factors/plant nutrition/mycorrhizas /vesicular arbuscular mycorrhizas/acid deposition/sulfate /nitrate /hydrogen ions/soil temperature/air temperature/phosphorus /soil chemistry/plant composition/biochemistry /mycorrhizal fungi/colonization /forest decline/environmental factors/seedling growth/roots /sugars /decline /plant pathology/*Acer saccharum*

Abstract: Accumulation of reducing sugars (i.e. glucose and fructose) in plant roots has been consistently correlated with forest dieback and decline, and therefore, has potential as a biological indicator of ecosystem stress. In this study, the relationships between acid deposition and 'natural' (temperature, mycorrhizas, and nutrition) factors with first-year sugar maple (*Acer saccharum*) seedling root sugar concentrations and growth were assessed in 2 sugar maple dominated forests in Michigan. Seedlings at the southern site (Wellston) had greater root growth, phosphorus, total sugar, and sucrose concentrations in the roots, but a lower reducing sugar concentration. In addition, percentage root length colonized by vesicular-arbuscular mycorrhizal fungi was less than that found for seedlings growing at the northern site (Alberta). Throughfall deposition of nitrate, sulfate, and hydrogen ions was not significantly correlated with seedling total or reducing sugar concentration. Total sugar concentration in seedling roots was positively correlated with air and soil temperatures at the southern site, but not at the northern site. Seedling tissue phosphorus concentration was correlated with total sugars at both sites, with sucrose at the southern site, and reducing sugars at the northern site. Mycorrhizal colonization rates at the Alberta site were positively correlated with reducing sugar concentration in seedling roots and negatively correlated with sucrose concentration. The results suggest that differences in seedling root sugar concentrations in these two forests are related to seedling root growth, and are most likely to be due to ecological variables (such as available soil phosphorus, temperature, and growing season length through some complex interaction with mycorrhizas) rather than acid deposition stress.

418. **Meteer JW and Linjala ET 1973. Tree growth and vigor class in northern hardwoods. Results from a continuous forest inventory. *Journal of Forestry* 71: 412-413.**

Keywords: increment /tree classes/broadleaves /yields /*Acer saccharum*/northern hardwoods

Abstract: Presents average annual diameter growth rates for *Acer saccharum* computed from measurements made over 32 years in permanent continuous-forest-inventory plots in stands in Michigan that had been given a heavy partial felling. Distinct differences in growth rate could be identified with individual tree vigour/risk classes (described), but there was no apparent correlation between periodic diameter growth and tree diameter at the start of the period.

419. Metzger FT and Schultz J 1981. Spring ground layer vegetation 50 years after harvesting in northern hardwood forests. *American Midland Naturalist* 105: 44-50.

Keywords: northern hardwoods /understory /vegetation survey /harvesting impacts /succession /disturbance /silviculture

Abstract: Ground layer vegetation on four approximately 50-year-old silviculture research plots at the Upper Peninsula Experimental Forest, Michigan, was surveyed in the spring of 1976. Species composition was typical of northern hardwood forests and similar among plots. The vegetation was denser but less diverse on clear-cut harvest plots than on less severely but more frequently disturbed selection harvest plots. Periodic reharvests of the selection harvest plots promoted development of an intermediate layer of tree seedlings and shrubs that was probably responsible for the differences in ground layer vegetation among harvest methods.

420. Metzger FT and Schultz J 1984. Understory response to 50 years of management of a northern hardwood forest in Upper Michigan. *American Midland Naturalist* 112: 209-223.

Keywords: northern hardwoods /herbaceous vegetation /silviculture /diversity /species composition /understory /harvesting

Abstract: Herbaceous and woody understory layers on five silvicultural research plots at the Upper Peninsula Experimental Forest, Michigan, were surveyed in summer for up to 5 years after the studies began and again 50 years later. Species composition and diversity showed the greatest change 4 and 5 years after harvest and by 50 years they were similar to original conditions. After 50 years the understory was denser and had greater cover than originally. Early treatment differences among plots had diminished after 50 years.

421. Metzger FT and Tubbs CH 1971. The influence of cutting method on regeneration of second-growth northern hardwoods. *Journal of Forestry* 69: 559-564.

Keywords: Acer saccharum/natural regeneration/silviculture/canopy /selective felling/vegetation type/Fraxinus americana/northern hardwoods /harvesting treatments /second growth /tree selection cut /diameter limit cut /clear cut /forest fragmentation

Abstract: Reports the condition of regeneration 15 years after nine felling treatments were applied to three second-growth hardwood stands, with Acer saccharum predominating, in the Argonne Experimental Forest, N. Wisconsin. Treatments were: individual tree selection felling to residual overstorey densities of 90, 75, and 60 ft² b.a./acre in trees of 5 in d.b.h.; diameter-limit felling of trees with stump diameter 8 in, to ca. 20 ft²/acre; clear felling of patches at 10-year intervals; clear felling of progressive strips at 5-year intervals; and clear felling of blocks at the start of the experiment. Generally, the diameter-limit and heavy fellings did not give regeneration of uniform size and distribution, or of desirable composition. By the end of 15 years, ca. half the quadrats were dominated by shrubs, grasses and sedges. Individual-tree selection fellings consistently produced abundant regeneration, usually >30 000 seedlings/acre regardless of overstorey stocking. Stocking was extremely variable on the clear-felled areas. A. saccharum occurred on almost all stocked quadrats in the partial fellings: its degree of dominance in the regeneration was inversely related to felling intensity, and on the more heavily felled areas Fraxinus americana became increasingly dominant.

422. Michie BR 1981. *An economic investigation of uneven-aged northern hardwood management*. PhD dissertation, University of Wisconsin, Madison. 154 pp.

Keywords: northern hardwoods /model /economics /competition

Abstract: The main emphasis of this thesis is the development and use of a matrix model of uneven-aged northern hardwood growth. The model improves on previous matrix models which

predicted exponential growth of forest stands unless regularly harvested. The model described here represents ingrowth as a function of growing stock. As growing stock increases ingrowth declines providing a feedback mechanism which restricts stand growth. Estimation of model parameters can be done by simple proportions and linear regression if appropriate data are available. Alternative estimation techniques are explored for situations in which data are very limited. Northern hardwood management regimes are investigated by linear programming, leading to the simultaneous determination of optimum harvest, residual stock, and cutting cycle. The study shows the key role played by fixed per-acre costs in the determination of optimum cutting cycles. The problem of conversion of a given initial diameter distribution to alternative economic distributions is also explored. A variety of price vectors along with fixed and variable harvest costs show the effect of prices and costs on economic management strategies. Side studies deal with a model of mixed species stands and identification of the feasible range of steady state harvests.

423. **Michie BR 1985. Uneven-aged stand management and the value of forest land. *Forest Science* 31: 116-121.**

Keywords: economics /forest management/simulation /profitability /Silvicultural systems/selection /model economics

Abstract: [See FA 42, 4333] A matrix growth model of a selection forest was used to investigate the land expectation value (LEV, the present value of harvests during a conversion from the existing stand structure to an economically superior stand structure plus the discounted sum of all future yields once the conversion has been completed). The LEV was demonstrated to be dependent on the initial stand structure and the length of the conversion period. Forest values were calculated, giving the total value of land and growing stock.

424. **Michie BR and Buongiorno J 1984. Estimation of a matrix model of forest growth from re-measured permanent plots. *Forest Ecology and Management* 8: 127-135.**

Keywords: model growth/forest management/Stand characteristics/development

Abstract: [See FA 42, 4333] Various techniques were evaluated for estimating coefficients in a model of a selection forest developed previously. The data originated from 161 plots re-measured in 1961, 1964 and 1969. The detailed individual tree data available permitted a very simple and unbiased estimation of the growth matrix parameters. It was shown that, in situations where less information would lead to very serious bias and meaningless results. A constrained estimation procedure is proposed to alleviate this bias.

425. **Mielke ME and Charette DA 1989. The incidence of sapstreak disease of sugar maple in Menominee County, Wisconsin, and its relationship to wounds and season of logging. *Northern Journal of Applied Forestry* 6: 65-67.**

Keywords: fungal diseases/Injuries /Logging /damage /forest trees/plant pathology/plant pathogenic fungi/Acer saccharum /Ceratocystis coerulea /Armillaria spp. /Xylaria spp. /Ustilina spp. /Daldinia spp. /sapstreak disease

Abstract: Stands of sugar maple [*Acer saccharum*] along a 0.5 chain-wide strip on both sides of 6.1 miles of major skid and haul roads logged in 1977-82 were examined for sapstreak disease caused by *Ceratocystis coerulea*. There were an average of 0.89 wounded sugar maple per chain (0.1 acre) of roadside, and sapstreak was found in 4.8% (21 of 431) of the wounded sugar maples. No significant differences existed in the incidence of sapstreak in stands logged during frozen and non-frozen conditions. All trees infected with sapstreak were also infected by 1 or more of: *Armillaria* sp., *Xylaria* sp., *Ustilina* sp. and *Daldinia* sp.

426. **Miller WE, Kessler KJ Jr., Ohman JH, and Eschle JT 1978. Timber quality of northern hardwood**

regrowth in the Lake States. *Forest Science* 24: 247-259.

Keywords: insect pests/grading /damage /stem form/roundwood /wood defects/pith flecks/ discoloration /Acer saccharum/northern hardwoods /bud miners /Lepidoptera /Proteoteras moffatiana /Obrussa ochrefasciella /Phytobia setosa /Diptera

Abstract: Exterior defects up to 33 ft above ground were surveyed on 2313 trees (d.b.h. 1-15 inches) in 90 plots in broadleaf [predominantly *Acer saccharum*] stands in Wisconsin and Upper Michigan, and were grouped into 6 types: (a) branchiness-forkedness-holes; (b) miscellaneous (e.g. sprouting, lean, sweep and crook); (c) disease; (d) direct insect damage or presence; (e) scars from damage by vertebrates; and (f) scars from skidding and felling. The number of exterior defects was used to grade trees of d.b.h. 4-15 inches into 4 quality classes. Samples of 236 trees in the 3 better quality classes and 166 trees of *A. saccharum* from one forest, were felled and examined for interior defects. Results are tabulated by species, noting the contribution of each exterior defect type to the observed quality class distribution, and the incidence of interior defect (stain, decay, and parenchyma fleck caused by the dipterous *Phytobia setosa*). Most trees (52-69%) were of poor quality (class 4), the major defect types being (a), followed by (b). The prevalence of (a) is probably due to sapling damage by the terminal bud-mining lepidopterans *Proteoteras moffatiana* and *Obrussa ochrefasciella*, which were observed on freshly injured *A. saccharum* terminals in the present study [see FA 36, 2592].

427. **Miyata ES, Steinhilb HM, Mroz GD, and Coyer LA 1983. Productivity of a large-wheeled skidder and roller chopper for preparing sites. U.S. For. Serv. Research Paper NC-238, 8 pp.**

Keywords: site preparation/mechanical methods/operation costs

Abstract: A Fleco Corporation Model SS812 single drum roller chopper pulled by a Pettibone Master 1500 skidder was tested for preparation of a 9.5-ha gently rolling site (av. slope 7%) near Rhinelander, Wisconsin, which had been recently logged for pulpwood. The remaining stand had approx. 1730 stems/ha with an av. d.b.h. of 5.1 cm. The combination gave satisfactory site preparation for conifer establishment without excessive soil compaction. Productivity was approx. 0.78 ha per productive h with a machine only cost of \$65.07/h (1981 prices).

428. **Mladenoff DJ 1987. Dynamics of nitrogen mineralization and nitrification in hemlock and hardwood treefall gaps. *Ecology* 68: 1171-1180.**

Keywords: Cycling /nitrogen /Soil chemistry/vegetation types/nitrification /forest soils/ mineralization /Soil types ecological/transformation /Acer saccharum/Tsuga canadensis

Abstract: Nitrogen mineralization and nitrification were measured in gaps (0-3 yr old) and in adjacent undisturbed plots dominated by sugar maple or eastern hemlock in Porcupine Mts. Wilderness State Park, Michigan. Mineralization was greater in hemlock gaps than in maple gaps, but was less under hemlock canopy than under maple canopy. Nitrification in hemlock gaps was more than twice that under hemlock canopy, but was similar to that in maple gaps and under maple canopy. Results are discussed in relation to current hypotheses concerning community compositional change.

429. **Mladenoff DJ 1990. The relationship of the soil seed bank and understory vegetation in old-growth northern hardwood-hemlock treefall gaps. *Canadian Journal of Botany* 68: 2714-2721.**

Keywords: Synecology /canopy gaps/gap dynamics/seeds /seed banks/vegetation types/Acer saccharum/Betula alleghaniensis/Tsuga canadensis/northern hardwoods

Abstract: In mature northern hardwood forests, small treefall gaps constitute an important mode of compositional and structural change within the long return time (>1000 yr) of larger catastrophic disturbances. The soil seed bank and patterns in vegetation layers are described in this

disturbance regime context for a forest in the western upper peninsula of Michigan. In these small treefall gaps, herbaceous and woody species were similar to those of forest understorey plots, differing primarily in abundance. Seed bank communities were compositionally more similar among gaps than forest understorey plots, but vegetation similarity was equal among forest plots and among gaps. Seed bank/vegetation similarity was greater among forest plots than in gaps. Seed bank strategies differed among the plant species characteristic of the different forest layers. Dominant canopy tree species (*Acer saccharum*, *Tsuga canadensis*, *Betula alleghaniensis*) were not an important component of the seed bank. Bird-dispersed shrub and herbaceous species and ant-dispersed herbs were important in the seed bank, especially in gaps. Based on gap seed-bank response, it appears that understorey shrub abundance and pattern within the forest change with the time since large-scale disturbance, in accordance with species adaptations to the size and increase in number of small treefalls in the mature forest. These species patterns may relate to the patchy nature of resource availability that develops, especially that of nitrogen, which is controlled by the canopy species/gap mosaic.

430. **Mladenoff DJ and Stearns F 1993. Eastern hemlock regeneration and deer browsing in the northern Great Lakes region: a re-examination and model simulation. *Conservation Biology* 7: 889-900.**

Keywords: wildlife /browsing damage/natural regeneration/model *Tsuga canadensis* regeneration/ *Tsuga canadensis*/deer /*Odocoileus virginianus*

Abstract: White-tailed deer (*Odocoileus virginianus*) populations are currently extremely high in the upper Great Lakes region. It is argued that extrapolations should not be made from studies in single stands to explain regional failures of tree regeneration. A review is given of the life history characteristics of eastern hemlock (*Tsuga canadensis*), its long-term behaviour on a regional scale and recent studies in the context of long-term forest ecosystem processes. Computer simulations over 400 yr were conducted within a neutral framework to test whether factors other than deer browsing may explain the lack of hemlock regeneration in the northern lake states. Results suggested that browsing is not the critical step blocking forest re-establishment on a regional scale; the interaction of climate, disturbance, hemlock life history, ecosystem processes and historic land use produce positive feedbacks that prevent hemlock regeneration before deer browsing can occur.

431. **Mladenoff DJ, White MA, Crow TR, and Pastor J 1994. Applying principles of landscape design and management to integrate old-growth forest enhancement and commodity use. *Conservation Biology* 8: 752-762.**

Keywords: logging /clear felling/ecosystem management/forest management/landscape ecology/biodiversity /*Acer saccharum*/*Populus tremuloides*/*Betula papyrifera*/*Tsuga canadensis*/northern hardwoods

Abstract: Geographic information systems (GIS) and spatial analysis techniques were used to develop a landscape design to maintain old-growth forest remnants and integrate commodity production in the surrounding second-growth matrix. The 4500-ha forest landscape in northern Wisconsin contains scattered patches of old-growth eastern hemlock (*Tsuga canadensis*) and northern hardwoods, predominately sugar maple (*Acer saccharum*). The design incorporates an old-growth restoration zone surrounding old-growth patches to buffer and enhance forest-interior habitat and link nearby old-growth remnants. This addition restores aspects of landscape patch size and structure and ecosystem juxtaposition that characterize a nearby, large, and contiguous natural old-growth landscape. A larger secondary zone is delineated for uneven-aged forest management. This zone provides a matrix structurally similar to the old-growth patches but also accommodates harvesting. A larger outer zone is retained primarily in even-aged forest of aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera*), but traditional clear-felling practices are modified to partial felling and mixed-species rotations. This design meets limited goals of biodiversity enhancement and integrated commodity production in a landscape that will remain

largely harvested. The landscape design is therefore improved not only by buffers and corridors provided to old-growth ecosystems, but by modifying the management of the majority commodity lands matrix as well.

432. **Mohamed HK, Pathak S, Roy DN, Hutchinson TC, Mclaughlin DL, and Kinch JC 1997. Relationship between sugar maple decline and corresponding chemical changes in the stem tissue. *Water, Air, and Soil Pollution* 96: 321-327.**

Keywords: forest decline/soil acidity/soil pH/soil chemistry/aluminum /wood chemistry/stems /soil toxicity/acid soils/calcareous soils/Acer saccharum/soil podzols/soil brunisols

Abstract: Wood cores were taken at breast height from mature sugar maple (*Acer saccharum*) trees of approximately the same age from four sites in Ontario, Canada, differing in soil characteristics and general tree health. The soils of two of the sites were acidic (podzols), while the soils of the other two sites were calcareous (brunisols). Selected elemental analyses using Neutron Activation Analysis were conducted on the soils and the xylem wood of the trees, and the results were analysed in relation to tree health. Aluminum in stem xylem was significantly higher in declining trees (mean 7.7 ppm) than in healthy trees (mean 4.0) from the acidic sites, where aluminium was freely available in the soil. Soil extractable aluminium was also significantly higher in the soil adjacent to the declining trees (mean 5.10) than in that adjacent to the healthy trees (mean 3.20). These results show that xylem aluminium contents reflect the increased availability of aluminium in acidifying soils and provide additional evidence that dendrochemistry may be used as a proxy environmental monitoring tool.

433. **Monserud RA 1974. *Methodology for simulating Wisconsin northern hardwood stand dynamics*. PhD dissertation, University of Wisconsin, Madison. 173 pp.**

Keywords: northern hardwoods /model /stand dynamics

434. **Monserud RA and Ek AR 1977. Prediction of understory tree height growth in northern hardwood stands. *Forest Science* 23: 391-400.**

Keywords: stand tables/stand characteristics/understorey/increment /height /northern hardwoods

Abstract: A stand-table projection methodology in which the ht. increment of individual understory trees is predicted, within each ht. class, from the ht. increment of a representative tree (with a ht. equal to the midpoint of the ht. class), the site-index curve for the species, and a competition index, was applied to uneven-aged hardwood stands in Wisconsin. Results showed this method to be adequate. The most effective competition index (described) was based on the relative ht. of each overstorey tree weighted by their relative distance. The influence of understory density was unimportant. Only 5 understory ht. classes were necessary, with upper limits of 0.5, 2.0, 4.5, 10 and 25 ft.

435. **Moser JW Jr. 1972. Dynamics of an uneven-aged forest stand. *Forest Science* 18: 184-191.**

Keywords: stand characteristics/structure /development /age structure/increment /forecasting

Abstract: Describes a system of first-order ordinary differential equations that correspond with the components of net growth expressed in terms of stem numbers and b.a. Coefficients of the equations were derived from data (for a 6-year period in the history of an unthinned mixed hardwood stand in Wisconsin) used in a study already noticed [see FA 31, 1175]. Predicted growth showed good agreement with data for a subsequent 13-year period. Some discrepancies were caused by a decline in the incidence of Dutch Elm disease, so that mortality was less than expected.

436. **Moser JW Jr. 1967. *Growth and yield models for uneven-aged forest stands*. PhD dissertation, Purdue**

University, West Lafayette. 166 pp.

Keywords: Increment /Yield forecasting/Yield models/Yield theoretical studies/model

Abstract: In a study of a model in which elapsed time from a given condition provided a variable for integrating a survivor growth-rate function to derive a compatible survivor yield function, results indicated that it is feasible to obtain compatible growth and yield functions for uneven-aged stands from permanent plot data, and that the resulting equations provide a basis for a computer subroutine to simulate the periodic changes in the growth components of a forest stand.

437. Moser JW Jr. and Hall OF 1969. Deriving growth and yield functions for uneven-aged forest stands. *Forest Science* 15: 183-188.

Keywords: Increment/Stand composition /Yield

Abstract: In a study of a model in which elapsed time from a given condition provided a variable for integrating a survivor growth-rate function to derive a compatible survivor yield function, results indicated that it is feasible to obtain compatible growth and yield functions for uneven-aged stands from permanent plot data, and that the resulting equations provide a basis for a computer subroutine to simulate the periodic changes in the growth components of a forest stand. Based on the thesis by Moser already noticed [cf. F.A. 29 No. 6164].

438. Moser JW Jr., Tubbs CH, and Jacks RD 1979. Evaluation of a growth projection system for uneven-aged northern hardwoods. *Journal of Forestry* 77: 421-423.

Keywords: increment /felling /selection /forecasting /broadleaves /yields /silvicultural systems/Acer saccharum/northern hardwoods /model growth

Abstract: [See FA 36, 7938] A model for growth simulation of sugar maple stands based on felling studies in Michigan from 1926 to 1966, was evaluated using data from selection fellings to different residual densities, collected between 1951 and 1971. B.a. and vol. were more accurately predicted than the numbers of trees by size classes, but all estimates were adequate for planning purposes.

439. Mroz GD 1983. *An evaluation of whole tree harvest effects on northern hardwoods soils-site relationships and coppice regrowth*. PhD dissertation, North Carolina State University, Raleigh. 98 pp.

Keywords: Acer rubrum/northern hardwoods /soil site study /whole tree harvesting /aboveground biomass /soil moisture /soil chemistry /phosphorus /calcium /magnesium/nitrogen /soil leaching /fertilizer /sprouting /nutrient losses /harvesting impacts

Abstract: Soil site relationships were investigated in three northern hardwood stands in Upper Michigan to evaluate susceptibility to change following whole tree harvesting. The three sites were on sandy out-wash soils and represented site index 15, 19 and 20 meters for red maple at age 50. Biomass estimates on the sites were 110, 170 and 98 Mg ha⁽⁻¹⁾. The soil property most related to site quality was available water which affects productivity and nutrient availability. Available P was also significantly correlated with site quality increases. Available P was extremely variable after harvest, resulting in nonsignificant increases on the low and medium sites and decreases on the high site. Whole tree harvesting resulted in large decreases in forest floor horizon weight due to whole tree skidding and accelerated organic matter decomposition. This disruption of forest floor horizons and subsequent leaching resulted in N decreases of 1.3 Mg ha⁽⁻¹⁾ from the litter layer and top meter of soil on all sites. Decreases in soil exchangeable K of over 1 Mg ha⁽⁻¹⁾ were also evident on all sites while changes in Ca and Mg were much smaller on the low and medium than on the high site. These losses from surface soil horizons are higher than those previously reported for till soils after clearcutting northern hardwoods. The magnitude of the

losses, make it important to identify sites on which there may be a danger of permanently lowering site quality and productivity. This can be done by identifying critical soil factors on sites of varying quality prior to treatment and evaluating changes after treatment. Early growth of Northern hardwood stump sprouts was investigated to determine the short rotation biomass production of coppiced pole-sized stands. This included evaluating the effects of fertilizer amendments and site quality on sprout numbers and height as well as biomass. Sprout numbers were related to stump diameter and species but independent of site quality and fertilizer additions. Sprout height growth on a stump was independent of numbers and showed increases with NPK fertilization on the medium and high sites due to increased available water capacity. Mean annual increments after 4 years ranged from 0.1 Mg ha⁽⁻¹⁾ yr⁽⁻¹⁾ on the low site to 1.6 Mg ha⁽⁻¹⁾ yr⁽⁻¹⁾ with NPK fertilization on the high site. . . . (Author's abstract exceeds stipulated maximum length. Discontinued here with permission of author. UMI)

440. **Mroz GD and Berner JF 1983. Artificial regeneration of conifers in the upper Great Lakes region. Misc. symposium proceedings.**

Keywords: Artificial regeneration/conifers /site preparation /site evaluation/forest management

Abstract: Proceedings of a symposium held in Oct. 1982 at Green Bay, Wisconsin, sponsored by Mead Paper, Champion International, the USDA Forest Service and the School of Forestry, Michigan Technological University. There are 44 papers on topics including site evaluation, species selection, site preparation, stock production, planting and seeding, early plantation maintenance, and future considerations.

441. **Mroz GD, Frederick DJ, and Jurgensen MF 1985. Site and fertilizer effects on northern hardwood stump sprouting. *Canadian Journal of Forest Research* 15: 535-543.**

Keywords: Coppice /biomass production/growth /soil /silviculture /energy /Fertilizers /NPK fertilizers/responses /Acer rubrum/Prunus serotina/Betula alleghaniensis/northern hardwoods /short rotation /fertilizers

Abstract: Early growth of stump sprouts [coppice shoots] of northern broadleaved species (mainly *Acer rubrum*, *A. saccharum* with *Prunus serotina* and *Betula alleghaniensis*) was studied at 3 sites in Michigan to determine the short rotation biomass production of coppiced, pole-sized stands. This included studying the effects of fertilizer amendments (NPK) and site quality (low, medium and high) on shoot numbers and height as well as biomass. Coppice shoot numbers were related to stump diam. and species, but were independent of site quality and fertilizer additions. Height growth of shoots on a stump was independent of numbers and showed increases with site quality. Biomass per stump and per hectare showed increases with NPK fertilizing on the medium and high quality sites because of increased available water capacity. Mean annual increments after 4 yr ranged from 0.1 t/ha on the low quality site to 1.6 t/ha with NPK fertilizer on the high quality site. Comparisons of 3- and 4-yr-old coppice shoot growth showed large 4th-yr biomass increases with p.a.i. reaching 4.8 t/ha on the high quality site NPK treatments. Biomass responses to fertilizing were mostly not significant owing to a wide variability of biomass on blocks within sites. This may be due to inherent soil factors or large N and K losses following whole-tree harvesting of the original stands. Coppicing of northern broadleaves may be an alternative to intensive poplar culture for energy production.

442. **Mroz GD, Gale MR, Jurgensen MF, Frederick DJ, and Clark A III 1985. Composition, structure, and aboveground biomass of two old-growth northern hardwood stands in Upper Michigan. *Canadian Journal of Forest Research* 15: 78-82.**

Keywords: Synecology /layer structure/site factors/Stand characteristics/structure /composition /Biomass production/broadleaves /Acer saccharum/northern hardwoods

Abstract: Two climax broadleaved stands growing on sites of differing quality were characterized

on the basis of stand composition and above-ground biomass as estimated by regression techniques. Both stands were dominated by sugar maple. Total above-ground biomass was estimated at 284 and 325 t/ha on the sites. These values are much lower than estimates for other climax stands in the region because of the lack of shade-tolerant conifers. Site differences are probably caused by differences in altitude and soil rooting volume.

443. **Mroz GD, Jurgensen MF, and Frederick DJ 1985. Soil nutrient changes following whole tree harvesting on three northern hardwood sites. *Soil Science Society of America Journal* 49: 1552-1557.**

Keywords: forestry management/whole tree logging/Clear felling/nutrient cycling /logging /soil chemistry/Acer rubrum/northern hardwoods /leaching /potassium /calcium /magnesium

Abstract: Three northern hardwood stands were clearcut to evaluate the effect of whole tree harvesting on sites of varying quality. Stands were growing on sandy, outwash soils and had red maple (*Acer rubrum*) site indices of 15, 19, and 20 and biomass values of 114, 165, and 181 Mg ha⁻¹. Harvesting did not alter extractable soil P levels significantly on any site. Forest floor weights decreased to similar values on all sites 1.5 yr after harvest. Nitrogen losses of over 1.3 Mg ha⁻¹ occurred in the top meter of soil on all sites. This was attributed to the mixing of the forest floor with the surface mineral soil by the full tree skidding and the subsequent leaching of mineralized N. Soil exchangeable K decreased more than 1 Mg ha⁻¹ on all sites. Changes in Ca and Mg were much smaller on the low and medium than on the high site. These losses from surface soil horizons are higher than reported previously for clearcutting northern hardwoods on till soils. The greatest impact of whole tree harvest on soil nutrients occurred on the better sites in this study rather than on the poor quality site.

444. **Mroz GD and Reed DD 1992. Emerging issues in northern hardwood management: air pollution, climate change and biodiversity. *Canadian Journal of Forest Research* 22: 1725-1813.**

Keywords: Air pollution/Climatic change/Nature conservation/Vegetation types/Forest management/Acer saccharum/Fagus grandifolia/Prunus serotina/Tilia americana/Betula alleghaniensis/northern hardwoods

Abstract: A special section of this journal issue contains an introduction (pp. 1725-1726 in English and French) and 10 papers selected from a conference held at Mission Point Resort, Mackinac Island, Michigan, 21-23 May 1991. The abstracts of papers presented at the conference but not reported in this section are available in a separate publication from the School of Forestry and Wood Products, Michigan Technological University. The conference was the third in a series of meetings concerning the northern hardwood resource of North America. The forests are a mixture of long-lived, shade-tolerant trees composed primarily of sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*), American basswood (*Tilia americana*), American beech (*Fagus grandifolia*) and black cherry (*Prunus serotina*) along with numerous other species. The first conference in the series, 'The Northern Hardwood Resource: Management and Potential', was held at Michigan Technological University in Houghton in August 1986. The second, 'New Perspectives on Silvicultural Management of Northern Hardwoods', was held at the University of New Hampshire in Durham in June 1988.

445. **Mroz GD, Reed DD, and Frayer WE 1990. An evaluation of bole form and microsite conditions for birdseye maple growing in the western upper peninsular of Michigan. *Northern Journal of Applied Forestry* 7: 44-45.**

Keywords: Broadleaves /Stand characteristics/density /Grain and figure/wood defects/growth stress/Acer saccharum /wood products /soil site study /birdseye grain

Abstract: A grain abnormality which often occurs in sugar maple [*Acer saccharum*], as well as other broadleaf species, called 'birdseye', is highly prized for use in fine furniture or panelling, and

may be worth 40X as much as non-birdseye material (e.g. up to \$13 000 per mbf in Michigan in 1989). Following field observations on 7 sites, 14 sawlog size birdseye trees were inspected for birdseye in bark or cambium. Diameter at breast height, total height and stand density were measured and soil samples taken (K, Ca, Mg, P and N, texture and organic matter were analysed). Birdseye occurrence was related to higher stand density (average basal area 99 ft²/acre compared with 80 ft²/acre for non-birdseye trees), and slightly greater proportions of sand in soil. It is suggested that stress factors (growth suppression and possibly water stress) may lead to birdseye, in which case current management guidelines (which recommend a residual basal area of <90 ft²/acre) may be selecting against continued development of birdseye maple trees.

446. **Mroz GD and Trettin CC 1985. Forest soils: a resource for intensive forest management. Faculty of Forestry and Wood Products (Michigan Technological University) Misc. Publication No. 85-1, 91 pp.**

Keywords: Soil /stand conversion /intensive management

Abstract: Eleven papers discussing soil interpretations and management and the effects of stand conversion, intensive management and utilization on the soil resources.

447. **Naurois M de and Buongiorno J 1986. Economics of red pine plantation management in Wisconsin. *Northern Journal of Applied Forestry* 3: 118-123.**

Keywords: plantations /economics /forest management/conifers /*Pinus resinosa* /pulpwood /sawlog /wood products /density

Abstract: Management alternatives (pulpwood production alone or with sawlogs), two growth and yield prediction models and two economic criteria (soil expectation value and internal rate of return) for evaluating the management alternatives are discussed in relation to red pine [*Pinus resinosa*] plantations in Wisconsin. It is concluded that it is better to manage the plantations for both pulpwood and sawlogs, even on low quality sites. On site index 45, new plantations are unlikely to be economic. At site index 60-75, plantations have real rates of return of 4-5.5% and soil expectation values of \$125-350/acre at 3% interest. Planting at densities of 690 stems/acre (8X8 ft), heavy thinning at 15-yr intervals and short (45-yr) rotations gave the maximum returns.

448. **Nautiyal JC, Kant S, and Williams JS 1995. A transaction evidence based estimate of the stumpage value of some southern Ontario forest species. *Canadian Journal of Forest Research* 25: 649-658.**

Keywords: economics/stumpage value/timber trade/*Fraxinus americana* /model economics

Abstract: Most of the timber harvested in southern Ontario is sold in an open market. Sales are mainly conducted on mixed-species woodlots and include a range of timber qualities. An econometric model based on the transaction evidence approach and 506 sales data for over 30 species from 1983 to 1993 is developed to estimate the stumpage value of a stand as well as species components most important in determining value. Volume of timber of different species put on sale in a lot was the prime determinant of sale-value. For some species the product of average tree size and volume sold was important. Per cubic metre value of standing timber generally increased with tree size, but the nature of the relationship was not clearly identifiable. Ash (*Fraxinus pennsylvanica*) was the most valuable hardwood in southern Ontario. Ownership was a significant determinant of value, privately owned timber fetching much higher value than that on public lands. This may be due to differences in size of trees on the two types of land. Site characteristics such as slope, underbrush, and distance from mills were not important in determining values. The reason most probably was that high per cubic metre values commanded by hardwoods rendered site differences and transportation costs in a well-roaded region relatively insignificant. Stand quality might have been an important factor, but the poor quality of the data did not permit any useful analysis.

449. Niese JN 1993. *An economic comparison of even- and uneven-aged management in Lake States northern hardwoods*. PhD dissertation, Michigan State University, East Lansing. 211 pp.

Keywords: northern hardwoods /economics /harvesting methods /even-aged management /uneven-aged management

Abstract: Current economic information is inadequate to compare the financial productivity of even- and uneven-aged management in Lake States northern hardwood forests. Forest managers need more detailed economic information on northern hardwood cutting methods from long-term replicated studies. This study summarizes the results of a 40-year management study in Wisconsin and gives economic returns for 9 even- and uneven-aged northern hardwood cutting methods on good northern hardwood sites. It also considers the effects of varying cutting method on the diversity of northern hardwood tree species and future tree quality. Under most economic conditions tested, the medium to heavy basal area cuts produced the highest total economic returns; a heavy diameter-limit treatment had the highest returns when discount rates were high and price expectations were low. Even-aged management methods yielded the highest regeneration diversity, but economic returns were low to moderate. The heavy selection treatment had the highest net present values of total lumber yields and harvests. However, the medium selection treatment gave the best combination of total economic return, improved tree quality, and regeneration diversity. Forest managers have a variety of treatment options that can yield good economic returns. However, this study confirms that, in the long-term, medium or heavy basal area treatments will provide superior economic returns in northern hardwood management.

450. Niese JN and Strong TF 1992. *Economic and tree diversity trade-offs in managed northern hardwoods*. *Canadian Journal of Forest Research* 22: 1807-1813.

Keywords: Silvicultural systems/clear felling/selection /selective felling/shelterwood /ecology /economics /profitability /Acer saccharum/Tilia americana/Fraxinus americana/Betula alleghaniensis/Tsuga canadensis/northern hardwoods /diversity

Abstract: An analysis is presented of how management of northern hardwood forests affects tree species diversity and economic returns, using data from a long-term study of silvicultural systems in the Argonne Experimental Forest, Wisconsin. The study was established in 1951 in a 45-yr-old, even-aged, pole-sized stand dominated by sugar maple (*Acer saccharum*) with basswood (*Tilia americana*), yellow birch (*Betula alleghaniensis*), white ash (*Fraxinus americana*), red maple (*A. rubrum*) and hemlock (*Tsuga canadensis*). Shannon's index was used to measure regeneration diversity for 8 even- and uneven-aged felling methods (treatments): (i) light, medium or heavy selection (leaving residual basal areas of 20.7, 17.3 and 13.8 m²/ha, respectively), (ii) crop tree treatment (crown released 74 to 124 crop trees/ha), (iii) diameter limit felling (fell all trees with stump diameters ≥ 20.3 cm), (iv) clear felling (all trees with a diameter at breast height (d.b.h.) ≥ 11.7 cm or all trees with a d.b.h. ≥ 2.54 cm), (v) shelterwood felling or (vi) a control. The selection and crop tree treatments were cut in 1952, 1962, 1972 and 1982. The diameter limit and clear felling treatments were cut in 1958, 1965 and 1975. The medium selection treatment produced the highest diversity index and the highest economic return of all uneven-aged treatments. Regeneration diversity in diameter limit treatments was half that in the medium and heavy selection treatments. The heavy selection and the crop tree treatments provided greater economic returns than the diameter limit treatment. Of the even-aged treatments, shelterwood produced positive financial returns and a high initial revenue but value after 30 yr was not great. If species diversity is the primary objective, the shelterwood treatment is recommended. If high economic returns are the primary objective, a medium selection treatment produces the best combination of economic results and species diversity.

451. Niese JN, Strong TF, and Erdmann GG 1995. *Forty years of alternative management practices in second-growth, pole-size northern hardwoods. II. Economic evaluation*. *Canadian Journal of Forest Research* 25: 1180-1188.

Keywords: selection system/selective felling/merchantable volume/vegetation types/deciduous forests/silvicultural systems/economics/Acer rubrum/Acer saccharum/Tilia americana/Fraxinus americana/Betula alleghaniensis/Tsuga canadensis/northern hardwoods

Abstract: Potential economic returns to tree quality were analysed for four uneven-aged cutting treatments (heavy, medium or light individual tree selection, and a stump diameter limit) and an uncut control in a Wisconsin northern hardwood stand. The stand was dominated by Acer saccharum with Fraxinus americana, Betula alleghaniensis, Tilia americana, Tsuga canadensis and Acer rubrum. The economics of tree quality changes were analysed over a 20-year period (1971-1992), using a marginal analysis that included tree grade, lumber volume yields, reported lumber values, and hardwood management costs. Net present values were highest for the heavy individual tree selection (residual basal area of 13.8 m²/ha) treatment, and residual tree quality improved significantly. The medium selection (17.3 m²/ha) treatment had the greatest improvement in tree quality as well as high economic returns. The light selection (20.7 m²/ha) treatment had the highest residual stand value, but low harvest revenues. A 20.3-cm diameter-limit treatment had the lowest economic returns and the poorest tree quality.

452. **Norby RJ and Jackson RB 2000. Root Dynamics and Global Change: Seeking an Ecosystem Perspective. *New Phytologist* 147: 3-12.**

Keywords: fine roots/root dynamics/turnover/climatic change/global change/elevated CO₂/nitrogen deposition/mycorrhizas/atmospheric carbon-dioxide/northern hardwood /CO₂/turnover/responses/growth /review

Abstract: Changes in the production and turnover of roots in forests and grasslands in response to rising atmospheric CO₂ concentrations, elevated temperatures, altered precipitation, or nitrogen deposition could be a key link between plant responses and longer-term changes in soil organic matter and ecosystem carbon balance. Here we summarize the experimental observations, ideas, and new hypotheses developed in this area in the rest of this volume. Three central questions are posed. Do elevated atmospheric CO₂, nitrogen deposition, and climatic change alter the dynamics of root production and mortality? What are the consequences of root responses to plant physiological processes? What are the implications of root dynamics to soil microbial communities and the fate of carbon in soil, Ecosystem-level observations of root production and mortality in response to global change parameters are just starting to emerge. The challenge to root biologists is to overcome the profound methodological and analytical problems and assemble a more comprehensive data set with sufficient ancillary data that differences between ecosystems can be explained. The assemblage of information reported herein on global patterns of root turnover, basic root biology that controls responses to environmental variables, and new observations of root and associated microbial responses to atmospheric and climatic change helps to sharpen our questions and stimulate new research approaches. New hypotheses have been developed to explain why responses of root turnover might differ in contrasting systems, how carbon allocation to roots is controlled, and how species differences in root chemistry might explain the ultimate fate of carbon in soil. These hypotheses and the enthusiasm for pursuing them are based on the firm belief that a deeper understanding of root dynamics is critical to describing the integrated response of ecosystems to global change.

453. **Nordin JO and Grigal DF 1976. Vegetation, site and fire relationships within the area of the Little Sioux fire, northeastern Minnesota. *Canadian Journal of Forest Research* 6: 78-85.**

Keywords: synecology /site factors/fire /fire effects/forest fires/vegetation

Abstract: Data were obtained from random samples from maps of the forest cover type in 1948 and 1970, topography, soils and fire intensity in the area of the Little Sioux fire that occurred in 1971. The closest relationship was between dominant vegetation in 1948 and that in 1970. Relationships between soil mapping units and slope position and between vegetation and soils were also relatively high. The vegetation/soil relationships were influenced by the close

associations of lowland vegetation to lowland soils and of upland vegetation to upland soils. Specific categories of upland vegetation were not, however, well related to specific categories of upland soils.

454. **Nyland RD 1998. Selection System in Northern Hardwoods. *Journal of Forestry* 96: 18-21.**

Keywords: northern hardwoods /stand age conversion /uneven-aged management

Abstract: Northern hardwood stands with multiple age classes allow immediate use of selection system to control the diameter and age-class distributions. This ensures consistency in yields, ecological conditions, visual qualities, and other values. To convert even-aged communities, landowners must partition the cut of upper canopy trees over many decades, regenerating a new age class with each entry. In both cases, landowners must commit to the long-term program of deliberate management that selection system requires.

455. **Nyland RD, Behrend DF, Craul PJ, and Echelberger HE 1977. Effects of logging in northern hardwood forests. *Tappi* 60: 58-61.**

Keywords: logging /soil /logging labor efficiency/felling /selective felling/silvicultural systems/northern hardwoods /strip clearcut /patch clearcut /residual tree damage /soil properties /soil moisture /birds /aesthetics

Abstract: Timber was harvested at 3 locations using individual tree selection, strip clear felling, and patch clear felling. Special practices did not significantly reduce injuries to residual trees, except for skidding at one location. Logging reduced the distribution and density of regeneration. Skidding affected 16-18% of the surface within partial fellings and about twice that in clear fellings due to more minor disturbance. Soil bulk density increased, while macroporosity, available water, and infiltration rates decreased. Erodibility appeared limited. Songbird numbers and diversity increased. Species dominant before harvesting remained so. Effects upon other animals were unclear. Crews spent 80% of work time in productive activity. Time devoted to various jobs was similar between methods. Skidding took 30-40% longer than felling. Top lopping and sapling felling reduced output significantly. Different viewer groups reported different overall impressions. Lopped partial cuts were most preferred. Viewers disliked logging slash in all treatments. No method had significant detrimental effect upon the forest and associated resources. Prepared by IPC.

456. **O'Hara KL 1998. Silviculture for structural diversity. *Journal of Forestry* 96: 4-10.**

Keywords: uneven-aged management /natural disturbance patterns /diverse stand structure /biodiversity /landscape ecology

Abstract: Movement away from even-aged silviculture and toward maintenance of continuous cover and structural diversity has generated renewed interest in two-aged and uneven-aged silvicultural systems. New approaches for multiaged stands suggest managers can achieve many goals with systems that integrate the structural features associated with natural disturbance processes with systems that are simpler than the uneven-aged silviculture of the past. The result is flexible systems for designing and implementing diverse stand structures for many objectives, including biodiversity. An understanding of forest stand dynamics and landscape ecology is a prerequisite.

457. **O' Hara KL, Seymour RS, Tesch SD, and Guldin JM 1994. Silviculture and our changing profession: leadership for shifting paradigms. *Journal of Forestry* 92: 8-13.**

Keywords: sustainability /biodiversity /forest management/multiple use/silviculture /non-timber products

Abstract: It is argued that, in determining the optimum management plan for any forest, silviculturalists should assume a leadership role, especially as shifting paradigms seek to balance timber and non-timber production with maintenance of biological diversity and sustainability at the landscape level. Silviculturalists will need to broaden their perspective, education and training to incorporate a landscape-level approach.

458. **Ohmann LF and Grigal DF 1985. Biomass distribution of unmanaged upland forests in Minnesota. *Forest Ecology and Management* 13: 205-222.**

Keywords: vegetation types/Synecology /layer structure /survey /aboveground biomass /understorey biomass /overstorey biomass

Abstract: [See FA 37, 4429] A previous floristic analysis of undisturbed stands and stands disturbed by logging identified 12 forest and one non-forest community within the Boundary Waters Canoe Area Wilderness. Data collected for the floristic analysis were applied to biomass estimation equations to produce estimates by species for stands within each type of community. Total above ground biomass in forest communities was 121-268 t/ha. Biomass was greatest in communities with long-lived tree species. All communities had similar biomass m.a.i. Distribution of biomass between understorey strata varied significantly with community, but total understorey biomass varied little (1.9-4.4 t/ha). Biomass in overstorey and understorey were related, but did not fully explain the variation of biomass in those strata between communities. Results suggest that the original floristic classification provided a valid basis for comparing ecosystem properties.

459. **Ohmann LF and Grigal DF 1979. Early revegetation and nutrient dynamics following the 1971 Little Sioux forest fire in northeastern Minnesota. *Forest Science Monograph* 21.**

Keywords: fire /fire effects/succession /natural regeneration/nutrients /burning /Pinus strobus/Pinus banksiana/Abies spp./Picea mariana /Quercus spp. /Populus spp. /Betula spp. /litter /nitrogen /potassium

Abstract: Three virgin plant communities dominated by Pinus banksiana (with Abies, Quercus or Picea mariana), three by Populus/Betula (with Abies or Pinus banksiana) and one mixed community (Populus/Betula/Pinus strobus) were studied over 5 growing seasons after burning. From 1971 to 1975 tree and tall shrub reproduction generally decreased in density and increased in biomass. Low shrub cover and biomass increased for 3 yr and then levelled off as tree and tall shrub competition increased. Herb cover and biomass increased most rapidly until 1972 and then slowed substantially. By 1975 total net annual primary productivity averaged 850 g/m² for all 7 stands, and over 1,200 g/m² in the broadleaf-dominated stands. The forest floor 01 horizon increased in mass until 1974, and then apparently stabilized at about 620 g/m². The 02 horizon averaged about 1,000 g/m² and was still increasing in 1975. By the 1975 growing season the total amount of nutrients in aboveground vegetation on burned plots ranged from 33% of the N to 65% of the K found in nearby unburned forest communities. By 1973 the nutrients in the aboveground vegetation and the 01 horizon of the forest floor was greater than the quantity estimated to have been mobilized by the fire. The vegetation was an effective sink for the released nutrients. From authors' summary.

460. **Ohmann LF and Grigal DF 1985. Plant species biomass estimates for 13 upland community types of northeastern Minnesota. U.S. For. Serv. Resource Bulletin NC-88, 52 pp.**

Keywords: vegetation types/biomass /vertical stratification

Abstract: Estimates of overstorey biomass are tabulated by stratum and species for each community type.

461. **Ohmann LF and Grigal DF 1990. Spatial and temporal patterns of sulfur and nitrogen in wood of trees across the north central United States. *Canadian Journal of Forest Research* 20: 508-**

513.

Keywords: ecology /wood properties/wood chemistry/growth effects/sulfur /nitrogen /soil chemistry/acid deposition/Acer saccharum/Populus tremuloides/Pinus banksiana/Pinus resinosa/Abies balsamea

Abstract: Cones were sampled in 169 forest stands, representing 5 forest types (Populus tremuloides, Abies balsamea, Pinus banksiana, Pinus resinosa and Acer saccharum), across Minnesota, Wisconsin and Michigan. The molar ratio of elemental S to N for 3 decades of wood growth (1956 to 1985) was related to location (as defined by 5 sampling zones), the molar ratio of elemental S to N in soils, and also to wet sulfate deposition. There were also differences in molar S:N ratios among tree species. There were no significant interactions between species and zone. The S:N ratios of both soil and wood increased from W. to E. across the sulfate deposition gradient. This trend is consistent with increasing evidence that sulfate and other S ions in wet deposition are accumulating in various compartments of forest ecosystems in the N.-central USA. These results also support studies that indicate that more S is being taken up by trees than is needed for normal nutrition.

462. **Ohmann LF, Grigal DF, Shifley SR, and Berguson WE 1994. Vegetative characteristics of five forest types across a Lake States sulfate deposition gradient. U.S. For. Serv. Resource Bulletin NC-154, 30 pp.**

Keywords: botanical composition/stand structure/vegetation types/acid deposition/monitoring

Abstract: Study plots were established in 1985 to test general hypotheses concerning acid deposition across the Lake States. This bulletin describes the vegetative characteristics of the 5 forest types inventoried on the study plots. Species composition, density, basal area, biomass and importance value are tabulated.

463. **Oliver CD 1980. Even-aged development of mixed-species stands. Journal of Forestry 78: 201-203.**

Keywords: synecology /stand characteristics/structure /age structure/natural regeneration/management /pathogens

Abstract: Stratified forests in E. and NE USA are not necessarily all-aged, as previously assumed, and selective logging on this basis has produced stand degradation. Development patterns and management of mixed even-aged stands are discussed with examples. Trees of the lowest strata keep those of upper strata well-pruned and can be used for low quality products such as pulp. Certain mixtures may be more resistant to pathogens. Even-aged management can produce more and better quality wood.

464. **Ondro WJ and Love DV 1979. Growth response of northern hardwoods to partial cutting in southern Ontario. Forestry Chronicle 55: 13-16.**

Keywords: increment /thinning /harvesting trial /basal area/yields /Acer saccharum/Fagus grandifolia/Betula alleghaniensis/northern hardwoods

Abstract: Stands of 'Fagus grandiflora' [grandifolia?], Acer saccharum and Betula alleghaniensis near Dorset, Ontario, were subjected to 3 treatments: (a) a light improvement cut based on individual tree selection; (b) an improvement cut based on group tree selection; and (c) a commercial cut. These removed about 20% of the stand vol. Comparison of b.a. and d.b.h. measurements after 10 yr showed that (c) resulted in the greatest d.b.h. increment, and (b) gave a higher d.b.h. increment than (a).

465. **Orr B, Buongiorno J, Young T, Lothner DC, and Kallio E 1985. Future timber harvest on the Chippewa and Superior National Forests in Minnesota. U.S. For. Serv. Resource Bulletin**

NC-89, 11 pp.

Keywords: Yield forecasting/forest management/Populus spp. /aspen /pulpwood /sawtimber /fuelwood /species shortages

Abstract: Projected harvest of pulpwood, sawtimber and fuelwood was analysed in 3 species groups (conifers, aspen [Populus spp.] and other broadleaves). Timber harvests were projected to increase substantially by 2030, with increasing demand for aspen affecting the total harvest. Both forests should give high priority to aspen management.

466. **Orr BD, Reed DD, and Mroz GD 1994. Three basal area level harvest trials in uneven-aged northern hardwoods. *Northern Journal of Applied Forestry* 11: 117-123.**

Keywords: forest management/returns /silvicultural systems/stand structure/quality /vegetation types/rotations /economics/basal area/northern hardwoods

Abstract: Beginning in 1958, northern hardwood stands with initial basal areas ranging from 93 to 106 ft²/acre were harvested to residual basal areas of 70, 55, and 40 ft²/acre in Baraga County, Michigan. Subsequent harvests of the stands over a 32-yr period illustrated potential treatments available to absentee owners of similar stands in small woodlots. In all cases stand quality improved and stand structure became more balanced, with a reduction in the number of trees greater than 20 inches in diameter at breast height. At discount rates of 2 to 4%, economic returns were greatest for the 70 ft² treatment with a 10 yr cutting cycle. At discount rates of 6, 8 and 10%, the 55 and 40 ft² treatments with 18- and 22-yr cutting cycles, respectively, outperformed the 70 ft² treatment because of the greater volume removed during the first (1958) harvest.

467. **Ouyang H 1994. *Nitrogen cycling and availability of two forest ecosystems in the upper peninsula of Michigan*. PhD dissertation, Michigan Technological University, Houghton. 230 pp.**

Keywords: Pinus resinosa/northern hardwoods /second-growth /nitrogen cycling /productivity /model nitrogen mineralization/nitrogen mineralization /soil nitrogen cycling /soil carbon/soil temperature

Abstract: Nitrogen cycling in northern temperate forests has received considerable attention because available N levels often limit tree growth on many sites. The objectives of my study were: (1) to evaluate N cycling and availability in two second-growth northern hardwood stands in relation to stand net primary production in the Upper Peninsula of Michigan, (2) to evaluate N cycling and availability in two young red pine plantations which were established after clearcutting previous hardwood stands, (3) to develop a process model for soil N mineralization, and (4) to use this model to simulate N mineralization in both the hardwood stands and red pine plantations. Net N mineralization and nitrification rates in two northern hardwood stands were significantly different in the surface mineral soil horizons (0-10 cm) ($p < 0.05$), but not in the forest floor. In contrast, N mineralization and nitrification rates in the forest floor and the surface mineral soil were not significantly different between the two red pine plantations ($p > 0.05$). Other aspects of N cycling, such as throughfall N inputs, and forest floor and mineral soil leaching losses, were generally not different between the hardwood stands or the plantations. Clear seasonal trends of net N mineralization and nitrification in both the forest floor and surface mineral soils were obvious in both stand types. Soil temperature and organic matter C:N ratio were major factors related to the seasonal variations, but available water was not. A significant relationship between stand NPP and soil N availability was found in the hardwood stands, but not in the red pine plantations. This indicated that soil N availability limited the productivity in the hardwood stands, but did not limit red pine growth. Agreement was found between the N mineralization model's results and field observations in both stand types. The model also adequately described the seasonal trends of observed net nitrification values, but agreement was not as good as for seasonal N mineralization. The results of sensitivity analysis showed that increasing temperature and organic N content increased N mineralization and nitrification rates in both the red pine

plantations and the hardwood stands. The sensitivity of the model to fluctuations in soil moisture and C:N ratio was different for the forest floor and the mineral soil; the model was most sensitive to the moisture changes in the forest floor. In contrast, C:N ratio was influential in the mineral soil, but had little effect on N mineralization in the forest floor. Using this model, net N mineralization and nitrification rates in the forest floor and surface mineral soil (0-15 cm) were simulated for six years (May 1986 to April 1992) in both the hardwood stands and the red pine plantations. The model indicated that converting northern hardwood stands to red pine plantations significantly decreased net N mineralization and nitrification rates. Over a six-year period N mineralization rates in the forest floor decreased by 55%, while nitrification rates decreased by 43%. Net N mineralization and nitrification rates in the surface mineral soil (0-15 cm) also decreased after the establishment of red pine plantations, but the effect was smaller. Changes in C:N ratios, litterfall, and fine roots after timber harvesting were major factors causing the decrease of N mineralization and nitrification rates in the forest floor and the surface mineral soil.

468. **Overpeck JT, Rind D, and Goldberg R 1990. Climate-induced changes in forest disturbance and vegetation. *Nature* 343: 51-53.**

Keywords: Climate /carbon dioxide enrichment/climatic change/Vegetation /model FORENA

Abstract: A discussion of new and previously published climate-model results which indicate that global warming would increase forest disturbance via forest fires, wind storms, coastal flooding and hurricanes. The mixed species (72 total), mixed-age model FORENA was used to simulate effects of global warming (+1°C and +2°C, -15% rainfall, X2 CO₂) on four forest types in eastern N. America including a mixed conifer-broadleaf forest in Wisconsin and a southern boreal forest in Quebec. Significant changes in forest composition were observed; also forest responses to climate change accelerated. In all transient-perturbation simulations, the vegetation took <180 yr to regain equilibrium. These models suggest that in contrast to previous modelling studies, fossil-pollen data may be capable of resolving climate-change to within 100-150 yr under sensitive forest-disturbance regimes.

469. **Owens KE, Reed DD, Londo AJ, Maclean AL, and Mroz GD 1999. A Landscape Level Comparison of Pre-European Settlement and Current Soil Carbon Content of a Forested Landscape in Upper Michigan. *Forest Ecology and Management* 113: 179-189.**

Keywords: Mineral Soil/Carbon Storage/Geographic Information Systems/Northern Hardwood Stands/Dissolved Organic Carbon/Oak Forest/Storage/ Floor/ Temperature/ Succession/ Nitrogen/ *Tsuga canadensis*/*Quercus* spp.

Abstract: A large forested landscape (18 640 ha) located in Michigan's central Upper Peninsula was examined to estimate current and pre-European mineral soil carbon (C) content. Utilizing current forest stand information and pre-European settlement forest data, a landscape level soil C estimate was made for each time period and the change in soil C over the 150-year interval was quantified. Soil, forest type, and age class information were entered into a geographical information system (GIS); high medium, and low C levels were assigned to soils based on forest type and age class groupings. Using organic matter data from soil surveys of the area, a range of mineral soil C values was determined for each soil mapping unit and vegetation combination, and a percent C value was estimated based on previously assigned C levels. Estimates of average percent C were calculated for both current and pre-European landscapes to be 9.7% and 11.7%, respectively. Overall, there appears to be a decrease in soil C content since European settlement as a result of changes in forest cover and land use. Due to the strong relationship between forest type and soil C content, an increase of urban/brush areas, and a shift from hemlock and conifer forest types to hardwoods and mixed pine/hardwood forests since European settlement, there has been a reduction of the average landscape level soil C on a g/m² basis. The net reduction in mineral soil C content on this landscape is estimated to be approximately 0.3 to 0.8 Tg C (in the upper 10- 25 cm of mineral soil) over the 150 years since European settlement of the area.

470. **Padley EA 1989. *Associations among glacial landforms, soils, and vegetation in northeastern lower Michigan*. PhD dissertation, Michigan State University, East Lansing. 294 pp.**

Keywords: northern hardwoods /ecosystem classification /soil morphology /nitrogen mineralization /nutrient cycling /potassium /phosphorus /magnesium /litter chemistry

Abstract: Relationships among ecosystem components were studied on 24 upland forested sites in northeastern Lower Michigan. The objectives of this study were to investigate relationships among ecosystem components and discuss approaches to ecosystem classification of the area. Sites were grouped based on depositional environment as indicated by soil morphology. Principal component analyses (PCA) of soils data did not contradict site groupings based on depositional environment, although sites formed in loamy textured till deposited by two different glacial substages were not consistently separated. PCA produced similar site groupings from laboratory or field data. Individual comparisons of variables among depositional environment groups found significant differences among sites formed in outwash, outwash with till inclusions, and loamy tills. The tills of different deposition were different only with respect to a few variables. First-dimensional site ordinations obtained by reciprocal averaging of ground flora data, overstory basal area, and PCA of soils data were all significantly correlated with each other. Differences in overstory composition occurred on till sites of different glacial depositions, on soils which were texturally and chemically similar. Nitrogen mineralized during anaerobic incubation was correlated with the ordination of ground flora, and was significantly different for sites of different overstory composition. Composition differences and nitrogen mineralization may be related to historic patterns of disturbance. Weights of Oe forest floor layers were similar among ecosystems. Production and nutrient quality of autumn litterfall was similar to that reported for other studies in the region. Return of potassium, phosphorous, and magnesium in autumn litterfall was associated with litter production, and was greatest for mixed oak-northern hardwood sites. Return of nitrogen and calcium was associated with species composition. Glacial landforms mapped in the area do not provide divisions of sufficient detail to serve as a basis for ecosystem mapping. Separations based on localized depositional environments are required. Ground flora are effective in making these separations, and also distinguish positionally similar sites of different successional potential. Six ecosystem groups were identified among the study sites, with divisions based on depositional environment, flora, and soil properties important in land management.

471. **Paillet FL and Rutter PA 1989. Replacement of native oak and hickory tree species by the introduced American chestnut (*Castanea dentata*) in southwestern Wisconsin. *Canadian Journal of Botany* 67: 3457-3469.**

Keywords: broadleaves /acclimatization /natural regeneration /*Quercus* spp. /chestnut /*Castanea dentata* /*Carya* spp. /exotic species /chestnut blight

Abstract: American chestnut was introduced at West Salem, Wisconsin, in about 1880 and had begun to replace native tree species in adjacent oak/hickory (*Quercus/Carya*) woodland before 1930. Chestnut is now an important canopy species over about 20 ha of forested ridge extending N. and S. of the original plantation. A smaller area (<5 ha) is dominated by chestnut in both the canopy and understorey. Chestnut seedlings and small saplings are more numerous along woodland edges and in recently disturbed soil, rare in the interior of ungrazed pasture and entirely absent from intensively grazed areas adjacent to chestnut-dominated woodland. Random sampling of recently established seedlings indicated that 1-5 seedlings/ha became established annually in undisturbed woodland during 1986-88. The general pattern of chestnut distribution indicates the importance of woodland edges in chestnut propagation and the effects of livestock grazing in excluding chestnut. Replacement of native species by chestnut appears to have occurred in two steps: isolated groups of trees became established at favourable locations, after which many additional chestnut stems became established in the understorey. The recent discovery of blight indicates that the West Salem site may not be available for study of blight-free chestnut in the future.

472. **Palik BJ and Pregitzer KS 1992. The age and height structure of red maple (*Acer rubrum*) populations in northern Michigan bigtooth aspen (*Populus grandidentata*) forests. *Canadian Journal of Forest Research* 22: 1449-1462.**

Keywords: broadleaves /stand characteristics/composition /stand development/stand structure/*Acer rubrum*/ *Populus grandidentata* /stem analysis /competition

Abstract: Red maple (*Acer rubrum*) is often the most abundant later successional tree species recruiting in the understories of aspen and oak dominated forests on dry-mesic sites in eastern North America. Limited evidence suggests that this species is capable of recruiting to dominant canopy positions on these sites. The age and height structures were examined of red maple populations in a bigtooth aspen (*Populus grandidentata*) dominated area in N. lower Michigan. Stem analysis was used to examine relations between establishment times, heights, and height growth rates for overstorey and understorey red maple from 20 replicate plots in 5 stands located within an 18-km² area. Red maple was a minor overstorey component in the forests of the study area, but the understories of all stands were overwhelmingly dominated by red maple. The populations were composed of 2 clearly defined age cohorts. The first cohort contained mostly sprout-origin individuals that had established concurrently with bigtooth aspen within a 10-yr period, beginning 70 yr before the time of sampling. Mean age and height of the sprout-origin red maple cohort was not significantly different among stands, and mean age did not differ from the mean age of bigtooth aspen. Within each stand, height growth rates of sprout-origin red maples were highly variable, but variability was not related to differences in stem age. Recent height growth increment of the sprout-origin stems was weakly related to position of an individual in the overstorey, suggesting that most red maple were competitively suppressed by taller bigtooth aspen. Some sprout-origin red maple in all stands approached the dominant bigtooth aspen in height growth rate. These were probably stems that were never competitively suppressed. The second red maple cohort contained seedling-origin individuals that began establishing 30-35 yr after stand initiation, immediately after culmination of height increment in dominant overstorey bigtooth aspen and red maple. This suggests that increasing resource availability, as a result of declining overstorey vigour and canopy closure, may be a factor triggering understorey re-initiation in these even-aged forests. In general, heights of seedling-origin red maple were more dependent on stem age than sprout-origin individuals. However, height growth rates for similar-aged individuals within the seedling cohort were still highly variable. The tallest individuals generally had the greatest rates of recent height increment, and thus were at a competitive advantage within the understorey environment, but these were not always the oldest stems. There was a trend of increasing initial height growth rate over time for the fastest growing seedling-origin individuals, again suggesting that resource availability in the understorey was increasing over the course of stand development. The overwhelming understorey dominance of red maple and its ability to reach dominant canopy positions in the stands examined suggests a potential for increasing overstorey importance on dry-mesic sites. Life history attributes, including shade tolerance, vigorous resprouting potential, and the ability to respond with increased growth upon release, may foster the development and maintenance of a red maple dominated cover type in the Great Lakes region.

473. **Palik BJ and Pregitzer KS 1995. Height growth of advance regeneration under an even-aged bigtooth aspen (*Populus grandidentata*) overstory. *American Midland Naturalist* 134: 166-175.**

Keywords: height /growth /regeneration /canopy /natural regeneration/advance growth/increment /deciduous forests/*Acer rubrum*/*Populus grandidentata*/*Pinus strobus*

Abstract: Height and age structures and recent height growth rates of white pine (*Pinus strobus*) and red maple (*Acer rubrum*) advance regeneration were examined in a mature even-aged bigtooth aspen (*Populus grandidentata*) ecosystem in northern Lower Michigan. It was hypothesized that the overstorey was inhibiting height growth of understorey stems and that the degree of inhibition would vary with overstorey basal area and the relative contribution to total basal area of species

differing in light-attenuating ability. Correlations between age and height of advance regeneration on replicate plots were significant in 14 of 16 cases, but were highly variable and, on average, not very high. Correlations were stronger for white pine, indicating more consistent height growth than for red maple. However, red maple advance regeneration had greater mean height growth rates than white pine. Height distributions of advance regeneration, distributions of relative height increment over 5 years and mean 5-year relative height increment were unrelated to plot-level measures of total overstorey basal area and relative basal area of bigtooth aspen. These results indicate that height growth of advance regeneration was occurring in this forest, but height growth rates varied among individuals and species. The degree of inhibition in height growth was unrelated to plot-level measures of total overstorey competition, as reflected in basal area. Further, variation in height growth rate was unrelated to the relative contribution to total basal area of canopy species differing in light-attenuating ability. The results of this study indicate that large overstorey gaps are not required to promote establishment and height growth of advance regeneration in all even-aged aspen forests and that controls other than overstorey structure may lead to variation in height growth rates of advance regeneration.

474. **Palik BJ and Pregitzer KS 1991. The relative influence of establishment time and height-growth rates on species vertical stratification during secondary forest succession. *Canadian Journal of Forest Research* 21: 1481-1490.**

Keywords: plant succession/seral stages/Stand characteristics/stand structure/understorey /Acer rubrum/Quercus rubra/Fraxinus americana/Populus tremuloides /Populus grandidentata

Abstract: The height-growth histories were reconstructed of individual *Quercus rubra*, *Fraxinus americana* and *Acer rubrum* growing in a 42-year-old *Populus grandidentata*/*P. tremuloides*-dominated forest in Michigan. All three species were established early in the year, but periods of peak individual establishment were different; most *Q. rubra* were established before most *F. americana* and *A. rubrum*. Most *Q. rubra* were taller than *F. americana* and *A. rubrum*. Height-growth rates for the three species were similar throughout much of the 42-year-old period, suggesting that the vertical stratification of the species is primarily a function of differences in species establishment patterns.

475. **Palik BJ and Pregitzer KS 1993. The repeatability of stem exclusion during even-aged development of bigtooth aspen dominated forests. *Canadian Journal of Forest Research* 23: 1156-1168.**

Keywords: broadleaves /stand characteristics/stand development/*Populus grandidentata*/*Pinus strobus* /stem analysis /stem exclusion

Abstract: Forest development following major disturbance is thought to follow a fairly repeatable temporal pattern. An initial cohort of trees establishes relatively rapidly (stand initiation), new establishment is precluded for an extended period (stem exclusion), and finally, new individuals again begin to establish, creating new age-classes in the forest understorey (understorey reinitiation), eventually leading to an uneven-aged condition. The current study was designed to assess the generality of this developmental pattern at the landscape level and gain insight into the possible mechanisms controlling stem exclusion and understorey reinitiation in even-aged forests. Research was conducted within two bigtooth aspen (*Populus grandidentata*) dominated landscapes in northern Lower Michigan; the landscapes had similar physical site characteristics, overstorey compositions, and disturbance histories. Stem analysis was used to reconstruct establishment and growth histories of surviving stems in mature forest on replicate plots within each landscape. The age distributions of surviving individuals of all tree species in both forests reflected a developmental pattern characterized by rapid initial cohort establishment lasting 5-15 years, stem exclusion lasting 25-35 years, and understorey reinitiation. The duration and timing of the developmental stages on the replicate plots were similar both within and between the two landscapes. There were, however, a small number of plots in landscape 2 that had substantially reduced stem exclusion lengths, relative to the remaining plots in both forests. Variation in the timing of understorey reinitiation in landscape 2 was related to characteristics of remnant eastern

white pine (*Pinus strobus*) seed trees. The stem exclusion period was shorter, or almost nonexistent, on plots close to several large seed trees because of early, low-frequency establishment of white pine in the understorey. Substantial increases in the frequency of understorey establishment on all plots in landscape 2, as well as all new understorey establishment on plots in landscape 1, were often associated with radial growth increases in overstorey stems. The radial growth increases presumably reflected an increase in resource availability, possibly occurring in response to a concentrated wave of natural thinning within the bigtooth aspen dominated overstorey. These results suggest that the timing of understorey reinitiation may have been influenced by variation in seed availability interacting with changes in resource availability in the forest understorey. A limited amount of new establishment occurred relatively early in forest development on plots that experienced abundant early seed rain, yet the bulk of new establishment occurred only after an increase in resource availability in the understorey.

476. **Palik BJ and Pregitzer KS 1993. The vertical development of early successional forests in northern Michigan, USA. *Journal of Ecology* 81: 271-285.**

Keywords: plant succession/stand development/increment /height /understorey /*Acer rubrum*/*Quercus rubra*/*Populus grandidentata* /competition

Abstract: Studies have shown that differences in height growth rates are characteristic of tree species that differ in understorey tolerance and relative successional status. Less-tolerant species have greater juvenile height growth rates than more-tolerant species and thus, in a mixed-species forest, the former gain an early competitive advantage after a stand-initiating disturbance. Species-level height stratification is the predicted outcome under this model. Silvicultural evidence suggests that a species-level differential growth rate model is idealistic because height stratification among species differing in understorey tolerance is not consistently expressed within an even-aged forest. Stratification may fail to develop if individuals of a relatively tolerant species are competitively uninhibited, establish earlier than less-tolerant species, or are of vegetative origin. The establishment and height growth histories of three species differing in understorey tolerance were examined within two forests in northern Michigan. Objectives of the study included: (i) determining if species height stratification paralleling understorey tolerance was a characteristic of these forests; (ii) assessing the degree of height variation within species populations; and (iii) determining if species age distributions, changes in individual competitive environments, or regenerative origin influenced population height structures. In both forests, *Populus grandidentata*, an intolerant, early successional species, was typically taller than *Quercus rubra*, a mid-tolerant, later successional species, which in turn was taller than *Acer rubrum*, a tolerant, later successional species. However, within *Q. rubra* and *A. rubrum* populations, heights were often highly variable, with some individuals equalling the heights of *P. grandidentata*. Age differences had no influence on height patterns. Growth rate differences among surviving stems determined species stratification patterns and height variation within populations. *P. grandidentata* typically outgrew both *Q. rubra* and *A. rubrum*, although some individuals of the latter two species had height growth rates equivalent to *P. grandidentata*. Most *Q. rubra* and *A. rubrum* appeared to be of vegetative origin, as were all *P. grandidentata* ramets. For individuals of the former two species, potential juvenile height growth rates were likely to be greater than that of true seedlings, thus allowing some individuals to match growth rates of *P. grandidentata*. *P. grandidentata* numerically dominated the forests because a large proportion of growing space was occupied by its root systems and ramets, relative to the other species. Vertical domination by *P. grandidentata* was apparently the result of competitive inhibition of most, but not all, *Q. rubra* and *A. rubrum*, not because of inherent, species-specific differences in juvenile height growth rates.

477. **Palik BJ and Pregitzer KS 1994. White pine seed-tree legacies in an aspen landscape: influences on post-disturbance white pine population structure. *Forest Ecology and Management* 67: 191-201.**

Keywords: plant succession/seed trees/natural regeneration/stand characteristics/species composition/*Acer rubrum*/*Populus grandidentata*/*Pinus strobus* /*Quercus* spp. /disturbance

Abstract: White pine (*Pinus strobus*) trees that survived late 19th century logging and wildfires in the Great Lakes region act as seed-sources for white pine regeneration in aspen (*Populus* spp.) and oak (*Quercus* spp.) ecosystems that developed following these disturbances. The local abundance of remnant white pines may influence the direction of succession following disturbance, yet no studies have quantified relations between characteristics of remnant white pine seed-sources and the structure of post-disturbance white pine populations. The objective of the present study was to relate the number, size, and location of remnant white pine seed trees to the structure of post-disturbance white pine populations. The study was conducted in a 75 to 80 yr old bigtooth aspen (*P. grandidentata*)-dominated forest in northern Michigan. White pine seed-source characteristics varied considerably, as did stem density, age and height of post-disturbance white pine populations. Regenerating white pine populations which were located close to several large remnant trees were larger, began establishing sooner after disturbance, and contained a greater diversity of age and height classes relative to populations with less favourable seed-source characteristics. Additionally, plots with small post-disturbance white pine populations often had large populations of red maple (*Acer rubrum*) advanced regeneration. Variable successional pathways in the study area may reflect the influence of remnant white pine seed-sources, and ultimately, a disturbance history that allowed some seed trees to survive logging and wildfires. Retention of large white pine seed trees in commercial aspen forests may be an important silvicultural tool if a goal of management is to maximize structural and compositional diversity in managed stands.

478. Parshall T 1995. **Canopy mortality and stand-scale change in a northern hemlock-hardwood forest.** *Canadian Journal of Forest Research* 25: 1466-1478.

Keywords: canopy mortality/succession /drought /species composition/forest ecology/ dendrochronology /recruitment /broadleaves /*Acer saccharum*/*Tsuga canadensis*

Abstract: Ring-width patterns from 348 trees on a 5.25-ha mapped plot in the Sylvania Wilderness, Upper Michigan, were used to infer the pattern of canopy mortality for the past 140 years. Estimates of average canopy turnover rate (0.54% per year) and average canopy residence time (186 years) are similar to other estimates for the region. The temporal pattern of release events detected in the cores is closely related to the occurrence of extreme drought with sugar maple (*Acer saccharum*) trees showing increased growth in the years directly following drought and eastern hemlock (*Tsuga canadensis*) trees showing increased growth 3-4 years following drought. Drought seems to be synchronizing canopy recruitment by influencing the temporal pattern of canopy mortality. In particular, 22% of all sampled stems show a response to canopy turnover during the 1930s and a large portion of the recruitment consisted of sugar maple stems originating in gaps. Individuals of this sugar maple cohort are clustered up to 30-40 m. Along the border between the hemlock and hardwood stands, remnant hemlock by sugar maple has occurred. Diameter distributions of stems indicate that sugar maple is regenerating in hardwood stands and in areas of mixed species composition. In contrast, smaller size classes of hemlock are conspicuously absent from areas of mixed species composition and are restricted to the hemlock stand. In this hemlock-hardwood forest mosaic, sugar maple has been slowly increasing in abundance at the expense of hemlock.

479. Parshall T and Calcote RR 2001. **Effect of Pollen From Regional Vegetation on Stand-Scale Forest Reconstruction.** *Holocene* 11: 81-87.

Keywords: Palaeoecology/Vegetation History/Pollen Analysis/Forest Hollow/Modern Analogues/Surface Samples/Dispersal/Hollows/*Fagus* spp./*Tsuga* spp./*Acer saccharum*/*Fagus grandifolia*/*Tilia americana* / northern hardwoods

Abstract: To investigate the influence of regional pollen inputs on reconstructing local vegetation, we compared modern pollen assemblages deposited in forest hollow sediments from two study areas, Michigan and Wisconsin. Local forest-stand composition (within 50 m) at all sites is

dominated by hemlock and northern hardwood trees, but the regional abundance of tree taxa in the two study areas is not the same. Modern pollen assemblages differ between the two study areas, corresponding with differences in regional vegetation. Oak and pine pollen are more abundant in Wisconsin samples, whereas sugar maple, birch and hemlock pollen are more abundant in Michigan samples. Pollen assemblages differed most between study areas for hardwood stands, reflecting lower pollen production of sugar maple and basswood, which exaggerates regional pollen inputs. However, within each study area, surface pollen assemblages are sufficiently different to permit differentiation of hemlock and hardwood stand types, suggesting that regional pollen inputs are similar on the scale of tens of kilometres. Therefore, stand-scale forest histories can be derived from forest-hollow sediments using modern analogues, but our results emphasize the importance of understanding the regional vegetation context and inferring how regional vegetation has changed in the past.

480. **Pastor J, Aber JD, and McClaugherty CA 1984. Aboveground production and N and P cycling along a nitrogen mineralization gradient on Blackhawk Island, Wisconsin. *Ecology* 65: 256-268.**

Keywords: nitrogen mineralization /cycling /phosphorus /nitrogen mineralization /soil texture /nitrification /soil types ecological/biomass production/seasonal variability /forest litter/nutrients /nitrogen cycle/soil fertility/Tsuga canadensis

Abstract: Net aboveground production (4.1-9.5 Mg ha⁻¹yr⁻¹) across a series of edaphic climax forests was highly correlated with field measurements of soil N mineralization (26-84 kg ha⁻¹ yr⁻¹; $r^2 = 0.902$, P less than .001) and with soil silt + clay content (5-74%; $r^2 = 0.883$, P less than .001). Soil N mineralization was positively correlated with litter production and N and P return in litter. Soil N mineralization was negatively correlated with litter C:N and C:P ratios and with efficiency of P use in litter production. Efficiency of N use in litter production declined with increasing N mineralization except for inefficient use of N in a hemlock stand at low N mineralization. Changes in litter quality across the mineralization-soil texture gradient were due to species replacement rather than changes in litter quality within each species. Nitrification was not correlated with aboveground production. Both mineralization and nitrification were highly correlated with humus P content. Differences in nitrification among the soils appeared to be related to PO₄-P supply in the spring and early summer and to NH₄-N supply in mid- to later summer.

481. **Pastor J and Bockheim JG 1981. Biomass and production of an aspen-mixed hardwood-spodosol ecosystem in northern Wisconsin. *Canadian Journal of Forest Research* 11: 132-138.**

Keywords: biomass production/quantitative techniques /Acer saccharum/Populus tremuloides

Abstract: Total biomass was 197 t/ha and net primary production 11.5 t/ha per yr. Populus tremuloides accounted for 60% of the total biomass and 56% of annual production; Acer saccharum for 25% and 28% respectively, bole wood 63% and 33%, bole bark 12% and 7%. Crowns accounted for 15% of total biomass, but 49% of net annual production. Root biomass and production were estimated at 10% of total biomass and production. The av. rate of total production/g leaf tissue was 5.7 g for P. tremuloides and 3.7 g for A. saccharum. From authors' summary.

482. **Pastor J and Bockheim JG 1984. Distribution and cycling of nutrients in an aspen-mixed-hardwood-Spodosol ecosystem in northern Wisconsin. *Ecology* 65: 339-353.**

Keywords: nutrient cycling /nutrients /soil chemistry /forest soils/spodosols /podzols /phosphorus /calcium /magnesium /sulfur /iron /zinc /nitrogen /soil types/vegetation types/Acer saccharum/Populus tremuloides /soil fragipan /biomass productivity

Abstract: The distribution and cycling of N, P, Ca, Mg, S, Fe and Zn were examined over a 2-yr period in an aspen-mixed-hardwood-Spodosol ecosystem in order to determine the roles of

overstory aspen and understory sugar maple in nutrient retention. Stand biomass and net primary production (NPP) were 198 Mg/ha and 12.5 Mg ha⁻¹ yr⁻¹, respectively. Overstory quaking aspen (*Populus tremuloides*) comprised 60% of the biomass and 50% of the NPP, and understory sugar maple (*Acer saccharum*) comprised 24 and 25% of these values, respectively. The total soil N pool and extractable soil P and Mg pools were larger than the respective vegetation nutrient pools. Nutrient cycling within this ecosystem is characterized by large uptake rates, retention of between 40 and 60% of nutrient uptake in perennial tissues, and leaching losses of <3 kg ha⁻¹ yr⁻¹ for each nutrient. Between 22 and 40% of total stand nutrient uptake is retained in perennial tissues of quaking aspen and between 4 and 20% in perennial tissues of sugar maple. Translocation of nutrients out of leaves back into perennial tissues was an important retention mechanism for N, P, and K; was less important for S, Mg, and Fe; and did not occur for Ca and Zn. Uptake as rainwater passed through the canopy, and immobilization within the A1 horizon were additional retention mechanisms for NH₄-N and NO₃-N. A fragipan at the base of the rooting zone also slowed leaching losses.

483. **Payandeh B and Haig RA 1991. A management-oriented model for assessing early stand establishment. Great Lakes Forestry Centre (Canadian Forestry Service) Frontline Technical Note No. 5, 4 pp.**

Keywords: forest plantations/artificial regeneration/stand establishment/simulation models/assessment /model

484. **Peet RK 1984. Twenty-six years of change in a *Pinus strobus*, *Acer saccharum* forest, Lake Itasca, Minnesota. *Bulletin of the Torrey Botanical Club* 111: 61-68.**

Keywords: Synecology /conifers /broadleaves /*Acer saccharum*/*Pinus strobus* /succession

485. **Perala DA 1974. Growth and survival of northern hardwood sprouts after burning. U.S. For. Serv. Research Note NC-176, 4 pp.**

Keywords: natural regeneration/controlled burning/fire /slash /disposal/*Quercus rubra*/*Tilia americana*/*Populus tremuloides*/*Betula papyrifera*/northern hardwoods /shoot growth

Abstract: The growth of shoots from the root-collar of nine hardwoods was measured annually for five years after prescribed burning in *Populus tremuloides* slash in Minnesota [cf. FA 35, 7668]. *Tilia americana*, *Quercus rubra* and *Betula papyrifera* produced the most vigorous growth of shoots. The diameter of the parent tree directly influenced the number of shoots from each root-collar.

486. **Perala DA 1974. Prescribed burning in an Aspen-mixed hardwood forest. *Canadian Journal of Forest Research* 4: 222-228.**

Keywords: fire /controlled burning/suckering /broadleaves /*Populus tremuloides*

Abstract: The effects of (a) prescribed burning and (b) complete clear felling on *Populus tremuloides* and associated hardwoods and shrubs were compared for 8 years after commercial logging of a 60-year-old *P. tremuloides* stand in Minnesota. Lack of suitable weather prevented burning before the *P. tremuloides* suckers were 2 years old. All the original suckers were killed by fire, but new suckers were produced; these were more numerous but less vigorous (for reasons discussed). The results showed that (a) can be used effectively to control residual hardwood overstoreys detrimental to the growth and survival of suckers, where (b) (or some other means of removing the overstorey) is not practicable. The long-term effect of fire on sucker growth of *P. tremuloides* is, however, unknown. Burning should be done during the first dormant season after logging. Advice is given on the distribution of slash, and prescriptions for burning are suggested.

487. **Perala DA 1974. Some invert formulations of picloram to prepare brushy sites for conversion to**

conifers. *Down to Earth* 30: 24-25.

Keywords: crops /picloram (herbicide) /2,4,5 T/2,4 D/weeds /woody weeds/herbicides /forest nurseries/damage /deformities /herbicide nozzles /physiology /interactions /leaching /residues /soil /site preparation/chemicals /Pinus resinosa /site preparation /competition /silvicultural conversion

Abstract: Invert emulsion sprays of picloram, 2,4,5-T and 2,4-D were applied at the Chippewa National Forest in N. central Minnesota to prepare a site densely infested with common shrubs and low-quality hardwood regeneration up to 10 ft high for conversion to conifers. The sprays were applied in August 1970 from a truck equipped with a turret gun nozzle system in a 30-ft swath at 20 gal/acre and the site was planted with red pine [*Pinus resinosa*] seedlings in May 1972. One year after application all the mixtures of picloram + 2,4-D or + 2,4,5-T (1:4) at 2-2.5 lb, 5-6 lb and 10-12 lb/acre had controlled the vegetation better than 2,4-D + 2,4,5-T (1:1) at 5-6 lb and 10-12 lb/acre or 2,4,5-T by itself at 2-2.5 and 5-6 lb. The low rate of picloram + 2,4,5-T sufficed to kill all the vegetation, while all the other picloram mixtures, except the low rate of picloram + 2,4-D, gave 90% control or more. Bioassays with *P. resinosa* seedlings carried out in June 1971 showed that picloram at rates up to 2 lb/acre did not influence germination or survival, though some twisting of the cotyledons and late casting of seed were induced. Between 3 and 6% of the original application was still active in the top 6 inches of soil. *P. resinosa* planted the second growing season after treatment showed excellent overall survival. All picloram + phenoxyacetic acid mixtures averaged 94% survival and the phenoxyacetic acids alone averaged 95%. Survival was not affected by the amount of picloram applied.

488. **Perala DA 1985. Using glyphosate herbicide in converting aspen to conifers. U.S. For. Serv. Research Paper NC-259, 4 pp.**

Keywords: silvicultural conversion/herbicide /glyphosate /weed control/woody weeds /control /plantations /crops /broadleaves /conifers /*Populus tremuloides* /*Picea glauca*

Abstract: Sites at Cloquet Forestry Center, Minnesota, and near Ontonagon, Michigan, were clear felled in summer 1979 or early 1980. In late summer 1980, aspen (*Populus tremuloides*) regeneration was sprayed with glyphosate at rates of 0, 1.0, 1.5 and 2.0 lb/acre on 4 dates between 8 Aug. and 17 Sep. at Cloquet and at rates of 0 and 2.0 lb/acre on 12-13 Aug. at Ontonagon. Both sites were planted with container-grown white spruce in spring 1981. At Cloquet, all rates of glyphosate reduced aspen biomass, and aspen and shrub stem density when applied up to 2 Sep. Results for treatment on 17 Sep. were highly variable. No treatment controlled other broadleaved trees and herbaceous cover was not significantly reduced. At Ontonagon, woody plant control was significant, but not as good as at Cloquet. Survival of white spruce after 2 yr did not differ significantly by site or treatment. Results suggested intersite variability in the efficacy of glyphosate.

489. **Perala DA and Alm AA 1989. Regenerating paper birch in the Lake States with the shelterwood method. *Northern Journal of Applied Forestry* 6: 151-153.**

Keywords: natural regeneration/seedbeds /site preparation/stand characteristics/silvicultural systems/shelterwood /seed production/germination /*Populus* spp. /aspen /*Betula papyrifera* /discing

Abstract: Although paper birch [*Betula papyrifera*] regenerates successfully after clear felling in New England, Alaska and Canada, it does not do so in the upper Great Lakes region (attributed to frequent summer drought and competition from aspen [*Populus* sp.] suckers). This study initiated in 1979 in a 60-yr-old birch stand at the Cloquet Forestry Centre, N. Minnesota, USA, evaluated factors critical to birch seedling establishment and growth. Four 2.5-acre blocks were partially felled to give crown cover densities of 8-64% and b.a. 8-87 ft²/acre. The following year, 2 of 4 plots in each block were sprayed with glyphosate and all plots were cross-disced. Residual shelterwood was removed in one block each year beginning 3 yr after discing. Results from seed

traps showed that seed production was similar in shelterwood and uncut (control) stands; seedlings were more abundant (but grew more slowly) on sprayed plots. Cross-discing after seed dispersal was beneficial, as it incorporated organic material into the soil, buried birch seed (to an optimum depth for germination) and controlled vegetation. Although glyphosate treatment set back competing vegetation for at least a year, stocking of birch was sufficient without the treatment. Based on this study, recommendations are made to cross-disc shelterwood with a 20-40% crown cover within 2 yr after a good seed crop.

490. **Perala DA and Alm AA 1990. Regeneration silviculture of birch: a review. *Forest Ecology and Management* 32: 39-77.**

Keywords: literature review /review /broadleaves /coppice /artificial regeneration/advance growth /seedbeds /silviculture /clear felling/nurse trees/afforestation /silvicultural systems/natural regeneration/shelterwood system/Betula papyrifera/Betula alleghaniensis /Betula pendula /Betula pubescens /Betula alba

Abstract: A literature review is presented which summarizes silvicultural measures used to regenerate commercially important birch species in North America (yellow birch, *Betula alleghaniensis*; paper birch, *B. papyrifera*) and in northern Europe and Asia (silver birch, *B. pendula*; hairy birch, *B. pubescens* - in early literature these two were collectively known as white birch, *B. alba*). Birches are usually regenerated using even-aged systems, mainly clear felling. Seed trees or shelterwoods may be used for additional seed and site protection. Uneven-aged systems are not recommended except for group selection of *B. alleghaniensis*. Coppice systems do not provide full stocking except in short rotation biomass production. Topics covered include: natural seeding; stand regeneration by coppicing; artificial regeneration; afforestation; and use of birch as a nurse tree for conifers.

491. **Perala DA and Alm AA 1990. Reproductive ecology of birch: a review. *Forest Ecology and Management* 32: 1-38.**

Keywords: climate /broadleaves /seed dispersal/seed germination/coppice /seedbeds /autecology /reproductive behaviour/review /literature review /Betula papyrifera/Betula alleghaniensis /Betula pendula /Betula pubescens /soil relations

Abstract: A literature review is presented of the reproductive processes and environmental requirements for natural regeneration of commercially important birch species in North America, northern Europe and Asia. Species discussed are *Betula alleghaniensis*, *B. papyrifera*, *B. pendula* and *B. pubescens*. Topics covered are: taxonomy and distribution; microclimate; soil relations; symbiotic relations; root development; reaction to biotic and abiotic influences; and reproduction - including coppice, sexual reproduction, flowering, seed production, seed dispersal and germination, and seedbed requirements.

492. **Perttunen J, Nikinmaa E, Lechowicz MJ, Sievanen R, and Messier C 2001. Application of the Functional-Structural Tree Model LIGNUM to Sugar Maple Saplings (*Acer Saccharum* Marsh) Growing in Forest Gaps. *Annals of Botany* 88: 471-481.**

Keywords: Tree Architecture/Sugar Maple/Model LIGNUM/Growth /Northern Hardwoods /Plant Growth/Light/Nitrogen/Availability/Respiration/Simulation/Patterns/*Acer saccharum*/*Fagus grandifolia*/*Betula alleghaniensis*

Abstract: LIGNUM is a functional-structural model that represents a tree using four modelling units which closely resemble the real structure of trees: tree segments, tree axes, branching points and buds. Metabolic processes are explicitly related to the structural units in which they take place. Here we adapt earlier versions of LIGNUM designed to model growth of conifers for use with broad-leaved trees. Two primary changes are involved. First, the tree segment for broadleaved trees consists of enclosed cylinders of heartwood, sapwood and bark. Leaves

consisting of petioles and blades are attached to the segments. Secondly, axillary buds and rules governing their dormancy are included in the model. This modified version of LIGNUM is used to simulate the growth and form of sugar maple saplings in forest gaps. The annual growth of the model tree is driven by net production after respiration losses are taken into account. The production rate of each leaf depends on the amount of photosynthetically active radiation it receives. The radiation regime is tracked explicitly in different parts of the tree crown using a model of mutual shading of the leaves. Forest gaps are represented by changing the radiation intensity in different parts of the model sky. This version of LIGNUM modified for use with broad-leaf, deciduous trees and parameterized for sugar maple, yields good simulations of growth and form in saplings from different forest gap environments.

493. **Peterson CJ and Squiers ER 1995. Competition and succession in an aspen-white-pine forest. *Journal of Ecology* 83: 449-457.**

Keywords: competition/succession /stand characteristics/stand structure/secondary forests/second growth forest /forest ecology/plant succession/plant competition/*Populus grandidentata*/*Populus tremuloides* /*Pinus strobus* /soil sandy

Abstract: Changes in relative abundance, dominance, diversity, size inequality, and growth of trees was documented in a c. 60-yr-old second-growth aspen-white-pine (*Populus grandidentata*, *Populus tremula* [tremuloides?], *Pinus strobus*) forest in northern Michigan, USA over a 10-yr period. Abundance and dominance decreased for aspen but increased for white pine. Size inequalities, measured as coefficient of variation (CV) of diameter, of aspen decreased over the 10 yr, while that of white pine increased. Decrease in CV for aspen appears to have been caused by mortality among small aspen stems. Few white pines grew close to aspens and their growth was unexpectedly greater than that of pines further away from aspens, suggesting a net facilitation of white pine growth. The mechanism of this interaction is unknown, although strong intraspecific competition was found among pines in areas where aspen ramets were less dense. This may have outweighed competitive effect of aspen on pine growth, resulting in net indirect facilitation. Asymmetry of intraspecific competitive effects on growth was substantially less at local scale than that reported in other studies, which is attributed to greater relative importance of below-ground competition in this site of excessively drained, nutrient-poor sandy soil. For aspen, amount of asymmetry which resulted in the best-fit model tended to decrease with increasing distance, suggesting that competition with immediate neighbours is likely to be more asymmetric than competition with more distant neighbours in closed-canopy plant communities such as forests. It is hypothesized that in closed-canopy vegetation, the contested resource may primarily be light at short distances, changing to entirely soil resources at greater distances. This study suggests that both population and community dynamics may be governed by physiological senescence of connections within individual clones of dominant aspens. As a result, successional species turnover can be considered as a function of clone dynamics, which is an alternative to more common, smaller-scale, gap dynamics that drive tree-by-tree replacement in many mature and primary forests.

494. **Peterson CJ and Squiers ER 1995. An unexpected change in spatial pattern across 10 years in an aspen-white-pine forest. *Journal of Ecology* 83: 847-855.**

Keywords: spatial distribution/plant succession/prediction /change /theory /botanical composition/vegetation types/second growth forest/stand characteristics/mortality /competition /plant competition/*Populus tremuloides* /*Populus grandidentata*/*Pinus strobus*/*Pinus banksiana*

Abstract: The change in spatial pattern due to mortality over a period of 10 years was examined in a c. 60-year-old second-growth aspen (*Populus grandidentata* and *Populus tremuloides*)/white pine (*Pinus strobus*) forest in northern Michigan, USA. It is predicted that unitary plants undergoing competitive thinning will shift toward a more regular distribution of stems. Such a pattern has been reported for temperate jack pine (*Pinus banksiana*) and four tropical tree species, but was not seen in this population of canopy aspen. The distribution of aspen living in 1989

tended toward greater clumping than that expected from random mortality of aspen living in 1979. It is suggested that this contrast to theoretical predictions was due to the clonal nature of aspen. White pine invading under aspen was clumped at all scales, both in 1979 and 1989, and its distribution showed significant repulsion from aspen at scales of 11 m and 14 m in 1989. This suggests that the net effect of the initially dominant aspen on invading white pine was one of inhibition of establishment, and that the spatial location and therefore the abundance of white pine was constrained by the locations of aspen ramets.

495. **Pickens JB, Lee A, and Lyon GW 1992. Optimal bucking of northern hardwoods. *Northern Journal of Applied Forestry* 9: 149-152.**

Keywords: economics /models /broadleaves /hardwoods /cross cutting/simulation /Acer saccharum/Quercus rubra/Tilia americana/Betula alleghaniensis/northern hardwoods

Abstract: Development and application of a cross-cutting optimization model (using dynamic programming) is described. A study of 166 cross-cut trees in Michigan (Upper Peninsula) - sugar maple [Acer saccharum], red maple [A. rubrum], red oak [Quercus rubra], yellow birch [Betula alleghaniensis], basswood [Tilia sp.] - indicated that the model gave gross values 39-55% higher than those chosen by the cross-cutters.

496. **Pickens JB, Lyon GW, Lee A, and Frayer WE 1993. HW-BUCK game improves hardwood bucking skills. *Journal of Forestry* 91: 42-45.**

Keywords: hardwoods /cross cutting/instruction tool /model /technical training /harvesting practices

Abstract: A description is given of a computerized cross cutting decision simulator, developed at Michigan Technological University as a training tool for buckers of hardwood logs and their supervisors.

497. **Pickens JB, Throop SA, and Frenthewey JO 1997. Choosing prices to optimally buck hardwood logs with multiple log-length demand restrictions. *Forest Science* 43: 403-413.**

Keywords: hardwoods /prices /logs /demand /cross cutting/length /veneers /constraints /optimization /model economic/markets

Abstract: A hierarchical optimization approach is presented that selects prices, which when used in a single stem bucking (cross cutting) optimization model, produce a specified mix of logs by grade and length. The model is developed to address the demand constrained optimal bucking situation for northern US hardwoods. The demand constraints are minimum percentages needed in 4 log lengths (3.0 m (10 ft), 3.7 m (12 ft), 4.3 m (14 ft), and 4.9 m (16 ft)) to meet order requirements from veneer buyers. There are 2 levels in the hierarchical optimization system: at the lower level, a dynamic programming model is used to optimize the value of each individual tree, while the upper level is a linear programming model which finds one or more sets of prices, each used some portion of the time, that produce the required product mix in the lower level model. The hierarchical model is solved iteratively until a single set of prices satisfies all demand constraints. This approach is distinctly different from traditional approaches, which pass different information between the upper and lower level models to solve 2-level optimization problems. The parameters passed in traditional approaches are shadow prices in one direction and production levels in the reverse direction. The model developed could be adapted to other species and log grading rules whenever several competing demand constraints exist. Furthermore, the approach could be adapted to a wide range of hierarchical planning applications where inputs, and therefore the production possibilities curve, are fixed, and constraints apply.

498. **Plantinga AJ, Buongiorno J, Alig RJ, and Spencer JS Jr. 1989. Timberland area change in the Lakes States: past trends, causes, and projections. U.S. For Serv. Research Paper NC-287, 17 pp.**

Keywords: land use /history

Abstract: A brief overview is given of changes in the forest acreage since the 1960s in Minnesota, Michigan and Wisconsin. Major factors affecting land use trends are discussed and future changes in timberland area are projected to 2040.

499. **Post WM, Pastor J, and Smith TM 1996. LINKAGES - an individual-based forest ecosystem model. *Climatic Change* 34: 253-261.**

Keywords: carbon cycle/nitrogen cycle/nitrogen mineralization /nitrogen /water supply/plant water relations/responses /synecology /botanical composition/plant succession/vegetation types/climatic change/cycling /simulation /Abies spp. /Picea spp./northern hardwoods /model LINKAGES

Abstract: Carbon storage and flow through forest ecosystems are major components of the global carbon cycle. The cycle of carbon is intimately coupled with the cycle of nitrogen and the flow of water through forests. The supply of water for tree growth is determined by climate and soil physical properties. The rate at which nitrogen mineralization occurs depends on climate and the type of carbon compounds with which the nitrogen is associated. Species composition, which is also affected by climate, can greatly influence the composition of carbon compounds and subsequently nitrogen availability. Climate change can, therefore, have a direct effect on forest ecosystem production and carbon storage through temperature and water limitations, and an indirect effect through the nitrogen cycle by affecting species composition. Model simulations of these interactions show that climate change initiates a complex set of direct and indirect responses that are sensitive to the exact nature of the projected climate changes. Results using 4 climate-change projections (from the general circulation models GFDL, GISS, OSUM, UKMO) are given for a location in NE Minnesota - currently a mixed spruce-fir [*Picea-Abies*]/northern hardwood forest. Modelled forest responses to each of these climate projections is different, indicating that uncertainties in the climate projections may be amplified further as a result of shifts in balance between positive and negative ecosystem feedbacks.

500. **Pregitzer KS and Burton AJ 1991. Sugar maple seed production and nitrogen in litterfall. *Canadian Journal of Forest Research* 21: 1148-1153.**

Keywords: Broadleaves /Seeds /periodicity /seed production/Forest litter/nutrients /Nitrogen cycle/*Acer saccharum*

Abstract: The influence of sugar maple (*Acer saccharum*) seed production on litterfall was studied for 2 years at five northern broadleaved sites located across the Great Lakes region in Upper and Lower Michigan. Flower and seed litter contributed >1 t/ha dry matter in several instances, accounting for as much as 34% of total litter deposition. Significant differences between years were measured for both foliar and reproductive litter inputs at the sites. Production of reproductive litter and foliar litter were negatively correlated at the stand level ($r = 0.99$, $P < 0.001$), suggesting a direct trade-off between leaf biomass and reproductive biomass. Bumper seed crops had a large effect on total aboveground N litterfall. Annual reproductive N flux was as high as 41 kg/ha. For both years and all sites, reproductive litter accounted for 36% of total N in aboveground litterfall (range = 14-61%). When compared with the amount of N returned in foliage, reproductive litter averaged 67% (range = 18-174%). The results indicate that N uptake and return in litterfall can be underestimated, especially during periods of heavy seed production, if flowers and seeds are ignored. Seed production plays an important role in ecosystem-level processes such as N cycling.

501. **Pregitzer KS, Burton AJ, Mroz GD, Liechty HO, and MacDonald NW 1992. Foliar sulfur and nitrogen along an 800-km pollution gradient. *Canadian Journal of Forest Research* 22: 1753-1760.**

Keywords: Acid deposition/Air pollution/nitrogen oxides/sulfur dioxide/Nitrogen cycle/Cycling /sulfur /forest litter/Foliage /chemistry /nutrients /Acer saccharum/northern hardwoods

Abstract: Emissions of sulfur and nitrogen oxides in the mid-W. and NE USA result in pronounced regional gradients of acidic deposition. A study was made of the extent to which atmospheric deposition alters the uptake and cycling of S and N in 5 analogous northern hardwood forests located along one of the most pronounced regional gradients of SO₄²⁻-S and NO₃⁻-N deposition in the USA (i.e. from a site in Minnesota on the N. shoreline of Lake Superior to sites in Michigan on the E. shoreline of Lake Michigan). The hypothesis that acidic deposition would alter foliar S and N ratios and nutrient cycling in aboveground litter fall was tested. Sulfate in both wet deposition and throughfall increased by a factor of two across the 800-km deposition gradient. The July concentration of S in sugar maple (*Acer saccharum*, the dominant species in all 5 forests) leaves increased from about 1600 µg/g at the N. research sites to 1800-1900 µg/g at the S. sites. Differences in leaf litter S concentration were even more pronounced (872-1356 µg/g), and a clear geographic trend was always apparent in litter S concentration. The 3-yr average S content of leaf litter was 63% greater at the S. end of the pollution gradient. Nitrate and total N deposition were also significantly greater at the S. end of the gradient. The concentration of N in both summer foliage and leaf litter was not correlated with N deposition, but the content of N in leaf litter was significantly correlated with N deposition. The molar ratios of S:N in mid-July foliage and leaf litter increased as atmospheric deposition of SO₄²⁻-S increased. Ratios of S:N were always much greater in leaf litter than in mid-July foliage. The molar ratios of S:N retranslocated from the canopies of these northern hardwood forests were less than those in mid-July foliage or litter fall and showed no geographic trend related to deposition, suggesting that S and N are retranslocated in a relatively fixed proportion. Significant correlations between SO₄²⁻-S deposition and foliar S concentration, S cycling, and the molar ratio of S:N in foliage suggest that sulfate deposition has altered the uptake and cycling of S in northern hardwood forests of the Great Lakes region.

502. Pregitzer KS, Hendrick RL, and Fogel R 1993. The demography of fine roots in response to patches of water and nitrogen. *New Phytologist* 125: 575-580.

Keywords: roots /root systems/soil water content/soil chemistry/nitrogen /vegetation types/deciduous forests/plant nutrition/plant water relations/*Acer rubrum*/*Fagus grandifolia*/*Quercus rubra*/*Populus grandidentata* /northern hardwoods /second growth forest

Abstract: Fine root demography was quantified in response to patches given increased water and nitrogen availability treatments in a natural, second-growth, mixed hardwood forest in northern Michigan (dominants were *Populus grandidentata*, *Quercus rubra*, *Acer rubrum* and *Fagus grandifolia*). As expected, the addition of water and water + nitrogen resulted in a significant overall increase in the production of new fine roots. New root production was much greater in response to water + nitrogen when compared with water alone, and the duration of new root production was related to the length of resource addition in the water + nitrogen treatments; the average difference in new root length between the 20 versus 40 d additions of water + nitrogen amounted to almost 600%. Roots produced in response to the additions of water and water + nitrogen lived longer than roots in the control treatments. Thus, additions of water and water + nitrogen influenced both the proliferation of new roots and their longevity, with both proliferation and longevity related to the type and duration of resource supply. The results suggest that root longevity and mortality may be plastic in response to changes in soil resource availability, as is well known for root proliferation.

503. Pregitzer KS, King JS, Burton AJ, and Brown SE 2000. Responses of tree fine roots to temperature. *New Phytologist* 147: 105-115.

Keywords: literature review /reviews /mortality /nutrient availability/phenology /respiration /growth /soil water content/soil temperature/responses /roots /seasonality /photosynthesis /soil fertility/climatic change

Abstract: Soil temperature can influence the functioning of roots in many ways. If soil moisture and nutrient availability are adequate, rates of root length extension and root mortality increase with increasing soil temperature, at least up to an optimal temperature for root growth, which seems to vary among taxa. Root growth and root mortality are highly seasonal in perennial plants, with a flush of growth in spring and significant mortality in the fall. At present it is not understood whether root growth phenology responds to the same temperature cues that are known to control shoot growth. It is also not understood whether the flush of root growth in the spring depends on the utilization of stored nonstructural carbohydrates, or if it is fuelled by current photosynthate. Root respiration increases exponentially with temperature, but Q₁₀ values range widely from c. 1.5 to >3.0. Significant questions yet to be resolved are: whether rates of root respiration acclimatize to soil temperature, and what mechanisms control acclimatization if it occurs. Limited data suggest that fine roots depend heavily on the import of new carbon (C) from the canopy during the growing season. It is hypothesized that root growth and root respiration are tightly linked to whole-canopy assimilation through complex source-sink relationships within the plant. Understanding of how the whole plant responds to dynamic changes in soil temperature, moisture and nutrient availability is poor, even though it is well known that multiple growth-limiting resources change simultaneously through time during a typical growing season. The interactions between soil temperature and other growth-limiting factors are reviewed to illustrate how simple generalizations about temperature and root functioning can be misleading.

504. Pregitzer KS, Kubiske ME, Yu CK, and Hendrick RL 1997. Relationships Among Root Branch Order, Carbon, and Nitrogen in Four Temperate Species. *Oecologia* 111: 302-308.

Keywords: Fine Roots/Architecture/Nitrogen/Turnover/Northern Hardwoods /Fine Roots/Dynamics/Plant/Ecosystems/Water/Decomposition/Turnover/Systems/Length/Acer saccharum/Fagus grandifolia/Fraxinus americana /Hydrophyllum canadense /Viola pubescens

Abstract: The objective of this study was to examine how root length, diameter, specific root length, and root carbon and nitrogen concentrations were related to root branching patterns. The branching root systems of two temperate tree species, *Acer saccharum* Marsh. and *Fraxinus americana* L., and two perennial herbs from horizontal rhizomes, *Hydrophyllum canadense* L. and *Viola pubescens* Ait., were quantified by dissecting entire root systems collected from the understory of an *A. saccharum*-*Fagus grandifolia* Ehrh. forest. The root systems of each species grew according to a simple branching process, with laterals emerging from the main roots some distance behind the tip. Root systems normally consisted of only 4-6 branches (orders). Root diameter, length, and number of branches declined with increasing order and there were significant differences among species. Specific root length increased with order in all species. Nitrogen concentration increased with order in the trees, but remained constant in the perennial herbs. More than 75% of the cumulative root length of tree seedling root systems was accounted for by short (2-10 mm) lateral roots almost always <0.3 mm in diameter. Simple assumptions suggest that many tree roots normally considered part of the dynamic fine-root pool (all roots < 2.0 mm in diameter) are too large to exhibit rapid rates of production and mortality. The smallest tree roots may be the least expensive to construct but the most expensive to maintain based on an increase in N concentration with order.

505. Pregitzer KS, Laskowski MJ, Burton AJ, Lessard VC, and Zak DR 1998. Variation in Sugar Maple Root Respiration With Root Diameter and Soil Depth. *Tree Physiology* 18: 665-670.

Keywords: Acer Saccharum/Model /Root Function/Root Respiration/Root Nitrogen/Northern Hardwood Forest/Fine Root/Douglas Fir/Nitrogen/Carbon/ Dynamics/ Ecosystems/ Turnover/ Temperature/ Systems

Abstract: Root respiration may account for as much as 60% of total soil respiration. Therefore, factors that regulate the metabolic activity of roots and associated microbes are an important component of terrestrial carbon budgets. Root systems are often sampled by diameter and depth

classes to enable researchers to process samples in a systematic and timely fashion. We recently discovered that small, lateral roots at the distal end of the root system have much greater tissue N concentrations than larger roots, and this led to the hypothesis that the smallest roots have significantly higher rates of respiration ratio than larger roots. This study was designed to determine if root respiration is related to root diameter or the location of roots in the soil profile. We examined relationships among root respiration rates and N concentration in four diameter classes from three soil depths in two sugar maple (*Acer saccharum* Marsh.) forests in Michigan. Root respiration declined as root diameter increased and was lower at deeper soil depths than at the soil surface. Surface roots (0-10 cm depth) respired at rates up to 40% greater than deeper roots, and respiration rates for roots < 0.5 mm in diameter were 2.4 to 3.4 times higher than those for roots in larger diameter classes. Root N concentration explained 70% of the observed variation in respiration across sites and size and depth classes. Differences in respiration among root diameter classes and soil depths appeared to be consistent with hypothesized effects of variation in root function on metabolic activity. Among roots, very fine roots in zones of high nutrient availability had the highest respiration rates. Large roots and roots from depths of low nutrient availability had low respiration rates consistent with structural and transport functions rather than with active nutrient uptake and assimilation. These results suggest that broadly defined root classes, e.g., fine roots are equivalent to all roots < 2.0 mm in diameter, do not accurately reflect the functional categories typically associated with fine roots. Tissue N concentration or N content (mass x concentration N) may be a better indicator of root function than root diameter.

506. **Prusas ZC, Rourke MJ, and Uhrig LO 1987. Variables in chemi-thermomechanical pulping of northern hardwoods. *Tappi Journal* 70: 91-95.**

Keywords: pulping /thermomechanical pulping/chemimechanical pulping/*Acer rubrum*/*Prunus serotina*/*Fraxinus* spp. /*Populus* spp. /aspen/*Betula papyrifera*/*Betula alleghaniensis*/northern hardwoods /*Ulmus* spp. /*Tilia* spp.

Abstract: A study was undertaken to determine relationships between the main operating variables in a 2-stage CTMP process and the properties of the pulp obtained. The wood supply from Michigan comprised 40% sugar maple, 20% white and yellow birch [*Betula alleghaniensis*, *B. papyrifera*], 15% red maple [*Acer rubrum*], 10% aspen [*Populus* sp.] and 15% linden, ash, elm and cherry [*Prunus* sp.]. In the first stage, varying the caustic charge had the greatest effect on refining energy and on the optical and physical properties of the pulp. In the second stage, the effect of S was significant particularly at high cooking temp.

507. **Puettmann KJ and Ek AR 1999. Status and trends of silvicultural practices in Minnesota. *Northern Journal of Applied Forestry* 16: 203-210.**

Keywords: artificial regeneration/clear felling/forest diversity /forest management/harvesting /regeneration /silvicultural systems/site preparation/thinning /forestry practices/trends /yields /logging /silviculture /land management

Abstract: Land managers in Minnesota were surveyed with respect to silvicultural systems and practices employed during 1996. Results were compared to corresponding information from 1991. The study obtained input from ownerships covering approximately 50% of the acreage and timber volume harvested in the state. The statewide harvest volume increased 8% from 1991 to 1996, and the estimated acreage subject to harvesting increased 1%. An increased emphasis on thinning was a significant factor in the rise in total acreage harvested. From 1991 to 1996, clearcutting (> 5 ac) decreased from 89 to 85% of the acreage harvested. Residuals were left on 77% of the acreage clearcut, a level nearly twice as high as in 1991. Reliance on natural versus artificial regeneration increased by 7% since 1991. At the same time, artificial regeneration efforts showed greater emphasis on site preparation rather than later release, especially on land owned by forest industry. Overall, forest management trends in Minnesota are moving toward a more intensively managed but also more diverse forest across ownerships.

508. **Puettmann KJ and Reich PB 1995. The differential sensitivity of red pine and quaking aspen to competition. *Canadian Journal of Forest Research* 25: 1731-1737.**

Keywords: biological competition/diameter /plant height/wood density/natural pruning/plant competition/increment /Populus tremuloides/Pinus resinosa

Abstract: Growth of red pine (*Pinus resinosa*) and quaking aspen (*Populus tremuloides*) target trees with varying degrees of competition by neighbouring aspen was measured in a 7-year-old clearcut in northeastern Minnesota. Competitive conditions were measured using indices of resource availability (percentage open sky) and neighbourhood stand density. Three-year diameter growth of target trees was reduced by more than 50% in both species because of competition from neighbouring quaking aspen. The last 2 year's height growth was also reduced by approximately 30% for both species. The relationship between growth and percentage open sky was convex for red pine and concave for quaking aspen, potentially indicating a greater sensitivity in aspen to any reduction below optimal resource availability. Competition reduced crown size in both species, but self-pruning occurred only in quaking aspen. Needle and leaf size were not affected by competition, but red pine needle density was lower in highly competitive environments. Red pine had a higher specific gravity when growing under competition, partially offsetting the reduction in wood volume.

509. **Puettmann KJ and Saunders MR 2000. Eastern white pine (*Pinus strobus*) growth response to partial hardwood overstorey release. *Northern Journal of Applied Forestry* 17: 89-94.**

Keywords: liberation felling/increment /diameter /plant height/plant competition/broadleaves /Populus spp. /Pinus strobus /release

Abstract: The response of white pine (*Pinus strobus* L.) saplings after partial release of a hardwood overstorey was measured on three sites in central Minnesota. The 3 stands were similar in age and structure, with a moderately dense, approx. 65-year-old aspen (*Populus* spp.) and hardwood overstorey (830-1560 stems/ha) and an understorey/midstorey of white pine natural regeneration (250-750 stems/ha). In 1991 or 1992 all white pine trees more than 0.7 m tall were released from overtopping competition, and aspen/hardwood stems more than 7.6 cm dbh or within 6.1 m of each white pine were girdled. Pine growth response was assessed in 1997. Both height and diameter growth increased quickly after release compared to prerelease growth. Diameter growth response was related to prerelease diameter growth, but not to initial size of the sapling (diameter at time of release). On the other hand, height growth response was strongly influenced by the initial height of all trees, but not related to prerelease height growth in the largest saplings (initial heights > 8.76 m). Increased release intensity (i. e., difference between prerelease and post-release overstorey densities) resulted in higher diameter and height growth responses. The height/diameter ratios decreased after release, indicating that stability as well as growth increased after the release.

510. **Radeloff VC, Mladenoff DJ, and Boyce MS 2000. Effects of interacting disturbances on landscape patterns: budworm defoliation and salvage logging. *Ecological Applications* 10: 233-247.**

Keywords: forest pests/plant pests/insect pests/habitats /landscape ecology/spatial distribution/defoliation /salvage felling and logging/clear felling/fire effects/forest management/outbreaks /savannas /stand development/wildlife /birds/ecology /agricultural entomology/*Pinus banksiana* /*Choristoneura pinus pinus* /jack pine budworm /sharp-tailed grouse /*Tympanuchus phasianellus*

Abstract: Prior to European settlement, the 450th000-ha Pine Barrens region in north-western Wisconsin, USA, was characterized by a landscape mosaic of large, open patches, savannas, and closed forest stands of jack pine (*Pinus banksiana*). Crown-fires created large open patches that persisted on the droughty soils, providing important habitat for a number of area-sensitive, open-habitat species. Insect outbreaks may have contributed to periodic fires by increasing the fuel load. Today, fires are suppressed in the managed landscape, but insect defoliation remains a major

disturbance. Salvage logging commonly follows insect outbreaks. Our objective was to evaluate landscape pattern changes caused by this interaction of natural disturbances and forest management. We examined changes in landscape pattern during the most recent (1990-95) outbreak of jack pine budworm (*Choristoneura pinus pinus*) in northwestern Wisconsin using four Landsat TM satellite images (1987, 1991, 1993, and 1995). The 1987 image provided the basis for a species-level forest classification identifying mature jack pine and open habitat prior to the budworm outbreak. Each subsequent image was used to identify clearcuts in mature jack pine. The 1995 image was also used to classify stand development in the open habitat of the 1987 image so that the overall availability of open habitat in 1995 could be assessed. GIS data layers were used to analyze logging rates and clearcut sizes separately for different classes of land ownership and soils. Approximately 12,500 ha were salvage logged during the 1990-1995 outbreak. Logging rates were highest on the most infertile soils, and on private, industrial forest land. Annual logging rates of different landowners were 3-6 times higher during the outbreak than previous to it. Salvage cut sizes were larger than clearcuts prior to the outbreak. New cuts were mostly located next to previous cuts, thus increasing the size of openings on the landscape. Initial survey results by N. Niemuth show that populations of one area-sensitive open-habitat species (Sharp-tailed Grouse, *Tympanuchus phasianellus*) thrive on the salvage cuts. Insect defoliation and subsequent salvage logging did create new habitat for open-habitat species that were declining. Landscape pattern changes due to multiple interacting disturbances have rarely been studied. The interaction of jack pine budworm defoliation and salvage logging substantially changed landscape pattern in the Pine Barrens. We speculate that interaction between insect defoliation and fire may have significantly shaped the presettlement landscape.

511. **Randlett DL, Zak DR, and MacDonald NW 1992. Sulfate adsorption and microbial immobilization in northern hardwood forests along an atmospheric deposition gradient. *Canadian Journal of Forest Research* 22: 1843-1850.**

Keywords: Soil chemistry/sulfur /acid deposition/Cycling /soil /Soil biology/microorganisms /Air pollution/sulfates /*Acer saccharum*/northern hardwoods

Abstract: While a number of studies have investigated adsorption and microbial immobilization as sulfate (SO₄²⁻) retention mechanisms, few have investigated these processes under field-like conditions on a regional, ecosystem basis. Adsorption and microbial immobilization of SO₄²⁻ were studied in 4 northern hardwood stands that spanned an atmospheric deposition gradient (5 to 10 kg SO₄²⁻-S per yr) in Michigan. The overstorey of each stand was dominated by sugar maple (*Acer saccharum*). Soil cores collected on 9 May, 10 July and 23 October 1990 were labelled with ³⁵SO₄²⁻ to trace the flux of S between physical and biological sinks, and to investigate seasonal variation in sink strength. Intact soil cores were injected with Na²³⁵SO₄ and incubated for 8 d in the laboratory at field temperature to study rates of adsorption and microbial immobilization. The amount of ³⁵S recovered within these pools was significantly different between surface and subsurface soil horizons. Microbial immobilization was the dominant S sink in the A+E horizon, whereas adsorption was the most important S sink in the B horizon. During the 8-d incubation, ³⁵S was immobilized in the A horizon adsorbed in the B horizon. Microbial immobilization sequestered an additional 25% of the applied ³⁵S in the B horizon. Adsorption and microbial immobilization were not significantly different among sampling dates. It is concluded that sulfur retention in forested ecosystems should be viewed as a combination of geochemical and microbially mediated processes. However, given current levels of S deposition at these sites, neither process seems to represent a significant mechanism for long-term S retention.

512. **Raulier F and Bernier PY 2000. Predicting the Date of Leaf Emergence for Sugar Maple Across Its Native Range. *Canadian Journal of Forest Research* 30: 1429-1435.**

Keywords: Northern Hardwoods /Bud Dormancy/Productivity/Phenology/Canopy/model growth/Root/Photosynthesis/Simulation/*Acer saccharum*

Abstract: A combined winter chilling and spring warming model is presented for predicting the

date for the onset of foliation of sugar maple (*Acer saccharum* Marsh.) trees. The model is calibrated using both local data obtained in two sugar maple stands during two consecutive years with contrasting foliation dates and data obtained from the literature and chosen to span the full range of sugar maple distribution. Despite the disparity of the data used, more than 84% of the variation for the observed foliation date is explained by the model. Forty-one days separate the earliest and the latest foliation dates, and on average, the predicted date is within an interval of +/- 1.5 days of the observed date. Unusual events like exceptionally cool or warm springs are also well represented by the model. The counts for chilling days and degree-days are both started on December 1, but choosing any other date between November 1 and April 1 would yield nearly as good a fit to the foliation data. Temperature thresholds for chilling days and degree-days are both set at 10°C. Although this temperature gives the best fit to the foliation data, any temperature down to about 3°C would give good results as long as both threshold temperatures are the same.

513. **Rauscher HM, Benzie JW, and Alm AA 1990. A red pine forest management advisory system: knowledge model and implementation. *AI Applications in Natural Resource Management 4*: 27-43.**

Keywords: forest management/expert systems/*Pinus resinosa*

Abstract: A red pine (*Pinus resinosa*) forest management advisory system was developed to capture, organize and disseminate the available expertise on managing red pine forests in the upper Great Lakes region (Minnesota, Michigan and Wisconsin).

514. **Reader RJ 1987. Loss of species from deciduous forest understorey immediately following selective tree harvesting. *Biological Conservation 42*: 231-244.**

Keywords: ecology /Logging /Forest ecology/Understorey /broadleaves /*Quercus alba*/*Quercus velutina*

Abstract: In a mature broadleaved forest dominated by *Quercus alba* and *Q. velutina* in S. Ontario, Canada, 33% or 66% of b.a. of canopy trees was removed from plots 12.5, 25 or 50 m in diam. The % of species lost by the next growing season after felling increased with felling intensity but not with plot diam. Woody plants in the understorey were more affected than herbaceous species since meristems of herbs were protected below ground during harvesting (Nov. to April). Understorey plants present at low density before felling (<9 occurrences/plot) were more likely to be lost than commonly occurring species. Loss of uncommon species was more likely to be minimized by reducing surface disturbance than felling intensity or area felled.

515. **Reader RJ, Bonser SP, Duralia TE, and Bricker BD 1995. Interspecific variation in tree seedling establishment in canopy gaps in relation to tree density. *Journal of Vegetation Science 6*: 609-614.**

Keywords: natural regeneration/canopy gaps/variation /establishment /density /selective felling/stand density/synecology /broadleaves /*Acer rubrum*/*Prunus serotina*/*Quercus alba*/*Quercus rubra* /*Hamamelis virginiana* /*Sassafras albidum*

Abstract: A study was made of the relation between interspecific variation in tree seedling establishment in canopy gaps and interspecific variation in tree density, for seven deciduous forest tree species (*Quercus alba*, *Hamamelis virginiana*, *Acer rubrum*, *Sassafras albidum*, *Quercus rubra*, *Prunus serotina* and *Ostrya virginiana*) at a site in S. Ontario. For each species, seedling establishment was calculated as the difference in seedling density before experimental gap creation versus three years after gap creation. In each of the six experimentally-created gap types (33% or 66% removal of tree basal area from 0.01-ha, 0.05-ha or 0.20-ha patches), differences in seedling establishment among species were significantly related to differences in their density in the tree canopy. A regression model with loge tree density as the independent variable accounted for between 93% and 98% of interspecific variation in seedling establishment. The results provide

empirical support for models of tree dynamics in gaps that assume seedling establishment depends on canopy tree density.

516. **Reed DD, Holmes MJ, and Johnson JA 1986. A 22-year study of stand development and financial return in northern hardwoods. *Northern Journal of Applied Forestry* 3: 35-38.**

Keywords: silviculture /economics /Silvicultural systems/selective felling/Improvement fellings/broadleaves /Acer saccharum/northern hardwoods /Pinus spp.

Abstract: A study was begun in 1956 on plots at the Ford Forestry Centre, Michigan. The area supported pine/broadleaved forest from which the pine was removed in 1938; a second harvest in 1938 removed 70% of the vol. of broadleaved sawlogs. Sugar maple was the dominant species. Eight silvicultural treatments were applied: light improvement thinning, thinning to 22-, 16-, 12- or 5-inch diam. and thinning to leave b.a. of 90, 70 or 50 ft²/ac. A reserve area was not thinned. Plots were logged in 1957, 1968, and 1978. Stand tables recommended for northern broadleaved species in earlier papers could be achieved fastest using a light improvement or b.a. limit cut. The greatest economic return was obtained with the most severe diam. limit cuts (5-, 12- or 16-inch), but using these limits may eliminate further returns for at least 20 yr. Thinning to a 16-inch diam. limit gave the best combination of total return and even flow of returns over the 22-yr study.

517. **Reed DD, Jones EA, Holmes MJ, and Fuller LG 1992. Modeling diameter growth in local populations: a case study involving four North American deciduous species. *Forest Ecology and Management* 54: 95-114.**

Keywords: increment /diameter /Acer rubrum/Quercus rubra/Populus tremuloides /Populus grandidentata/Betula papyrifera /model growth

Abstract: Many existing models representing the growth of forest overstorey species as a function of environmental conditions make a number of assumptions which are inappropriate when applied to local populations. For example, maximum tree diameter and height are often assumed to be constant limiting factors for a given species even though growth functions can often be localized by utilizing information in the forest growth and yield literature to make site-specific estimates of these values. Most existing models also use an annual timestep which may be inappropriate when attempting to model the growth response of individual trees to environmental conditions. In this study, a model utilizing a weekly timestep is described and applied to data from Michigan for four widespread species - red maple (*Acer rubrum*), northern red oak (*Quercus rubra*), aspen (*Populus tremuloides* or *P. grandidentata*) and paper birch (*Betula papyrifera*). Because response to environmental conditions can vary regionally as a result of genetic heterogeneity, the resulting model should not be considered as universally appropriate for these species. This study illustrates methods which can be utilized to develop models for application to local populations.

518. **Reed DD, Jones EA, Liechty HO, Mroz GD, and Jurgensen MF 1992. Impacts of annual weather conditions on forest productivity: a case study involving four North American deciduous tree species. *International Journal of Biometeorology* 36: 51-57.**

Keywords: Climate /Increment /diameter /Biomass /production /Acer rubrum/Quercus rubra/Populus grandidentata/Betula papyrifera /soil physical properties /soil chemistry

Abstract: The growth response was studied of 4 northern broadleaved tree species (*Quercus rubra*, *Betula papyrifera*, *Acer rubrum* and *Populus grandidentata*) to annual climate variation at 2 field sites in N. Michigan. Cambial growth and selected weather variables were measured continuously from 1984 and complete growing season observations were available for the period 1985-88. Soil physical and chemical properties were also measured. Response to changes in temperature and moisture differed between species and was dependent on other site conditions. The relationships identified indicate that projected climate changes may have dramatic effects on the productivity of at least some commercially important tree species in N. USA.

519. **Reed DD, Jones EA, Mroz GD, Liechty HO, Cattelino PJ, and Jurgensen MF 1993. Effects of 76 Hz electromagnetic fields on forest ecosystems in northern Michigan: tree growth. *International Journal of Biometeorology* 37: 229-234.**

Keywords: growth models/increment /radio waves/Acer rubrum/Quercus rubra/Populus tremuloides /Populus grandidentata/Pinus resinosa/Betula papyrifera

Abstract: Since 1984, the possible effects have been studied of extremely low-frequency electromagnetic (EM) fields generated by a (United States Navy Radio Transmitting Facility) 76 Hz communication antenna on the growth and productivity of northern red oak (*Quercus rubra*), paper birch (*Betula papyrifera*), aspen (*Populus tremuloides* and some *P. grandidentata*), red maple (*Acer rubrum*) and red pine (*Pinus resinosa*) in the Upper Peninsula of Michigan. Results from 2 research sites are discussed: one site near the antenna element, and a control site 50 km from the communication system. Growth models were developed for individual trees of each species. Average differences between the observed and predicted growth were calculated for both sites and for each growing season and then compared. For aspen and red maple there was a stimulation of diameter growth at magnetic flux density levels of 1 to 7 milliGauss; there was a stimulation of red pine height growth at similar magnetic flux densities. There were no clear indications of an EM effect on total annual diameter growth of red oak or paper birch.

520. **Reed DD and Mroz GD 1997. Rate of sawtimber volume and value growth of individual sugar maple trees in managed, uneven-aged stands in the Lake States. *Northern Journal of Applied Forestry* 14: 78-83.**

Keywords: volume /growth /roundwood /prices /increment /stumpage value/valuation /grading /growth models/tree classes/*Acer saccharum*/northern hardwoods /uneven-aged forests

Abstract: While volume growth of individual sawtimber trees is dependent on changes in diameter and merchantable height, value growth is dependent on these along with changes in tree quality, the quality of logs recovered from the tree, and market prices. For sugar maple [*Acer saccharum*] and other northern hardwood species, quality development is at least as important as biological growth in determining value growth, making development of silvicultural prescriptions and marking guidelines complex but extremely important for maximizing returns. This paper utilizes projection methods from the literature to develop expected rates of biological and value growth for sugar maple in managed, uneven-aged forests. These rates are presented by 2 inch diameter class and one-half 16 ft log merchantable height classes. Based on the models, the projected rate of biological growth increases with tree diameter and decreases with merchantable height. The rate of value growth generally increases with tree diameter and decreases with merchantable height, but the relationships with tree grade are complex.

521. **Reed DD, Pregitzer KS, Liechty HO, Burton AJ, and Mroz GD 1994. Productivity and growth efficiency in sugar maple forests. *Forest Ecology and Management* 70: 319-327.**

Keywords: vegetation types/deciduous forests/stand development/growth /air pollution/basal area/biomass /acid deposition/climate /*Acer saccharum*/northern hardwoods

Abstract: Second-growth, sugar maple (*Acer saccharum*)-dominated northern hardwood forests were examined at four locations along an acid deposition and climatic gradient in the Great Lakes (central to northern Michigan, USA). The study sites were matched in terms of physiography, soils, stand history, and vegetative characteristics. Measurements of basal area and biomass growth were made for the growing seasons from 1988 to 1991. There were no significant differences in either basal area or biomass increment among the four sites over the 4 year period. There was a great deal of year-to-year variability with relative basal area growth rates ranging from as low as 0.2% to as high as 2.4% on a single site in successive years. Growth efficiency measures reflected this variability with as much as an 800% difference between successive years on a single site. When coupled with year-to-year variability of up to 34% in leaf area related to

heavy seed years and defoliation, this indicates that growth efficiency and leaf area measures are not consistent indicators of aboveground productivity for tolerant deciduous species, especially if derived from short-term measurements or temporary plots.

522. Reich PB, Abrams MD, Ellsworth DS, Kruger EL, and Tabone TJ 1990. Fire affects ecophysiology and community dynamics of central Wisconsin oak/forest regeneration. *Ecology* 71: 2179-2190.

Keywords: natural regeneration/fires /canopy gaps/plant succession/controlled burn /forest fires/fire ecology/Acer rubrum/Prunus serotina/Quercus ellipsoidalis /Rubus allegheniensis

Abstract: The response was evaluated of northern pin oak (*Quercus ellipsoidalis*), red maple (*Acer rubrum*), black cherry (*Prunus serotina*) and blackberry (*Rubus allegheniensis*) to a low-intensity controlled surface fire in intermediate-size gaps in a 30-year-old forest in central Wisconsin during April 1987. Effects during the following growing season included: *A. rubrum* seedling density was reduced by 70%; there was a large increase in percentage cover in *R. allegheniensis*; increases in foliar concentrations of N, P and K; and rates of photosynthesis were 30-50% greater on burned than unburned plots for *P. serotina*, *Q. ellipsoidalis* and *R. allegheniensis*. Compared with other species, *A. rubrum* seedlings responded negatively after fire, both in terms of survival/reproduction and in relative leaf physiological performance.

523. Reich PB, Ellsworth DS, and Walters MB 1998. Leaf Structure (Specific Leaf Area) Modulates Photosynthesis- Nitrogen Relations: Evidence From Within and Across Species and Functional Groups. *Functional Ecology* 12: 948-958.

Keywords: functional groups/net photosynthesis/nitrogen/specific leaf area/use efficiency/leaf life span/leaves/CO₂/plants/water/mass/carbon/ecophysiology/assimilation

Abstract: 1. Net photosynthetic capacity ($A(\max)$, defined as light-saturated net photosynthesis under near optimal ambient environmental conditions) of mature leaves often depends on the level of leaf nitrogen (N), but an assortment of relationships between these variables has been observed in studies of diverse plant species. Variation in leaf structure has been identified as an important factor associated with differences between the area- and mass-based expressions of the $A(\max)$ -N relationship. In this paper we test the hypothesis that leaf structure, quantified using a measure of leaf area displayed per unit dry mass invested [specific leaf area (SLA)], is more than just a conversion factor, but itself can influence $A(\max)$ -N relationships. We test this using several kinds of comparisons, based on field data for 107 species from sites representing six biomes and on literature data for 162 species from an equally diverse set of biomes. 2. Species and genera with thicker and/or denser leaves (lower SLA) consistently have flatter slopes of the $A(\max)$ -N (mass-based) relationship than those with higher SLA. These and all other contrasts usually applied as well using area-based expressions, although such relationships were less consistent and weaker overall. A steeper slope indicates greater incremental change in $A(\max)$ per unit variation in N. 3. Functional groups (e.g. needle-leaved evergreen trees, broad-leaved trees or shrubs, forbs) show the same patterns: groups with lower SLA have lower $A(\max)$ -N slopes. Functional groups differ in mean leaf traits as well as in $A(\max)$ -N relationships. Forbs have the highest SLA and mass-based N and $A(\max)$, followed by deciduous species (whether needle-leaved or broad-leaved, shrub or tree), with lowest values in evergreen species (again regardless of leaf type or functional group). 4. Interspecific variation in mass-based $A(\max)$ is highly significantly related to the combination of leaf N and SLA ($r^2 = 0.86$). At any value of leaf N, $A(\max)$ increases with increasing SLA and at any value of SLA, $A(\max)$ increases with increasing leaf N. Because this relationship, between $A(\max)$ and the combination of N and SLA, is similar in two independent data sets, and as well, across broad taxonomic and geographic gradients, we hypothesize that it is universal in nature. Therefore, for broad interspecific contrasts among dicotyledons in any biome, we can reasonably well predict $A(\max)$ based on the combination of SLA and leaf N. These findings have important implications for convergent evolution of leaf adaptation and great potential utility in models of global vegetation functioning.

524. Reich PB, Ellsworth DS, Walters MB, Vose JM, Gresham C, Volin JC, and Bowman WD 1999. **Generality of Leaf Trait Relationships: a Test Across Six Biomes.** *Ecology* 80: 1955-1969.

Keywords: leaf life span/leaf diffusive conductance/nitrogen/photosynthesis/scaling/specific leaf area/tropical forest/photosynthesis-nitrogen relations/life-span/ plant/ leaves/ ecophysiology/ diffusion/ defense

Abstract: Convergence in interspecific leaf trait relationships across diverse taxonomic groups and biomes would have important evolutionary and ecological implications. Such convergence has been hypothesized to result from trade-offs that limit the combination of plant traits for any species. Here we address this issue by testing for biome differences in the slope and intercept of interspecific relationships among leaf traits: longevity, net photosynthetic capacity (A(max)), leaf diffusive conductance (G(s)), specific leaf area (SLA), and nitrogen (N) status, for more than 100 species in six distinct biomes of the Americas. The six biomes were: alpine tundra-subalpine forest ecotone, cold temperate forest-prairie ecotone, montane cool temperate forest, desert shrubland, subtropical forest, and tropical rain forest. Despite large differences in climate and evolutionary history, in all biomes mass-based leaf N (N-mass), SLA, G(s), and A(max) were positively related to one another and decreased with increasing leaf life span. The relationships between pairs of leaf traits exhibited similar slopes among biomes, suggesting a predictable set of scaling relationships key leaf morphological, chemical, and metabolic traits that are replicated globally among terrestrial ecosystems regardless of biome or vegetation type. However, the intercept (i.e., the overall elevation of regression lines) of relationships between pairs of leaf traits usually differed among biomes. With increasing aridity across sites, species had greater A(max) for a given level of G(s) and lower SLA for any given leaf life span. Using principal components analysis, most variation among species was explained by an axis related to mass-based leaf traits (A(max) N, and SLA) while a second axis reflected climate, G(s), and other area-based leaf traits.

525. Reich PB, Grigal DF, Aber JD, and Gower ST 1997. **Nitrogen mineralization and productivity in 50 hardwood and conifer stands on diverse soils.** *Ecology* 78: 335-347.

Keywords: nitrogen mineralization /nitrogen /cycling /productivity /soil types/soil alfisols/soil entisols/soil parent materials/soil types genetic/entisols /alfisols /site factors/nitrogen cycle/soil chemistry

Abstract: The generality of relationships between soil net nitrogen (N) mineralization, aboveground N cycling, and aboveground net primary production (ANPP) for temperate forest ecosystems is unclear. It is also not known whether these variables and their relationships differ between evergreen and deciduous forests, or across soil types. To address these questions, data were compiled on annual rates of in situ net N mineralization and ANPP for 16 conifer and 34 hardwood forests, including forest plantations and natural stands, on a range of soils at six locations in Wisconsin and Minnesota, USA. The results are discussed. It is concluded that soil properties had significant effects on N mineralization and ANPP, which supports the hypothesis that control of productivity in temperate forest ecosystems is linked to their N status. However, the question remains as to whether other site factors lead to greater productivity and higher N status, whether N status is an effect and not a cause, or both cause and effect. The authors suggest that the latter case is the most likely\dash\the data, which cover a range of climatic, soil and vegetation types within the same biome, indicate intrinsically higher N status and greater productivity on Alfisol soils compared to Entisols, and greater productivity even at a given N status. Possible limitations due to water-retention characteristics and base cation status of Entisols are suggested as an important factor governing N availability.

526. Reich PB, Kloeppel BD, Ellsworth DS, and Walters MB 1995. **Different photosynthesis-nitrogen relations in deciduous hardwood and evergreen coniferous tree species.** *Oecologia* 104: 24-30.

Keywords: species /foliage /leaves /leaf area/photosynthesis /plant nutrition/nitrogen /nutrition

Abstract: The relationship between photosynthetic capacity (A_{max}) and leaf nitrogen concentration (N) among all C₃ species can be described roughly with 1 general equation, yet within that overall pattern species groups or individual species may have markedly different A_{max}-N relationships. To determine whether 1 or several predictive, fundamental A_{max}-N relationships exist for temperate trees measurements were made of A_{max}, specific leaf area (SLA) and N in 22 broadleaved deciduous and 9 needle-leaved evergreen tree species in Wisconsin, USA. For broadleaved deciduous trees, mass-based A_{max} was highly correlated with leaf N. For evergreen conifers, mass-based A_{max} was also correlated with leaf N and the slope of the regression (rate of increase of A_{max} per unit increase in N) was lower by two-thirds than in the broadleaved species (1.9 vs. 6.4 μmol CO₂ g⁻¹ N s⁻¹), consistent with predictions based on tropical rain forest trees of short vs. long leaf lifespan. On an area basis, there was a strong A_{max}-N correlation among deciduous species and no correlation in the evergreen conifers. Compared to deciduous trees at a common leaf N (mass or area basis), evergreen trees had lower A_{max} and SLA. For all data pooled, both leaf N and A_{max} on a mass basis were correlated with SLA; in contrast, area-based leaf N scaled tightly with SLA, but area-based A_{max} did not because of low A_{max} per unit N in the evergreen conifers. Multiple regression analysis of all data pooled showed that both N (mass or area basis) and SLA were significantly related to A_{max} on mass and area bases, respectively. These results provide further evidence that A_{max}-N relationships are fundamentally different for ecologically distinct species groups with differing suites of foliage characteristics: species with long leaf lifespans and low SLA, whether broadleaved or needle-leaved, tend to have lower A_{max} per unit leaf N and a lower slope and higher intercept of the A_{max}-N relation than do species with shorter leaf lifespan and higher SLA. A single global A_{max}-N equation overestimates and underestimates A_{max} for temperate trees at the upper and lower end of their leaf N range, respectively. Users of A_{max}-N relationships in modelling photosynthesis in different ecosystems should appreciate the strengths and limitations of regression equations based on different species groupings.

527. **Reiners WA 1968. Carbon dioxide evolution from the floor of three Minnesota forests. *Ecology* 49: 471-483.**

Keywords: litter /root respiration /soils /Thuja occidentalis litter /humus /Quercus spp. /microclimate

Abstract: CO₂ evolution rates from forest floors, measured weekly for 54 weeks in Oak forest, marginal fen and Cedar [Thuja occidentalis] swamp, were related to soil temperature (especially) and moisture conditions. Consequently, microclimatic and drainage characteristics of the three forests produced nearly equal cumulative annual totals of CO₂ evolution. Total CO₂ evolution was >3 times higher than expected from an equivalent amount of C release from annual litter fall; this disparity was tentatively attributed to respiration by tree roots, although methodological problems related to flow rate may have been involved.

528. **Reiners WA 1972. Nutrient contents of canopy throughfall in three Minnesota forests. *Oikos* 23: 14-22.**

Keywords: precipitation /solutes /Quercus ellipsoidalis /Fraxinus nigra/Thuja occidentalis /throughfall chemistry/nutrients

Abstract: Ca, Mg, N and P were measured in the throughfall of three contiguous forests: upland Oak (dominated by Quercus ellipsoidalis), marginal fen (with Fraxinus nigra), and Cedar swamp (dominated by Thuja occidentalis). Annual totals for the three sites in kg/ha were respectively 7.6, 10.5 and 10.7 for Ca; 3.1, 3.8 and 3.7 for Mg; 5.5, 5.5 and 6.0 for NH₄- and organic N; and 0.7, 0.6 and 0.5 for P. Throughfall deposits as %s of the sum for throughfall + litter fall were 13, 10 and 10 for Ca; 23, 22 and 23 for Mg; 11, 10 and 12 for N; and 11, 8 and 7 for P. [Cf. FA 30, 43, 1777; 31, 19].

529. **Reiners WA 1972. Structure and energetics of three Minnesota forests. *Ecological Monographs* 42: 71-94.**

Keywords: vegetation types/swamps /fens /forest litter/quantitative techniques/synecology /*Quercus ellipsoidalis* /*Fraxinus nigra*/*Thuja occidentalis* /aboveground productivity /detritus

Abstract: Three contiguous ecosystems - an upland *Quercus ellipsoidalis* forest, *Fraxinus nigra* marginal fen, and *Thuja occidentalis* swamp [cf. FA 30, 43, 1777; 31, 19] - were analysed along a gentle topographic gradient on the Anoka Sand Plain in east-central Minnesota. The organic structure and above-ground primary productivities of these forests were compared with similar data for other natural ecosystems of the sand plain. Living above-ground biomass totals of the Oak forest, fen, and swamp were 124.6, 98.8, and 159.6 tonnes/ha, respectively. Above-ground net annual productivities were 8.9, 7.1, and 10.3 tonnes/ha, respectively, which compared well with other forest data for the region and with a predicted value based on actual evapotranspiration. Several measures of structure were compared in the analysis. Species richness and equitability were greatest in the marginal fen, where biomass and productivity were the least. Richness and equitability were lowest in the Oak forest. The swamp showed the highest ratio of biomass to production, although it had the highest annual production. Apparently the high production in the swamp resulted from the large mass of relatively inefficient *T. occidentalis* foliage. The percentages of primary production entering detritus pathways were 52, 62, and 48 for Oak, fen, and swamp, respectively. Total detritus, including dead boles, branches, and forest floors, was large in relation to living biomass in all three forests, but was especially important in the fen and swamp systems where deep forest floors had accumulated. Total detritus was 61%, 331%, and 577% of above-ground biomass in the Oak, fen and swamp, respectively. All data were produced in caloric as well as weight units.

530. **Reiners WA and Reiners NM 1970. Energy and nutrient dynamics of forest floors in three Minnesota forests. *Journal of Ecology* 58: 497-519.**

Keywords: forest litter/*Quercus ellipsoidalis* /*Fraxinus nigra*/*Thuja occidentalis* /calcium /magnesium /nitrogen /phosphorus /litter chemistry

Abstract: Gives results of measurements of energy, total ash, Ca, Mg, N and P content of litter fall and forest floors in three contiguous forests: upland Oak forest (with *Quercus ellipsoidalis* and other hardwoods); marginal fen (with *Fraxinus nigra* and other tree species); and Cedar swamp (dominated by *Thuja occidentalis*). [Cf. FA 30, 43, 1777; 31, 19].

531. **Reynolds PE, Bell FW, Simpson JA, Gordon AM, Lautenschlager RA, Gresch DA, and Buckley DA 1997. Alternative conifer release treatments affect leaf area index of competing vegetation and available light for seedling growth. *Forestry Chronicle* 73: 83-89.**

Keywords: vegetation management/plant succession/leaf area index/seedling growth/woody weeds/weed control/chemical control/herbicides /glyphosate /triclopyr /physical control/brush cutters/cutting /forest plantations/plant competition/light /tending /weeds /*Populus tremuloides* /*Picea glauca* /*Picea mariana* /artificial regeneration /competition

Abstract: Leaf area index (LAI) of competing vegetation and photosynthetically-active radiation (PAR) for spruce seedling growth were measured during the first growing season after application of alternative conifer release treatments: brush saw, Silvana Selective, Release (triclopyr) herbicide, Vision (glyphosate) herbicide, and control (no treatment). Bareroot white (*Picea glauca*) and black (*Picea mariana*) spruce were planted between 1987 and 1991 at the site SW of Thunder Bay, Ontario, and averaged 82 cm height in 1993 compared with 2.6 m for major competitors. Treatments were applied in 1993, the primary competitor being trembling aspen (*Populus tremuloides*). After the first growing season following treatments, LAI at seedling base differed ($P=0.002$) among treatments, ranging from 2.04 (Vision) to 3.88 (control) m^2/m^2 . The Vision treatment had significantly lower LAI than the brush saw, Silvana Selective, and Release

treatments (means = 2.76, 2.76, and 2.74 m²/m², respectively), and the control treatment had significantly greater LAI than all other treatments. LAI correlated well ($r=0.81$) with measured competition levels, increasing as competition levels increased. Mean tip angle (MTA) did not differ among treatments, but was higher for the Vision treatment, presumably because of reduced broadleaved tree and shrub cover. PAR decreased as LAI increased ($r=-0.90$). In 1994, few released seedlings were overtopped by competing vegetation, and available PAR at leader height was generally 100%. For control seedlings, available PAR at leader height varied among blocks, ranging from 20 to 50%. PAR at seedling base differed among treatments, was lowest (13%) for controls, highest (36%) for the Vision, and intermediate (26%) for all other treatments. Available PAR on a whole seedling basis (i.e. average of leader and base) ranged from 25% for control seedlings to 68% for seedlings released with Vision.

532. **Reynolds PE, Simpson JA, Lautenschlager RA, Bell FW, Gordon AM, Buckley DA, and Gresch DA 1997. Alternative conifer release treatments affect below- and near-ground microclimate. *Forestry Chronicle* 73: 75-82.**

Keywords: microclimate /relative humidity/weed control/chemical control/physical control/cutting /brush cutters/herbicides /glyphosate /triclopyr /woody weeds/forest plantations/light intensity/soil temperature/soil moisture/tending /Populus tremuloides/Picea glauca/Picea mariana

Abstract: Li-Cor weather stations and thermistor/resistance soil cells were used during 1994 to monitor microclimate in young (3-8 years old) spruce plantations (*Picea mariana* and *P. glauca*) during the first growing season after the following replicated alternative conifer release treatments: brush saw, Silvana Selective, Release (triclopyr) herbicide, Vision (glyphosate) herbicide, and control (no treatment). Treatments to the plantations SW of Thunder Bay, Ontario, designed to control *Populus tremuloides* and other broadleaved species, were conducted in mid-August (herbicides) and late October and early November (cutting) 1993. Photosynthetically-active radiation (PAR) near (0.25 m) and above (2 m) the forest floor increased on all conifer release treatments. By July, PAR near the forest floor declined on both the cut and herbicide treatments. That decline occurred in early July for the brush saw treatment, but in late July for the Vision treatment. PAR at 2 m was similar among conifer release alternatives and significantly greater than for controls throughout the growing season. Increased solar radiation resulted in significant soil warming following the conifer release treatments. During the growing season, duff (5 cm) and mineral (15 cm) soil temperatures were highest for the Vision and Release treatments, and lower on the brush saw and control treatments. November soil temperatures were slightly cooler in released than control plots. Frequent rains resulted in relatively high RH and soil moisture readings during the 1994 growing season. Relative humidity near the forest floor was lowest for the Vision, intermediate for the brush saw, and highest for the control treatments. During the growing season after treatments, soil moisture levels were higher on treated than control plots.

533. **Ribbens E, Silander JA Jr., and Pacala SW 1994. Seedling recruitment in forests: calibrating models to predict patterns of tree seedling dispersion. *Ecology* 75: 1794-1806.**

Keywords: forest ecology/botanical composition/stand characteristics/seed dispersal/models /vegetation types/seedlings /model SORTIE/recruitment /simulation /spatial distribution/wind /*Acer rubrum*/*Fagus grandifolia*/*Prunus serotina*/*Quercus alba*/*Quercus rubra*/*Fraxinus americana*/ *Pinus strobus*/*Betula alleghaniensis*/*Tsuga canadensis*/northern hardwoods

Abstract: A method is presented for calibrating spatial models of plant recruitment that does not require identifying the specific parent of each recruit. This method calibrates seedling recruitment functions by comparing tree seedling distributions with adult distributions via a maximum likelihood analysis. The models obtained from this method can then be used to predict the spatial distributions of seedlings from adult distributions. Recruitment functions for 10 tree species characteristic of transition oak/northern hardwood forests were calibrated. Data were collected from forests in Connecticut and Michigan. Species were: *Acer rubrum*, *A. saccharum*, *Betula alleghaniensis*, *Fraxinus americana*, *Pinus strobus*, *Tsuga canadensis* (wind pollinated), *Prunus*

serotina (seeds dispersed by birds), *Quercus alba* and *Q. rubra* (seeds dispersed by mammals and birds), and *Fagus grandifolia* (which reproduces largely through root sprouts). Significant differences were found in seedling abundances and spatial distributions. Predicted seedling recruitment limitation for test stands varied substantially between species, with little recruitment limitation for some species and strong recruitment limitation for others. Recruitment was limited due to low overall recruit production or to restricted recruit dispersion. When these seedling recruitment parameters were incorporated into a spatial, individual-based model of forest dynamics, called SORTIE, alterations of recruitment parameters produced substantial changes in species abundance, providing additional support for the potential importance of seedling recruitment processes in community structure and dynamics.

534. **Ribe RG 1989. The aesthetics of forestry: what has empirical preference research taught us? *Environmental Management* 13: 55-74.**

Keywords: public opinion/forest management/multiple use/landscape /aesthetic value

Abstract: Multiple-use forest management has come to include an attention to scenic values, and methods are being developed to incorporate aesthetic considerations into decision making. A survey is given of published research exploring public preferences for forest landscapes and their reactions to silvicultural practices.

535. **Ribe RG 1990. *The perception of scenic beauty in northern hardwood landscapes: forest structure and differences across recreational needs.* PhD dissertation, University of Wisconsin, Madison. 254 pp.**

Keywords: northern hardwoods /aesthetics /multiple-use management /survey /literature review

Abstract: The increased demands upon public forests have placed these landscapes under increased public scrutiny and recreational use. As a result, forest managers must consider the scenic-recreational value of plans effecting the condition of forests seen and visited by the public. To aid these decisions, a large body of research has investigated public preferences for forest landscapes. This work is comprehensively reviewed regarding the beauty of forest conditions, such as tree density and size, ground cover, species makeup, thinnings and harvests. These findings are found to be largely intuitive and of limited practical value for at least two reasons. First, they do not indicate a generally valid means of meaningfully predicting the relative beauty of whole forests with many attribute combinations. Second, they report findings about the general public's perception of forests' beauty, or that of arbitrarily defined subsets of the public, and do not consider more relevant differences in the preferences of different visitor types engaged in different activities. These two problems have not been effectively addressed because of an inadequacy in the psychophysical scenic beauty estimation method frequently employed in forest perception studies, namely, its measurement of perceived beauty on an interval rather than a ratio scale. A solution to this methodological deficiency is developed and explained for use in the research. An approach toward finding general models for predicting forests' beauty is proposed. It is pursued in discovering a general model of perceived beauty in northern hardwood forests. A variety of such forests are sampled photographically and for structural attributes and scenic beauty estimates are found from respondents' judgments of them. These estimates are successfully predicted by an efficient model combining theoretically reasonable forest attributes suggested by past studies. The respondents who judged the forests' beauty are classified into recreational types by activity and setting preferences and recreational motives. The aesthetic standards, needs and discriminative abilities of these recreation types are compared. 'Wildernist' recreationists and those engaged in activities motivated by self actualization are found to be most discriminating of settings' scenic acceptability across forests.

536. **Ribe RG 1994. Scenic beauty perceptions along the ROS. *Journal of Environmental Management* 42: 199-221.**

Keywords: amenity forests/environmental impact/tourism impact/evaluation /landscape /perception /areas of outstanding natural beauty/outdoor recreation/forest recreation /survey

Abstract: The relationship between types of recreation experiences described by the recreation opportunity spectrum (ROS) and perceived scenic satisfactions is investigated. A total of 196 respondents were classified into several subsets preferring 'primitive' versus more 'motorized' experiences and activities based upon motivations, setting preferences and favourite activities. They evaluated forest landscapes for scenic beauty and for scenic satisfaction as settings for favourite activities. Thirty-one forests in Wisconsin, USA, served as the sample of recreation settings for the study. Differences in recreation experience preferences accounted for only 10% of the explained variation in perceived scenic satisfactions, with shared scenic beauty perceptions accounting for the rest. All recreation participants, except hunters, wanted scenic beauty, but differences among types of participants were observed in their standards for, and discriminations of, scenic satisfaction in settings. More primitive activities were most demanding of, and sensitive to, differences in scenic beauty. More urban activities were also more demanding of scenic beauty but were less sensitive to differences in that quality.

537. **Richards CH and Reed DD 1986. A volume estimation system for four northern hardwood species. *Northern Journal of Applied Forestry* 3: 25-28.**

Keywords: volume determination/equations /merchantable volume/Acer saccharum /Acer rubrum/ Populus spp. /aspen/Betula alleghaniensis/northern hardwoods

Abstract: A volume estimation system based on Schumacher's total vol. equation is developed for sugar maple, red maple [*Acer rubrum*], yellow birch [*Betula alleghaniensis*] and aspen [*Populus* sp.] in upper Michigan. From measurements of d.b.h. and ht., the system provides a method of predicting total tree vol., upper stem diam. to any ht. and merchantable vol. to any ht. or diam. limit. Coefficients are given for vol. estimates o.b. and u.b. An example demonstrates the potential of the system.

538. **Richter DL and Bruhn JN 1993. Mycorrhizal fungus colonization of *Pinus resinosa* Ait. transplanted on northern hardwood clearcuts. *Soil Biology and Biochemistry* 25: 355-369.**

Keywords: mycorrhizae - Cenococcum & Suillus /succession /Conifers /plantations /ecology /*Pinus resinosa*/northern hardwoods

Abstract: An ordered succession in mycorrhizal fungus colonization occurred on *P. resinosa* root systems transplanted on 3 recently-cleared northern hardwood sites in northern Michigan, USA. Ordered changes were related to tree age from transplanting, and were demonstrated experimentally by quantification of mycorrhizal morpho-types, lab. isolation of fungi from mycorrhizae, physiological categorization of fungi recovered from mycorrhizae and surveys of fruiting bodies associated with seedlings and transplants. With increasing plantation age (1) the number of non-mycorrhizal root tips encountered declined to zero, (2) the common nursery mycorrhizae decreased in abundance, (3) new mycorrhizal types (especially *Cenococcum* and *Suillus*) became more abundant, (4) cellulolytic fungi and ectendomycorrhizal fungi were isolated from mycorrhizae less frequently and (5) ectomycorrhizal fungi were isolated from mycorrhizae more frequently. The number of apparently different mycorrhizal fungus species isolated from mycorrhizae increased from 5 in the first year after transplanting to 22 in the fourth year.

539. **Rishikof RH 1997. *The residual effects from clearcutting or farm management on the biotic and internal nutrient dynamics of a northern hardwood forest (Ontario)*. MS thesis, Trent University, Peterborough (Canada). 142 pp.**

Keywords: northern hardwoods /floral diversity /litter chemistry /nitrogen /phosphorus /potassium /calcium /magnesium /grazing /harvesting /succession

Abstract: Floral diversity, community composition, and forest structure along with the litter and soil dynamics of the internal nutrient cycle were analyzed in (a) part of the forest which was clearcut 65-70 years ago and (b) part of the same forest used in conjunction with cattle farming since the turn of the century. Adjacent old growth systems were used as reference sites. Both disturbed sites showed the same general trends when compared to reference systems: lower amounts of N, P, K, Ca, and Mg input from litter; more early successional tree species in the overstory; a more open canopy associated with an increase in herbaceous and shrub ground cover; and higher levels of floral diversity. The most dramatic differences associated with the farm managed site were the severely reduced sapling and seedling densities and a higher diversity of herbaceous and shrub species resulting from the invasion of weedy and exotic species. The occasional limited harvest of trees in the farm managed site, combined with grazing and trampling pressure from 15-60 cattle were the most likely causes of the lower levels of internal nutrient cycling and higher levels of herbaceous and shrub diversity. Differences in nutrient dynamics were most prominent in the clearcut site despite the cut being made 65-70 years ago. Nutrient input from the litter in the clearcut site was greatly reduced compared to the reference site, with N (48%) and Ca (33%) input being most notably reduced. The overstory in the clearcut site was in a state of transition from early to late successional species while the floral diversity at ground level was higher than in the old growth reference system. (Abstract shortened by UMI.)

540. **Roberts MR 1992. Stand development and overstory-understory interactions in an aspen-northern hardwood stand. *Forest Ecology and Management* 54: 157-174.**

Keywords: Stand characteristics/stand structure/stand development/Light /Recruitment /Understorey /Acer rubrum/Fagus grandifolia/Fraxinus americana/Populus grandidentata/northern hardwoods /Amelanchier spp. /Acer pensylvanicum

Abstract: A 1-ha permanent plot dominated by aspen (*Populus grandidentata*) in northern lower Michigan was analysed to determine past stand development trends and interactions between overstorey (trees, 5 cm diameter or greater) and understorey (saplings, 1 cm or over and less than 5 cm diameter) populations. The overstorey consisted of *P. grandidentata* in the canopy (30-35 m) and *Acer rubrum*, *A. saccharum* and *Fagus grandifolia* in the subcanopy (up to 25 m). Most of the subcanopy trees were multiple stems. The understorey was composed of saplings of several shade-tolerant and midtolerant broadleaved species. Most of the saplings were single stems. Stand age and diameter structures indicated that the young stand was composed of root suckers of aspen along with vegetative sprouts and seedlings of the northern hardwood species established following disturbance 68 years ago. Continuous recruitment of seedlings and sprouts has occurred throughout the period. An increase in recruitment of seedlings of *A. rubrum*, *Fraxinus americana*, *Ostrya virginiana*, *Amelanchier* spp., and *Acer pensylvanicum* began 35 years ago and has continued to the present. Spatial pattern analysis indicated that saplings of midtolerant species are strongly segregated away from shade-tolerant trees but only weakly segregated away from intolerant trees (aspens). These results suggest that the aspen overstorey has had little effect on the development of the understorey, except that the recent wave of recruitment may be partially related to aspen senescence. The shade-tolerant northern hardwood species inhibit sapling recruitment. Light appears to be the limiting factor that controls temporal and spatial patterns of succession in this mixed stand. Current trends indicate that an understorey of midtolerant species will become dominant in areas without a broadleaved subcanopy. In areas under the dense subcanopy, a sparse understorey of shade-tolerant species will continue to slowly develop. As the aspen overstorey senesces, this mosaic of understorey species will be left to dominate the stand.

541. **Roberts MR and Gilliam FS 1995. Patterns and mechanisms of plant diversity in forested ecosystems: implications for forest management. *Ecological Applications* 5: 969-977.**

Keywords: forest management/patterns /diversity /ecosystems /stand characteristics/species diversity/simulation models /literature review

Abstract: The objectives of this paper are to (1) review existing diversity models, (2) identify

principles that explain patterns of plant species diversity, (3) discuss implications for forest management, and (4) identify research needs. Many current theories cast disturbance as the key player in maintaining species diversity by preventing competitive dominance of one or a few species. Equilibrium and nonequilibrium theories alike agree that maximum diversity should occur at intermediate size, frequency, and intensity of disturbance. These models do not adequately predict patterns at all spatial scales or across community types. A mechanistic theory is needed to explain diversity patterns at the patch, stand, and landscape scales, as well as across site quality and successional gradients. Such a theory should be based upon the interaction between species' life-history characteristics and the nature of disturbance. New research is needed in the following areas: identifying disturbance-life-history interactions, particularly with respect to the short-term and long-term effects of disturbance; quantifying patch diversity and determining its relationship with species diversity; and identifying appropriate standards of comparison for managed stands. Comparative studies in different ecosystem types, such as boreal and tropical forests, should be encouraged to help clarify the relative importance of processes that influence diversity.

542. **Robinson AP and Ek AR 1998. ACRONYM a hierarchical tree and forest growth model framework. Department of Forest Resources (University of Minnesota) Staff Paper Series No. 127, 20 pp.**

Keywords: model ACRONYM /growth models/increment /forest ecology/forest inventories/silviculture /forest management

Abstract: ACRONYM is an extensible tree-level forest growth and dynamics model framework for the synthesis and assessment of models and submodels of forest ecosystem processes. The framework is designed for research in forest ecology and silviculture, and testing of silvicultural guidelines, forest inventory updates and long-term projections of forest and landscape dynamics.

543. **Rockel M, Buongiorno J, Lothner DC, and Kallio E 1983. Future consumption of timber growth in northern Minnesota: 1980-2030. U.S. For. Serv. Research Paper NC-244, 15 pp.**

Keywords: timber trade/simulation /pulpwood /fuelwood /sawtimber /wood products

Abstract: Consumption projections are presented by major species groups for pulpwood used in pulp and construction board, fuelwood and sawn timber. The projections indicate that total consumption of pulpwood, fuelwood and sawn timber could increase by 97 to 116%.

544. **Rogers RS 1981. Mature mesophytic hardwood forest: community transitions, by layer, from east-central Minnesota to southeastern Michigan. *Ecology* 62: 1634-1647.**

Keywords: synecology /vegetation types/succession /climax communities/ecotones /Acer saccharum/Fagus grandifolia/Tilia americana

Abstract: Late successional forest stands, dominated by *Acer saccharum*, were sampled in summer 1978 across a floristic gradient including the northern maple/basswood region and the north western beech/maple region. Results supported earlier findings [see FA 13, 175] that 'climax' forests on mesic sites west of the beech border are characterized by basswood (*Tilia americana*) as co-dominants, but as soon as the beech border is crossed, beech (*Fagus americana*) is the principal co-dominant. Regional differences in composition were not readily apparent in inferior layers (vascular plants less than 2 m tall).

545. **Rooney TP, McCormick RJ, Solheim SL, and Waller DM 2000. Regional Variation in Recruitment of Hemlock Seedlings and Saplings in the Upper Great Lakes, USA. *Ecological Applications* 10: 1119-1132.**

Keywords: deer browsing/ecosystem management/geographic subsections/limiting factors/path analysis/regional survey/sapling recruitment/seedling establishment/tree demography/*Tsuga canadensis*/old-growth/spatial pattern/landscape/deer/diversity/age/northern hardwoods

/*Odocoileus virginianus*

Abstract: Mature eastern hemlock-northern hardwood forest cover decreased drastically in the upper Midwest following European settlement and has yet to rebound substantially. Previous studies show that stands retaining substantial hemlock canopy coverage have low hemlock seedling and sapling densities. Results from various geographically restricted studies suggest several possible mechanisms that could cause low seedling or sapling density. We examined the relative importance of these proposed mechanisms in the Southern Superior Uplands Section of the Laurentian Forest Province. We surveyed 294-m² plots in 100 hemlock stands in northern Wisconsin and western upper Michigan to assess how these proposed mechanisms affect the number of hemlock seedlings and saplings in four sequential size classes. Seedling and sapling abundance increases with greater light availability and differs significantly among geographically distinct ecological units (ecological subsections). In contrast, the abundance of medium and large saplings (30-99 and 100-300 cm tall) appears unrelated to light and geographic factors but declines as deer browsing increases, diminishing recruitment of larger saplings. The abundance of seedlings and saplings in each size class also depends strongly on the number of seedlings or saplings in the next smaller size class at the same site, reflecting demographic inertia. Path analysis integrates and separates these effects, explaining 24% of the regional variation in seedling abundance, 63% of small sapling abundance, and similar to 80% of medium and large sapling abundance. Light and ecological subsection directly affect the number of seedlings and small saplings, whereas deer browsing directly affects the number of medium saplings. Demographic inertia remains important for all larger size classes. These results imply that restoring hemlock populations requires both appropriate microsites for seedling establishment and sanctuary from excessive browse for successful recruitment.

546. **Rooney TP and Waller DM 1998. Local and regional variation in hemlock seedling establishment in forests of the upper Great Lakes region, USA. *Forest Ecology and Management* 111: 211-224.**

Keywords: seedlings /basal area/natural regeneration/surveys /survival /recruitment /site factors/ forest litter/dead wood/sampling /stand characteristics/spatial variation/*Acer saccharum*/*Tsuga canadensis*/ deer /*Odocoileus virginianus*

Abstract: Successful tree regeneration requires both successful seedling establishment and subsequent survival and growth sufficient to ensure recruitment. Patterns of initial seedling establishment were examined in randomly selected stands of eastern hemlock (*Tsuga canadensis*) distributed across northern Wisconsin and eastern Upper Michigan, USA. In 1990, all hemlock seedlings (defined as 4-29 cm tall) were counted and substrate conditions sampled in two 7X7 m quadrats of 142 hemlock and hemlock/hardwood stands. In 1996, 109 of these stands were resampled more intensively using six 7X7 m quadrats. In 1997, an intensive survey was made of which substrates supported hemlock seedlings in three 50 m² replicate areas from each of 5 stands. In the 1990 survey, no hemlock seedlings were found in 64 of the 142 stands sampled, and 46% of the stands had >100 hemlock seedlings ha⁻¹ (mean density=480±90 ha⁻¹). In contrast, only 14 (13%) of the 109 stands resampled in 1996 had no seedlings and 66% had over 100 seedlings ha⁻¹ (mean density=840±200 ha⁻¹). These results suggest that seedling establishment is patchy, causing the estimated frequency of successful establishment to depend strongly on the area sampled. Seedling abundance within sites was correlated between years, suggesting that site history may in part account for the abundance of seedlings. Analysis of variance to mean ratios showed that seedlings were strongly clumped at the 7X7 m scale or smaller. Such clumping probably results from the tendency for hemlock seedlings to occur most frequently on particular substrates (i.e. decaying wood). Hemlock seedlings occurred less frequently in stands with a high basal area of sugar maple (*Acer [saccharum]*) but did not decline in stands with greater hemlock basal area, suggesting that maple litter may restrict local opportunities for seedling establishment. Seedling densities did not vary among habitat types, and no other stand or regional variable significantly affected hemlock seedling density. These results suggest that ground surveys are needed to assess hemlock seedling abundance, and that such surveys should be based on quadrats of at least 100 m². Successful hemlock regeneration should capitalize on local patches of existing

hemlock seedlings where interference by hardwoods is minimal. Even high initial seedling establishment, however, may not guarantee regeneration in areas where high deer densities preclude recruitment into larger size classes.

547. **Ross MR 1976. Forest regeneration in the rural-urban fringe: a study of secondary succession in the Niagara Peninsula. *Canadian Geographer* 20: 141-157.**

Keywords: succession /seral stages/land use/planning

548. **Roth S, Lindroth RL, Volin JC, and Kruger EL 1998. Enriched atmospheric CO₂ and defoliation: effects on tree chemistry and insect performance. *Global Change Biology* 4: 419-430.**

Keywords: defoliation /poplars /starch /tannins /carbon dioxide/damage /chemical composition/ plant composition/water content/nitrogen /broadleaves /agricultural entomology/Acer saccharum/ Populus tremuloides /Malacosoma disstria

Abstract: The effects were examined of CO₂ and defoliation on tree chemistry and performance of the forest tent caterpillar, *Malacosoma disstria*. Quaking aspen (*Populus tremuloides*) and sugar maple (*Acer saccharum*) trees were grown in open-top chambers under ambient or elevated concentrations of CO₂. During the second year of growth, half of the trees were exposed to free-feeding forest tent caterpillars, while the remaining trees served as nondefoliated controls. Foliage was collected weekly for phytochemical analysis. Insect performance was evaluated on foliage from each of the treatments. At the sampling date coincident with insect bioassays, levels of foliar nitrogen and starch were lower and higher, respectively, in high CO₂ foliage, and this trend persisted throughout the study. CO₂-mediated increases in secondary compounds were observed for condensed tannins in aspen and gallotannins in maple. Defoliation reduced levels of water and nitrogen in aspen but had no effect on primary metabolites in maple. Similarly, defoliation induced accumulations of secondary compounds in aspen but not in maple. Larvae fed foliage from the enriched CO₂ or defoliated treatments exhibited reduced growth and food processing efficiencies, relative to larvae on ambient CO₂ or nondefoliated diets, but the patterns were host species-specific. Overall, CO₂ and defoliation appeared to exert independent effects on foliar chemistry and forest tent caterpillar performance.

549. **Rothstein DE 1999. *Ecophysiology of three deciduous forest herbs: Relationships between physiology, life history and ecosystem-level nitrogen cycling*. PhD dissertation, University of Michigan, Ann Arbor. 134 pp.**

Keywords: northern hardwoods /*Allium tricoccum* /*Viola pubescens* /*Tiarella cordifolia* /light /vernal dam hypothesis /nitrogen cycling /soil microorganisms

Abstract: The dramatic, yet predictable, changes in light availability beneath the canopy of temperate deciduous forests have given rise to communities of sympatric herbaceous plants that differ in their life histories. I have investigated the physiological and growth characteristics of three co-occurring herbs of a northern hardwood forest, each representative of a different phenological guild: the spring ephemeral *Allium tricoccum*, the summergreen *Viola pubescens*, and the semi-evergreen *Tiarella cordifolia*. In addition, I examined the influence of the spring ephemeral guild on ecosystem-level nitrogen (N) cycling. Leaf CO₂ exchange, structure, and biochemistry differed, both among species and within species between seasons, to match the changing light environment below the forest canopy. *Viola* exhibited remarkable plasticity of photosynthesis across the spring-summer transition. *Tiarella* acclimated both from spring to summer, and from summer to fall. Modeling of seasonal assimilation, and an analysis of whole-plant growth, demonstrated that acclimation allowed *Viola* and *Tiarella* to exploit the high light intensities of spring and fall (*Tiarella* only), without going into negative carbon balance in the deep shade of summer. These results demonstrate the importance of brief, seasonal periods of high light availability to the growth of deciduous forest herbs, even to shade-tolerant species that are primarily associated with the shaded conditions of summer. There were dramatic disjunctions

between the physiology of C assimilation and that of N capture in *Tiarella* and *Allium*. The most striking example of this was in *Allium*, which took up the bulk of its yearly N increment in the summer months when it was leafless. These data suggest that *Allium* should only be considered a spring ephemeral in terms of photosynthetic C assimilation. Finally, contrary to the 'vernal dam' hypothesis, I found no evidence that spring ephemerals in this northern hardwood forest have a significant influence on ecosystem-level patterns of N-cycling and loss. Instead, it appears that immobilization of N by soil microorganisms is the primary mechanism of springtime N retention in this ecosystem.

550. Rothstein DE 2000. Spring Ephemeral Herbs and Nitrogen Cycling in a Northern Hardwood Forest: an Experimental Test of the Vernal Dam Hypothesis. *Oecologia* 124: 446-453.

Keywords: vernal dam/spring ephemerals/NO₃⁻ leaching/microbial biomass/N immobilization/ion-exchange resins/nutrient dynamics/ soil/ ecosystems/ plants/ mineralization/ nitrification/ competition/ nitrate/growth/northern hardwoods

Abstract: In the late 1970s R.N. Muller and E.H. Bormann posited their "vernal dam" hypothesis, stating that spring-ephemeral herbs in deciduous forests serve as a temporary sink for N when overstorey trees are dormant, and then release this N later, in the summer, when the trees are active. This hypothesis has gained wide acceptance yet two of its critical assumptions have never been experimentally tested: (1) that N taken up by spring ephemerals would otherwise be lost from the ecosystem, and (2) that N from senesced ephemeral tissues contributes to increased rates of summertime N mineralization. To test these assumptions, I quantified patterns of N cycling and loss from a set of paired plots, half of which served as controls and from half of which all spring-ephemeral plants were removed. There were no significant differences in NO₃⁻ leaching between plots with and without spring ephemeral vegetation. These results are consistent with the relatively low rates of N uptake by the dominant spring ephemeral, *Allium tricoccum*, and its apparent preference for NH₄⁺, which is far less mobile in soil than NO₃⁻. In addition, based on sequential sampling, I found that soil microorganisms took up 8 times as much N during the spring than did spring-ephemeral herbs (microbial uptake=3.19 vs, plant uptake=0.41 g N m⁻²), suggesting that microbial immobilization of N is the dominant sink for N during this season. Removal of spring ephemeral vegetation also had no effect on summertime rates of net N mineralization. Furthermore, the addition of spring ephemeral litter to soil+forest floor microcosms did not significantly increase rates of N mineralization in a laboratory incubation. Instead, this experiment demonstrated the overwhelming influence of forest floor litter in controlling the release of mineral N from these soils. Overall, neither assumption of the vernal dam hypothesis holds true in this ecosystem, where patterns of N cycling and loss appear to be dominated by microbial decomposition of forest floor material and soil organic matter.

551. Rothstein DE, Zak DR, and Pregitzer KS 1996. Nitrate deposition in northern hardwood forests and the nitrogen metabolism of *Acer saccharum* marsh. *Oecologia* 108: 338-344.

Keywords: nitrate reductase/nitrogen metabolism/nitrate /deposition /deciduous forests/air pollution/plant nutrition/*Acer saccharum*/northern hardwoods

Abstract: It is generally assumed that plant assimilation constitutes the major sink for anthropogenic nitrate NO₃⁻ deposited in temperate forests because plant growth is usually limited by nitrogen (N) availability. Nevertheless, plants are known to vary widely in their capacity for NO₃⁻ uptake and assimilation, and few studies have directly measured these parameters for overstorey trees. Using a combination of field and greenhouse experiments, the N nutrition of *Acer saccharum* was studied in four northern hardwood forests receiving experimental NO₃⁻ additions equivalent to 30 kg N ha⁻¹ per year. Leaf and fine-root nitrate reductase activity (NRA) of overstorey trees using an in vivo assay and used ¹⁵N to determine the kinetic parameters of NO₃⁻ uptake by excised fine roots. In two greenhouse experiments, leaf and root NRA were measured in *A. saccharum* seedlings fertilized with 0-3.5 g NO₃⁻-N m⁻² and NH₄⁺ uptake in excised roots of seedlings. In both overstorey trees and seedlings, rates of leaf and fine root NRA

were substantially lower than previously reported rates for most woody plants and showed no detectable response to NO_3^- fertilization. Maximum rates of NO_3^- uptake in overstorey trees were also low, ranging from 0.2 to 1.0 $\mu\text{mol g}^{-1}$ per hour. In seedlings, the mean V_{max} for NO_3^- uptake in fine roots (1 $\mu\text{mol g}^{-1}$ per hour) was approximately 30 times lower than the V_{max} for NH_4^+ uptake (33 $\mu\text{mol g}^{-1}$ per hour). The results suggest that *A. saccharum* satisfies its N demand through rapid NH_4^+ uptake and may have a limited capacity to serve as a direct sink for atmospheric additions of NO_3^- .

552. **Ruark GA 1990. Evidence for the reserve shelterwood system for managing quaking aspen. *Northern Journal of Applied Forestry* 7: 58-62.**

Keywords: silvicultural systems/shelterwood /*Populus tremuloides* /competition /timber quality /wildlife

Abstract: An alternative management system for quaking aspen [*Populus tremuloides*] is proposed, based on the known biology of the species, and on field data collected from even-aged fully stocked 8- to 32-year-old stands in Wisconsin, USA in 1983. Field data indicated that the stands were overstocked at an early age (e.g. 13 630 stems/ha at age 8, of which only 10% would eventually be crop trees at age 40). At age 8, only 15% of above ground net primary production was channelled to future harvestable stems, and at age 18 only 40% of aspen biomass would be harvestable at 40 years. This is an inefficient use of ecosystem pools due to interspecific as well as intraspecific competition. The alternative strategy, of leaving some dominant trees uncut following harvest at 32 years, in order that they suppress initial restocking levels, should give improved aspen timber quality, as well as benefits to wildlife.

553. **Ruben JA, Bolger DT, Peart DR, and Ayres MP 1999. Understory Herb Assemblages 25 and 60 Years After Clearcutting of a Northern Hardwood Forest, USA. *Biological Conservation* 90: 203-215.**

Keywords: distribution patterns/deciduous forest/clearcut/edge/dynamics/layer/northern hardwoods / understory /disturbance /logging /succession

Abstract: The abundance of understory herbs in 25- and 60-year old clearcuts was compared to adjacent old secondary stands to infer how herb assemblages change in space and time following clearcutting of secondary forest. Herb densities and environmental conditions were sampled along 100 m transects crossing the clearcut/old secondary forest boundary, at three sites with 25-year old clearcuts and three sites with 60-year old clearcuts. At the 25-year sites, species densities of the 23 most frequent species were compared between clearcuts and adjacent old secondary forest to classify species into response groups. Species were classed as "insensitive" if there was little or no difference in density (seven species), "sensitive" if densities were lower in the clearcuts (six species), "enhanced" if densities were higher in clearcuts (four species), and "edge-enhanced" if densities were highest near clearcut edges (six species). Densities of two of the six sensitive species declined significantly with distance from the edge into the clearcut. Further, when regression results for all 23 species were combined, the mean slope of density vs. distance was significantly negative, indicating an overall trend to lower density with distance into the clearcuts. Most species classed as sensitive at 25 years did not show similar sensitivity at the 60-year sites; only one species had lower density in 60-year clearcuts than adjacent old secondary stands. Overall, there were substantial residual effects of clearcutting on herb assemblages within 50 m of the historical edge at 25-year sites, but not at 60-year sites. This difference may be due to different logging practices at the two historical times, as well as the difference in time for recovery since logging.

554. **Rutkowski DR and Stottlemeyer R 1993. Composition, biomass and nutrient distribution in mature northern hardwood and boreal forest stands, Michigan. *American Midland Naturalist* 130: 13-30.**

Keywords: vegetation types/boreal forests/deciduous forests/stand characteristics/botanical composition/stand structure/forest litter/nutrient reserves/biomass /calcium /nitrogen /sulfur /potassium /phosphorus /magnesium /forest soils/northern hardwoods

Abstract: Aboveground vegetation stand structure and composition were compared in two watershed ecosystems located in Michigan's Upper Peninsula and on Isle Royale National Park, dominated by mature northern hardwoods and the other by mature boreal forest, respectively; biomass and nutrient content of ecosystem components were quantified. The boreal forest stand contained 10 canopy species and had an aboveground biomass of 108 t/ha while the northern hardwood stand had 15 canopy species and a biomass of 267 t/ha. The boreal understorey had a larger number of saplings (10 440 stems/ha) and much greater biomass (2275 kg/ha) than the northern hardwood stand (2938 stems/ha, 85 kg/ha). Its vascular ground cover also contained more biomass (1180 kg/ha vs 34 kg/ha for northern hardwoods). The forest floor contained 21% of the aboveground organic matter in the boreal forest and 4% in the northern hardwood stand. Calcium was the most abundant nutrient in the biomass of both stands, followed by N > K > Mg > S > P (P > S in northern hardwoods). The largest reservoirs were: Ca (92 kg/ha) in northern hardwood bark; K(85 kg/ha) and P(39 kg/ha) in northern hardwood bole; and Mg(77 kg/ha), N (113 kg/ha) and S (58 kg/ha) in boreal forest Oa horizon. Overall, the biomass in northern hardwoods had the larger nutrient content. In the boreal ecosystem, the Oi, Oe and Oa horizons had the largest nutrient content with most of it in the Oa horizon.

555. **Ryan DAJ, Allen OB, McLaughlin DL, and Gordon AM 1994. Interpretation of sugar maple (*Acer saccharum*) ring chronologies from central and southern Ontario using a mixed linear model. *Canadian Journal of Forest Research* 24: 568-575.**

Keywords: air pollution/climate /temperature /precipitation /age /increment /volume /dendrochronology / forest decline/*Acer saccharum*

Abstract: A new method is presented for assessing the effect of environmental factors on the radial growth rate of trees. The natural logarithms of the specific volume increments (SVI) were fitted to a mixed linear model, which included fixed effects for tree age when the increment occurs, year, precipitation, temperature (both in the year of growth and in the preceding year) and geographical location. The model also incorporates stand and tree as random effects. By fitting trees of different ages, the model was able to separate year effects from age effects. Age and year were treated as categorical variables and hence no specific form of growth curve is assumed. The model was fitted to log SVI from 84 mature sugar maple (*Acer saccharum*) trees from 42 uneven-aged stands in 6 regions of southern and central Ontario representing a known gradient of air pollution. After adjusting for age, precipitation and temperature effects, the log SVI increased during the first half and declined during the second half of the 20th century in 5 of the 6 regions, suggesting that factors other than those included in the model have affected growth. Air pollution remains a likely causal agent in this observed decline.

556. **Sakai AK 1990. Sex ratios of red maple (*Acer rubrum*) populations in northern lower Michigan. *Ecology* 71: 571-580.**

Keywords: Broadleaves /*Acer rubrum*/*Quercus rubra*/*Populus grandidentata* /soil moisture /nutrients /edaphic characteristics /seed /sprout

Abstract: Red maple on 9 different sites (representing stands 29- to >128-yr-old, in plots dominated by bigtooth aspen *Populus grandidentata*, red oak *Quercus rubra* as well as maple) showed generally male-biased sex ratios across a wide variety of habitats and through time. These ratios were not correlated with moisture or nutrient conditions, and for more mesic sites, ratios did not appear to be affected by stand age, although more xeric sites showed greater male bias in sex ratios with stand age. On xeric sites, sex ratio of regularly flowering trees was more male biased than ratio of trees at first reproduction. Although data appear to support resource allocation theory predicting more male-biased ratios in older or poorer habitats, the male-biased sex ratios did not

result from measurable differences in sex expression of trees originating from sprouts vs. seeds, sex-related differences in size at first reproduction, sex-related differential mortality, or patterns of sex lability. Differences in sex ratio were of minor importance in reproductive success of individuals in xeric plots, given the lack of reproduction from seed. Reproduction from seed was higher in mesic areas, but sex-related differences in life history characteristics were not evident in these areas. The similarity of ratios in a diversity of habitats and through time suggests that the ratios may reflect underlying genetic patterns of sex expression, rather than environmental responses.

557. **Sakai AK 1990. Sexual reproduction of red maple (*Acer rubrum*) in Northern Lower Michigan. *American Midland Naturalist* 123: 309-318.**

Keywords: reproductive behaviour/natural regeneration/site factors/vegetative propagation/seed production/seed banks/*Acer rubrum* /edaphic characteristics

Abstract: Sexual reproduction of red maple was studied on 9 sites in Cheboygan County, Michigan, USA, in 1982-84. The relative importance of vegetative and sexual reproduction depended both on soil conditions and time since last disturbance. On xeric sites, sexual reproduction was limited not by density of seed-bearing trees, but by low seed production of female and bisexual trees (especially by low seedling survival). On more mesic sites, sexual reproduction was more important; more seeds were produced and remained in the seed bank, and seedling and sapling survival was greater. Large numbers of seeds and new seedlings were produced in old-growth forest, but seedlings did not survive the understorey conditions. These observations of seed production and seedling population dynamics support general observations that on xeric sites, recruitment after disturbance is through stump-sprouting, and on mesic-wet sites, initial recruitment after disturbance through stump-sprouting is followed by sexual reproduction.

558. **Saunders MR and Puettmann KJ 1999. Effects of overstorey and understorey competition and simulated herbivory on growth and survival of white pine seedlings. *Canadian Journal of Forest Research* 29: 536-546.**

Keywords: plant competition/seedlings /survival /canopy /mortality /herbivores /seedling growth/understorey /light /browsing damage/brush control/cutting /underplanting /deciduous forests/shelterwood system/*Pinus strobus*/northern hardwoods/deer /*Odocoileus virginianus*

Abstract: The interactive effect of overstorey canopy closure, understorey brush control (cutting and removing all vegetation within 2 m of each seedling), and simulated white-tailed deer (*Odocoileus virginianus*) herbivory via clipping on the growth and survival of underplanted white pine (*Pinus strobus*) seedlings was studied 3 years after underplanting a strip thinned northern hardwood forest near Grand Rapids, Minnesota. Clipping was conducted in April 1996 and 1997 at 3 intensities; control (0% previous year's growth removed); lightly clipped (terminal and 50% previous year's growth removed); and heavily clipped (100% of previous-year's growth removed). Clipping was also undertaken at 3 frequencies (never clipped, clipped once or clipped 2 years in a row). Decreasing overstorey canopy closure and brush competition generally increased growth of seedlings under all clipping regimes, with heavily clipped seedlings showing the least benefit of reduced competition. Although first-year height growth was stimulated after light-intensity clipping, this effect did not persist the following year, and these trees still were significantly shorter than controls at the end of the experiment. Diameter growth was reduced at any clipping intensity or frequency, and remained below controls throughout the experiment. Seedling mortality was higher without brush control and after clipping. Results suggest that increased overstorey and understorey competition reduced seedling growth and survival. In regards to clipping, initial height growth stimulation may result from (i) resource reallocation away from diameter and root growth and/or (ii) hormonal redistributions from loss of apical control in the seedling. Since both high competition levels and increased herbivory reduced seedling vigour, it is suggested that understorey brush control and deer protection (e.g., budcapping) are used together

to regenerate white pine.

559. Scarpa R, Buongiorno J, Hseu JS, and Abt KL 2000. Assessing the non-timber value of forests: a revealed-preference, hedonic model. *Journal of Forest Economics* 6: 83-107.

Keywords: amenity value of forests/income /land use/prices /non market benefits/model economic/ private forestry/ownership/economics/socioeconomics /returns /profitability /valuation /nontimber value /Acer spp. /Betula spp.

Abstract: Based on revealed preference theory, the value of non-timber goods and services obtained by forest owners, private or public, should be at least equal to the difference between the value of what they could have felled had they tried to maximize timber revenues, and of what they actually felled. This definition was applied to estimate the non-timber value (NTV) of Forest Inventory and Analysis plots in the Wisconsin (USA) maple-birch [Acer/Betula] forest type, with a Markov decision model to predict the decision that would have maximized the timber income. Then hedonic regression was applied to determine how the biophysical characteristics of stands and the socioeconomic setting influenced NTV. In these forests, the NTV was highest for national forests: about \$50 ha-1yr-1, ten times the timber revenues. The estimated NTV was similar for all non-national forests, at about \$20-24 ha-1yr-1. For non-national public forests, NTVs were four times larger than timber revenues. They were almost twice as large as timber revenues for private non-industrial forests. Even for industrial forests, NTVs were slightly higher than timber revenues. However, these NTVs could be biased due to constraints limiting the potential economic return from forest stands not reflected by the profit-maximizing model. The hedonic pricing model showed that stands with the same tree distribution had significantly higher NTVs for national forests, and similar NTVs for other ownership types. The marginal value of trees of various species and size was also different for national forests. At constant prices, from 1966 to 1984, the non-timber value of maple-birch forests in Wisconsin increased by 30% for national forests, and 55% for other forests.

560. Schaetzl RJ 1994. Changes in O horizon mass, thickness and carbon content following fire in northern hardwood forests. *Vegetatio* 115: 41-50.

Keywords: forest litter/mass /thickness /carbon /fire /forest fires/forest ecology/Pinus spp. /Acer spp. /Betula spp. /Betula papyrifera /Tsuga spp. /Populus spp. /northern hardwoods

Abstract: This study examines temporal changes in the thickness, mass, and organic carbon content of the O horizon (forest floor) of eight forested plots in northern Michigan, USA. Each plot had experienced a recent burn (prescribed or accidental); burn dates ranged from 1798 to 1980. The climax forest in this region is mixed Pinus-Acer-Betula-Tsuga, whereas the fire successional species are predominantly Populus spp. and Betula papyrifera. O horizon data were fitted to logarithmic functions (chronofunctions) that depicted rapid accumulations of mass and thickness in the first years after fire, followed by decreasing rates of increase after ~100 yr. Extension of the chronofunctions to ~5000 yr allowed for a theoretical examination of forest floor conditions, e.g. steady state and time to steady state, after long periods without disturbance. The models predicted greater O horizon thicknesses and slightly lower mass for steady state conditions than have been reported for old-growth stands elsewhere. Steady state accumulations of litter in these mixed, temperate forests requires at least 200 and possibly >1000 yr, which is markedly longer than most other estimates. Although frequent disturbance by fire in these forests would probably preclude such values from being attained, the data provide theoretical maximum values for forest floor conditions in these ecosystems.

561. Scheiner SM and Istock CA 1994. Species enrichment in a transitional landscape, northern lower Michigan. *Canadian Journal of Botany* 72: 217-226.

Keywords: species diversity/botanical composition/site types/vegetation types/plant survey /synecology /pines /Acer saccharum/Fagus grandifolia/Larix laricina/Quercus rubra/Thuja

occidentalis/Populus grandidentata/Pinus spp. /Pinus strobus /Picea spp./Betula papyrifera/Tsuga canadensis/northern hardwoods

Abstract: The hemlock (Tsuga canadensis)/white pine (Pinus strobus)/northern hardwood forest region of North America is a transition between the broadleaved deciduous forests to the south and the boreal forests to the north. Species diversity and landscape pattern were examined in a survey of vascular plant communities in northern lower Michigan. Results from 47 sites revealed 483 vascular plant species: 37 trees, 67 shrubs, 4 vines and 375 herbaceous species; there was a mean of 74.3 ± 4.2 species per site. Mean Jaccard similarity among sites was 0.22 ± 0.01 and mosaic diversity, a measure of landscape complexity, was 3.01 ± 0.03 . Using nonmetric multidimensional scaling and cluster analysis, two distinct groups of communities were differentiated: group I consisted of communities on mesic upland to wet lowland sites dominated by sugar maple (*Acer saccharum*), beech (*Fagus grandifolia*), hemlock, cedar (*Thuja occidentalis*), tamarack (*Larix laricina*) and spruce (*Picea* spp.); group II consisted of communities on xeric to dry-mesic upland moraines and level plains dominated by pines (*Pinus* spp.), red oak (*Quercus rubra*), birch (*Betula papyrifera*) and aspen (*Populus grandidentata*). Each group encompassed a separate south to north transition. Contrary to continental trends, species richness was greatest in sites with the greatest percentage of northern species. The region is more species-rich than adjacent regions to the south and north. Four hypotheses are presented to explain this species enrichment.

562. Scheiner SM, Sharik TL, Roberts MR, and Kopple R Vande 1988. Tree density and modes of tree recruitment in a Michigan pine-hardwood forest after clear-cutting and burning. *Canadian Field Naturalist* 102: 634-638.

Keywords: Plant succession/logging /fires /Clear felling/ecology /Site preparation/burning /Natural regeneration/vegetative propagation/stand characteristics/mortality /composition /density /pines /*Acer rubrum* /*Prunus pensylvanica*/*Quercus rubra*/*Populus tremuloides* /*Populus grandidentata* /*Pinus strobus*/*Pinus resinosa*/*Betula papyrifera* /*Prunus pensylvanica*/*Amelanchier arborea*

Abstract: Changes in stem density and the relative amount of recruitment by both vegetative reproduction and seedling establishment were assessed for 5 yr following clear felling and burning of slash in northern lower Michigan. Prior to disturbance, the community consisted primarily of a mixture of *Quercus rubra*, *Populus grandidentata*, and *Pinus strobus*. Following disturbance, *Populus grandidentata* and *Acer rubrum* comprised 66% and 25%, respectively, of all stems. Stem density declined by 41% in the first 5 yr following fire. There was no change in the relative number of stems of each species during this time. Animal- and wind-dispersed species had different rates of seedling recruitment. *Populus grandidentata*, *P. tremuloides*, and *Acer rubrum* were recruited exclusively by vegetative means. *Q. rubra*, *Amelanchier arborea*, and *Betula papyrifera* were recruited both vegetatively and by seed. *Prunus pensylvanica* was recruited only by seed. No recruitment of *Pinus strobus* and *P. resinosa* occurred in the first 4 yr following disturbance and any future recruitment would have to be from seed.

563. Schimpf DJ and Danz NP 1999. Light passage through leaf litter: variation among northern hardwood trees. *Agricultural and Forest Meteorology* 97: 103-111.

Keywords: leaves /foliage /forest litter/light transmission/seed germination/photosynthesis /seedlings /seeds /plant succession/seral stages/shade /tolerance /*Acer rubrum*/*Acer saccharum* /*Fagus grandifolia*/*Quercus rubra*/*Tilia americana*/*Populus tremuloides* /*Populus grandidentata* /*Betula papyrifera*/*Betula alleghaniensis*/northern hardwoods

Abstract: Leaf litter may influence the environment for germination and photosynthesis of seedlings and other small plants through its effects on transmitted light. In this study, measurements were made of red:far-red ratios (R/FR) and photosynthetically active radiation (PAR) transmitted through individual dead leaves from 10 species of deciduous trees of the northern hardwood region of eastern North America. The leaf samples came from one forest in

Michigan and 2 in Minnesota. The species were: *Betula papyrifera*, *Populus balsamifera*, *P. tremuloides* and *P. grandidentata* (classified as shade intolerant early successional), *Tilia americana*, *Acer rubrum*, *B. alleghaniensis* and *Quercus rubra* (moderately shade tolerant, mid successional), and *Fagus grandifolia* and *A. saccharum* (highly shade tolerant late successional). The leaves were collected from the forest litter between spring snowmelt and canopy budbreak, when irradiances on the forest floor are highest. Mean transmittance of PAR varied among species from about 0.5 to 20% for dry leaves and from about 2 to 38% for wet leaves. Transmittance of PAR was greatest for dead leaves from shade-tolerant late-successional species, least for those from shade-intolerant early-successional species, and intermediate for those from moderately shade-tolerant species. Shade leaves transmitted more PAR than sun leaves of the same species, significantly so for *Q. rubra*, *A. saccharum* and *F. grandifolia*. Transmitted R/FR was greater for late-successional species than for early-successional species, especially for shade leaves. These ratios tended to be higher for wet leaves than for dry leaves. Shade leaves tended to have higher ratios of transmitted R/FR than sun leaves of the same species, significantly so for *Q. rubra*, *A. saccharum* and *F. grandifolia*. It is concluded that changes in both canopy species composition and the proportion of shade leaves during succession in these forests should bring about concomitant environmental trends toward greater favourability for the germination of seeds or spores needing high R/FR, as well as for photosynthesis by plants that are short enough to be covered by leaf litter.

564. **Schmoldt DL, Martin GL, and Bockheim JG 1985. Yield-based measures of northern hardwood site quality and their correlation with soil-site factors. *Forest Science* 31: 209-219.**

Keywords: site class assessment/increment /soil chemistry /calcium /magnesium /site index /soil characteristics/topography /yield forecasting/soil fertility/responses /broadleaves /*Acer saccharum*/ *Tilia americana*/*Betula alleghaniensis*/northern hardwoods

Abstract: The Chapman-Richards function was fitted to yield data collected in 1961-74 from 47 permanent sample plots in stands in N. Wisconsin and upper Michigan, dominated by *Acer saccharum* (70-75% of the b.a. of the stand), with *Tilia americana* or *Betula alleghaniensis* forming at least 20% of stand b.a. Soil samples were collected and analysed and slope and aspect recorded. The upper asymptote (b.a. and vol.) and max. growth rate (b.a.) of the fitted curves were found to be significantly correlated with the concn. of exchangeable Ca and Mg, and aspect. There was no significant correlation between site index and any of the 13 soil-site factors tested. It was concluded that measures of site quality derived from fitted yield curves are a practical alternative to site index, provided that the curves are based on sufficient data.

565. **Schultz JR 1989. Using disease resistant white pine to meet multiple resource objectives. *Northern Journal of Applied Forestry* 6: 38-39.**

Keywords: conifers /broadleaves /forest management/multiple use/underplanting /silvicultural systems/shelterwood /*Pinus strobus*/*Abies balsamea*/*Betula papyrifera* /white pine weevil /*Pissodes strobi* /white pine blister rust /*Cronartium ribicola* /artificial regeneration

Abstract: A summary of a project in which white pine [*Pinus strobus*] was underplanted in a paper birch [*Betula papyrifera*] stand located in a visually sensitive recreation area in the Chequamegon National Forest, Wisconsin. After 5 yr, birch mortality from post-logging shock was <10%, the pines were 3-6 ft high, with no evidence of white pine weevil [*Pissodes strobi*] or white pine blister rust [*Cronartium ribicola*] and very little paper birch or balsam fir [*Abies balsamea*] had regenerated. Local landowners and recreation users were reported to be satisfied with the appearance of this stand.

566. **Shaw RH and Zhang XJ 1992. Evidence of pressure-forced turbulent flow in a forest. *Boundary Layer Meteorology* 58: 273-288.**

Keywords: Broadleaves /atmosphere /Forest influences/air /northern hardwoods /wind

Abstract: Studies were made at a northern hardwood forest site in Ontario, Canada, in autumn 1987 and summer 1987 on the phase relation between (1) longitudinal wind velocities at several heights within and above the forest and (2) the flow field and surface pressure fluctuations. The data indicated that turbulence in the sub-crown region of the forest was largely driven by pressure perturbations. The analyses support earlier results based on examination of coherent structures observed in the same forest. The phase of the longitudinal velocity signal exhibits an increasing delay with decreasing height, indicative of a downwind tilted structure, until the upper region of the forest is reached, at which point the effect is reversed. It is suggested that positive pressure perturbations ahead of advancing microfronts induce longitudinal velocity accelerations in the bole space. This link between the pressure pattern and the wind field explains why velocity spectra in the bole space are depleted in the higher frequencies, relative to levels above.

567. **Shrive SC, McBride RA, and Gordon AM 1994. Photosynthetic and growth responses of two broad-leaf tree species to irrigation with municipal landfill leachate. *Journal of Environmental Quality* 23: 534-542.**

Keywords: refuse /phytotoxicity /municipal solid waste /hybrid poplar /interspecific hybridization/ leachates /photosynthesis /increment /plant physiology/irrigation water/waste water/pollution /growth /stems /Acer rubrum

Abstract: Leaf photosynthesis and stem growth responses of saplings of red maple (*Acer rubrum*) and a hybrid poplar (*Populus nigra* X *P. maximowiczii*) to irrigation with municipal solid waste (MSW) leachate were studied in a northern temperate climate near Hamilton, Ontario. Saplings were subjected to two consecutive seasons of leachate irrigation in a three factor, RCBD split-plot field experiment. The three factors were irrigant type (MSW leachate, water), mode of application (spray, surface trickle, subsurface irrigation), and rate of application (3.5, 7.0, and 14.0 mm/d). The main treatment plots in each of three blocks were split into subplots planted to different tree species. In the second irrigation season, the mean seasonal photosynthesis rates increased for irrigated saplings of both species relative to rain-fed control saplings, irrespective of irrigant type. Mean seasonal photosynthesis rates for red maple increased with irrigant application rate, but were unaffected by irrigant type. Incremental stem diameter and height growth for this species were largely unaffected by the experimental treatments. Mean seasonal photosynthesis rates for hybrid poplar were unaffected by either irrigant type or application rate, but stem growth did increase significantly with leachate irrigation. The mode of irrigant application was not a significant factor in explaining plant response for either species. Direct exposure of leaves to potentially phytotoxic compounds in MSW leachate (volatile organics, and inorganics including metals) by spraying did not induce phytotoxic symptoms in the saplings. Irrigation of an MSW leachate of relatively high ionic strength can be carried out successfully on clay soils under the Ontario climate without causing significant adverse effects on saplings of these species. Treatment and disposal of MSW leachates in tree plantations may offer a low technology, low cost option to municipalities.

568. **Simpson JA, Gordon AM, Reynolds PE, Lautenschlager RA, Bell FW, Gresch DA, and Buckley DA 1997. Influence of alternative conifer release treatments on soil nutrient movement. *Forestry Chronicle* 73: 69-73.**

Keywords: calcium /glyphosate /herbicides /nutrients /nitrogen /potassium /soil solution/tending /triclopyr /vegetation management/soil chemistry /nitrogen /ammonium /nitrate /potassium /calcium/ forest plantations/release /forest soils/weed control/chemical control/physical control/ cutting /brush cutters/*Picea glauca*/*Picea mariana*

Abstract: Zero tension soil solution samplers were used to collect soil solution at 75 cm for 1.5 years after the following treatments: (1) helicopter applied Release silvicultural herbicide (triclopyr at 1.9 kg/ha), and (2) helicopter applied Vision silvicultural herbicide (glyphosate at 1.5 kg/ha); (3) motor-manual cutting (brush saws); and (4) control (no treatment). The treatments were applied in 1993 to *Picea mariana* and *P. glauca* stands planted during 1987-91 SW of Thunder

Bay, Ontario. Results show no substantial treatment-related differences in the movement of selected nutrients (total organic N, NH₄⁺, NO₃⁻, K, Ca) among these treatments. Mean nitrate concentration was less than 1.5 µg/ml throughout the sampling period and was marginally higher, but not statistically different, following release treatments.

569. **Simpson TB 1990. *Landscape ecosystem and cover types of the reserve area and adjacent lands of the Huron Mountain Club, Marquette County, Upper Michigan*. PhD dissertation, University of Michigan, Ann Arbor. 326 pp.**

Keywords: Acer saccharum/Pinus banksiana/Picea mariana/Tsuga canadensis/northern hardwoods /ecosystem types /remote sensing /physiography /bedrock /Quercus spp. /soil depth

Abstract: Landscape ecosystem types were identified, classified, and mapped for the Reserve Area and adjacent lands (3,200 ha) of the Huron Mountain Club, Marquette County, Upper Michigan. Vegetative cover types were also mapped. Plot samples (438 total) were used to guide the classification of ecosystem and cover types and to aid in the description of the types. Fifty landscape ecosystem types were identified in the mapped area. Sugar maple, hemlock, and hemlock-northern hardwood ecosystems made up 21 of the types. Areas of exposed crystalline bedrock accounted six ecosystem types. Pine-oak and white pine-hemlock-hardwood forests were common in these areas. Nipissing beach landforms comprise six ecosystem types, the most extensive type covered by jack pine forest. Ten wetland ecosystem types were identified, ranging from graminoid marsh to black spruce swamp. The importance of direct and indirect influences of physiography (surface material depth and texture, slope steepness and position, distance to water, distance to ridge, watershed position, and wind and sun effects) to the development of landscape ecosystem and cover types was investigated through a statistical analysis of data obtained from the topographic map as well as the ecosystem type and cover type maps. Multiple discriminant analysis (MDA) of 584 sample points using cover type classes and the physiographic variables resulted in 56% correct classification for deep soil areas and 49% for shallow soil areas. Using the variables found significant ($p < 0.10$) in the MDA of cover types, an MDA of ecosystem types resulted in 63% correct classification for deep soil ecosystem types and 53% correct classification for shallow soil ecosystem types. Overall, the most important variables were depth of soil, slope steepness, and solar radiation effects. Additionally, three wind effects variables, distance to surface water, and distance to ridge were significant in the MDAs of deep-soil cover types and ecosystem types, and slope position was significant in the MDAs of shallow-soil cover types and ecosystem types.

570. **Singer MT and Lorimer CG 1997. *Crown release as a potential old-growth restoration approach in northern hardwoods*. *Canadian Journal of Forest Research* 27: 1222-1232.**

Keywords: crown /thinning /increment /basal area/diameter /secondary growth/silviculture /stand characteristics/growth models/Acer saccharum/northern hardwoods

Abstract: The question of whether crown release might hasten the development of large trees in second-growth northern hardwoods was examined by measuring 6- to 10-year growth response to a wide range of past thinning treatments in seven stands in northern Wisconsin. Percent increase in basal area growth after thinning was linearly correlated with percent plot basal area removed and with percent crown perimeter release of individual trees. Trees on untreated plots showed a mean 7% growth decline, while mean response on treated plots ranged from a 21% increase for trees given 25% crown perimeter release to an 88-107% increase for trees given full release. A basal area increment model calibrated with the data suggests that 30 cm DBH (diameter at breast height) sugar maples (*Acer saccharum*) given full crown release would reach 50 cm DBH (the mean size of canopy trees in old-growth stands) in 46-49 years, compared with 92 years with no treatment. In addition to accelerating the development of large trees, crown release has the potential for enhancing foliar height diversity and increasing the number of canopy gaps, standing snags, and fallen logs, all of which occur only to a limited extent in existing second-growth, even-aged stands.

571. **Slaughter KW, Grigal DF, and Ohmann LF 1998. Carbon Storage in Southern Boreal Forests Following Fire. *Scandinavian Journal of Forest Research* 13: 119-127.**

Keywords: Carbon Balance/Carbon Dioxide/Global Warming/Plant/Fire /Soil Carbon /Populus spp. /aspen /Coarse wood

Abstract: Changes in carbon (C) after fire were measured in seven southern boreal upland forest stands during the five immediate post-fire years and 23 years after the fire. Pre-fire above-ground C mass of the stands was estimated. Combustion losses were 19% of the pre-fire above-ground C mass (8.4 kg m⁻²), and an additional 4% of that C mass was lost in the following 3-4 years. After 23 years, neither C mass of understory (0.1 kg m⁻²) nor standing snags (0.3 kg m⁻²) differed from that estimated before the fire; tree C was less (2.4 vs. 6.0 kg C m⁻²), and forest floor (2.5 vs. 1.4 kg C m⁻²) and coarse woody debris (1.7 vs. 0.7 kg C m⁻²) C were higher. Above-ground C mass was 84% of pre-fire mass. There were no measured changes in surface soil C following the fire (2.9 kg C m⁻²). Total C mass, including surface soil, was 10.2 kg m⁻² at 23 years or 91% of the estimated pre-fire C. Although gross fluxes of C followed the fire, massive net losses of C did not occur either immediately or in the two decades after fire. Dynamics of C differed among the stands. Data from either a single stand or a chronosequence in space can lead to different conclusions than those derived from multiple stands through time.

572. **Smidt MF and Puettmann KJ 1998. Overstory and understory competition affect underplanted eastern white pine. *Forest Ecology and Management* 105: 137-150.**

Keywords: canopy /understorey /plant competition/seedlings /silvicultural systems/shelterwood system/artificial regeneration/underplanting /synecology /botanical composition/seedling growth/Pinus strobus/Abies balsamea

Abstract: The importance of canopy and understorey competition for white pine (*Pinus strobus*) seedling growth was evaluated in mixed-species stands with shelterwood treatments. Twenty stands in north-central Minnesota were sampled that had been underplanted with white pine 3-10 yr previously. The various canopy and understorey treatments were grouped into 6 stand types based on residual canopy composition. The effect of the shelterwood treatments (residual basal area and understorey cover) on white pine seedling growth varied significantly among the stand types. Reducing the basal area had a greater positive impact on seedling growth when shade tolerant softwood species, especially balsam fir (*Abies balsamea*), were present in the canopy. Where shade tolerant softwood species were absent, the white pine seedling growth increased only slightly or not at all in the presence of decreased residual basal area. It is hypothesized that the exclusion of the understorey by a shade tolerant midstorey, indicated by the presence of balsam fir prior to shelterwood treatment, created favourable conditions for white pine in the understorey following the shelterwood treatment. The results suggest that shelterwood treatments on mesic, more productive hardwood sites should be linked to stand development stages where the understorey is suppressed, e.g. following development of a shade tolerant midstorey or during the stem exclusion phase. This method should complement present shelterwood prescriptions for drier, low quality hardwood sites. This research indicates the importance of evaluating both vertical structure and site quality prior to designing white pine shelterwood treatments.

573. **Smith DM, Kelty MJ, Larson BC, and Oliver CD 1992. *The ecology and silviculture of mixed-species forests. A Festschrift for David M. Smith. Forestry Sciences Volume 40, 287 pp.***

Keywords: management /silviculture /ecology /book

Abstract: The 15 papers were presented at a symposium held 1-2 August 1990 on the occasion of the retirement of David M. Smith from his position of Professor of Silviculture at Yale University. The papers are in 5 sections: Stand structure and dynamics - overview of principles (2 papers); Stand structure and dynamics - case studies (5); Productivity of mixed-species stands (2); Silviculture and management of mixed-species stands (5); and Concluding remarks (Ideas about

mixed stands - Smith, D.M.).

574. **Snowman VR, Genco JM, Cole BJW, Kwon HB, and Miller WJ 1999. Bond Strength of Oxygen-Delignified Kraft Pulps. *Tappi Journal* 82: 103-109.**

Keywords: paper/kraft /northern hardwoods

Abstract: Interfiber bond strength of northern hardwood kraft was measured using the delamination procedure of Skowronski and Bichard (16) on sample withdrawn following each stage of a commercial OD(EOP)DD bleach sequence. Bond strength measurements were also conducted on brown-stock pulp following medium-consistency oxygen delignification in which the temperature (90-110 degrees C), time (0-60 min), and alkali charge (1.5-3.5%) were varied in the oxygen stage. The results show that interfiber bond strength for both the laboratory and commercial samples increased across the oxygen state, provided that high amounts of alkali are not added, making the reaction conditions harsh. The increased bond strength is thought to result from increased hydrogen bonding, which compensates for the loss of wet zero-span tensile strength of the pulp following exposure to oxygen.

575. **Solomon AM and Bartlein PJ 1992. Past and future climate change: response by mixed deciduous-coniferous forest ecosystems in northern Michigan. *Canadian Journal of Forest Research* 22: 1727-1738.**

Keywords: Stand characteristics/projections /simulation /Climatic change/Synecology /canopy gaps/Vegetation types/northern hardwoods /soil characteristics /model forest gap

Abstract: Global climate change is expected to become a significant factor redefining global biospheric boundaries and vegetation dynamics. In the northern hardwood/boreal forests it should, at the least, control reproductive success and failure among unmanaged mixed forest stands. One means by which to predict future responses by the mixed forests is to examine the way in which they have responded to climate changes in the past. Proxy climate data derived from Holocene (past 10 000 yr) pollen records in the W. Upper Peninsula of Michigan were used to develop forest gap models, in an attempt to define regional prehistoric vegetation dynamics on differing soils. The gap models mimic forest reproduction and growth as a successional process and, hence, are appropriate for defining long-term tree and stand dynamics. The period modelled included a mid-postglacial period that was warmer than the present climate. Model failures, made apparent from the exercise, were corrected and the simulations were repeated until the model behaved credibly. Then, the same gap model was used to simulate potential future vegetation dynamics, driven by projections of a future climate affected by predicted changes in greenhouse gases. This provided a continuously comparable record of change and stability in forest composition and density. The resulting projections of vegetation response to climate change were affected more by the rate than by the magnitude of climate change.

576. **Song B, Chen JQ, Desanker PV, Reed DD, Bradshaw GA, Franklin JF, and Chen JQ 1997. Modeling canopy structure and heterogeneity across scales: from crowns to canopy. *Forest Ecology and Management* 96: 217-226.**

Keywords: crown /canopy /model/scaling /geographical information systems/stand structure/canopy heterogeneity

Abstract: Canopy studies have been limited in ecological investigations due to problems of canopy accessibility, and the lack of efficient sampling and modelling methods. The primary objective of this study was to develop an efficient modelling approach to describe the 3-dimensional, hierarchical structure of individual crown shells within forest stands and corresponding canopy patches. Crown shells were modelled based on crown ratio, maximum cardinal radius, vertical position, and shape. Canopies were represented by adding unique crowns to simulated point patterns of trees of known aggregation as measured by Pielou's index of

nonrandomness. Canopy patches were delineated at multiple horizontal and vertical scales using the ARC/INFO geographic information system (GIS). The patterns of canopy patches are clearly variable and scale dependent. Canopy patterns become more diverse at broader horizontal scales, and change greatly from the lower to the upper canopies. The modelling approach used in this study has general utility in characterizing 3-dimensional canopies of many types of forests.

577. Soulliere GJ 1988. **Density of suitable wood duck nest cavities in a northern hardwood forest.** *Journal of Wildlife Management* 52: 86-89.

Keywords: Cavities /management /ecology /*Tilia americana*/Populus tremuloides/northern hardwoods /*Acer saccharinum* /*Acer saccharum* /wood duck /*Aix sponsa*

Abstract: The density of natural cavities suitable for wood duck (*Aix sponsa*) nesting, and the relative importance of cavity and potential-cavity tree species were determined on upland and lowland plots in a second growth broadleaved forest in central Wisconsin. Av. density of suitable cavities was 0.65/ha, with living *Acer saccharinum*, *A. saccharum* and *Tilia americana*, and dead *Populus tremuloides* containing suitable cavities. Upland plots contained more trees with cavities than lowland plots. These 4 tree species had the highest relative importance among trees ≥ 31 cm d.b.h. Although the density of cavities was not high, cavities are abundant because large areas of suitable forest are available for nesting and numbers of cavities should increase as secondary forests mature. It is recommended that wildlife managers should advise on forestry operations rather than actively provide nest boxes for wood ducks.

578. Spies TA 1983. **Classification and analysis of forest ecosystems of the Sylvania Recreation Area, Upper Michigan.** PhD dissertation, University of Michigan, Ann Arbor. 334 pp.

Keywords: northern hardwoods /ecosystem classification /groundcover /soil moisture /soil fertility /soil pH/physiography /vegetation characteristics

Abstract: An ecological method of multi-factor ecosystem classification was applied in the Sylvania Recreation Area, an 8,500 ha tract of old-growth northern hardwood-conifer forest in Upper Michigan. The major objectives of the study were to describe and quantitatively compare the ecosystems and to develop ecological species groups. The drylands and wetlands were subjectively classified into 25 ecosystems, termed site units, by a method combining reconnaissance, plot sampling (n = 123), data analysis, and ecosystem mapping. Each site unit was a characteristic combination of physiography, soil, and vegetation. Thirty-three ecological species groups, composed of groundcover species with similar responses to soil moisture, soil fertility, and light, were formed from 158 species with the aid of tabular analysis. The species groups facilitated the use of nearly the entire vegetation complement in classifying and mapping ecosystems. The classification of the dryland ecosystems was corroborated by canonical variates analysis and discriminant analysis. The lowest error rate (9.4%) in discriminant analysis was obtained by a model based on a combination of physiographic, soil, and vegetation variables. The error rates based on vegetation variables alone and soil and physiography variables alone were 40.6 and 25.0%, respectively. The scores of the first two principal components of the ground-cover vegetation were correlated with several measures of soil fertility and soil moisture including pH of the litter and surface soil, exchangeable cations, percent medium sand, and depth to mottling. Contour maps of the coverage of ground-cover species were plotted on the ordination of the samples along multivariate soil fertility and moisture gradients. The maps helped characterize the species-site relationships of many forest herbs and confirmed the make-up of the ecological species groups. The major conclusions were: (1) an ecologically valid and useful ecosystem classification could be developed subjectively using an ecological multifactor method, (2) the ecosystems were best distinguished by a combination of physiographic, soil, and vegetation characteristics, (3) ground-cover species could be formed into ecological groups which were valuable aids in discriminating ecosystems and indicating levels of soil fertility and moisture.

579. Spies TA and Barnes BV 1985. **Ecological species groups of upland northern hardwood-hemlock**

forest ecosystems of the Sylvania Recreation Area, Upper Peninsula, Michigan. *Canadian Journal of Forest Research* 15: 961-972.

Keywords: synecology /classification /methodology /soil /topography /site factors /ecology /*Tsuga canadensis*/northern hardwoods /mosses /herbaceous species /bryophytes

Abstract: A tabular, field-oriented method of developing ecological species groups was applied in a classification study of upland northern broadleaved/hemlock ecosystems. Sixteen species groups were formed, consisting of a total of 76 upland herb, shrub, and moss species. The groups were constituted based on patterns of presence and absence and coverage values of species along gradients of soil fertility and soil moisture. The ecological responses of species within many of the groups were very similar. The environmental tolerances of the species groups in relation to soil fertility, moisture, forest floor conditions, and shade tolerance are described and contrasted. The groups were more differentiated along a fertility gradient than along a moisture gradient. The tabular method was relatively simple, yet effective in determining the species groups. The method is suitable for extensive land-classification activities; its essential element is that physiography, soil, and vegetation are examined simultaneously in the field. Species groups are more reliable in site classification and mapping than a subset of a few key species and the groups also simplify the use of many indicator species for field workers and ecosystem mappers.

580. Spies TA and Barnes BV 1981. A morphological analysis of *Populus alba*, *P. grandidentata* and their natural hybrids in southeastern Michigan. *Silvae Genetica* 30: 102-106.

Keywords: genetics /broadleaves /hybrid poplar/*Populus grandidentata* /physiology /leaf morphology /*Populus alba*

Abstract: Eleven leaf, bud and shoot characters were measured for 41 clones of the hybrid, 5 clones of *P. alba* and 22 clones of *P. grandidentata*. Pollen abortion percentages of male hybrids were also determined. Of the morphological characters measured, leaf blade width, number of teeth per margin, leaf pubescence and bud pubescence best distinguished the parents from the hybrid. Pollen abortion percentages of the hybrids were higher than for the parents, and most of the hybrids had values which were higher than could be expected for backcrosses. The hybrids were distributed closer to *P. grandidentata* than to *P. alba* in the multi-character analyses. From authors' summary.

581. Spies TA and Barnes BV 1985. A multifactor ecological classification of the northern hardwood and conifer ecosystems of Sylvania Recreation Area, Upper Peninsula, Michigan. *Canadian Journal of Forest Research* 15: 949-960.

Keywords: synecology /classification /ecosystem classification /soil /topography /site factors/ ecology /old growth /northern hardwoods

Abstract: An ecological method of multifactor ecosystem classification was applied to an 8500-ha tract of old-growth northern broadleaved/conifer forests. The uplands and wetlands were subjectively classified into 25 ecosystems by a method combining reconnaissance, plot sampling, data analysis, and ecosystem mapping. Each ecosystem was a characteristic combination of physiography, ecological species groups (ground vegetation), and soil. Discriminant analysis was used to evaluate the distinctness of the upland ecosystems and to compare the discriminating abilities of different ecosystem components (physiography, ground vegetation, and soil). The classification was corroborated in the multivariate analyses. The lowest estimated error rate (9.4%) in discriminant analysis was obtained by a model based on a combination of physiographic and soil characteristics and ecological species groups. The estimated error rates based on the species groups alone, and physiography and soil alone, were 42.2 and 25.0%, respectively, indicating that neither of these methods could be used with high reliability in classifying and mapping ecosystems. An additional discriminant analysis of the three ecosystem components indicated that the ecosystems could be distinguished by field characteristics without information from soil

laboratory analyses. This analysis also demonstrated the particular value of the vegetation component as a readily observed, acceptable substitute for soil laboratory data in identifying and mapping ecosystem units.

582. **Spies TA and Barnes BV 1982. Natural hybridization between *Populus alba* L. and the native aspens in southeastern Michigan. *Canadian Journal of Forest Research* 12: 653-660.**

Keywords: hybrid poplar /broadleaves /*Populus tremuloides* /*Populus grandidentata* /*Populus alba* /moisture /disturbance /land-use change

Abstract: A systematic search was made for *P. alba* and its hybrids in parts of Washtenaw, Livingston and Jackson counties. Twenty-seven clones of *P. alba* were located; all were female. Forty-one hybrids between *P. alba* and *P. grandidentata* and 2 between *P. alba* and *P. tremuloides* were located. The mean density of all hybrids was one per 898 ha. Eighty-one % of hybrids occurred in groups of 2 or more and 91% were located within 1.6 km of a *P. alba* tree. Hybrids occurred only on disturbed sites, over a wide range of moisture regimes. Most became established in 1930-1945, when many farms were abandoned in SE Michigan. No effective phenological barrier to continued hybridization or backcrossing was found; the absence of hybrid establishment in the last 30 yr is attributed to a reduction in the number of suitable germination sites, due to reduced human activity and progressing succession near *P. alba* trees. From authors' summary.

583. **Stage AR and Monserud RA 1995. Modeling effects of management on dynamics of uneven-aged forest stands. In Skovsgaard JP, Burkhardt HE (eds.) Recent advances in forest mensuration and growth and yield research. Proceedings from 3 sessions of Subject Group S4.01 Mensuration, growth and yield at the 20th World Congress of IUFRO, Tampere, Finland.**

Keywords: growth models/forest management/silviculture /harvesting /stand structure/simulation /models /mensuration /IUFRO

Abstract: Classical paradigms for uneven-aged silviculture have simultaneously treated two aspects of forest management that are more logically kept separate. Meeting the ecological needs of the species and the site is one aspect, while meeting the need to regulate the flow of products from the forest is another. The first is properly addressed at the stand level. The second more effectively addressed at the landscape or forest-wide level. When these two problems are solved independently, a wide range of partial cutting treatments can be considered. A system that combines an individual-tree growth model with an efficient search algorithm is described for choosing optimal partial harvesting prescriptions. For such analyses to be useful, however, several problems in modelling stand dynamics also must have been resolved: how to adequately represent the complex spatial structures created by any-aged management, how to measure carrying capacity of the site for complex diameter distributions, and how to represent regeneration as the overstorey is opened. Mensurational techniques addressing these problems in a growth model applicable to any aged silviculture are also discussed.

584. **Steinhilb HM, Arola RA, and Winsauer SA 1984. Green weight tables for eight tree species in northern Michigan. U.S. For. Serv. General Technical Report NC-95, 23 pp.**

Keywords: weight tables/biomass prediction /*Acer saccharum*/*Acer rubrum* /*Populus tremuloides* /*Quercus rubra*/*Pinus resinosa*/*Abies balsamea*/*Picea glauca*/*Betula papyrifera*

Abstract: Tables are given of total green wt., bole wt. and residue wt. of *Populus tremuloides*, *Acer saccharum*, *A. rubrum*, *Betula papyrifera*, *Quercus rubra*, *Pinus resinosa*, *Picea glauca* and *Abies balsamea*. Regression equations, based on d.b.h. and total ht. or d.b.h. and bole ht., are included.

585. **Steinhilb HM and Dye GW 1973. Harvesting logging residue from a selectively cut northern hardwood stand. *Northern Logger* 21: 11, 12-14, 34, 36, 37.**

Keywords: logging /slash /utilization /chipping /broadleaves /northern hardwoods /residual damage /economics

Abstract: Studies were made in June 1971 in a northern hardwood stand in Michigan that had been selectively logged for sawtimber in autumn/winter 1970, to determine the technical and economic feasibility of extracting the hardwood logging residue and chipping it at roadside. In all, 270 pieces of residue were skidded and chipped, giving 182.6 tons of chips for an expenditure of 171 man-hours and 92.5 machine-hours. Profits were estimated at \$1.2 per ton, green weight, delivered to the mill. Damage to the residual stand during the trial was heavy, but this could be considerably reduced in sustained operations.

586. **Steinhilb HM, Miyata ES, and Crow TR 1982. Green above-stump weights for red oak, red maple, and white birch in northern Michigan. U.S. For. Serv. Research Paper NC-230, 4 pp.**

Keywords: weight tables/weight determination/biomass prediction /broadleaves /Acer rubrum/Quercus rubra/Betula papyrifera

Abstract: Tables are given of total green wt., bole wt. (from butt to 4 inches diam. o.b.) and residue wt. of red oak, red maple (*Acer rubrum*) and white birch (*Betula papyrifera*). Estimating equations are included for each species.

587. **Stiell WM, Heeney CJ, Moore LJ, Aird PL, Silversides CR, Miller JS, Wagner CE van, Methven IR, Coons CF, Fayle DCF, Pierpoint G, Struik H, Brace LG, Beckwith AF, McNeice WS, DeBoo RF, and Cameron DA 1978. White and red pine symposium. Great Lakes Forestry Centre (Canadian Forestry Service) Symposium Proceedings No. O-P-6, 178 pp.**

Keywords: plantations /conifers /*Pinus strobus*/*Pinus resinosa*

Abstract: The symposium, dealing with *Pinus strobus* and *P. resinosa* (with special reference to Ontario and Quebec), and sponsored by the Ontario Ministry of Natural Resources and the Canadian Forestry Service, was held at the Petawawa Forest Experiment Station, Chalk River, Ontario, 20-22 Sept., 1977. The following papers are included: Stiell, W.M. Characteristics of eastern white pine and red pine. Heeney, C.J. Silvicultural requirements of white and red pine management. Moore, L.J. White and red pine management practices: logging. Aird, P.L. Splendor undiminished: a management objective for red pine and eastern white pine ecosystems. Silversides, C.R. Trends in logging equipment development. Miller, J.S. Mechanical site preparation methods as part of a silvicultural system to regenerate white and red pine. Wagner, C.E. van; Methven, I.R. Prescribed fire for site preparation in white and red pine. Coons, C.F. Red and white pine planting. Fayle, D.C.F.; Pierpoint, G. Interpreting performance of recently outplanted pine seedlings. Struik, H. Tending of white pine and red pine. Brace, L.G. An intermediate cutting in pine mixedwoods. Improvement felling was applied to 121.4 ha of two-storeyed stands in Ontario. An av. net sawlog yield gain of approx. 8000 bd ft/ha was indicated after 20 yr; logging damage resulted in a gross vol. loss of 0.25% after 5 yr. Beckwith, A.F.; McNeice, W.S. Guides to growth in red pine plantations. DeBoo, R.F. Management of pine insect pests.

588. **Stiell WM, Robinson CF, and Burgess D 1994. 20-year growth of white pine following commercial improvement cut in pine mixedwoods. *Forestry Chronicle* 70: 385-394.**

Keywords: silvicultural systems/growth /natural regeneration/improvement fellings/release /*Pinus strobus*/*Pinus resinosa*

Abstract: Paper given at the white pine/red pine workshop, held 5-7 October 1993 at Chalk River, Ontario, Canada. Understorey 55-yr-old white pine (*Pinus strobus*) in mixedwood stands in Ontario were released in 1971 from an (80-yr-old) overstorey of intolerant hardwoods using

wheeled skidders in a commercial logging operation. The main aim of the study was to increase the growth and yield of white pine for sawlogs over the following 20- to 30-yr period by releasing suppressed pine. Growth of released, healthy white pine was assessed after logging for a range of stand densities (basal areas of 6.9, 11.5, 16.1 m²/ha) using suitable control plots and a randomized complete block design with five replicates. Plots were remeasured 10 and 20 years after treatment. By harvesting, much of the natural mortality associated with these stands over the 20-year-period was utilized. Growth responses associated with overstorey release were highly significant and demonstrated an 80% increase in sawlog volume increment for treated stands after 20 years. Herb diversity was higher in treated stands and browse potential was not affected. However, white pine regeneration was unacceptably low in all cases. Overstorey release increased the natural rate of succession in these stands, but without further management activities or wildfire, the study area will revert to the economically lower-valued hardwoods.

589. **Stoekeler JH and Arbogast C Jr. 1955. Forest management lessons from a 1949 windstorm in northern Wisconsin and Upper Michigan. U.S. For. Serv. Lake St. For. Exp. Sta. Station Paper LS-34, 11 pp.**

Keywords: forest protection/wind damage /aspect /physiography

Abstract: Losses in a storm on 10 Oct. 1949 were especially heavy on exposed S. and S.W. slopes, swamp margins, ridges and the exposed N. and N.E. shores of lakes and streams. Except in small, heavily damaged areas, most of the trees blown down were overmature or defective. Recommendations are made on measures to reduce future damage by removing species and classes of trees (briefly indicated) particularly liable to blow down, within various vegetation types.

590. **Stone DM 1997. A decision tree to evaluate silvicultural alternatives for mature aspen in the northern Lake States. *Northern Journal of Applied Forestry* 14: 95-98.**

Keywords: silviculture /decision making/management/*Populus tremuloides* /*Populus grandidentata*

Abstract: Data from stands in Ottawa National Forest, western Upper Michigan, were used to develop a stand-level decision tree to assist land managers to define management objectives, evaluate the present condition of stands containing a substantial proportion of mature or overmature aspens (*Populus tremuloides* and *P. grandidentata*), and develop silvicultural prescriptions for similar stands in the upper Great Lakes region.

591. **Stone DM 1986. Effect of thinning and nitrogen fertilization on diameter growth of pole-size sugar maple. *Canadian Journal of Forest Research* 16: 1245-1249.**

Keywords: thinning /fertilizers /nitrogen /nitrogen fertilizers/responses /broadleaves /*Acer saccharum*

Abstract: The study was established in spring 1972 in a 45-yr-old fully stocked stand in Hiawatha National Forest, Upper Michigan. Half the stand was thinned in late 1968 and the other half in 1974. Nitrogen as ammonium nitrate or urea, alone or with PK, was broadcast round each study tree in May 1972. D.b.h. was measured in the autumn, annually for 7 yr after treatment and after the 10th yr. Diam. increment was increased significantly by thinning, but not by fertilization, and was strongly related to initial tree size. Neither urea nor ammonium nitrate had a significant effect on diam. increment.

592. **Stone DM 1982. Fertilization fails to increase diameter growth of selectively managed northern hardwoods. *Proceedings, Indiana Academy of Science* 91: 590-594.**

Keywords: NPK fertilizers/responses /fertilizers /silvicultural systems/selection /broadleaves

/Acer saccharum/northern hardwoods

Abstract: Data for a 16.2 ha all-age hardwood stand near Amasa, Michigan with a site index (age 50) for sugar maple of about 21 m showed no response over 6 years to 2.61 kg per tree of 20-20-20 NPK fertilizer.

593. **Stone DM 1980. Fertilization of a pole-sized maple stand: 10-year results. *Canadian Journal of Forest Research* 10: 158-163.**

Keywords: increment /fertilizers /NPK fertilizers/responses /broadleaves /yields /Acer saccharum/northern hardwoods

Abstract: A 48-yr-old stand of *Acer saccharum* and *A. rubrum* in NE Wisconsin, USA, was fertilized with 168 kg/ha N, P, NP, or NPK in May 1966. Trees were stratified by crown class and initial diam. Diam. and b.a. increment at 10 yr were evaluated by analysis of covariance with initial plot b.a. (IBA) as the covariate and by stepwise multiple regression in hierarchical models. Both diam. and b.a. increment were influenced greatly by initial diam. and stand density. IBA accounted for 65% of the variation in diam. increment and 49% of the variation in b.a. increment. Fertilization reduced diam. increment and increased mortality of suppressed trees. Pole-sized maples in intermediate and co-dominant crown positions tended to respond to fertilization with N and NP but the differences were n.s.d. Dominant trees grew more than did intermediates or co-dominants, but fertilization response could not be evaluated. Treatment effects were confounded by widely varied stand and site conditions. Results illustrate conditions likely to be encountered in fertilizing northern hardwoods on an operational scale. From author's summary.

594. **Stone DM 1977. Fertilizing and thinning northern hardwoods in the Lake States. U.S. For. Serv. Research Paper NC-141, 7 pp.**

Keywords: fertilizers /responses /forestry practices/thinning /NPK fertilizers/*Acer saccharum*/*Betula alleghaniensis*/northern hardwoods

Abstract: Results of fertilizing and thinning pole-size sugar maple and yellow birch crop trees on six different sites are reported. Thinning significantly increased diameter growth but fertilization did not. Crop trees on moist (moderately well drained) soils have tended to respond to fertilization. On such soils with good site indices the diameter growth of the trees in even-age stands was limited more by competition than by the availability of N, P or K. The regulation of stand density should have first priority among the silvicultural practices adopted.

595. **Stone DM and Christenson DR 1975. Effects of thinning and fertilization on foliar nutrient concentrations of Sugar Maple. *Canadian Journal of Forest Research* 5: 410-413.**

Keywords: thinning /fertilizers /foliage /foliar chemistry /nitrogen /potassium /phosphorus /magnesium /zinc /copper /aluminum /boron /release /NPK fertilizers/nutrition physiology/physiology /broadleaves /*Acer saccharum*

Abstract: Describes the effects of thinning and/or application of fertilizer (N, NP, NK, NPK) after thinning on the foliar nutrient contents and growth of 47-year old *Acer saccharum* in Michigan. Thinning and fertilizing combined resulted in significantly lower concentrations of foliar N, P, K, Mg, Cu, Zn, B and Al in the first growing season and of Mg, Cu, Zn and Al in the second year after treatment. Foliar nutrients in released but unfertilized trees showed similar trends. These decreased foliar nutrient contents are attributed to dilution effects as a result of increased growth. Fertilizing with N, P, and K significantly increased foliar concentrations of these three nutrients but did not stimulate radial growth. Thinning resulted in highly significant increases in diameter growth in both years.

596. **Stone DM and Christenson DR 1974. Fertilizing and thinning Maple poles: preliminary results. U.S.**

For. Serv. Research Note NC-158, 4 pp.

Keywords: fertilizers /thinning /phosphorus /potassium /NPK fertilizers/responses /broadleaves /Acer saccharum /soil sandy

Abstract: Stands of Acer saccharum on two sandy soil types of good and medium quality in Michigan were thinned and NH₄NO₃ was applied alone or with additions of P and K. Measurements 2 years later showed that the thinning increased diameter growth, but the fertilizers did not. NH₄NO₃ in fact depressed diameter growth, though it improved foliage and crown development. It is suggested that the lack of response to fertilizers might be due to factors other than nutrient deficiency in the soil.

597. **Stone DM and Elioff JD 2000. Soil Disturbance and Aspen Regeneration on Clay Soils: Three Case Histories. *Forestry Chronicle* 76: 747-752.**

Keywords: Aspen Management/Site Disturbance/Sustainable Management/Logging Damage/Soil Rutting/Root Damage/Evapotranspiration/Soil Aeration/Clearcutting With Residuals/Populus spp. /aspen/northern hardwoods /soils clay

Abstract: Sustaining forest productivity requires maintaining soil productivity and prompt establishment of adequate regeneration following harvest. We determined effects of commercial, winter- logging of aspen-dominated stands on soil disturbance and development of regeneration on three sites with clay soils. We established transects across each site, recorded pre-harvest stand information, post-harvest site disturbance, and first- year aspen sucker density and height. Use of large logging equipment produced heavy disturbance on 38% of a well-drained site; 45% of the area had no aspen suckers and 82% had less than the recommended minimum of 15 000 (15 k) suckers per ha (6 k ac(-1)). Mean height of dominant suckers was 45 cm (18 in). Hand felling and a small skidder caused heavy disturbance on 12% of a moderately well-drained site. Sucker density averaged 34 k ha(-1) (14 k ac(-1)) and height was 97 cm (38 in). Cut-to- length (CTL) equipment produced heavy disturbance on 11% of a somewhat poorly-drained site, mean sucker density of 24 k ha(- 1) (9.6 k ac(-1)), and height of 101 cm (40 in). These severely disturbed areas essentially are removed from the aspen- producing land base. Retaining the northern hardwood and conifer growing stock would result in less site disturbance and help maintain natural hydrologic and nutrient cycling processes.

598. **Stone DM, Shetron SG, and Peryam J 1982. Fertilization fails to increase diameter growth of sawlog-sized northern hardwoods in upper Michigan. *Forestry Chron.* 58: 207-209.**

Keywords: fertilizers /NPK fertilizers/responses /broadleaves /Acer saccharum/Tilia americana/ Ulmus americana/Betula alleghaniensis/northern hardwoods

Abstract: Some 500 trees of d.b.h. 25-64 cm in a selectively managed stand (88% Acer saccharum with Betula alleghaniensis, Tilia americana and Ulmus americana) were each fertilized with 2.61 kg of NPK fertilizer in 1970. There was no significant effect of fertilization on d.b.h. or b.a. measured after 3 or 6 yr.

599. **Stottlemeyer R, Travis B, and Toczydlowski D 1995. Nitrogen mineralization in boreal forest stands of Isle Royale, northern Michigan. *Water, Air, and Soil Pollution* 82: 191-202.**

Keywords: inceptisols /spodosols /podzols /gleysols /nitrogen /mineralization /soil temperature/forests /boreal forests/forest soils/nitrogen cycle/vegetation types/soil chemistry/Acer saccharum/Picea glauca/Betula papyrifera /Alnus rugosa/northern hardwoods /ammonium /nitrate

Abstract: The correlation of soil temperature and moisture with inorganic N concn and net mineralization beneath major species types in mature boreal and northern hardwood forests was examined over a two year period in northern Michigan, USA. Soils (Podzols and Humic Gleysols)

beneath species types where the canopy was dominated by birch (*Betula papyrifera*), spruce (*Picea glauca*), alder (*Alnus rugosa*) or, in northern hardwoods, maple (*Acer saccharum*) were studied. Net NO₃⁻ mineralization varied by species type and net total inorganic N mineralization varied by month and the interaction of species type with month. Soil NO₃⁻ concn and NO₃⁻ mineralization were correlated for spruce, and inversely correlated for alder and maple. Soil NH₄⁺ concn and NH₄⁺ mineralization were inversely correlated for alder and maple. In laboratory temp. and moisture treatments of birch, spruce and maple soils, NH₄⁺ and total inorganic N-mineralization increased with temp. The response to moisture was most evident for NO₃⁻ mineralization in maple soils.

600. **Stout SL, Marquis DA, and Ernst RL 1987. A relative density measure for mixed-species stands. *Journal of Forestry* 85: 45-47.**

Keywords: Broadleaves /Stand characteristics/density /Growing stock/measurement

Abstract: It is argued that tree-area ratio equations are more accurate than stocking charts for estimating relative densities in various mixed broadleaved stands with a variety of species compositions.

601. **Stroempl G 1983. Thinning clumps of northern hardwood stump sprouts to produce high quality timber. Ontario Ministry of Natural Resources, Forest Research Information Paper No. 118, 17 pp.**

Keywords: Coppice /growth /silviculture /Thinning /*Acer rubrum*/*Quercus rubra*/*Tilia americana*/*Fraxinus americana*/*Betula papyrifera*/northern hardwoods

Abstract: Descriptions are given of (a) forms of coppice shoots, (b) the effects on shoot development of species, age and diam. of the parent stump, and location on the stump in relation to decay, and (c) theory and methods of thinning clumps of coppice shoots. Recommendations are given for techniques to encourage rapid growth of all shoots and of selected shoots. The data apply to *Fraxinus americana*, *Tilia americana*, *Betula papyrifera*, *Acer rubrum* and *Quercus rubra* which are frequently found in tolerant northern broadleaved forests of Ontario.

602. **Stroempl G and Secker PW 1995. Guide to the group shelterwood cutting method for regenerating northern red oak. Ontario Ministry of Natural Resources, Forest Research Information Paper No. 120, 45 pp.**

Keywords: silvicultural systems/shelterwood system/group fellings/natural regeneration/artificial regeneration/*Quercus rubra*/northern hardwoods /seed size

Abstract: Shelterwood cutting in the northern hardwood forests of North America is the silvicultural method recommended to regenerate heavy-seeded broadleaved trees such as northern red oak (*Quercus rubra*). The group shelterwood cutting method, applied on a small scale as opposed to using large-scale uniform shelterwood cutting, is particularly attractive because of the smaller risk of failure during the critical stages of establishment and early growth. This report describes and illustrates a field procedure for a 3-phase group shelterwood cutting method that can be used to regenerate red oak naturally or artificially in Ontario.

603. **Strong TF 1997. Harvesting intensity influences the carbon distribution in a northern hardwood ecosystem. U.S. For. Serv. Research Paper NC-329, 7 pp.**

Keywords: carbon cycle/silvicultural systems/selection system/selective felling/soil chemistry/carbon /northern hardwoods

Abstract: Field studies were carried out on the effects of 5 cutting methods (heavy, medium and light individual tree selection, diameter-limit cut and no thinning) on soil and vegetative carbon

after 40 years of management in a northern hardwood forest in Wisconsin, USA. Only slight differences were found for above-ground, below-ground and total ecosystem carbon. Light to moderate cutting did not alter carbon cycling.

604. **Strong TF and Erdmann GG 2000. Effects of residual stand density on growth and volume production in even-aged red maple stands. *Canadian Journal of Forest Research* 30: 372-378.**

Keywords: spacing /growth /increment /volume /diameter /branching /stem form/stand density/basal area/mortality /thinning /epicormics /*Acer rubrum*

Abstract: The effects of five residual stand densities (9.2, 13.8, 16.1, 18.4 m²/ha, and an unthinned control (27.2 m²/ha)) on 10-year stand and crop tree growth and bole quality were studied in an even-aged red maple (*Acer rubrum*) stand in Michigan. A secondary treatment of removing the understorey trees (5-10 cm DBH) was applied on half the plots. Diameter growth was significantly greater in all cutting treatments than in the control. Ten-year diameter growth in the heaviest cut treatment was nearly three times that of the control. The interaction between understorey removal treatments and density treatments was significant for net basal area growth. Ingrowth in the heavier cut treatments accounted for a significant portion of net basal area growth in the plots without understorey removal. Mortality was highest in the control and lowest in the heavier cut treatments. Epicormic branching significantly reduced clear bole length of crop trees in the heavier cut treatments, especially when the understorey was removed. For these reasons, a more conservative first entry thinning level of about 17-18 m²/ha without controlling the understorey is recommended for even-aged red maple stands.

605. **Strong TF, Erdmann GG, and Niese JN 1995. Forty years of alternative management practices in second-growth, pole-size northern hardwoods. I. Tree quality development. *Canadian Journal of Forest Research* 25: 1173-1179.**

Keywords: management /hardwoods /quality /development /selection system/selective felling/plant height/merchantable volume/diameter /vegetation types/silvicultural systems/increment /stand structure/second growth /*Acer rubrum*/*Acer saccharum*/*Tilia americana*/*Fraxinus americana*/*Betula alleghaniensis*/*Tsuga canadensis*/northern hardwoods

Abstract: The effects of six cutting methods on tree quality were observed for 20 years in a northern hardwood stand in NE Wisconsin. The stand was dominated by *Acer saccharum* with *Fraxinus americana*, *Betula alleghaniensis*, *Tilia americana*, *Tsuga canadensis* and *Acer rubrum*. Cutting treatments included an uncut control, three levels of individual tree selection (heavy, medium, and light), crop tree release, and diameter limit. Average annual diameter growth was least in the control treatment (0.33 cm/year) and greatest in the heavy individual tree selection and diameter-limit cuts (0.46 cm/year). Cull in trees in 1992 was significantly higher in the control and diameter-limit treatments. Changes in merchantable height (number of 4.9 m logs) over the period were not significantly different among treatments, but average merchantable heights were significantly greater in the individual tree selection treatments in 1992. Average tree grade increases were significantly better in the medium selection plots than in all other and diameter-limit treatments were below sawlog grade, significantly more than in the other treatments. Only 2% of the trees in the heavy selection plots were below grade. Tree quality improved the most overall in the medium selection plots. Stand structure in this treatment also most closely matched that recommended by guides developed to sustain yield over long periods of cutting under uneven-aged management.

606. **Sturos JA, Barron RM, Miyata ES, and Steinhilb HM 1983. The economics of a mechanized multiproduct harvesting system for stand conversion of northern hardwoods. U.S. For. Serv. Research Paper NC-237, 12 pp.**

Keywords: Logging /planning /economics /methodology /primary conversion/chipping /whole tree chips/*Acer saccharum*/*Acer rubrum* /*Prunus serotina*/*Quercus rubra*/*Betula alleghaniensis*/

northern hardwoods

Abstract: The economics were investigated of experimental clear fellings made in a hardwood pole timber stand by a conventional whole-tree chipping system and three sawtimber stands by several combinations of whole-tree chipping and saw log recovery. Sawlogs recovered were: *Acer saccharum*, *A. rubrum*, *Prunus serotina*, *Quercus rubra* and *Betula alleghaniensis*. The conventional harvesting yielded a projected profit of \$173/acre before tax. The most profitable integrated harvesting system, using the whole-tree chipper at the landing together with the saw log recovery system after sorting the logs at the landing, yielded a projected profit of \$209/acre.

607. **Tappeiner JC and Alm AA 1972. Effect of Hazel on the nutrient composition of annual litter and forest floor in Jack and Red Pine stands. Minnesota Forestry Research Note No. 235, 4 pp.**

Keywords: humus /understorey /forest litter/chemistry /interactions /soil fertility/conifers /broadleaves /litter plant/soil /*Pinus banksiana*/*Pinus resinosa* /*Corylus cornuta* /hazel

Abstract: Reports a study in NE Minnesota in 1970-1971 in two mature stands of *Pinus banksiana* and *P. resinosa* with a discontinuous understorey of Hazel (*Corylus cornuta*). Litter fall and forest floor (all organic material above the mineral soil) were sampled (a) under Hazel, where Hazel comprised ca. 25% of the total litter and Pine the remainder, and (b) under Pine, where the litter was nearly pure Pine. Litter fall, and the weight and concentration of nutrients in the litter, were significantly higher in (a) than in (b); the weight and nutrient content of the forest floor were slightly lower in (a) than (b). Results indicate that the addition of nutrients to the litter and the rate of nutrient release are increased by a Hazel understorey.

608. **Tappeiner JC and Alm AA 1975. Undergrowth vegetation effects on the nutrient content of litterfall and soils in red pine and birch stands in Northern Minnesota. Ecology 56: 1193-1200.**

Keywords: cycling /nutrients /humus /understorey /forest litter/chemistry /nitrogen /phosphorus /potassium /calcium /magnesium /magnesium /interactions /quantitative techniques/temperate zones/ground vegetation/litter plant/soil /*Pinus resinosa*/*Betula papyrifera* /hazel /herbaceous layer

Abstract: The role of hazel shrub and herbaceous undergrowth layers in nutrient cycling was studied in two red pine (*Pinus resinosa* Ait.) and two paper birch (*Betula papyrifera* Marsh.) stands on similar soil types. In the pine stands both undergrowth layers significantly added to the total dry weight of litterfall. Under hazel there was significantly more N, Ca, and Mn, and under herbs there was more than twice the amount of K in the litterfall than where these undergrowth layers were absent. In the birch stands the differences in the nutrient content of the litterfall beneath these undergrowth layers were not great, and undergrowth layers had less effect on the nutrient cycle. Although greater amounts of nutrients occurred in the litterfall under hazel and herbaceous layers, the amounts of total nutrients in the forest floor under each undergrowth type were not significantly different nor were total N, available P, or exchangeable K, Ca, Mg, and Mn in the top 3 cm of mineral soil. Turnover rates were different under each type of undergrowth and in red pine stands the forest floor under hazel and herbs appeared to decompose more rapidly than the forest floor of pure pine, but not as rapidly as the forest floor under either hazel or herbs in the birch stands.

609. **Taylor LA, Arthur MA, and Yanai RD 1999. Forest Floor Microbial Biomass Across a Northern Hardwood Successional Sequence. Soil Biology & Biochemistry 31: 431-439.**

Keywords: soil organic matter/nutrient content/soil/ecosystem/dynamics/nitrogen cycling/plant/microflora/northern hardwoods /soil temperature /soil pH /microorganisms /microbial biomass

Abstract: Microbial dynamics partially control forest productivity, yet are poorly understood in the northern hardwood forest. Following forest cutting, microbial biomass may reflect changes in

the forest floor environment. Using direct counts, forest floor microbial biomass was studied in a sequence of northern hardwood forest stands ranging in age since clearcutting from 3 to more than 120 yr. The organic horizon was collected 3 times in each of 1994 and 1995, in June, August and October. Samples were analyzed for active fungi, active bacteria, pH, forest floor moisture content and organic fraction. Forest floor temperature was measured in the field with each collection; forest floor mass was measured once in each stand. In 1995, forest floor samples were also analyzed for total N, nitrate and ammonium. Amounts of active microbial biomass (fungi plus bacteria) ranged from 38 to 103 $\mu\text{g g}^{-1}$ organic matter; active microbial biomass per unit area ranged from 40 to 800 mg m^{-2} forest floor organic matter. Microbial biomass varied significantly among sampling periods in 1994, but not in 1995, and was greater in early- and late-successional stands than in mid-successional stands. Microbial biomass was not very responsive to the environmental factors measured in this study. Moisture content was the environmental variable that most often contributed to variation in microbial biomass, and together with additional factors explained only 23% of the variation in 1994, and only 27% in 1995. Lower microbial biomass in mid-successional stands suggests that microbial dynamics in this forest are not controlled by factors directly related to forest harvesting.

610. **Teclaw RM and Isebrands JG 1993. An artificial regeneration system for establishing northern red oak on dry-mesic sites in the Lake States, USA. *Annales des Sciences Forestieres* 50: 543-552.**

Keywords: clear felling/weed control/herbicides /shelterwood system/silvicultural systems/bare rooted stock/container grown plants/silviculture /IUFRO /seedlings /seedling growth/height /plant height/understorey /artificial regeneration/planting stock/*Quercus rubra* /competition

Abstract: Artificial regeneration of northern red oak (*Quercus rubra*) is difficult to achieve in the Lake States. A replicated study was established in northern Wisconsin in 1990 to determine the effect of overstorey density and understorey competition on the performance of bareroot and containerized northern red oak seedlings on dry-mesic sites. The relationship between seedling performance and the number of first-order lateral roots on the seedlings was also tested. Seedling performance was evaluated under 3 overstorey densities (each 0.3 ha) - a clearcut, 25%, and 50% crown covers in combination with (and without) understorey vegetation control with herbicide. Height growth was greater for containerized seedlings than bareroot stock after 2 and 3 growing seasons. After 2 yr seedling height growth was greatest in the sprayed clearcut plots, but was only slightly greater than the unsprayed plots under the 25% crown cover (bareroot 25.5 vs 23.8 cm, and containerized 33.0 vs 31.2 cm, respectively). After 3 yr seedling height growth was significantly greater in the unsprayed plots under the 25% crown cover for both the bareroot and containerized seedlings when compared to all other overstorey/understorey treatment combinations examined in the study. Early performance results suggest that the light shelterwood silvicultural method (i.e., 25% crown cover) without chemical control of vegetation is preferred for establishing northern red oak on dry-mesic sites, when compared to the more traditional management schemes. Paper given at the 1992 IUFRO Centennial Conference, held in Berlin, September 1992.

611. **Tester JR, Starfield AM, and Frelich LE 1997. Modeling for Ecosystem Management in Minnesota Pine Forests. *Biological Conservation* 80: 313-324.**

Keywords: ecosystem management/fire/deer browsing/red pine /white pine/wind/disturbance /succession/regimes/*Pinus resinosa* /*Pinus strobus* /model growth/*Odocoileus virginianus*

Abstract: Ecosystem management implies a concern over time periods of tens to hundreds of years for sites on a scale of tens to hundreds of hectares. Decision makers need to be able to model the likely consequences of alternative management strategies at these temporal and spatial scales. They therefore require models that can be constructed quickly and cheaply, that capture the key components of the ecosystem, that respond plausibly to management actions, and are easy to explain, modify and understand. This paper presents the frame-based modeling paradigm as a response to these needs. Frame-based modeling is used to examine the effects of soil, weather, fire

and deer population density on management of the white pine ecosystem in northern Minnesota. The management objective is to maintain white pine forest. The paper describes how current understanding of seedling establishment, tree growth, competition, herbivory and the effects of fire and high winds, can be captured at a consistent level of resolution in a model that can be presented, completely, in a few pages of text. The paper goes on to describe how the model was tested at three sites in northern Minnesota, and was then used to explore alternative management strategies. Our results confirm that it is comparatively easy to maintain a forest in early successional stages by burning or clear-cutting, and in late stages by suppression of fires and control of cutting. Establishment and maintenance of mid-successional stages, such as red and white pine, is much more difficult and requires a finely-tuned balance between natural disturbance and management action. For example, the pine forest was only maintained on average for 117 years out of 1000 years (average among 1000 simulated stands) on poor soil with high fire frequency and high deer density. When the deer population was low, when all wild fires were suppressed, and when prescribed ground fires were used to promote pine establishment, years in pine was 804 out of 1000 years. The model provides guidance for management decisions to maintain the desired conditions. The paper draws some conclusions from this particular modeling exercise that are likely to be generally applicable. For example, the modeling exercise illustrates limits to what management can hope to achieve, the importance of maintaining strategies over long time periods, and the difficulties of predicting and measuring success when the time horizon is hundreds of years.

612. **Thevathasan NV and Gordon AM 1997. Poplar leaf biomass distribution and nitrogen dynamics in a poplar-barley intercropped system in southern Ontario, Canada. *Agroforestry Systems* 37: 79-90.**

Keywords: interactions /intercropping /nitrogen cycling/nitrogen mineralization /nitrification /biomass production/spatial distribution/agroforestry systems/agrosilvicultural systems/barley /litter/soil chemistry/carbon /maize /*Zea mays* /*Hordeum vulgare* /*Quercus rubra* /hybrid poplar/*Pinus strobus* /*Populus* spp.

Abstract: The effect of hybrid poplar (*Populus* 'DN 177', 7-9 yr old) leaf biomass distribution on soil nitrification was investigated in 2 experiments during the 1993-95 growing seasons in a poplar-barley (*Hordeum vulgare* cv. OAC Kippen) intercropping experiment at Guelph, Ontario. There were 3 rows of trees spaced 15 m apart in the experiment, with poplar the central one, and red oak (*Quercus rubra*) and white pine (*Pinus strobus*) in the outer 2 rows. The outer row trees grew poorly, and contributed little leaf biomass to the system, so were ignored for the purposes of the experiment. In experiment 1, poplar was intercropped with barley over all 3 yr and the poplar leaves shed during the autumn were removed from the soil surface during 1993 and 1994. In experiment 2, poplar was intercropped with barley in 1993 and with maize (*Zea mays* cv. Pioneer 3917) in 1994 and 1995, and the shed poplar leaves were not removed. In experiment 1, the nitrification rates were lower during 1994 and 1995 when the dropped leaves were removed from the field. The total above-ground biomass of barley within 2.5 m of the poplar tree row was 517, 500 and 450 g/m², respectively, during the 3 yr, whereas in the middle of the crop row (4-11 m from the poplar row), the corresponding figures were 491, 484 and 464 g/m². Mean nitrification rates, N availability and carbon content were higher in soils close to the poplar tree row (2.5 m) compared with corresponding values in the middle of the crop alley (4-11 m from the poplar row). In experiment 2, where poplar leaves were not removed from the field, nitrification rates in soils within 2.5 m distance from the poplar row were fairly constant (range 100-128 µg/100 g dry soil daily) during the 3 yr. The results suggest that soil nitrification rates, soil carbon content and plant N uptake adjacent to the poplar tree rows are influenced by poplar leaf biomass input in the preceding year.

613. **Thomas AH 1983. *First-year responses of wildlife and wildlife habitat to sewage application in a northern hardwood forest.* MS thesis, Michigan State University, East Lansing. 128 pp.**

Keywords: northern hardwoods /wildlife /sewage application

614. **Thompson DA 1980. Regeneration lessons from Ontario's clay belt forests. *Scottish Forestry* 34: 173-177.**

Keywords: artificial regeneration/plantations /logging /planting stock/*Picea mariana* /clay soil /peat /logging damage /*Populus* spp.

Abstract: A brief description of the problems faced in the mainly black spruce forests on peat over clay where large tracts have been logged by lumber and pulp companies under licence to the government which (since 1962) has responsibility for regeneration. Major problems with clear-felled sites are skidder-damage to unfrozen ground, lack of seed trees, predominance of poplars in natural regeneration and high stumps (after winter felling) which restrict the use of silvicultural machinery. Methods of planting are described, mainly using cold-stored bare-root stock. The roots are soaked in water for at least 4 h before planting.

615. **Thompson MA 1991. Thinning northern hardwoods with chain saws and forwarders. *Northern Journal of Applied Forestry* 8: 149-153.**

Keywords: wood products/roundwood /fuelwood /thinning /*Populus tremuloides*/northern hardwoods /harvesting efficiency/economics

Abstract: A work study, carried out to assess forwarder performance during poletimber thinning by three sawyers. Products removed included hardwood sawlogs (from 8 to 16 ft in 2 ft increments), pulpwood (hardwood, aspen [*Populus tremuloides*] and softwood in 100 inch bolts), and fuelwood (hardwood in 100 inch bolts). Chain saw productivity was about 1.5 cords per scheduled hour (SH), with 17% of time spent manually piling timber. Forwarding productivity averaged 3.6 cords per SH at average distance of 400 feet. Bole damage to residual trees was nearly non-existent. Estimated cost to roadside was \$19/cord. Total cost (with additional transport) was about \$30/cord.

616. **Thompson MA and Sturos JA 1984. Bunching with low-investment systems in northern hardwood pole thinnings. American Society of Agricultural Engineers Paper No. 84-1599, 21 pp.**

Keywords: winches /thinning costs /economics /tractors /forestry machinery/draught animals/skidders /northern hardwoods /harvesting efficiency

Abstract: Productivity, costs, advantages, and disadvantages of 3 low-investment bunching systems (a radio-controlled winch, a horse team, and a small logging tractor) were discussed. Costs and other factors of forwarding bunched wood versus forwarding from the stump were compared.

617. **Thompson MA and Sturos JA 1991. Performance of a portable chain flail delimeter/debarker processing northern hardwoods. U.S. For Serv. Research Paper NC-297, 14 pp.**

Keywords: barking /delimiting /forestry machinery/hardwoods /northern hardwoods /harvesting efficiency

618. **Timmer VR 1997. Exponential nutrient loading: a new fertilization technique to improve seedling performance on competitive sites. *New Forests* 13: 279-299.**

Keywords: mineral nutrition/weed control/weeds /plant competition/container grown plants/nutrient availability/performance /techniques /conditioning /nutrient uptake/nutrient reserves/nutrient balance/seedlings /planting stock/forest nurseries/plant nutrition/fertilizers /reviews /artificial regeneration

Abstract: Reforestation efforts in Ontario have become increasingly more reliant on containerized planting stock since these seedlings are less costly to produce and plant than bare rooted stock.

Container seedlings, however, tend to be more susceptible to competing vegetation when planted on weed-prone sites, often requiring release by chemical herbicides. Cultural techniques have been developed to improve the competitiveness of containerized seedlings by promoting initial outplanting performance, thus reducing the need for early vegetation control. The approach is based on 2 new preconditioning practices, exponential fertilizing and nutrient loading, which induce a steady-state build up of nutrient reserves in seedlings for outplanting. Exponential nutrient loading integrates these practices with high dose fertilizing inducing luxury consumption. Steady-state culture corresponds better with the competitive outplanting environment, since stable internal nutrient accumulation in the greenhouse phase conforms with steady-state nutrient uptake of natural exponentially growing vegetation in the field, and exponential nutrient delivery to container restricted root systems also better simulates nutrient flux reached by expanding roots in a field soil with constant nutrient availability. Combined with nutrient loading, the higher nutrient reserves and improved nutrient balance in seedlings contribute to enhanced stress resistance and increased growth performance. This paper reviews the theory and practice of exponential nutrient loading during seedling culture, presents results of growth and nutritional responses of seedlings planted on competitive sites, and suggests appropriate criteria for quality testing of nutrient loaded stock.

619. **Timmer VR and Aidelbaum AS 1996. Manual for exponential nutrient loading of seedlings to improve outplanting performance on competitive forest sites. Great Lakes Forestry Centre (Canadian Forestry Service) NODA-NFP Technical Report No. TR-25, 24 pp.**

Keywords: forest nurseries/planting stock/fertilizers /plant nutrition/nutrient reserves/container grown plants/weeds /plant competition/crop weed competition/seedling growth /artificial regeneration

Abstract: This manual provides a review of the principles and technology of exponential fertilization and nutrient loading for container stock production, an examination of the growth and nutritional responses of loaded seedlings planted on competitive sites, and information for implementing exponential nutrient loading practices on an operational basis in Ontario. The loading technique improves the competitiveness of seedlings planted on vegetation-rich mixedwood sites by promoting initial growth performance and weed suppression, thus reducing the need for early vegetation control.

620. **Toland DE and Zak DR 1994. Seasonal patterns of soil respiration in intact and clear-cut northern hardwood forests. *Canadian Journal of Forest Research* 24: 1711-1716.**

Keywords: patterns /soil /soil biology/vegetation types/deciduous forests/carbon cycle/root respiration /clear felling/*Acer saccharum*/*Quercus rubra*/*Tilia americana*/northern hardwoods /soil microorganisms

Abstract: The flux of CO₂ from forest soils is controlled by the respiration of plant roots and soil microorganisms, the rates of which are likely to change following forest harvesting. Root respiration should decrease, whereas microbial respiration should increase, in response to warmer soil temperatures and greater soil C availability following removal of the overstorey. A study was made of the influence of forest harvesting on seasonal patterns of soil respiration in 2 different northern hardwood ecosystems in Michigan. The overstorey of one ecosystem was dominated by *Acer saccharum* and *Quercus rubra*, and the other by *A. saccharum* and *Tilia americana*. Daily rates of soil respiration were measured using the soda-lime technique. Daily rates of soil respiration did not significantly differ between intact and clear felled plots, nor did they differ between ecosystems or sites nested within ecosystems. Maximum daily rates ranged from 2.75 to 3.00 g CO₂-C/m² during mid to late summer in both intact and clear felled plots. Soil temperature accounted for 43 and 58% of the variation in daily rates for intact and clear felled plots, respectively. Annual soil respiration rates in intact (478 g CO₂-C/m²) and clear felled (470 g CO₂-C/m²) plots did not differ significantly. The results suggest that greater rates of microbial respiration in clear felled plots proportionally offset a decrease in root respiration following clear

felling.

621. **Trettin CC, Davidian M, Jurgensen MF, and Lea R 1996. Organic matter decomposition following harvesting and site preparation of a forested wetland. *Soil Science Society of America Journal* 60: 1994-2003.**

Keywords: organic matter/site preparation/decomposition /harvesting /soil organic matter/wetlands

Abstract: The cotton strip assay (CSA) was used to measure the effect of harvesting and two different site preparation treatments, bedding and trenching, on organic matter decomposition in a forested wetland in Michigan, USA. A Latin square experimental design was used to determine the effect of harvesting, site preparation, and relative position within the wetland on organic matter decomposition at soil depths of 5, 10, and 20 cm. Repeated measures analysis of variance was used to test for treatment effects on organic matter decomposition, soil temperature, and soil oxidation depth. Cellulose decomposition increased at each soil depth as site disturbance increased, with bedding > trenching > whole-tree harvest > reference. The cellulose decomposition response was correlated with changes in soil temperature; the temperature coefficient Q10 equalled 6.0, greater than previously reported values. Position within the wetland relative to an adjoining river affected the decomposition and soil oxidation depth. Because the rate of decomposition is strongly controlled by temperature, higher rates of organic matter decay are expected to continue on harvested and regenerated sites until canopy closure reduces soil temperature.

622. **Tubbs CH 1977. Age and structure of a northern hardwood selection forest, 1929-1976. *Journal of Forestry* 75: 22-24.**

Keywords: silvicultural systems/stand structure/virgin forests/silviculture /felling /selection cut /stand characteristics/age structure/broadleaves /Acer saccharum/northern hardwoods

Abstract: A virgin stand in Michigan, USA, comprising 83% *Acer saccharum* and mainly saw-timber sized trees with little correlation between age and size, was selectively felled four times between 1938 and 1965. In 1976, close correlation was found between height, d.b.h. and age, and the distribution of age classes was more balanced. The stand illustrates the feasibility of developing, on a small area, an all-age structure that produces sustained yields due to continual recruitment into the smaller size classes.

623. **Tubbs CH 1973. Allelopathic relationship between Yellow Birch and Sugar Maple seedlings. *Forest Science* 19: 139-145.**

Keywords: allelopathy /broadleaves /Acer saccharum/Betula alleghaniensis /nursery

Abstract: Nursery experiments in Michigan showed that the presence of seedlings of *Acer saccharum* (a) inhibited the growth of seedlings of *Betula alleghaniensis* (b) despite the apparent absence of physical competition. In subsequent laboratory experiments root elongation in newly germinated seedlings of (b) was inhibited by leachates of actively growing root-tips of (a), and this inhibition was used as the basis for a bioassay. The inhibitory substance(s) lost effectiveness after several days' storage. When seedlings of (a) and (b) were grown together in an aerated nutrient solution, the number of new actively growing root-tips formed each day by (b) was inversely correlated with the activity of the inhibitor in the bioassay. Exudation of the inhibitor was related to periods of rapid root growth in (a), although not all individuals produced it. No necrotic reactions in (b) were found. The results agree with silvicultural experience of the effects of competition between (a) and (b). [Cf. FA 31, 2302].

624. **Tubbs CH 1963. Artificially constructed mounds show promise in Yellow Birch regeneration. U.S. For. Serv. Lake St. For. Exp. Sta. Research Note LS-32, 2 pp.**

Keywords: *Acer saccharum* /*Betula alleghaniensis* /direct sowing/regeneration /artificial regeneration/natural regeneration /coppicing /*Tsuga canadensis* /microtopography

Abstract: On three sites in a hardwood/Hemlock stand cut to a mean b.a. of 70 sq. ft./acre, 1/4-milliacre plots were established on (a) mounds constructed by a small bulldozer, (b) the exposed mineral soil between the mounds, and (c) the adjacent undisturbed humus, and sown heavily with Yellow Birch and Sugar Maple. Growth in the first year showed no great differences: in the second, growth of Yellow Birch was greatest on (a), least on (c), and intermediate on (b). Growth of Sugar Maple appeared unaffected by site differences and was inferior to that of Yellow Birch on all sites. It is concluded that artificial mounding (quickly and easily done at the time of each harvest felling) may be a useful method of increasing the proportion of Birch in stands of this kind. [Cf. F.A. 21 No. 4208.]

625. **Tubbs CH 1976. Effect of sugar maple root exudate on seedlings of northern conifer species. U.S. For. Serv. Research Note NC-213, 2 pp.**

Keywords: roots /exudation /allelopathy /seedlings /secretions /responses /conifers /growth regulators/broadleaves /*Acer saccharum*/*Larix laricina*/*Thuja occidentalis*/*Pinus banksiana*/*Picea glauca*/*Picea mariana*/*Betula alleghaniensis*

Abstract: A leachate of actively growing roots of sugar maple (*Acer saccharum*), known to have an allelopathic effect on seedlings of yellow birch (*Betula alleghaniensis*), was applied to newly germinated seedlings of *Picea mariana*, *Larix laricina*, *Pinus banksiana*, *Picea glauca*, *Thuja occidentalis* and yellow birch. After 24 hr, the leachate had significantly retarded the growth of all seedlings except those of *T. occidentalis*.

626. **Tubbs CH 1964. Germination of Yellow Birch seed following natural stratification in Upper Michigan. U.S. For. Serv. Lake St. For. Exp. Sta. Research Note LS-34, 2 pp.**

Keywords: *Betula alleghaniensis* /artificial regeneration/seed treatment stratification/silviculture

Abstract: Seed from an upland-site tree was placed in small nylon mesh bags set out in a hardwood stand in Michigan at intervals during Nov.-Feb. 1961/62, and picked up after snow-melt, just before germination tests were started on May 10th in the laboratory (a) at room temperature, and outdoors under a closed hardwood stand (b). In (a), the 'natural stratification' produced no change in total germination %, and time of stratification had little effect. In (b), seed stratified in Nov. and Dec. began to germinate after 19 days and reached peak rates 3 and 21 days respectively thereafter; the seed stratified later may not have reached peak germination by the time observations ended on July 2nd.

627. **Tubbs CH 1978. How to manage eastern hemlock [*Tsuga canadensis*] in the Lake States. U.S. For. Serv. misc. publication, 2 pp.**

Keywords: silviculture /felling /shelterwood /conifers /silvicultural systems/*Tsuga canadensis*/northern hardwoods

Abstract: A brief guide to the silviculture of hemlock in the northern hardwood forest type under a shelterwood system.

628. **Tubbs CH 1969. The influence of light, moisture and seedbed on Yellow Birch regeneration. U.S. For. Serv. Research Paper NC-27, 12 pp.**

Keywords: *Betula alleghaniensis*/*Betula alleghaniensis*/seed germination/natural regeneration/soil temperature/litter/site preparation

Abstract: In an experiment in a forest clearing in Michigan, imperfectly drained, lightly (30%) shaded seedbeds gave the highest % germination of *Betula alleghaniensis*. Moderately heavy (50%) shade gave highest germination on well drained sites, where mineral soils gave better results than organic soils. Soil surface temperatures on different sites under varying shade are recorded. Seedlings on the mineral soil were the only ones to survive in full sunlight. [Cf. F.A. 21 No. 4241.]

629. **Tubbs CH 1968. The influence of residual stand densities on regeneration in Sugar Maple stands. U.S. For. Serv. Research Note NC-47, 4 pp.**

Keywords: *Acer saccharum* /natural regeneration /logging/density

Abstract: This supplementary paper [cf. F.A. 22 No. 2944] gives results 10 years after cutting. *Acer saccharum* was found to be still the predominant species under all stand densities; nearly all regeneration reaching larger size classes had become established before cutting; heavier cuttings (residual b.a. of 30, 50 and 70 sq. ft.) are more rapidly making up deficits in sapling and pole-sized classes than the lightest cutting (90 sq. ft.).

630. **Tubbs CH 1965. Influence of temperature and early spring conditions on Sugar Maple and Yellow Birch germination in Upper Michigan. U.S. For. Serv. Lake St. For. Exp. Sta. Research Note LS-72, 2 pp.**

Keywords: *Acer saccharum*/plant ecology/Reproductive behaviour/Seed germination /soil temperature /*Betula alleghaniensis*/natural regeneration

Abstract: Observations in mature hardwood stands in April 1964 showed that most *Betula alleghaniensis* seeds were found (ungerminated) on top of the snow, whereas most *Acer saccharum* seeds were found under the snow and leaf litter and had begun to germinate. Stratification for 90 days, followed by incubation at 34, 41, 50, or 60°F., showed that *A. saccharum* seeds had the highest germination % at 34°, and *B. alleghaniensis* at 50°.

631. **Tubbs CH 1977. Manager's handbook for northern hardwoods in the north central States. U.S. For. Serv. General Technical Report NC-GTR-39, 29 pp.**

Keywords: silviculture /northern hardwoods /marking techniques /uneven-aged management /even-aged management

Abstract: One of the series of silvicultural manuals noticed elsewhere in FA, dealing with northern hardwoods. Major forest types are described and recommendations, techniques and data, are given for all-aged and even-aged silviculture. Instructions are given for marking of all trees, with stocking guides (but no yield data).

632. **Tubbs CH 1977. Natural regeneration of northern hardwoods in the northern Great Lakes region. U.S. For. Serv. Research Paper NC-150, 20 pp.**

Keywords: coppice /silviculture /natural regeneration /felling /selective felling/group fellings/shelterwood /clear felling/broadleaves /silvicultural systems/northern hardwoods

Abstract: The role of coppice shoots and seedlings in the establishment and composition of natural regeneration and the effects of different felling systems and environmental factors are discussed from studies in Michigan and Wisconsin. Descriptions are given of the natural form and quality of the main broadleaves and of the affect of damage on form and survival. The effects are considered of single tree selection, group selection, shelterwood felling and clear-felling on regeneration.

633. **Tubbs CH 1977. Root-crown relations of young sugar maple and yellow birch. U.S. For. Serv.**

Research Note NC-225, 4 pp.

Keywords: crown /plant morphology /dimensions /root morphology /broadleaves /Acer saccharum/Betula alleghaniensis /root-crown relations

Abstract: Tree height, d.b.h., average crown radius and average length of excavated roots were measured on 18 randomly chosen sugar (Acer saccharum) and yellow birch (Betula alleghaniensis) of 0.85 to 5.97 inches d.b.h. in an unthinned stand. Maple roots usually terminated within a few feet of crown perimeter whereas birch roots frequently extended further beyond the perimeter. Root distribution was more variable in birch than in maple. Where the crown mass was off-centre from the stem, roots tended to fill the part of the circle not covered by the crown.

634. **Tubbs CH and Metzger FT 1969. Regeneration of northern hardwoods under shelterwood cutting. Forestry Chronicle 45: 333-337.**

Keywords: natural regeneration/Acer saccharum/Betula alleghaniensis /stem form /shelterwood/release /silvicultural systems/Tsuga canadensis /northern hardwoods /natural regeneration

Abstract: Two separate trials were made near Marquette, Michigan, in mature forest of (a) nearly pure Acer saccharum and (b) Tsuga canadensis/hardwoods. In (a) two stocking levels were left in separate plots in the initial operations, viz. 75 and 95 sq. ft. b.a./acre in trees \geq 10 in. d.b.h.; the plots originally left with 95 sq. ft./acre were reduced after 5 years to 75 sq. ft. In (b) only the 95 sq. ft. level was used. Four understorey treatments were tested: (1) removal by poisoning of undesirable pole- and sapling-stage trees; (2) the same as (1), with additional removal of seedlings; (3) soil scarification combined with (2); and (4) no treatment. A. saccharum regeneration was good and it responded well to (4), where height growth was uniform. Betula alleghaniensis regeneration predominated in (b). In both forest types greatest numbers of B. alleghaniensis regeneration were produced by (3), though A. saccharum predominated in all plots of (a).

635. **Tubbs CH and Oberg RR 1966. Growth response of seedling Yellow Birch to humus-mineral soil mixtures. U.S. For. Serv. Research Note NC-6, 2 pp.**

Keywords: Betula alleghaniensis /greenhouse /plant ecology/humus /nurseries/plant nutrition /seedlings /soils - humic/artificial regeneration

Abstract: Tests with seedlings in greenhouse pots of six different volumetric mixtures of Michigan humus and mineral soil showed that mineral-soil additions to the humus depressed growth generally, but root growth decreased less than did that of leaves, thus increasing root/shoot ratios. A 50:50 humus/ mineral mixture is recommended, since height growth does not increase greatly with humus proportions $>50\%$, and root/shoot ratios are still relatively good.

636. **Tubbs CH and Oberg RR 1978. How to calculate size-class distribution for all-age forests. U.S. For. Serv. misc. publication, 6 pp.**

Keywords: felling /selection /forest management /Q factor /silviculture /silvicultural systems/northern hardwoods

Abstract: A practical guide to silvicultural management under the selection system using the 'q' factor, with reference to the northern hardwoods forest type in the USA.

637. **Twight PA and Minckler LS 1972. Ecological forestry for the northern hardwood forest. National Parks and Conservation Association publication, 14 pp.**

Keywords: management /silvicultural systems/silviculture /felling /selection /wildlife /Acer saccharum/northern hardwoods /economics

Abstract: Describes the history of the Goodman Lumber Company forest in Wisconsin, including upland and swampland ecosystems, since 1907. Management according to ecological principles (including wildlife conservation) began in 1927 with the adoption of a system of sustained-yield selection. The system has resulted in an increased proportion of *Acer saccharum* and other high-value species, and is regarded as profitable.

638. **Urbrock WJ 1998. Oak savannas and woodlands. Transactions of the Wisconsin Academy of Sciences, Arts and Letters, 86: 1-234.**

Keywords: forest ecology/vegetation types/savannas /savanna woodlands/population dynamics/wildlife /revegetation /natural regeneration/forest management/wild animals/reviews /forest pests/soils/nature conservation/species diversity/botanical composition/history /forest fires/fire ecology/woodland grasslands

Abstract: Eighteen articles are presented from the 1997 Midwest Oak Savanna and Woodland Conference held at the University of Wisconsin Madison, concerning the ecology, management and restoration of oak savannas and woodlands in Wisconsin and the Midwest. Topics covered include vegetational changes associated with oak wilt, incentives for savanna protection on private lands, the effects of *Sericea lespedeza* invasion in clearings in Kansas oak savannas in terms of biodiversity and forage, restoration techniques, small mammals of the Wisconsin pine barrens, characterization of dry site calcareous oak savanna and adaptive management (a heuristic approach).

639. **Vasievich JM and Webster HH 1997. Lake States regional forest resources assessment: technical papers. U.S. For. Serv. General Technical Report NC-GTR-189, 314 pp.**

Keywords: forest resource assessment/employment analysis/economic development/trends /sustainability /forest products/tourism

Abstract: The report includes 21 technical working papers which were prepared for the Lake States regional forest resources assessment of 1995. Subjects covered include physical setting, history and health of Lake States forests, timber supply and demand, tree species diversity, ecosystem management, recreation and tourism, employment, and community and social aspects of forestry development and utilization.

640. **von Althen FW 1983. Animal damage to hardwood regeneration and its prevention in plantations and woodlots of southern Ontario. Great Lakes Forestry Centre (Canadian Forestry Service) Information Report No. O-X-351, 28 pp.**

Keywords: wildlife /browsing /damage /deer /voles /*Microtus pennsylvanicus* /squirrels /*Sciurus carolinensis* /rabbits /*Sylvilagus floridanus* /snowshoe hares /*Lepus americanus* /European hares /*Lepus europaeus* /groundhogs /*Marmota monax* /deer /*Odocoileus virginianus* /cattle /*Bos taurus*

Abstract: Damage to natural and artificial regeneration by voles (*Microtus pennsylvanicus*), squirrels (*Sciurus carolinensis*), rabbits (*Sylvilagus floridanus*), snowshoe hares (*Lepus americanus*), European hares (*Lepus europaeus*), groundhogs (*Marmota monax*), deer (*Odocoileus virginianus*), and cattle (*Bos taurus*) is discussed. Possible control methods and their relative effectiveness are described and estimates given of the cost of the most promising methods.

641. **von Althen FW 1978. Artificial reforestation of a *Fomes annosus* [*Heterobasidion annosum*] infected red pine plantation. I. Survival and early growth of natural and artificial hardwood and conifer regeneration. Great Lakes Forestry Centre (Canadian Forestry Service) Information Report No. O-X-276, 11 pp.**

Keywords: resistance /artificial regeneration/regeneration /*Acer saccharum*/*Quercus rubra*/*Tilia*

americana/Fraxinus americana /Juglans cinerea /Juglans nigra /Liriodendron tulipifera/Pinus strobus/ Pinus resinosa /Larix decidua /Acer rubrum/Heterobasidion annosum

Abstract: Seedlings of the following species were planted in a 0.57-ha clear-felled area of a 59-yr-old Pinus resinosa plantation in Ontario: Acer saccharum; A. rubrum; Liriodendron tulipifera; Quercus rubra; Fraxinus americana; Tilia americana; Juglans nigra; J. cinerea; Pinus strobus; P. resinosa; and Larix decidua; natural regeneration was also recorded. Six yr after planting (with the fungus still active in the clear-felled area), survival and total ht., respectively, of the first 5 spp. ranged from 93 to 97% and from 121 to 190 cm. Survival and ht. of basswood and the Juglans spp. were poor; as was survival in the pines and larch.

642. **von Althen FW 1988. Effects of spatial arrangement in mixed-species hardwood plantations. *Northern Journal of Applied Forestry* 5: 203-207.**

Keywords: Plantations /silviculture /Weed control/Herbicides /simazine /glyphosate /Planting /group planting/row orientation/usage /crops /Weeds /control /management /shading /artificial regeneration /release

Abstract: To determine the effects of species mixtures and planting arrangements, 16 broadleaf species were planted in different arrangements in 2 experiments in a former field in Middlesex County, Ontario, Canada. With few exceptions planting arrangement had little effect on 10-yr survival or on ht. and diam. increment. However, overall survival and growth were slightly better in row planting than in completely random planting. Applications of 3.3 kg/ha of active simazine in Apr. of the first 3 yr after planting provided adequate weed control. One application of 2 kg/ha of active glyphosate in June of the sixth growing season eliminated 80% of the competition, renewed tree vigour, and enabled the tree canopy to close, thereby providing weed control through shading.

643. **von Althen FW, Wood JE, Mitchell EG, and Hoback K 1994. Effects of different intensities of yellow birch and sugar maple crop tree release. Great Lakes Forestry Centre (Canadian Forestry Service) NODA-NFP Technical Report No. TR-4, 13 pp.**

Keywords: thinning /increment /growth /diameter /plant height/plant competition/control /epicormics /stem form/quality /silvicultural systems/natural regeneration/clear strip felling/crown /Acer saccharum/Betula alleghaniensis /spacing/release

Abstract: Twenty-year-old yellow birch (*Betula alleghaniensis*) and sugar maple (*Acer saccharum*) saplings (originating from natural regeneration after strip clear felling) were thinned near Thessalon, Ontario, by a work crew employed under a Canada Job Development program. Treatments consisted of either a control or the removal of all competing trees at 1, 2 or 3 metres around the boles of sugar maple crop trees. Crop tree release increased the 5-year diameter increment and crown width of both species. The greater the release the larger the increase. Height increment of the yellow birch crop trees decreased with intensity of release while height increment of the sugar maple crop trees was higher in all thinning treatments than in the control. Few epicormic sprouts developed on the stems of both species released at 1 to 3 metres. However, release of yellow birch at 4 metres increased the number of epicormic sprouts and greatly increased their size. Five years after release at 1 and 2 metres the space available for yellow birch crown expansion had nearly filled. Release at 3 metres provided a good balance between diameter increment and stem quality maintenance. Release at 4 metres degraded stem quality. Release at 1 metre was inadequate for crown expansion of sugar maple crop trees while release at 2 and 3 metres increased diameter increment by 114 and 171%, respectively, with adequate space for crown expansion for a further 5 years. The Job Development program improved the participants' employment opportunities. Recommendations are made for the release of crop trees in similar stands.

644. **Walters DK and Ek AR 1993. Whole stand yield and density equations for fourteen forest types in**

Minnesota. *Northern Journal of Applied Forestry* 10: 75-85.

Keywords: vegetation types/increment /volume /growth models/yield forecasting/stand characteristics/stand development

Abstract: Models that estimate per acre basal area, number of stems, quadratic mean diameter, volumes to specified top diameters, and biomass per acre by stand age and site index were developed and fitted to data for 14 forest types in Minnesota. The resulting equations were developed from linear and nonlinear least squares analyses using USDA Forest Service Forest Inventory and Analysis data. These equations are intended for projecting future forest characteristics, including yield, on a statewide basis assuming the continuation of the level of management inherent in the data. Parameter estimates and goodness-of-fit statistics are provided for each model. Also discussed are the implementation procedures, assumptions, consistency of estimates, estimates for mixed species stands, and other considerations in applications.

645. **Walters DK, Ek AR, and Czysz D 1990. Construction of variable-density empirical yield equations from forest management inventory data. *Northern Journal of Applied Forestry* 7: 110-113.**

Keywords: Yield forecasting/Yield tables/Populus spp. /aspen

Abstract: Forest management inventory data and analysis by microcomputer are used to illustrate a methodology for constructing yield equations quickly and economically. An example using aspen [*Populus* spp.] in the Lake States region is used to describe the model and the adjustments, made through ratios, which can be made to reflect specific stand information. Model fitting, skewness of plot data and provision of independent validation data are discussed, as well as implementation of the model.

646. **Walters MB 1994. *The physiological ecology of shade tolerance in northern hardwood seedlings*. PhD dissertation, University of Minnesota, Twin Cities. 134 pp.**

Keywords: *Acer saccharum*/*Quercus rubra*/*Betula papyrifera*/*Betula alleghaniensis*/northern hardwoods /*Ostrya virginiana* /shade tolerance /photosynthesis /growth rates /seedlings /tissue allocation /nitrogen mineralization /plant succession

Abstract: Three assumptions underlie our notions of the nature of shade tolerance: growth rates are the measure of success in low light; photosynthetic rates are related to growth in low light; and light solely limits growth in natural low-light habitats. I tested these assumptions with three experiments using different combinations of five species of northern hardwoods that vary in shade tolerance: *Betula papyrifera*, *Betula alleghaniensis*, *Ostrya virginiana*, *Quercus rubra*, and *Acer saccharum*. Specifically I asked: (1) are leaf photosynthetic rates responsible for differences in growth in high and low light, or are other traits, such as allocation to leaves or respiration rates more important; (2) are growth rates in low light positively related to reported shade tolerance classifications; (3) is survival in low light related to growth and/or to reported shade tolerances; (4) do belowground resources affect growth and survival in low light. Results indicated that in both high and low light photosynthesis and leaf allocation were related to growth. Shade tolerant species had higher growth rates than intolerants only in very low light where growth for all species was near zero. Shade-intolerant species generally outgrew tolerants at higher light levels. Except for *Q. rubra*, which grew slowest and had the highest proportion of mass in roots in all light levels, these data indicate that there is a tradeoff between maximizing growth rate in high resource conditions and minimizing the light level at which positive growth can occur. During two years of growth in shadehouses, survival in low light was related to relative but not absolute growth rate for all five species. Survival was also related to seed size but only for the first growing season. Nitrogen additions to seedlings growing in a moderately infertile forest soil had no effect on growth, survival or allocation parameters. In contrast, for *A. saccharum* seedlings growing in low light forest understories, growth correlated with in situ nitrogen mineralization rates. Across this natural N mineralization gradient growth correlated positively with leaf biomass allocation and

leaf nitrogen concentrations.

647. **Walters MB, Kruger EL, and Reich PB 1993. Growth, biomass distribution and CO₂ exchange of northern hardwood seedlings in high and low light: relationships with successional status and shade tolerance. *Oecologia* 94: 7-16.**

Keywords: photosynthesis /respiration /seedlings /seedling growth/gas exchange/light /plant succession/seral stages/broadleaves /Acer saccharum/Quercus rubra/Betula papyrifera/Betula alleghaniensis/northern hardwoods /Ostrya virginiana

Abstract: The physiology, morphology and growth were compared of first-year seedlings of *Betula papyrifera*, *Betula alleghaniensis*, *Ostrya virginiana*, *Acer saccharum* and *Quercus rubra* seedlings, in a controlled environment experiment. These species vary widely in reported successional affinity and shade tolerance. The seedlings were grown in relatively high light conditions (average photosynthetic photon flux density (PPFD) at top of seedling canopy = 610 $\mu\text{mol m}^{-2} \text{s}^{-1}$), and high nutrient and moisture conditions. *B. papyrifera*, *B. alleghaniensis* and *O. virginiana* were also grown under low-light conditions (average PPFD at top of seedling canopy = 127 $\mu\text{mol m}^{-2} \text{s}^{-1}$). Under high light conditions *B. papyrifera* and *B. alleghaniensis* (early-successional, shade-intolerant species) had relatively high relative growth rates (RGR) and high rates of photosynthesis, N uptake and respiration in comparison with *A. saccharum* and *O. virginiana* (late-successional, shade-tolerant species). Fire adapted *Q. rubra* had intermediate photosynthetic rates, but had the lowest RGR and leaf area ratio, and the highest root weight ratio of all 5 species. Under high light conditions interspecific variation was positively correlated with allocation to leaves and rates of photosynthesis and respiration, and negatively correlated with seed mass and leaf mass per unit area. Under low-light conditions *B. papyrifera* and *B. alleghaniensis* had higher growth rates than *O. virginiana*. The rapid growth habit of early-successional species in low light was associated with a greater proportion of biomass distributed to leaves, lower leaf mass per unit area, a lower proportion of root biomass, and a greater height per unit stem mass.

648. **Walters MB, Kruger EL, and Reich PB 1993. Relative growth rate in relation to physiological and morphological traits for northern hardwood tree seedlings: species, light environment and ontogenetic considerations. *Oecologia* 96: 219-231.**

Keywords: photosynthesis /respiration /leaf area/biomass /age /plant morphology/seedlings /seedling growth/plant physiology/foliage /light /ontogeny /broadleaves /growth /Acer saccharum/Quercus rubra/Betula papyrifera/Betula alleghaniensis/northern hardwoods /Ostrya virginiana

Abstract: First-year seedlings of *Betula papyrifera*, *B. alleghaniensis*, *Ostrya virginiana*, *Quercus rubra* and *Acer saccharum* were grown in a common high resource environment (photosynthesis saturating or near-saturating light, 610 $\mu\text{mol-2s}^{-1}$ PPFD; low vapour pressure deficits; and high nutrient and water availability). The first 3 species were also grown in a moderately low light environment (127 $\mu\text{mol-2s}^{-1}$) that was otherwise identical to the high light environment. Various physiological traits (including in situ rates of average canopy net photosynthesis, A; and leaf, stem and root respiration) and morphological (foliage) traits (including leaf area ratio, LAR; and leaf weight ratio, LWR) were measured after 41, 62, 83 and 104 d. Age and biomass were used as indicators of ontogeny (stage of development). For all species in high light, relative growth rate (RGR) was positively related to LWR and LAR, A, and rates of leaf, stem and root respiration. In low light, RGR was not correlated with A, but was positively correlated with LAR, LWR and rates of stem and root respiration. RGR generally declined with age and biomass. Whole-plant respiration rates per unit of leaf mass also decreased. LWR and A explained as much as 74% of the variation in RGR across light, species and ontogeny.

649. **Walters MB and Reich PB 1996. Are shade tolerance, survival, and growth linked? Low light and nitrogen effects on hardwood seedlings. *Ecology* 77: 841-853.**

Keywords: growth /nitrogen /photosynthesis /light /effects /seedling growth/plant nutrition/plant morphology/foilage /leaf area index/seedlings /shade /tolerance /survival /broadleaves /light intensity/Acer saccharum/Quercus rubra/Betula papyrifera/Betula alleghaniensis/northern hardwoods /Ostrya virginiana

Abstract: Seedlings of *Betula papyrifera*, *Betula alleghaniensis*, *Ostrya virginiana*, *Acer saccharum*, and *Quercus rubra* were grown for 2 yr in outdoor shade houses (in Madison, Wisconsin) in a complete factorial of low light (2 and 8% open sky) and nitrogen (forest soil and forest soil plus 200 kg N ha⁻¹ yr⁻¹). For these seedlings the effects of light and nitrogen on the interrelationships among survival, growth, and shade tolerance were examined, and the physiological bases of shade tolerance were explored by examining the relationship of plant morphology and photosynthesis to growth. Nitrogen amendments did not have a significant effect on any plant trait at either light level. In 8% light, growth and survival were highest for shade-intolerant *Betula papyrifera* and mid-tolerant *B. alleghaniensis*, lower for shade-tolerant *O. virginiana* and *A. saccharum*, and lowest for disturbance-adapted *Q. rubra*. In 2% light, species rankings were reversed as *O. virginiana* and *A. saccharum* had higher growth and survival than the other species. Second-year survival was strongly related to 1st-yr growth ($P < 0.001$), whereas relationships with 1st-yr plant mass and 1st-yr absolute growth rates were weak. Therefore, survival of shade-tolerant species at 2% light was related to their maintenance of positive growth, whereas intolerant species had growth near zero and high rates of mortality. In both 2 and 8% light photosynthetic rates on mass (but not area) bases and the proportion of the plant in leaves (leaf area ratio and leaf mass ratio) were positively related to growth. Greater rates of growth and survival for shade-tolerant species in very low light, and for intolerant species in higher light, suggest that there is a species-based trade-off between maximizing growth in high light and minimizing the light compensation point for growth. This trade-off may be an important mechanism driving forest community dynamics in northern hardwood forests.

650. **Walters MB and Reich PB 1997. Growth of Acer Saccharum Seedlings in Deeply Shaded Understories of Northern Wisconsin: Effects of Nitrogen and Water Availability. *Canadian Journal of Forest Research* 27: 237-247.**

Keywords: resource availability/seedlings/carbon gain/maples /leaf mass/ photosynthesis/ light/Acer saccharum/soil moisture /soil chemistry /nitrogen cycling

Abstract: Availability of soil nitrogen, soil moisture, and light were examined, along with the growth, biomass allocation, and leaf nitrogen concentration of naturally established *Acer saccharum* Marsh. seedlings, in the understories of 12 forest sites in northern Wisconsin. The sites represented a nutrient and moisture gradient (poor to rich) according to a habitat classification system. We asked (1) Are seedling growth rates, biomass allocation patterns, and leaf nitrogen related to soil water and nitrogen availability? and (2) Do soil resource rankings predicted by habitat classifications mirror our direct observations? Across sites compared in a low-light data set (plots with <5% canopy openness), rich sites had 2- to 4-fold higher seedling growth, percent leaf nitrogen, nitrogen mineralization rates, and nitrification rates than poor sites. Seedling growth in low light correlated (P less than or equal to 0.05) positively with nitrification, total nitrogen mineralization, percent leaf nitrogen, soil moisture, and organic carbon, and negatively with fine root density. In multiple regression, soil moisture ($P = 0.033$) and nitrification ($P = 0.015$) together explained 79% of the variation in growth. Thus, seedling growth in shade was enhanced on richer sites in part because of higher nitrate N and water availability. This has potential implications for forest dynamics, since the probability of sugar maple becoming the dominant woody regeneration in any given understory may be partially dependent upon the level of soil resources.

651. **Walters MB and Reich PB 1997. Growth of Acer saccharum seedlings in deeply shaded understories of northern Wisconsin: effects of nitrogen and water availability. *Canadian Journal of Forest Research* 27: 237-247.**

Keywords: seedbeds /recruitment /plant succession/water availability/seedling growth/effects /nitrogen /soil chemistry/soil water content/spatial distribution/biomass /foliage /leaves /plant composition/plant nutrition/nitrification /mineralization /light /soil organic matter/roots /density /shade /nitrate/dynamics /stand characteristics/seedlings /understorey /soil /natural regeneration/ *Acer saccharum*

Abstract: Availability of soil nitrogen, soil moisture, and light were examined, along with the growth, biomass allocation, and leaf nitrogen concentration of naturally regenerated *Acer saccharum* seedlings, in the understories of 12 forest sites in northern Wisconsin. The sites represented a nutrient and moisture gradient (poor to rich) according to a habitat classification system. Two questions were addressed: (1) whether seedling growth rates, biomass allocation patterns, and leaf nitrogen are related to soil water and nitrogen availability, and (2) whether soil resource rankings predicted by habitat classifications mirror direct observations. Across sites, for plots with low-light (those with <5% canopy openness), rich sites had 2- to 4-fold higher seedling growth, percentage leaf nitrogen, nitrogen mineralization rates, and nitrification rates than poor sites. Seedling growth in low light correlated positively with nitrification, total nitrogen mineralization, percentage leaf nitrogen, soil moisture and organic carbon, and negatively with fine root density. In multiple regression, soil moisture and nitrification together explained 79% of the variation in growth. Thus, seedling growth in shade was enhanced on richer sites in part because of higher nitrate N and water availability. This finding has potential implications for forest dynamics, since the probability of sugar maple becoming the dominant woody regeneration in any given understorey may be partially dependent upon the level of soil resources.

652. **Walters MB and Reich PB 1999. Low-Light Carbon Balance and Shade Tolerance in the Seedlings of Woody Plants: Do Winter Deciduous and Broad-Leaved Evergreen Species Differ? *New Phytologist* 143: 143-154.**

Keywords: Low Light/Carbon Balance/Shade Tolerance/Woody Plants/Relative Growth Rate/Nitrogen Concentration/Hardwood Seedlings/Root Morphology/Tree Seedlings/CO₂ Exchange/Leaf/Understory/Photosynthesis

Abstract: A popular conceptual model asserts that shade tolerance is characterized by morphological and physiological traits that enhance the net rate of carbon capture in low light. We tested this model by quantitatively reviewing growth, leaf lifespan, CO₂ exchange and morphological data from 76 studies on woody seedlings grown under conditions of low light. Data were placed into three tolerance categories (intolerant, intermediate, tolerant), two light categories (less than 4% and 4-12%) and two leaf phenology categories (broad-leaved evergreen and winter deciduous). For both evergreen and deciduous groups, intolerant species had traits conferring greater growth potential than tolerant species in both light categories. These traits included greater leaf mass ratio, leaf area ratio, specific leaf area and mass-based photosynthetic rates above light compensation. However, in 0-4% light, growth rates were similar for intolerant and tolerant species, because low light together with higher respiration rates for intolerant species limited the expression of their growth potential differences. Deciduous and evergreen intolerant species were similar in many respects. However, both intermediate and tolerant deciduous species had markedly lower leaf mass ratios and higher root mass ratios than intermediate and tolerant evergreen species. In addition, deciduous species and intolerant evergreens must cope with as much as sixfold higher leaf turnover rates than tolerant evergreen species. Thus, rather than maximizing growth rates in low light, tolerant evergreen species minimize biomass loss through long leaf lifespans and low respiration rates. Tolerant deciduous species also minimize biomass losses by minimizing whole-plant respiration rates but they accomplish low biomass turnover through low leaf mass ratio and not low leaf turnover rates. Furthermore, unlike most tropical evergreens, tolerant deciduous species can gain large fractions of their total growing season carbon during short periods when the overstory is leafless and then allocate this carbon to storage (as reflected by high root mass ratios) rather than new leaves. In conclusion, we found no support for the low-light-enhanced carbon capture model of shade tolerance as viewed strictly from the perspective of physiological growth capacity. This can be explained by the disadvantages to net growth and

survival of maintaining a high growth potential at low light, because high growth potential results in greater rates of whole-plant respiration, tissue turnover, herbivory and mechanical damage and in decreased storage. Thus, shade tolerance can be characterized by traits that maximize survival and net growth, where net growth includes losses to all agents.

653. **Walters MB and Reich PB 2000. Seed Size, Nitrogen Supply, and Growth Rate Affect Tree Seedling Survival in Deep Shade. *Ecology* 81: 1887-1901.**

Keywords: Biomass Allocation/Low Light/Nitrogen Availability/Relative Growth Rate/Seed Size/Shade Tolerance/Survival/Tree Seedlings/Phylogenetically Independent Contrasts/Low-Light/Rain-Forest/Interspecific Variation/Hardwood Seedlings/Sapling Mortality/Woody-Plants/Tolerance/Leaf/Larix laricina/Populus tremuloides/Pinus strobus/Pinus banksiana/Pinus resinosa/Abies balsamea/Picea mariana/Betula papyrifera/Betula alleghaniensis /Acer saccharum

Abstract: Species differences in seedling survival in deeply shaded understories (i.e., shade tolerance) may depend on both seed size and growth rates, but their relative contributions to survival and how they change with time and with variation in light and below-ground resource availability is unknown. With a greenhouse experiment we investigated these relationships by examining responses of growth, growth-related morphology, survival, and their interrelationships to a range of nitrogen (3.4×10^{-9} - 3.4×10^{-3} mol/L N fertilizer solutions) and low light (0.6-7.3% of open sky) availabilities for young seedlings of 10 North American tree species that vary in observational shade tolerance rankings and seed size (Populus tremuloides, Betula papyrifera, Betula alleghaniensis, Acer saccharum, Larix laricina, Pinus banksiana, Pinus resinosa, Pinus strobus, Picea mariana, and Abies balsamea). Within all species, relative growth rate (RGR) and survival increased with light. RGR and survival also increased with N supply but only at the two highest light levels, and then only for the shade-intolerant, broad-leaved Populus and Betula spp.. In every species, survival was positively related to RGR. Moreover, each species differed in the relationship of survival to RGR, and these differences were related to seed mass: at any given RGR, large-seeded, shade-tolerant species had higher survival than smaller-seeded, intolerant ones. Across species, in most light and N treatments, seed mass was positively related to young seedling survival, but RGR was not. In very low light the relative benefits of greater seed mass to survival were temporary. As seedlings aged, interspecific mortality rates became more dependent on observational shade tolerance rankings than on seed size, but mortality was still unrelated to RGR. Our results indicate potentially important interactions among light, N, and species that could influence regeneration dynamics. For young seedlings in deeply shaded microsites, N supply does not matter, and only shade-tolerant species survive due, in part, to large seeds and physiological traits other than RGR. In moderate shade, RGR is greater, and survival is high for all species, except that small-seeded, broad-leaved, intolerant species have low survival and RGR at low N supply. This suggests that broad-leaved shade-intolerant species compete more effectively in moderate shade on richer soils than on poorer soils. Although we found that both seed mass and vegetative physiology influenced survival in shade, they did not covary tightly, suggesting that they are under somewhat separate selection pressures.

654. **Walters MB and Reich PB 2000. Trade-Offs in Low-Light CO₂ Exchange: a Component of Variation in Shade Tolerance Among Cold Temperate Tree Seedlings. *Functional Ecology* 14: 155-165.**

Keywords: CO₂ Exchange/Shade Tolerance/Trade-Offs/Tree Seedlings/Whole Plant/Relative Growth-Rate/Successional Status/Hardwood Seedlings/Root Morphology/ Nitrogen/ Respiration/ Leaf/ Photosynthesis/Traits/Acer saccharum/Populus tremuloides/Betula papyrifera/Betula alleghaniensis /Ostrya virginiana

Abstract: 1. Does enhanced whole-plant CO₂ exchange in moderately low to high light occur at the cost of greater CO₂ loss rates at very-low light levels? We examined this question for first-year seedlings of intolerant Populus tremuloides and Betula papyrifera, intermediate Betula alleghaniensis, and tolerant Ostrya virginiana and Acer saccharum grown in moderately low (7.3% of open-sky) and low (2.8%) light. We predicted that, compared with shade-tolerant species,

intolerant species would have characteristics leading to greater whole-plant CO₂ exchange rates in moderately low to high light levels, and to higher CO₂ loss rates at very-low light levels. 2. Compared with shade-tolerant *A. saccharum*, less-tolerant species grown in both light treatments had greater mass-based photosynthetic rates, leaf, stem and root respiration rates, leaf mass:plant mass ratios and leaf area:leaf mass ratios, and similar whole-plant light compensation points and leaf-based quantum yields. 3. Whole-plant CO₂ exchange responses to light (0.3-600 $\mu\text{mol quanta m}^{-2} \text{s}^{-1}$) indicated that intolerant species had more positive CO₂ exchange rates at all but very-low light (< 15 $\mu\text{mol quanta m}^{-2} \text{s}^{-1}$). In contrast, although tolerant *A. saccharum* had a net CO₂ exchange disadvantage at light > 15 $\mu\text{mol quanta m}^{-2} \text{s}^{-1}$, its lower respiration resulted in lower CO₂ losses than other species at light < 15 $\mu\text{mol quanta m}^{-2} \text{s}^{-1}$. 4. Growth scaled closely with whole-plant CO₂ exchange characteristics and especially with integrated whole-plant photosynthesis (i.e. leaf mass ratio x in situ leaf photosynthesis). In contrast, growth scaled poorly with leaf-level quantum yield, light compensation point, and light-saturated photosynthetic rate. 5. Collectively these patterns indicated that: (a) no species was able to both minimize CO₂ loss at very-low light (i.e. < 15 $\mu\text{mol quanta m}^{-2} \text{s}^{-1}$) and maximize CO₂ gain at higher light (i.e. > 15 $\mu\text{mol quanta m}^{-2} \text{s}^{-1}$), because whole-plant respiration rates were positively associated with whole-plant photosynthesis at higher light; (b) shade-intolerant species possess traits that maximize whole-plant CO₂ exchange (and thus growth) in moderately low to high light levels, but these traits may lead to long-term growth and survival disadvantages in very-low light (< 2.8%) owing, in part, to high respiration. In contrast, shade-tolerant species may minimize CO₂ losses in very-low light at the expense of maximizing CO₂ gain potential at higher light levels, but to the possible benefit of long-term survival in low light.

655. Wang N 1994. *Application of remote sensin in detecting and monitoring forest regeneration process in a disturbed environment*. MA thesis, Carleton University, Ottawa (Canada). 134 pp.

Keywords: remote sensing /regeneration /competition /allelopathy /herbaceous species /*Kalmia angustifolia* /nitrogen /Landsat /disturbance

Abstract: The successful regeneration of areas deforested by natural or human-caused disturbances can be facilitated by monitoring regrowth patterns with remote sensing. One factor influencing the species mix and succession is the presence of undesirable, naturally occurring competitive species on the site. In particular, the allelopathic properties of certain herbaceous species is recognized as a potentially significant threat to reforestation and natural site reclamation in boreal forest regions and northern Great Lakes-St. Lawrence forests regions. *Kalmia angustifolia*, for example, can inhibit regrowth of desirable tree species by depleting soil nitrogen levels in the vicinity. Previous work by Gillespie et al. (1992) demonstrated that *Kalmia* could be detected by airborne scanner. This thesis reports on a demonstration of potential for the operational use of Landsat TM in the detection of *Kalmia*. The Sudbury Basin was chosen as the study site as the landscape of this area has a long history of natural and human-caused disturbance with reclamation effects ranging from intensive site preparation to natural regeneration. The *Kalmia* study is part of a long term effort in this area to assess the potential of satellite imagery for a wide range of geobotanical investigations. A multi-date approach to methodology testing was adopted in view of the fact that the ability to differentiate trees and ericaceous plants varied greatly with season. Visual interpretation of *Kalmia* required a two step process of PCA to differentiate between trees and shrubs, and Infrared Index analysis to highlight within shrub species variation. A complex supervised classification of a combination of bands, ratios and principal components which each individually highlight vegetation, offers considerable promise. *Kalmia* could be identified with both techniques when representing over 40% of a shrub community. (Abstract shortened by UMI.)

656. Watmough SA and Hutchinson TC 1997. Metal resistance in red maple (*Acer rubrum*) callus cultures from mine and smelter sites in Canada. *Canadian Journal of Forest Research* 27: 693-700.

Keywords: resistance /callus /cultures /in vitro culture/heavy metals/soil pollution/mined land/air

pollution/tissue culture/Acer rubrum

Abstract: The response of red maple (*Acer rubrum*) to elevated heavy metal concentrations in surface soil, arising from either atmospheric deposition or mining activities, was investigated using callus tissue studies. Callus cell lines were established from shoot tips of mature red maple growing at 5 sites in rural and industrial locations in Ontario and Quebec differing in metal contamination. At Sudbury and Rouyn-Noranda, the trees were stunted and were established before smelting operations began. Surface soil in the rooting zone of many of the trees in the industrial areas was heavily contaminated with metals, and large differences in soil metal concentration at the bases of different trees were found. A significant positive linear relationship between Ni resistance, measured as an increase in fresh weight of callus on Ni-amended media, and total extractable Ni in soil at the base of trees was identified. Resistance to Ag and Co was also significantly greater in cell lines established from trees growing in soils containing highly elevated concentrations of these metals. It appears that red maple is able to produce an adaptive response to metal exposure which is identified in cells derived from shoot tips. This metal-specific, adaptive response may be particularly crucial for the survival of trees to rapid environmental changes.

657. **Watmough SA, Hutchinson TC, and Sager EPS 1998. Changes in tree ring chemistry in sugar maple (*Acer saccharum*) along an urban-rural gradient in southern Ontario. *Environmental Pollution* 101: 381-390.**

Keywords: trace elements/pollution /urbanization /wood chemistry/growth rings/woodlands /xylem /dendrochronology /heavy metals/urban areas/rural areas/gradients /soil pollution/*Acer saccharum* /lead /copper /zinc /chromium /calcium /iron /potassium /magnesium /manganese /phosphorus /strontium /vanadium

Abstract: Changes in xylem chemistry were examined in sugar maple sampled from 4 woodland sites along an urban-rural gradient. Two sites were located 4 km apart within metropolitan Toronto, a third was adjacent to a major highway 24 km NE of Toronto and a rural site was chosen 150 km to the NE of Toronto along the prevailing wind direction. Concentrations of Pb and Cu in surface soil were increased at the 2 city centre sites and the highway site compared with the rural woodland, but only the city site (which was located close to major roads) and the highway site had increased Zn, Cr and V. Pb concentrations in tree rings were highest at the 2 city centre sites, but a steady decline from around 1 mg kg⁻¹ dry weight in wood formed in the early 1920s to the present levels of 0.5 mg kg⁻¹ dry wt was recorded. In contrast, Pb levels were low at the highway site in wood formed before the 1940s, but increased dramatically to peak around 1.5 mg kg⁻¹ dry weight in the 1950s and then declined during the 1960s to levels comparable to those of the city sites. Pb concentrations at the rural woodland were consistently less than 0.2 mg kg⁻¹ dry weight. Concentrations of all other trace elements in xylem were approaching detection limits by inductively coupled plasma mass spectrometry (ICP-MS). No difference in Ca, Fe, K, Mg, Mn, P or Sr concentrations existed between sites; however, principal component analysis indicated that the distribution of Fe and P was similar in the xylem, increasing sharply in the outer rings. Ca and Sr concentrations were related, declining steadily from the pith to the cambium, whilst the distribution of Mg, K and Mn was similar in having no radial trend.

658. **Webb SL 1989. Contrasting windstorm consequences in two forests, Itasca State Park, Minnesota. *Ecology* 70: 1167-1180.**

Keywords: Wind damage/ecology /shade tolerance /wood strength /fungal pathogens /*Acer saccharum*/*Fraxinus pennsylvanica*/*Populus tremuloides*/*Pinus strobus*/*Pinus resinosa*/*Abies balsamea*/*Picea glauca*/*Betula papyrifera*

Abstract: Following a moderate (approximately 27-34 m/s or 60-75 m.p.h.) windstorm in July 1983, damaged trees in 2 stands 8 km apart, in Minnesota, USA, were surveyed in order to identify mortality patterns, evaluate consequences for shade-intolerant species and investigate

light-gap formation. Risk of direct wind damage was predicted best by tree size (in both stands) and species in the Pinus/Acer stand dominated by Pinus resinosa, P. strobus, Acer saccharum, or species wood strength in the Pinus/Abies stand dominated by P. resinosa, P. strobus, Abies balsamea. Tree mortality in the Pinus/Acer area was related to tree size, species, species wood strength, and incidence of species-specific fungal pathogens. In the Pinus/Abies area, where many understorey trees were killed, mortality was not predictable on the basis of tree size, but mortality risk was affected by tree species and species wood strength. Within most populations, size distribution of windstruck trees differed from population size distribution; however, mortality risk increased with tree size only for Populus tremuloides. In one study area, smaller trees were most vulnerable within Picea spp. and Pinus strobus populations. The difficulty of generalizing about windstorm consequences is illustrated by large intraspecific variation in amount of damage between different populations of Betula papyrifera, Pinus resinosa, and P. strobus. For shade-intolerant species expected to benefit from disturbance, windstorm consequences differed in the 2 stands, despite shared postfire origins and several species in common. In the Pinus/Acer stand, heavy mortality to shade-intolerant Populus tremuloides, Pinus resinosa, and Pinus strobus combined with a well-developed understorey to benefit existing shade-tolerant, windfirm Acer saccharum and tall shrubs. In the Pinus/Abies stand, the windstorm produced more regeneration opportunities for shade-intolerant species (Betula papyrifera, Populus tremuloides, Fraxinus pennsylvanica), because shade-tolerant understorey species of this stand (Abies balsamea, Picea glauca) were more heavily damaged, and because more light-gaps formed, although such light-gaps were small. Differences between the 2 communities in their responses to the same storm event appear to result from differences in forest structure and differences in the windfirmness of shade-tolerant understorey taxa.

659. **Webb SL 1988. Windstorm damage and microsite colonization in two Minnesota forests. *Canadian Journal of Forest Research* 18: 1186-1195.**

Keywords: Wind damage/ecology /Natural regeneration/site factors/pines /Acer saccharum /Acer rubrum /Abies balsamea /Picea spp. /Ostrya virginiana /microtopography

Abstract: Scattered trees were uprooted, snapped or bent during a 1983 windstorm in two NW Minnesota pine forests. A test was made of potential correlates (tree species, tree size, cause of damage) of damage type; consequences of the uprooting, snapping and bending of trees were compared by assessing postdamage survival and surveying formation and colonization of microsities (mounds, pits, stumps, and dead boles). Larger trees damaged directly by wind were usually snapped and killed in both study areas, regardless of tree species. Smaller trees damaged by falling neighbours were either bent without sustaining mortality or forming microsities (a damage type prevalent among strong-wooded Acer saccharum and Ostrya virginiana in a Pinus/Acer study area) or uprooted, forming small mounds and pits (a damage type prevalent among weak-wooded Abies balsamea and Picea spp. in a Pinus/Abies study area). Bent trees usually survived, at least for several years. Uprooted and snapped trees, however, were equally unlikely to survive their damage. Windstorm-related microsities covered small proportions (6 and 18%) of the floor of the two forests, most as dead stems rather than as stumps, mounds or pits. Microsities from uprooting or snapping and background substrates did not differ in colonizing tree flora but did differ in density of colonists. The role of microsities varied with the autecology of tree species present. In the Pinus/Abies area, rotting wood of stumps and stems was the major establishment substrate for all regenerating tree species. In the Pinus/Acer area, Acer saccharum and A. rubrum were numerically dominant over other species on all substrates, with seedling densities highest away from microsities. Observed patterns of survival and tree regeneration indicated that uprooting and snapping of trees did not differ strongly in their consequences for either forest.

660. **Weber JA and Gates DM 1990. Gas exchange in Quercus rubra (northern red oak) during a drought: analysis of relations among photosynthesis, transpiration, and leaf conductance. *Tree Physiology* 7: 215-225.**

Keywords: Photosynthesis /transpiration /seasonal variation/Plant water relations/water stress/Foliage /gas exchange/water relations/Quercus rubra /climate /drought

Abstract: During the summers of 1987 and 1988, extended droughts provided an opportunity to study the effect of water stress on a sapling and two mature *Q. rubra* trees (15-20 m in height) growing in a mixed-species second-growth forest at the University of Michigan Biological Station. Each day (10.00-20.00 h) gas exchange was measured in a sunlit leaf. Development of water stress in leaves caused a marked midday depression in photosynthesis (A) and transpiration (E). At external CO₂ partial pressures of 100-110 Pa, a constant temperature of 30°C and a constant photosynthetic photon flux density of about 1000 μmol-2s⁻¹, A was 8 μmol m-2s⁻¹ at low leaf water potentials (-1.5 to -2.0 MPa), whereas it was 20 μmol m-2s⁻¹ in non-stressed leaves (-1.0 MPa). At lower external CO₂ partial pressures, the effect of low leaf water potential on A was less. The midday depression in gas exchange was relieved by an overnight rain of 2.5 cm. No difference in carboxylation efficiency or CO₂ compensation point was found between leaves before and after rain. The relationship between A and E was linear for a given external CO₂ partial pressure, but the slope varied with CO₂ concentration. Modification of a model of stomatal response produced a linear relation between leaf conductance and a factor incorporating A, relative humidity, and CO₂. The data indicate that gas exchange in leaves of mature northern red oak responds rapidly to relief of drought with no indication of long-term photoinhibition.

661. **Weidensaul TC and Wood FA 1973. Sources of species of Fusarium in northern hardwood forests. *Phytopathology* 63: 367-371.**

Keywords: plant pathology/plant pathogenic fungi/Acer saccharum/northern hardwoods /Fusarium spp. /Fusarium solani /Fusarium roseum /Fusarium tricinctum /Fusarium rigidiusculum /Calonectria rigidiuscula /canker

Abstract: Several spp. capable of causing canker of sugar maple (*Acer saccharum*) were found in the soil and air of forest stands and in bark of healthy maple trees. Two isolates each of *F. solani* and *F. roseum*, and 3 of *F. tricinctum* were collected from 25 000 ft³ of air sampled. Of 111 isolates from soil and bark, 60, 26 and 15 were of *F. solani*, *F. roseum* and *F. tricinctum*, respectively, and 1 of *F. rigidiusculum* [*Calonectria rigidiuscula*]. One isolate of *F. roseum* and 32 of the *F. solani* isolates from soil caused cankers in 1 or more of 8 inoculations. Of the bark isolates, 16, 12, 11 and 1 of *F. solani*, *F. tricinctum*, *F. roseum* and *C. rigidiuscula*, respectively, caused cankers, as did all 3 isolates of *F. tricinctum* and 1 of *F. roseum* from the air. All the pathogenic spp. were obtained from bark 5.5 m or less above ground level. More pathogenic isolates were recovered from stands with moderately and severely cankered trees than from stands with trees only slightly affected.

662. **Weingartner DH and MacDonald GB 1994. A survey of mixed wood research and development needs in Ontario. Ontario Forest Research Institute, Forest Research Information Paper No. 118, 17 pp.**

Keywords: silviculture /surveys /development /pest control/plant disease control/site preparation/boreal forests/forest management /public input

Abstract: A survey of 174 stakeholders across the state of Ontario, Canada, including Ontario Ministry of Natural Resources (OMNR) resource managers, the forest industry, researchers and non-governmental organizations, was conducted to identify the most important research and development issues for mixed wood silviculture. The survey highlighted several broad management issues which were considered of high importance, namely utilization and market development, site preparation and regeneration, stand tending, management planning and forest measurement (growth and yield). Within these categories, a number of specific issues were considered of particular importance: wider species utilization; modified cutting to secure natural regeneration; ecologically sensitive site preparation techniques; adaptive artificial regeneration species control; stand quality control and density control; silvics and species-site relationships;

mixed-species variable-density yield tables; impacts on residual stand quality; the physiology of growth and development; pest and disease control; and linkages with fish and wildlife habitat issues.

663. **Werner SM and Raffa KF 2000. Effects of Forest Management Practices on the Diversity of Ground-Occurring Beetles in Mixed Northern Hardwood Forests of the Great Lakes Region. *Forest Ecology and Management* 139: 135-155.**

Keywords: *Tsuga canadensis*/Forest Management/Diversity/northern hardwoods/Carabid Beetles/Old-Growth/Pitfall Traps/Ecosystem Reliability/Patch Formation/ Biodiversity/ Coleoptera/ Conservation/Assemblages/northern hardwoods /*Halpalus fulvilabris* /*Pterostichus coracinus* /*Carabus nemoralis* /*Glischrochilus siepmanni* /*Nicrophorus orbicollis* /*Nicrophorus sayi* /*Carabus sylvosus* /*Platynus decentis* /*Oiceoptoma novaboracensis* /*Calosoma frigidum* /*Necrophila americana* /*Nicrophorus vespilloides*

Abstract: Ground-occurring Coleoptera were sampled over 2 years using pitfall traps in 23 northern hardwood or eastern hemlock- dominated sites representing even-aged, uneven-aged, or old growth forests. Overall, 65,586 individuals were obtained, representing 33 families and 192 species. Carabids comprised 54% of the total catch in 1996, when all the families were tallied. There was little variation in the number and relative abundance of carabid species caught between seasons. No differences in overall species richness or abundance were observed among forest management regimes or habitat types. However, there were substantial differences in species composition. Thirteen species showed significant habitat associations among the five forest management regimes, and 21 species were associated with specific habitat features of the sites, such as dominant tree species or canopy structure. More species (16) were affected by the presence of forest management than by tree species dominance (6) or canopy structure (5). *Halpalus fulvilabris*, *Pterostichus coracinus*, *Carabus nemoralis*, *Glischrochilus siepmanni*, *Nicrophorus orbicollis*, and *Nicrophorus sayi* were more commonly caught in managed than in old growth forest sites, while *Carabus sylvosus*, *Platynus decentis* and *Oiceoptoma novaboracensis* were more commonly associated with old growth sites. *Calosoma frigidum* and *Necrophila americana* were associated with northern hardwood sites, while *Platynus decentis* was significantly associated with sites dominated by eastern hemlock. *Calosoma frigidum*, *Necrophila americana*, and *Nicrophorus vespilloides* were more common in even-aged sites, while a lampyrid and a leiodid morphospecies were more common in sites with an uneven-aged canopy structure. The importance of microsite features was reflected in the high variability observed among sites and among traps within sites. Results indicate that conservation of a range of forest types is required in order to maintain the diversity of ground-occurring beetles on a regional scale. This will be quite challenging, since forest types such as old growth hemlock-hardwood are rare across the landscape due to habitat fragmentation and logging.

664. **White MA and Mladenoff DJ 1994. Old-growth forest landscape transitions from pre-European settlement to present. *Landscape Ecology* 9: 191-205.**

Keywords: geographical information systems/spatial distribution/surveys /landscape /plant succession/*Acer saccharum*/*Betula alleghaniensis*/*Tsuga canadensis*/northern hardwoods

Abstract: A multi-temporal spatial analysis of forest cover for a 9600 ha landscape in northern Wisconsin, USA, used data from pre-European settlement (1860s), post-settlement (1931), and current (1989) periods. Using GIS, forest landscape changes and trajectories were in line with those generally described in aggregate for the northern Great Lake States region. The pre-European settlement map was created from witness tree data of the original federal General Land Office survey notes, 1931 cover from the Wisconsin Land Economic Inventory, and the 1989 cover map was based on colour infrared photography. GIS was used to analyse land area occupied by different forest types at different dates, temporal transitions between dates and their driving processes, and successional trajectories with landforms and spatial associations of forest types. Over the 120 yr period, forest cover changed from a landscape dominated by old-growth hemlock

(*Tsuga canadensis*) and hardwood forests (*Acer saccharum*, *Betula alleghaniensis*) to largely second-growth hardwoods and conifers. Former dominant hemlock was largely eliminated from the landscape. From 1860 to 1931, large-scale disturbances associated with logging were the dominant processes in the landscape. Early successional forest types covered much of the landscape by the 1930s. From 1931 to 1989, succession was the dominant process driving forest transitions as forest types succeeded to a diverse group of upland hardwood and conifer forest types. If successional trajectories continue, a more homogeneous landscape may develop comprised of both a northern hardwood type dominated by sugar maple, and a boreal conifer/hardwood forest.

665. **Whited D, Galatowitsch S, Tester JR, Schik K, Lehtinen R, and Husveth J 2000. The Importance of Local and Regional Factors in Predicting Effective Conservation - Planning Strategies for Wetland Bird Communities in Agricultural and Urban Landscapes. *Landscape and Urban Planning* 49: 49-65.**

Keywords: Wetland Conservation/Land Use/Birds/Prairie Potholes/ Fragmentation/ northern hardwoods

Abstract: Wetland assessment techniques have generally focused on rapid evaluations of local and site impacts; however, wetland biodiversity is often influenced both by adjacent and regional land use. Forty wetlands were studied in the Red River Valley (RRV), Southwest Prairie (SWP), and the Northern Hardwood Forest (NHF) ecoregions of Minnesota, USA, to assess the strength of association between local and landscape condition and avian community composition. We examined the relationship between bird assemblages and local and landscape factors (connectedness, isolation, road density, and site impacts). Landscape variables were calculated for three spatial scales at 500 m (79 ha), 1000 m (314 ha), and 2500 m (1963 ha). Connectedness and road density are important measures for predicting bird assemblages in both agricultural ecoregions (SWP and RRV). Connectedness and its relationship with wetland bird assemblages were most pronounced at the larger scale (2500 m), where the largest remnant patches can be discerned. In contrast, road effects on bird assemblages were most pronounced at the smallest scale (500 m). Wetland isolation corresponded to bird community patterns as well, but only in one ecoregion (SWP). In the urbanizing ecoregion (NHF), species richness was considerably lower than elsewhere but community patterns did not correspond to landscape variables. The focus of wetland conservation planning needs to shift from the site scale to the landscape scale to ensure that connection with the regional wetland pattern is accounted for, therefore, affording the best opportunity to successfully maintain wetland avian diversity.

666. **Whitman AA, Hunter ML, and Witham JW 1998. Age Distribution of Ramets of a Forest Herb, Wild Sarsaparilla, *Aralia nudicaulis* (Araliaceae). *Canadian Field Naturalist* 112: 37-44.**

Keywords: wild sarsaparilla/*Aralia nudicaulis*/age distributions/recruitment/canopy disturbance/population structure/ vegetation/ demography/ seedlings/ biomass/ layer/ northern hardwoods

Abstract: We measured ages of *Aralia nudicaulis* (Wild Sarsaparilla) ramets and site variables in a northern hardwood forest to determine how their age distributions might be affected by local environment and forest canopy disturbances. We measured ages in ten populations and at random points on two 600 m transects. Age distributions at ten sites ranged from negative exponential to uniform. Sites with many young ramets were moist and had high light intensities, conditions that may promote the establishment of new clones and recruitment of new ramets. Sites with many older ramets were dry and had low light intensities, and thus probably have fewer resources with which clones could initiate ramets. The forest-wide age distribution was a negative exponential distribution and represented a composite of different sites each of which reflected local environmental conditions and disturbance histories. Ramet recruitment may increase following any forest canopy disturbance with the greatest response after logging and the smallest after gypsy moth outbreaks.

667. **Whitney GG 1987. An ecological history of the Great Lakes forest of Michigan. *Journal of Ecology* 75: 667-684.**

Keywords: history /forest inventories/vegetation /disturbance /logging

Abstract: Printed and manuscript materials and contemporary forest survey records were used to compare pre- and post-settlement species composition of a small segment (Crawford and Roscommon Counties, Michigan) of the Great Lakes forest, to consider the effects of past harvesting and management practices on the composition, structure and extent of the forest and to contrast the natural disturbance regime of the pre-settlement period with the selective logging of the late 19th century and the more intensive utilization practices of this century.

668. **Whitney GG 1986. Relation of Michigan's presettlement pine forests to substrate and disturbance history. *Ecology* 67: 1548-1559.**

Keywords: vegetation /history /synecology /soil /fires /vegetation types/soil physics/texture /coniferous forests/temperate zones/conifers /*Pinus strobus*/*Pinus banksiana*/*Pinus resinosa* /coarse soils /glacially-formed landscape

Abstract: Government Land Office Survey records of 2 counties were used to determine the composition and disturbance history of the pine forests of northern Lower Michigan. The abundance of pine (mainly *Pinus banksiana*, *P. resinosa* and *P. strobus*) in this area between lobes of the Wisconsin Laurentide ice sheet was correlated with the presence of coarse-textured soils derived from outwash and ice-contact deposits. These soils promoted a vegetation type that was extremely susceptible to fire.

669. **Williams PA and Gordon AM 1992. The potential of intercropping as an alternative land use system in temperate North America. *Agroforestry Systems* 19: 253-263.**

Keywords: Agroforestry /Agroforestry systems/land use/Intercropping /Temperate fruits/cropping systems

Abstract: A general discussion, using many examples from Ontario. The success of many intercropping systems in North America is attributable to the generation of a short-term return from an agricultural crop during the early, unprofitable years of a longer term crop that consists of fruit, nuts or wood. This highly efficient use of land and related profitability are important not only in the development of intercropping systems per se, but also in other applications which have tremendous potential independent of profitability. For example, intercropping can effectively be used during the establishment phases of broadleaved plantations and orchards where it is essential to have a high level of weed control; the costs are often recovered by the agricultural production. Intercropping can also be used in the rehabilitation of marginal land, and can provide an opportunity to integrate silvipasture into the later stages of plantation development. It can be used to grow trees rapidly and in a form that can be easily integrated into recreational or park situations, or urban fringe areas. In an urban context, intercropping can be used to grow trees in agricultural areas that are likely to be developed where traditional forestry options are not appropriate, and the value of younger, thrifty trees may enhance property values far in excess of the cash value of the wood.

670. **Willis GL, Bourdo EA, and Crowther CR 1975. Throughfall and stemflow in a northern hardwood forest. *Ford Forestry Center (Michigan Technological University) Research Note No. 16*, 12 pp.**

Keywords: hydrology /precipitation /throughfall /stemflow /*Acer saccharum*/northern hardwoods

Abstract: Throughfall was sampled beneath the crown of a 14.3 inch d.b.h. Sugar Maple [*Acer saccharum*] in Alberta, Canada, during the summers of 1957-61 and 1963. Stemflow was

measured by a spiral gutter placed around the stem near the base of the study tree and 2 other Sugar Maples of 11.3 and 9.1 inch d.b.h., respectively. Throughfall increased with increase in storm intensity and in distance from the trunk. Duration also affected throughfall, storms of high intensity and short to moderate duration resulting in greatest throughfall. Stemflow was negligible during rainfall of 0.3 inch or less, and increased geometrically during rainfall of 0.3 inch and greater, the smallest tree demonstrating the most rapid increase. Regression equations were developed which allow the prediction of the amount and rate of forest soil moisture recharge during the growth season from the official rainfall measurements taken in the open.

671. **Willis GL and Coffman MS 1975. Composition, structure, and dynamics of climax stands of Eastern Hemlock and Sugar Maple in the Huron Mountains, Michigan. Department of Forestry (Michigan Technological University) Technical Bulletin No. 13, 43 pp.**

Keywords: soil characteristics/ecology /stand structure/natural regeneration /vegetation types/
Acer saccharum/Tsuga canadensis

Abstract: Reports a study of the differences in structure and composition of 26 climax stands of Tsuga canadensis and/or Acer saccharum in the Huron Mountains, to determine how these stands perpetuate themselves. Four forest types were identified: mesic T. canadensis, mesic wet T. canadensis, A. saccharum/T. canadensis transition and A. saccharum. Each type displayed a unique association of tree and ground vegetation that is described in detail. Regeneration in each forest type is discussed. Differences in the soils supporting each forest type are also noted.

672. **Willis GL and Johnson JA 1978. Regeneration of yellow birch following selective cutting of old growth northern hardwoods. Ford Forestry Center (Michigan Technological University) Research Note No. 26, 13 pp.**

Keywords: natural regeneration /site preparation /scarification/broadleaves /Acer rubrum /Acer saccharum/Betula alleghaniensis/northern hardwoods

Abstract: Improvement fellings (at 3 rates, reducing av. b.a. from 147 ft² to 85-110 ft²) with/without scarification (root rake) were made in 1966/67 in experimental plots in an Acer saccharum/Betula alleghaniensis/A. rubrum-dominated forest in Michigan. Initially, B. alleghaniensis regeneration (in the 1-6 inch ht. class) was prolific, but by 1975 seedling numbers were low. Possible reasons are discussed for this poor regeneration; it was concluded that management for B. alleghaniensis regeneration may depend on simulation of conditions similar to those created by windthrown dominants.

673. **Wilson DM and Grigal DF 1995. Effects of pine plantations and adjacent deciduous forests on soil calcium. Soil Science Society of America Journal 59: 1755-1761.**

Keywords: plantations /calcium /soil characteristics /soil pH/deciduous forests/broadleaves /soil chemistry/Pinus resinosa /northern hardwoods

Abstract: Previous studies from the north-central USA have reported depletion of Ca in soil but increased amounts in the overstory of deciduous compared with coniferous forests, with total system Ca remaining constant. To determine if those reports were generalizable, 38 pairs of red pine (Pinus resinosa) plantations and adjacent deciduous stands were sampled across the area. Records indicated site similarity before plantation establishment. Neither the texture of the rooting zone (0-32 cm), nor the texture, pH, or Ca content of the 32- to 100-cm soil layer differed between forest types, further supporting site similarity. Stands were similar in biomass, but because of lags in plantation establishment, the deciduous stands were older (60 vs. 45 yr). The deciduous stands had a greater mass of Ca in the overstory and higher Ca concn in the 0- to 4-cm mineral soil layer. Both Ca concn and mass were greater in lower layers of the rooting zone (to 32 cm) under pine. Neither mass of Ca in the forest floor nor in mineral soil to 100 cm differed between types. Contrary to earlier reports, total system Ca was greater in deciduous stands. These results and

others from glaciated areas suggest that deeper soil layers provide minimal Ca to forest stands during a normal rotation. The initial quantity of Ca in the near-surface soil and the input-output balance determine Ca status of a site, but the role of deciduous forests in conserving the inputs requires further study.

674. **Wilson DW, Kucab JS, Meter JW, and Johnson JA 1982. Lumber recovery and board foot yield equations for northern hardwoods. Ford Forestry Center (Michigan Technological University) Research Note No. 30, 61 pp.**

Keywords: sawnwood /yield equations /sawmilling /log grade/Acer saccharum/Tilia americana/Ulmus americana/Betula alleghaniensis/northern hardwoods /wood products

Abstract: Yield equations for lumber grades by log grades were developed using lumber recovery data for sugar maple, yellow birch, American elm, basswood, red maple [respectively Acer saccharum, Betula alleghaniensis, Ulmus americana, Tilia americana and A. rubrum] and other hardwoods.

675. **Winsauer SA and Mattson JA 1992. Calculating competition in thinned northern hardwoods. U.S. For. Serv. Research Paper NC-306, 10 pp.**

Keywords: plant competition/measurement /thinning /northern hardwoods /second growth

Abstract: Competition index, area potentially available, crown release quotient and basal area in 1/20 acre were evaluated as methods for measuring plant competition in a 60-yr-old, second-growth northern hardwood stand in the western Upper Peninsula of Michigan.

676. **Wolter PT, Mladenoff DJ, Host GE, and Crow TR 1995. Improved forest classification in the northern Lake States using multi-temporal Landsat imagery. *Photogrammetric Engineering and Remote Sensing* 61: 1129-1143.**

Keywords: classification /vegetation types/remote sensing/Landsat /Acer saccharum/Larix laricina/Quercus rubra/Quercus ellipsoidalis /Fraxinus nigra/Populus tremuloides

Abstract: Forest classifications using single date Landsat Thematic Mapper (TM) data have been only moderately successful in separating forest cover types in the northern Lake States region. Few regional forest classifications have been presented that achieve genus or species level accuracy. A more specific forest cover classification was developed using TM data from early summer in conjunction with four multispectral scanner (MSS) dates to capture phenological changes of different tree species. Among the 22 forest types classified, multi-temporal image analysis aided in separating 13 types. Of greatest significance, trembling aspen (*Populus tremuloides*), sugar maple (*Acer saccharum*), northern red oak (*Quercus rubra*), northern pin oak (*Q. ellipsoidalis*), black ash (*Fraxinus nigra*), and tamarack (*Larix laricina*) were successfully classified. The overall classification accuracy was 83.2% and the forest classification accuracy was 80.1%. This approach may be useful for broad-scale forest cover monitoring in other areas, particularly where ancillary data layers are not available.

677. **Wood JE, von Althen FW, and Mitchell EG 1996. Crown release improves growth of 20-year-old *Betula alleghaniensis* in tolerant northern hardwood stands. *New Forests* 12: 87-99.**

Keywords: cleaning /improvement felling/release /competition /crown /increment /stems /stem form/epicormics /diameter /volume /growth /thinning /*Betula alleghaniensis*/northern hardwoods

Abstract: In winter 1987, 20-year-old overstocked (up to 8800 stems/ha) naturally regenerated yellow birch (*Betula alleghaniensis*) trees growing in clear-cut 20-m wide strips near Thessalon, Ontario, were thinned. Treatments consisted of either a control, or the removal of all competing trees located 1, 2, 3, or 4 m distance from the boles of selected crop trees. Sample crop trees were

measured in spring 1987, and in autumn 1991 (after 5 growing seasons). The size of the openings created around the crop tree crowns was found to be more strongly correlated to diameter, clear bole length, and crown increment than the removal of competing trees using fixed distance from the stem. Crop trees responded well to thinning. Five-year diameter increment and crown diameter growth were positively correlated to size of the opening created around the crop tree crown. However, the relationship between height growth and size of canopy opening was weak. Clear bole length was found to be negatively correlated to the size of canopy opening. Few epicormic sprouts developed on the stems when all competing trees were removed at 1, 2, or 3 m around the crop tree boles. However, release at 4 m greatly increased the number and size of epicormic sprouts. Providing about a 15-m² opening around the crop tree crown, corresponding to approximately a 3-m removal of competing trees around the bole, provided a good balance between diameter increment and stem quality maintenance. Such release treatments should be repeated at 10-yr intervals.

678. **Woods KD 2000. Dynamics in Late-Successional Hemlock-Hardwood Forests Over Three Decades. *Ecology* 81: 110-126.**

Keywords: *Acer saccharum*/*Betula alleghaniensis*/canopy dynamics/competition/soil pH/long-term studies/old-growth forest/permanent plots/succession/tree demography/*Tsuga canadensis*/term vegetation dynamics/presettlement forests/field measurements/catastrophic wind/*Tsuga canadensis*/growth/disturbance/*Tilia americana*

Abstract: Permanent plots in old-growth hemlock-northern hardwood forests of Michigan's upper peninsula have been remeasured over periods of 16-32 yr. A gradient from hemlock (*Tsuga canadensis*) to sugar maple (*Acer saccharum*) dominance is associated with increasing soil pH and calcium. Secondary species include yellow birch (*Betula alleghaniensis*) and basswood (*Tilia americana*). From 1962 to 1994 hemlock increased in basal area and dominance in most plots. Sugar maple showed little overall change, while basswood and especially yellow birch showed sporadic but often large declines in basal area. Birch populations declined due to lack of recruitment, and sugar maple and basswood may be subject to similar decline; only hemlock showed a fairly stable size structure. Mortality rates were lowest for hemlock (0.3%/yr) and highest for yellow birch (1.6%/yr), corresponding to canopy residence times of 357 and 61 yr, respectively. Stem maps allowed assessment of neighborhood influences on growth and mortality. Growth and mortality rates were negatively correlated for all species. Growth rate was influenced by tree size and site conditions for all species, but hemlock and sugar maple growth rates were also affected by size- and distance-weighted indices of neighbor influence. Old-growth stands several centuries old continue to undergo compositional change related to both stand history and current population interactions. Yellow birch and basswood are probably maintained by significant disturbances and will decline under a disturbance regime of small gaps. Hemlock may be the ultimate competitive dominant in most sites but may require well over a millennium without major disturbance to displace sugar maple.

679. **Woods KD 2000. Long-Term Change and Spatial Pattern in a Late-Successional Hemlock-Northern Hardwood Forest. *Journal of Ecology* 88: 267-282.**

Keywords: *Acer saccharum*/succession/*Fagus grandifolia*/permanent plots/*Tsuga canadensis*/presettlement forests/field measurements/replacement/history/*Tsuga* spp./beech/ age/ maintenance/*Fagus grandifolia*/*Betula alleghaniensis*/northern hardwoods

Abstract: 1 Tree populations were monitored for six decades on a grid of 140 permanent plots in old-growth mesic (hemlock-northern hardwood) forests in northern Michigan, USA. Multiple remeasurements allow assessment of stability of late- successional forests and analysis of spatial patterns and environmental linkages. 2 This forest is not compositionally stable. *Betula alleghaniensis* has declined with little regeneration, suggesting dependence on episodic canopy disruption for persistence. *Tsuga canadensis* and *Fagus grandifolia* have increased in dominance in all size classes independently of major disturbances. *Acer saccharum* populations have remained

little changed overall. Dynamics appear to be successional in nature, even though there has been no major disturbance for at least 400 years. Different areas in the stand may have experienced different histories. 3 *Fagus grandifolia* has invaded the stand recently through range expansion, and has come to dominate regeneration in some parts of the stand. 4 Canonical correspondence analysis suggests that soil texture, chemistry, and drainage influence successional dynamics, producing strong spatial pattern. *Fagus grandifolia* has invaded only on relatively fine-textured soils with impeded drainage. 5 Trends suggest that *Fagus*, *Tsuga*, and perhaps *Acer saccharum* would, in different parts of the stand, achieve near- total dominance in the absence of large-scale disturbance, but only after elapsed time of a millennium or more. Estimated return times for major disturbance in this region are of similar magnitude.

680. **Woods KD and Davis MB 1989. Palaeoecology of range limits: beech in the Upper Peninsula of Michigan. *Ecology* 70: 681-696.**

Keywords: palaeoecology /distribution /vegetation /history /pollen /*Fagus grandifolia* /history /succession

Abstract: Fossil pollen was used to map American beech (*Fagus grandifolia*) populations in Wisconsin and Michigan, USA, during the last 8000 yr, in order to examine the routes and rates of expansion of natural range and to attempt to determine the parameters of beech distribution. Pre-European settlement distributions were mapped from land survey records, and expansion was reconstructed using pollen diagrams from 34 sites mostly within a 30-50 km grid. The study showed a relatively stable, presumably environmentally-controlled distribution, with expansions 8000-5000 BP, 3000-2500 BP and during the last millennium.

681. **Work TT 1996. *The impacts of gypsy moth (Lepidoptera: Lymantridae) on native arthropod abundance species richness, and diversity in two hardwood ecosystems in northern Michigan (Lymantria dispar)*. MS thesis, Michigan State University, East Lansing. 196 pp.**

Keywords: *Quercus rubra*/northern hardwoods /insect diversity /*Lymantria dispar* /arthropods /*Carabini limbatus* /Noctuidae /leaf area index/diversity

Abstract: Insects play a critical role in many forest processes. However, little is known about the extent or importance of insect diversity within forests. Ecosystems dominated by red oak and northern hardwoods were surveyed between 1993 and 1995 to obtain baseline data on insect diversity and determine whether gypsy moth (*Lymantria dispar*), an exotic forest defoliator, impacted native arthropods. A method for quantifying effects of defoliation using canopy transmittance was also tested in both ecosystems and stands that experienced differing levels of defoliation. Estimating leaf area index through canopy transmittance was useful in quantifying effects of severe defoliation. Northern hardwood and red oak ecosystems differed in species composition, diversity and abundance of carabid beetles and lepidoptera but not in overall community structure of arthropods. Gypsy moth defoliation negatively impacted abundance of the carabid, *C. limbatus*, and species richness and diversity of lepidoptera, particularly overstory and oak-feeding Noctuidae.

682. **Work TT and McCullough DG 2000. Lepidopteran Communities in Two Forest Ecosystems During the First Gypsy Moth Outbreaks in Northern Michigan. *Environmental Entomology* 29: 884-900.**

Keywords: Gypsy Moth/Forest Insect Communities/Biological Diversity/Exotic Species Invasion/Ecological Classification/*Lymantria dispar* /*Bacillus thuringiensis*/Phytophagous Insects/Nitrogen Mineralization/Nontarget Lepidoptera/Folivorous Insects/Biological control/Overstory Biomass/Plant responses/northern hardwoods /*Quercus* spp.

Abstract: We assessed lepidopteran communities in replicated stands representing two hardwood forest ecosystems in northern Michigan during a 3-yr period that coincided with the first gypsy

moth outbreaks experienced by this area Adult Lepidoptera were collected at 4-wk intervals each summer in 1993-1995 in eight forest stands. Four stands were classified as ecological landtype phase (ELTP) 20, and they were dominated by oaks (*Quercus* spp.), a favored host of gypsy moth, *Lymantria dispar* (L.). The other four stands were classified as ELTP 45, and they were dominated by northern hardwood species with few preferred hosts of gypsy moth. Gypsy moth populations and defoliation fluctuated dramatically in ELTP 20 stands during the 3 yr, reaching outbreak levels in at least one year in all four stands. In ELTP 45 stands, gypsy moth populations and defoliation were minimal. More than 12,000 adult Lepidoptera representing 453 taxa were collected from the eight stands. Lepidopteran species composition differed significantly between ELTPs for species collected in early season months (May and June), but not for late season months (July and August). Within ELTP 45 stands, abundance and species richness of Lepidoptera were not affected by differences between years, stands, or the interaction of the two factors. In ELTP 20 stands, the interaction of stand and year affected overall lepidopteran abundance and diversity of late season species. Species composition of late season lepidopteran communities in ELTP 20 stands may have been affected by gypsy moth population fluctuations, although patterns were not consistent in all years. A subset of oak-feeding species appeared to be negatively affected during outbreak years, but other native Lepidoptera appeared to be resilient, perhaps reflecting the spatially and temporally limited duration of gypsy moth outbreaks.

683. **Work TT, McCullough DG, and Mattson WJ 1998. Moth and carabid beetle species associated with two ecological landtype phases in northern Michigan. U.S. For. Serv. General Technical Report NC-GTR-201, 25 pp.**

Keywords: forest pests/microclimate /ecology /predatory insects/agricultural entomology/*Acer saccharum*/*Quercus alba*/*Quercus rubra* /Lepidoptera/Tortricidae /Noctuidae /Lyonetiidae /Geometridae /Hydriomena spp. /Blepharomastix ranalis /Pandemis canadana /Proteoteras moffatiana /Stenolophus comma /Stenolophus ochropezus /Carabus goryi /Synuchus impunctatus /Bembidion partreule

Abstract: More than 12 300 moths and 2500 carabid beetles were trapped between 1993 and 1995 in 2 different ecological land type phases (ELTPs) in the Huron-Manistee National Forest in Michigan, USA. One ELTP (number 20) was dominated by northern red oak (*Quercus rubra*) and white oak (*Q. alba*), and the other (number 45) by sugar maple (*Acer saccharum*). Species were collected from the overstorey canopy, shrub stratum and the ground. The Tortricidae, Noctuidae, Lyonetiidae and Geometridae accounted for 77% of all Lepidoptera collected. Of the Lepidoptera, 89% were common to both ELTPs. *Hydriomena* sp. and *Blepharomastix ranalis* were the main species unique to ELTP 20, and *Pandemis canadana* and *Proteoteras moffatiana* were the main species unique to ELTP 45. Of the carabids collected, 93% were common to both ELTPs. The dominant species were *Stenolophus comma*, *S. ochropezus*, *Carabus goryi*, *Synuchus impunctatus* and *Bembidion partreule*. Twenty-one species were unique to ELTP 20 and 12 to ELTP 45. The total abundances of the 489 moth and 59 carabid species are reported. Differences in carabid fauna and Lepidoptera are related to differences in microclimate and vegetation characteristics, respectively.

684. **Yeakley JA, Moen RA, Breshears DD, and Nungesser MK 1994. Response of North American ecosystem models to multi-annual periodicities in temperature and precipitation. *Landscape Ecology* 9: 249-260.**

Keywords: forest ecology/model /boreal forests/climate /temperature /precipitation /grasslands /northern hardwoods

Abstract: Results are presented from a study made in four ecosystems: a boreal forest in Ontario, Canada; a transition forest from boreal to northern hardwoods in Minnesota, USA; an eastern deciduous hardwood forest in Tennessee, USA; and a shortgrass prairie in Colorado, USA.

685. **Yin Y, Nelson JC, and Lubinski KS 1997. Bottomland hardwood forests along the Upper Mississippi**

River. *Natural Areas Journal* 17: 164-173.

Keywords: floodplains /deforestation /river regulation/logging /riparian forests/vegetation types/bottomland forests/nature conservation /land use /restoration /history

Abstract: Bottomland hardwood forests along the Upper Mississippi River (the main stem from St. Anthony Falls, Minnesota, to Cairo, Illinois) have been drastically reduced in acreage and repeatedly logged during the nineteenth and twentieth centuries. Conversion to agricultural land, timber harvesting, and river modifications for flood prevention and for navigation were the primary factors that caused the changes. Navigation structures and flood-prevention levees have altered the fluvial geomorphic dynamics of the river and floodplain system. Restoration and maintenance of the diversity, productivity, and natural regeneration dynamics of the bottomland hardwood forests under the modified river environment represent a major management challenge. This paper describes the natural river, river modifications since 1824, forest community types, acreage and species composition in southern Minnesota and northern Iowa, Missouri and southwestern Illinois.

686. **Younger PD and Kapustka LA 1981. Acetylene reduction (N₂ fixation) by *Alnus rugosa* (DuRoi) Sprengel and the allelochemic effects of *Populus tremuloides* (Michx.) in the northern hardwood forest. *Ohio Journal of Science* 81: April Program Abstracts, 23.**

Keywords: allelopathy /nutrition /roots /nodules /nitrogen fixation/broadleaves /*Populus tremuloides* /*Alnus rugosa*/northern hardwoods

Abstract: Intact nodules of alder from (a) pure stands and (b) mixed alder/aspen stands in N. Wisconsin were assayed for N₂ fixation from May 29 to Aug. 12 1980. In (a) fixation rates/h increased from 24.55 μ g N/g dry wt. on June 12 to a max. of 73.89 on June 26, and declined to 9.20 by Aug. 12. In (b) rates declined from 22.12 on June 12 to 3.56 on June 24, and increased to a max. of 28.57 in the latter half of the summer. Overall, the data show a 56.4% decrease in N₂ fixation activity by alder when it occurs with aspen, although alder is suggested as a major N source in the community.

687. **Younger PD and Kapustka LA 1983. N₂(C₂H₂)ase activity by *Alnus incana* ssp. *Rugosa* (betulaceae) in the northern hardwood forest. *American Journal of Botany* 70: 30-39.**

Keywords: nitrogen fixation/Allelopathy /Roots /root nodules/*Populus* spp. /aspen /*Alnus rugosa* /alder/northern hardwoods

Abstract: Field assays of N₂(C₂H₂)ase activity were performed with intact nodules from a pure alder site (alder) and a mixed alder-aspen site (aspen). Assays were performed between 12 June and 12 August 1980 and in May 1981. N₂(C₂H₂)ase rates are expressed as g N g nodule oven-dry wt-1hr-1 (g N g-1hr-1). Diurnal N(C₂H₂)ase activity showed an increase in both sites between 0600 and midday, then decreased to a low by 1800. Nighttime activity in the May 1981 assay was approximately 25% of the daytime peak. Mean (\pm SE) 1200 hr N₂(C₂H₂)ase activity (μ g N g-1hr-1) for all sizes in the alder stand rose from 24.56 \pm 2.56 by August. In the aspen stand activity decreased from the 12 June rate of 21.81 \pm 4.59 to 3.64 \pm 1.87 on 24 July but then increased to 30.00 \pm 7.39 by 12 August. Based on diurnal assays, the seasonal mean N influx (μ g N g-1hr-1) is statistically higher (P less than 0.05) in the alder stand with a value of 26.70 compared to 14.63 in the aspen stand. Small size class shrubs had significantly higher (P less than 0.05) N₂(C₂H₂)ase activity (μ g N g-1hr-1) in diurnal assays than medium or large class shrubs. The estimated mean (\pm SE) N₂(C₂H₂)ase activity (mg N g-1season-1) for all sizes was 44.4 \pm 18.6 in the alder stand compared to 16.2 \pm 5.2 in the aspen stand. Nodule excavations showed the g shrub-1 in the alder stand to be 16.48 \pm 10.29, 38.57 \pm 12.34 and 29.11 \pm 7.15 for small, medium and large size shrubs and 12.73 \pm 3.23, 28.21 \pm 4.36 and 56.45 \pm 16.23 for respective sizes in the aspen stand. Seasonal N influx was 4.69 kg ha-1 in the alder stand and 0.84 kg ha-1 in the aspen stand, representing 17.9% of the alder stand. Nitrogen feedback inhibition from uric acid-N influx

and allelochemic interference from aspen are discussed as explanations for the differences in N influx in the two stands.

688. **Zak DR, Grigal DF, Gleeson S, and Tilman D 1990. Carbon and nitrogen cycling during old-field succession: constraints on plant and microbial biomass. *Biogeochemistry* 11: 111-129.**

Keywords: microbial biomass/chronosequences /cycling /carbon /nitrogen /broadleaves /carbon cycle/nitrogen cycle/plant succession/fields /soil chemistry/nitrification /nitrogen mineralization /soil organic matter/Soil biology/microorganisms /northern hardwoods /*Quercus* spp.

Abstract: Surface soil samples collected from fields and forests in Minnesota, USA, were analysed for total C, water soluble C, total N, potential net N mineralization and nitrification, and microbial biomass. Above- and belowground plant biomass was estimated within each of the old field sites. Regression analyses were used to correlate changes in C and N dynamics with old field age and data were fit to a linear function, simple exponential equation [$Y = a(1 - e^{-kt}) + C$] and a gamma function [$y = atbcrd + f$] in which t represented time in years. Potential N mineralization and nitrification increased linearly with field age; however, rates were variable among the fields. Microbial biomass was highly correlated with soil C and N and well correlated with the plant biomass. Plant biomass was highly correlated with pools and rates of N cycling. C and N cycling patterns within old field sites were different from those in a northern hardwood forest and a xeric old forest, but those within an oak savanna were similar to those in the 60-year old field.

689. **Zak DR, Groffman PM, Pregitzer KS, Christensen S, and Tiedje JM 1990. The vernal dam: plant-microbe competition for nitrogen in northern hardwood forests. *Ecology* 71: 651-656.**

Keywords: Broadleaves /Nitrogen cycle/nitrogen immobilization/microorganisms /*Acer saccharum*/*Tilia americana*/northern hardwoods /*Allium tricoccum* /*Osmorrhiza* spp.

Abstract: Nitrogen uptake by spring ephemeral communities has been proposed as a mechanism that retains N within northern broadleaf forests during the season of maximum loss. To test the importance of these plants in retaining N, the movement of $^{15}\text{NH}_4$ and $^{15}\text{NO}_3$ into plant and microbial biomass was measured in a sugar maple [*Acer saccharum*]/basswood [*Tilia americana*]/*Osmorrhiza* forest ecosystem in N. Lower Michigan, USA. The herb layer was predominantly *Allium tricoccum*. Two days following isotope addition, microbial biomass represented the largest labile pool of N, containing 8.5X as much N as *A. tricoccum* biomass. Microbial immobilization of ^{15}N was 10-20X greater than uptake by *A. tricoccum*. Nitrification of $^{15}\text{NH}_4$ was 5X lower in cores containing *A. tricoccum* compared to those without the spring ephemeral: therefore, spring N retention within these forests cannot be fully explained by plant uptake, because microbial immobilization represented a significantly larger sink for N. Plant and microbial uptake of NH_4 may have reduced the quantity of substrate available for nitrification, thereby reducing the potential for NO_3 loss via denitrification and leaching.

690. **Zak DR, Holmes WE, Macdonald NW, and Pregitzer KS 1999. Soil Temperature, Matric Potential, and the Kinetics of Microbial Respiration and Nitrogen Mineralization. *Soil Science Society of America Journal* 63: 575-584.**

Keywords: Net Nitrogen/Sulfur Mineralization/Pollution Gradient/Root Respiration/Carbon Balance/Water/Turnover/Storage/Dependence/northern hardwoods /soil temperature /soil moisture

Abstract: Soil temperature and matric potential influence the physiological activity of soil microorganisms. Changes in precipitation and temperature can alter microbial activity in soil, rates of organic matter decomposition, and ecosystem C storage. Our objective was to determine the combined influence of soil temperature and matric potential on the kinetics of microbial respiration and net N mineralization. To accomplish this, we collected surface soil (0-10 cm) from two northern hardwood forests in Michigan and incubated samples at a range of temperatures (5, 10, and 25 degrees C) and matric potentials (-0.01, -0.15, -0.30, -0.90 and -1.85 MPa) that

encompass field conditions. Soils were maintained at each temperature-matric potential combination over a 16-wk laboratory incubation, during which we periodically measured the production of CO₂ and inorganic N. First-order kinetic models described the accumulation of CO₂ and inorganic N and accounted for 96 to 99% of the variation in these processes. First-order rate constants (k) for net N mineralization significantly increased with temperature, but the k for microbial respiration did not increase in a consistent manner; it was 0.107 wk⁻¹ at 5 degrees C, 0.123 wk⁻¹ at 10 degrees C, and 0.101 wk⁻¹ at 25 degrees C. Matric potential did not significantly influence k for either process. Substrate pools for microbial respiration and net N mineralization declined between -0.01 and -0.30 MPa, and the decline was greatest at the highest soil temperature; this response produced a significant temperature-matric potential interaction. We conclude that high rates of microbial activity at warm soil temperatures (e.g., 25 degrees C) are limited by the diffusion of substrate to metabolically active cells. This limitation apparently lessens as physiological activity and substrate demand decline at relatively cooler soil temperature (e.g., 5 degrees C).

691. **Zak DR, Host GE, and Pregitzer KS 1989. Regional variability in nitrogen mineralization, nitrification, and overstorey biomass in northern Lower Michigan. *Canadian Journal of Forest Research* 19: 1521-1526.**

Keywords: Biomass /production /Vegetation types/temperate zones/Site class assessment/Soil chemistry/nitrogen mineralization /nitrification /forest soils/Soil types ecological

Abstract: Potential net nitrogen mineralization, potential net nitrification, and overstorey (bole and branch) biomass were measured in 9 forest ecosystems commonly found within the well-drained uplands of N. Lower Michigan, ranging from oak (*Quercus* spp.)-dominated forests on coarse-textured outwash sands to mesic forests on sandy glacial till. Overstorey biomass was calculated using species-specific allometric equations developed for Lake States broadleaves. Potential net N mineralization and potential net nitrification were measured by a 30-day aerobic laboratory soil incubation. Analyses of (co)variance were used to determine differences in potential N mineralization, net nitrification, overstorey biomass and biomass increment among the ecosystem types. Linear and nonlinear regression analyses were used to predict overstorey biomass and biomass increment using potential net N mineralization as the independent variable. Overstorey biomass ranged from 92 t/ha in a xeric oak ecosystem to 243 t/ha in a northern broadleaf ecosystem; annual biomass production ranged from 1.3 to 3.5 t/ha p.a., respectively. Potential net N mineralization was lowest in the xeric oak ecosystem (52.0 µg/g N) and greatest in the mesic northern broadleaved ecosystem (127.8 µg/g N). Potential net nitrification was 45.5 µg NO₃-N/g in the northern broadleaved ecosystem, 10 to 230X times greater than in other ecosystems. A saturating exponential model produced the smallest residual mean squares in predicting overstorey biomass (R² = 0.822) and annual biomass increment (R² = 0.847) from potential net N mineralization. Maximum overstorey biomass and biomass increment predicted from this equation were 247 t/ha and 3.7 t/ha, respectively. Laboratory net N mineralization potentials were strongly correlated with annual rates of N mineralization determined by in situ incubation (r² = 0.849). Overstorey biomass and woody biomass increment were poorly correlated with potential net nitrification. The exponential function used to predict biomass increment from N mineralization suggests that the productivity of some northern broadleaved forests in N. Lower Michigan is not limited by N availability.

692. **Zak DR, Pregitzer KS, and Host GE 1986. Landscape variation in nitrogen mineralization and nitrification. *Canadian Journal of Forest Research* 16: 1258-1263.**

Keywords: cycling /nitrogen mineralization/synecology /soil /topography /site factors/*Acer saccharum*/*Quercus rubra* /*Vaccinium*/*Tilia americana* /*Osmorrhiza* spp. /*Maianthemum* spp. /*Vaccinium* spp.

Abstract: Studies were made in 3 ecosystems widely distributed across northern lower Michigan to test the hypothesis that variation in N mineralization and nitrification is strongly related to the

spatial distribution of forest ecosystems. Vegetation data and soil and litter samples were collected from 4 randomly selected stands separated by at least 3 km within each ecosystem, viz. (1) sugar maple-basswood/Osmorhiza, (2) sugar maple-red oak/Maianthemum and (3) black oak-white oak/Vaccinium. Potential N mineralization and nitrification were determined by aerobic soil incubation. Litter was sorted by species, weighed and analysed for N concn. The ecosystems were quite distinct in ground flora composition, which showed a consistent pattern associated with characteristic physiography, soil and overstorey. Litter production, N returned to the forest floor and net mineralization were greater by a factor of 2 in ecosystem (1) and (2) compared with (3). Potential nitrification was 4X greater in (1) than in (2), respectively, species-rich and species-poor ecosystems. Nitrification was almost absent in (3). Results suggest that the relationship between species composition and N turnover can be extended across the landscape.

693. **Zak DR, Pregitzer KS, King JS, and Holmes WE 2000. Elevated Atmospheric CO₂, Fine Roots and the Response of Soil Microorganisms: a Review and Hypothesis. *New Phytologist* 147: 201-222.**

Keywords: Elevated Atmospheric CO₂/Soil Microorganisms/Fine-Root Longevity/Fine-Root Biochemistry/Soil Respiration/Microbial Activity/Microbial N Transformations/Carbon-Dioxide Enrichment/Northern Hardwood Forest/Microbial Biomass Carbon/Eucalyptus pilularis /Pinus banksiana /Ponderosa Pine/Alpine Grassland/N Availability/Nitrogen Mineralization/Perennial Ryegrass

Abstract: There is considerable uncertainty about how rates of soil carbon (C) and nitrogen (N) cycling will change as CO₂ accumulates in the Earth's atmosphere. We summarized data from 47 published reports on soil C and N cycling under elevated CO₂ in an attempt to generalize whether rates will increase, decrease, or not change. Our synthesis centres on changes in soil respiration, microbial respiration, microbial biomass, gross N mineralization, microbial immobilization and net N mineralization, because these pools and processes represent important control points for the below-ground flow of C and N. To determine whether differences in C allocation between plant life forms influence soil C and N cycling in a predictable manner, we summarized responses beneath graminoid, herbaceous and woody plants grown under ambient and elevated atmospheric CO₂. The below-ground pools and processes that we summarized are characterized by a high degree of variability (coefficient of variation 80-800%), making generalizations within and between plant life forms difficult. With few exceptions, rates of soil and microbial respiration were more rapid under elevated CO₂, indicating that (1) greater plant growth under elevated CO₂ enhanced the amount of C entering the soil, and (2) additional substrate was being metabolized by soil microorganisms. However, microbial biomass, gross N mineralization, microbial immobilization and net N mineralization are characterized by large increases and declines under elevated CO₂, contributing to a high degree of variability within and between plant life forms. From this analysis we conclude that there are insufficient data to predict how microbial activity and rates of soil C and N cycling will change as the atmospheric CO₂ concentration continues to rise. We argue that current gaps in our understanding of fine-root biology limit our ability to predict the response of soil microorganisms to rising atmospheric CO₂, and that understanding differences in fine-root longevity and biochemistry between plant species are necessary for developing a predictive model of soil C and N cycling under elevated CO₂.

694. **Zavitkovski J 1976. Ground vegetation biomass, production, and efficiency of energy utilization in some northern Wisconsin forest ecosystems. *Ecology* 57: 694-706.**

Keywords: understorey/ground vegetation/ionizing radiation/temperate zones/vegetation /Acer rubrum/Populus tremuloides/Betula papyrifera/northern hardwoods /above-ground biomass /root biomass

Abstract: Data are given for above-ground biomass, root biomass and solar radiation of the ground vegetation in aspen (*Populus tremuloides*), maple (*Acer rubrum*)/aspen/birch (*Betula papyrifera*), birch, northern hardwood and logging road communities within the Enterprise

Radiation Forest before the area was irradiated [see FA 38, 6491].

695. **Zeide B 1985. Tolerance and self-tolerance of trees. *Forest Ecology and Management* 13: 149-166.**

Keywords: woody plants/theory /stand characteristics/competition

Abstract: The fact that tolerant species survive better than intolerants in mixed stands does not mean that, in pure stands, tolerants suffer less mortality than intolerants. Tolerance (interspecific competition) is not necessarily associated with self-tolerance, which can be defined as the ability of trees to survive and grow under the stress of intraspecific competition. The relative rate of volume growth with respect to the decrease in the number of trees can be used as a measure of self-tolerance. A positive correlation was not found between this measure and tolerance of southern pines as determined by tolerance tables. It is concluded that self-tolerance is a quality of stands and is independent of tolerance.

696. **Zhou MY and Sharik TL 1997. Ectomycorrhizal associations of northern red oak (*Quercus rubra*) seedlings along an environmental gradient. *Canadian Journal of Forest Research* 27: 1705-1713.**

Keywords: seedlings /canopy /seedling growth/ectomycorrhizae /mycorrhizae /solar radiation/ light intensity/nitrogen /mineralization /environmental factors/soil water content/ soils/ symbiosis / model/*Quercus rubra*/*Pinus resinosa*

Abstract: Ectomycorrhizas (ECM) of *Quercus rubra* seedlings were studied along an environmental gradient in oak and pine (*Pinus resinosa*) forests in northern Lower Michigan. The gradient was created by retaining canopy cover at 0%, 25% (50% in first year), and 75%, as well as uncut controls. All treatments were initiated in late summer/early autumn 1990. Acorns were sown on grids on each plot and seedlings were excavated during the growing seasons of 1991 and 1992. ECM development, seedling growth, and resource levels were analysed against the gradient of percent canopy cover. ECM development (percent ECM and total number of ECM tallied per seedling), seedling development (total biomass, stem diameter, shoot and root mass), and resources (photosynthetically active radiation (PAR), volumetric soil moisture (moisture), and nitrogen mineralization (N)) showed a quadratic, negative exponential, and negative linear relationship, respectively, with percent canopy cover. The best development of ECM was observed at 38% canopy cover, where N was 31-43 kg/ha per season (May-September), moisture was 12-18%, and photosynthetically active radiation was 48-56% of open sky conditions. Four general conceptual models of ECM relationships were hypothesized. 'Fungal parasitism' defines the low end of the percent canopy cover gradient and 'plant parasitism' defines the high end. 'True symbiosis' exists somewhere between the extremes. These models provide a conceptual framework for understanding ECM relationships in the context of ecosystem dynamics and a practical guide for oak regeneration management in forestry.

697. **Zhou MY, Sharik TL, Jurgensen MF, and Richter DL 1997. Ectomycorrhizal colonization of *Quercus rubra* seedlings in response to vegetation removals in oak and pine stands. *Forest Ecology and Management* 93: 91-99.**

Keywords: ectomycorrhizas /mycorrhizal fungi/colonization /seedlings /vegetation /removal /understorey /clear felling/felling /roots /canopy gaps/canopy /density /weed control/ground vegetation/vegetation management/mycorrhizas /silviculture /*Acer rubrum*/*Quercus rubra*/*Pinus resinosa* /*Pteridium aquilinum*

Abstract: Ectomycorrhizal (ECM) colonization of northern red oak (*Quercus rubra*) seedlings in response to different degrees of overstorey and understorey removal was investigated in *Q. rubra* and red pine (*Pinus resinosa*) stands in northern Lower Michigan. The experimental design consisted of 2 stand types (oak and pine), 3 blocks nested within stand type, 4 levels of canopy cover (clear felled, 25% (50% first year), 75%, and uncut), and 2 understorey treatments (removal

of vegetation \approx 25 cm tall (mainly *Pteridium aquilinum* and *Acer rubrum* saplings) and untreated control). *Q. rubra* acorns from a common seed source were sown in the spring of 1991 and the emerged seedlings were sampled to quantify their ECM during the first 2 growing seasons. Photosynthetically active radiation (PAR) transmittance was recorded during the second growing season. Soil moisture and temperature were also measured at 2-3 wk intervals for the first 2 yr. ECM colonization was significantly greater in the 50% canopy cover treatment (37.5%) than in the clear felled (22.3%) and uncut (20.8%) treatments during the first growing season. In contrast, during the second growing season, ECM in the 25% canopy cover treatment (45.8%) was significantly greater than in the clear felled treatment (20.4%), but did not differ from the 75% cover (40.4%) and uncut (37.6%) treatments. ECM number per gram dry root was also significantly larger in the 25% canopy cover treatment (4595) than in the clear felled treatment (2588). Significantly more ECM (number per 3 lateral roots) were found in the untreated understorey of the pine stand type (121) in comparison with the shrub-removal treatments (103 and 107 for oak and pine stands, respectively) and untreated understorey of the oak stand type (104) during the second growing season. The results indicated that intermediate canopy levels stimulated the development of ECM, whereas complete removal of overstorey and understorey reduced such development. These results may aid forest managers in manipulating the field mycorrhizal condition of oak seedlings through silvicultural practices.

698. **Zillgitt WM and Eyre FH 1945. Perpetuation of Yellow Birch in Lake States forests. *Journal of Forestry* 43: 658-661.**

Keywords: *Betula alleghaniensis*/natural regeneration/stand composition /logging impacts/microclimate /*Acer saccharum*/northern hardwoods/old-growth

Abstract: In order to determine the effect of kind and degree of cutting in old-growth northern hardwoods on the proportion of Yellow Birch (*Betula lutea* [alleghaniensis]) present in the young growth, a series of reproduction tallies was made in 1944 on 5 areas at the Upper Peninsula Experimental Forest, Dukes, Marquette County, Michigan, cut over in 1927 and 1928. The results of the enquiry show that, following ordinary commercial clear cutting, Yellow Birch maintains itself in the second-growth forest in about the same proportion as in the original stand. Light selection cuttings where an even canopy is maintained are unsuited to Yellow Birch regeneration, since this species cannot compete under shade with more tolerant species, especially Sugar Maple. Moderate selection cuttings with openings resulting from the removal of small groups of poor-risk trees without regard to seed trees, are also unsuccessful in this respect. Yellow Birch may be established successfully in Lake States stands if light partial cutting is practised by employing, a group selection method in which openings up to 0.1 acre in size are created within seeding distance of seed trees.

699. **Zogg GP, Zak DR, Burton AJ, and Pregitzer KS 1996. Fine root respiration in northern hardwood forests in relation to temperature and nitrogen availability. *Tree Physiology* 16: 719-725.**

Keywords: temperature /respiration /nitrogen /availability /plant nutrition/nitrogen fertilizers/ammonium nitrogen/nitrate nitrogen/nutrition /roots /vegetation types/*Acer saccharum*/northern hardwoods

Abstract: Fine-root (<2.0 mm diameter) respiration was examined throughout one growing season in four northern hardwood stands in Michigan, dominated by sugar maple (*Acer saccharum*), located along soil temperature and nitrogen (N) availability gradients. In each stand, three 50 X 50 m plots were fertilized with 30 kg NO₃-N ha⁻¹ year⁻¹ and an additional three plots received no N and served as controls. It was predicted that root respiration rates would increase with increasing soil temperature and N availability. It was hypothesized that respiration would be greater for trees using NO₃- as an N source than for trees using NH₄⁺ as an N source because of the greater carbon (C) costs associated with NO₃- versus NH₄⁺ uptake and assimilation. Within stands, seasonal patterns of fine-root respiration rates followed temporal changes in soil temperature, ranging from a low of 2.1 μ mol O₂ kg⁻¹ s⁻¹ at 6°C to a high of 7.0

$\mu\text{mol O}_2 \text{ kg}^{-1} \text{ s}^{-1}$ at 18°C . Differences in respiration rates among stands at a given soil temperature were related to variability in total net N mineralized ($48\text{-}90 \mu\text{g N g}^{-1}$) throughout the growing season and associated changes in mean root tissue N concentration ($1.18\text{-}1.36 \text{ mol N kg}^{-1}$). The hypothesized increases in respiration in response to NO_3^- fertilization were not observed. The best-fit model describing patterns within and among stands had root respiration rates increasing exponentially with soil temperature and increasing linearly with increasing tissue N concentration. It is concluded that, in northern hardwood forests dominated by sugar maple, root respiration is responsive to changes in both soil temperature and N availability, and that both factors should be considered in models of forest C dynamics.

700. **Zogg GP, Zak DR, Pregitzer KS, and Burton AJ 2000. Microbial Immobilization and the Retention of Anthropogenic Nitrate in a Northern Hardwood Forest. *Ecology* 81: 1858-1866.**

Keywords: Nitrate mobility/Microbial Immobilization/Nitrate/Anthropogenic/Nitrate Retention and Microbial Pathways/Nitrogen Deposition/Nitrogen Saturation/Plant and Microbial Competition for Nitrogen/Sugar Maple /*Acer saccharum*/Air-Pollution Gradient/Nitrogen Saturation/N-Deposition/N-15 Tracer/Soil/northern hardwoods

Abstract: To determine the importance of microorganisms in regulating the retention of anthropogenic NO_3^- , we followed the belowground fate and flow of $(\text{NO}_3^-)\text{-N-15}$ in a mature northern hardwood forest dominated by *Acer saccharum* Marsh. Total recovery of added N-15 (29.5 mg N-15/m^2) as NaNO_3 in inorganic N, microbial immobilization in forest floor and soil microbial biomass, soil organic matter, and root biomass pools (0-10 cm depth) was 93% two hours following application of the $(\text{NO}_3^-)\text{-N-15}$ but rapidly dropped to similar to 29% within one month, presumably due to movement of the isotope into other plant tissues or deeper into soil. Microbial immobilization was initially (i.e., at 2 h) the largest sink for $(\text{NO}_3^-)\text{-N-15}$ (21% in forest floor; 16% in soil microbial biomass). After one month, total N-15 recovery varied little (24-18%) throughout the remainder of the growing season, suggesting that the major N transfers among pools occurred relatively rapidly. At the end of the four-month experiment, the main fates of the N-15 label were in soil organic matter (7%), root biomass (6%), and N immobilized in forest floor and soil microbial biomass (6%). Temporal changes in the N-15 enrichment (atom % excess N-15) of plant and soil pools during the first month of the experiment indicated the dynamic nature of NO_3^- cycling in this Forest. The N-15 enrichment of soil microbial biomass and the forest floor significantly increased two hours after isotope additions, suggesting rapid microbial immobilization of NO_3^- . In contrast, the N-15 enrichment of soil organic matter did not peak until day 1, presumably because much of the added N-15 cycled through microorganisms before becoming stabilized in soil organic matter, or it directly entered soil organic matter via physical processes. Furthermore, the N-15 enrichment of root biomass (<0.5-mm diameter and 0.5-2.0 mm diameter) was greatest between day 7 and day 28, following significant increases in the N-15 enrichment of soil organic matter (day 1) and, more importantly, NH_4^+ (day 2). From these data we conclude that microorganisms are immediate short-term sinks for anthropogenic NO_3^- . Although the long-term fate of NO_3^- additions to this forest is likely in soil organic matter and plants, the cycling of N through microorganisms appears to be the major short-term factor influencing patterns of NO_3^- retention in this ecosystem.

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