PHYTOSOCIOLOGY, BIOMASS, PRODUCTIVITY, AND NUTRIENT BUDGET FOR THE TREE STRATUM OF A SOUTHERN NEW JERSEY HARDWOOD SWAMP

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ABSTRACT

Intensive biomass studies were performed for red maple (Acer rubrum), tupelo (Nyssa sylvatica), and sweetbay magnolia (Magnolia virginiana) trees growing on a 1.0 ha. hardwood swamp site located within the New Jersey Pine Barrens. Several trees 2.5-23.5 cm. dbh were cut and measured for stem, branch, and leaf dry weight. Estimates of community biomass were derived by combining biomass data for the three species with a vegetation inventory of the hardwood site. Analysis of various tree tissues for macro- and micronutrients was performed and used to construct a mineral budget for the three tree species growing on the hardwood site.

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The availability of water or nutrients can be and often is a limiting factor affecting the growth of individual forest tree species and the productivity of forest ecosystems as a whole. "Mineral cycling in forests, is, therefore, an important parameter affecting productivity" (Duvigneaud and Denaeyer-DeSmet 1970). Knowledge of which nutrients may be limiting in terms of forest productivity, could therefore, be an extremely valuable piece of information for assisting in increasing the growth of low productivity forests or in speeding the rate of growth for more productive forests. Such efforts aimed at increasing forest productivity, involving the application of forest fertilization techniques, should be expected to increase in intensity and importance as we approach the end of the twentieth century, and our virgin timber supply begins to dwindle.

Despite the obvious advantages which might be expected to result from understanding the cycling of minerals in North American forest ecosystems, very few of these forest communities are fully appreciated in terms of biomass, productivity, or mineral cycling. Limited numbers of investigations on only a few forest ecosystems within the United States have been undertaken, and many of these only within the past few years (Art and Marks 1971; Grier and Logan 1977; Harris et al. 1973; Howell et al. 1977; Madgwick 1970; Ovington et al. 1968; Schlesinger 1978; Sollins and Anderson 1971; Whittaker et al. 1974; and Whittaker and Woodwell 1968).

Studies relating to biomass and mineral cycling in southern hardwood and coniferous species characteristic of southern New Jersey swamp ecosystems are nonexistant. If these tree species were restricted in range to only southern New Jersey Pine Barrens swamps, this lack of knowledge might not be too serious. However, these tree species occur prominently throughout at least 60% of New Jersey's land mass, and more importantly, are characteristic of forested swamp ecosystems occurring throughout the southeastern United States.

Objectives of this paper, therefore, are to present information for a New Jersey Pine Barrens hardwood swamp pertaining to (1) community structure, (2) individual tree and whole forest biomass characteristics, and (3) the amounts of nutrients bound-up in individual tree tissues and in various tree populations of the forest as a whole.

EXPERIMENTAL

Site Description

The study site reported on in this paper is located in the Outer Coastal Plain of New Jersey (Robichaud and Buell 1973), within Atlantic County, and is a part of the Ecological Preserve located on the Richard Stockton State College campus. Stockton College is located 24 km. northwest of Atlantic City in the region known as the 'New Jersey Pine Barrens'. The study site, which is 1.02 ha. in size, is located at the south end of Cedick Run, and is part of a larger streambed swamp ecosystem approximately 2.0 km. in length. Cedick Run is an intermittently flowing stream which drains this watershed ecosystem by flowing northward into a man-made cranberry bog known as Lake Fred. Approximately 1.0 km. to the north of the hardwood swamp, along Cedick Run, is a large old Atlantic white cedar (*Chamaecyparis thyoides*) swamp. The cedars extend northward to the mouth of Lake Fred, and have constituted a second study site for investigations similar to those reported on in this paper (Reynolds et al. 1978a).

Dominant shrub species for the hardwood swamp include pepperbush (*Clethra alnifolia*) and highbush blueberry (*Vaccinium corymbosum*). The densities of both are very great. Important herbaceous species include marsh (*Dryopteris thelypteris*) and bracken (*Pteridium aquilinum*) ferns. In addition, cat-brier (*Smilax glauca*) is prominent. Scattered species include American holly (*Ilex opaca*), sweetgum (*Liquidambar styraciflua*) and gray birch (*Betula populifolia*). The swamp, which is approximately 60-70 meters wide, is flanked on either side of the streambed on the uplands by oak-pine or pine-oak forests consisting of pitch pine (*Pinus rigida*), white oak (*Quercus alba*), red oak (*Q. borealis*), black oak (*Q. velutina*), scarlet oak (*Q. coccinea*), post oak (*Q. stellata*), and blackjack oak (*Q. marilandica*).

Forest Inventory Data

Permanent 10 x 10 meter plots, marked with metal stakes, were established for the hardwood study site. The overall plot system was carefully laid out in order to closely approximate changing boundaries of the swamp vegetation in reference to the upland forest vegetation. A total of 102 plots (1.02 ha.) were installed. Following the establishment of the plot system, the diameters of all trees growing within each of the individual plots were determined and recorded. DBH's of all trees found were used in conjunction with weight regression equations for projecting stem, branch, or leaf biomass.

Biomass Estimation Procedures

The development of regression equations for predicting weight biomass was coupled with the intensive vegetation inventory described above. A total of 20 trees were cut and measured for a number of parameters. All trees were separated into their individual branch, stem, and leaf components. These were transported to the lab and placed in large drying ovens monitored with moisture meters. Dried tissues were subsequently weighed, and this information was used in developing $\log_{10}$ dbh-$\log_{10}$ dry weight linear regressions. Regression coefficients were used for predicting stem, branch, and leaf weights for those trees inventoried as described above.

Estimates of Productivity

In order to determine estimates of productivity for each of the three tree species, radial increment studies were performed using sanded stem discs for each of the species. All trees were aged, and annual biomass productivity was estimated by using these ages in conjunction with stem dry weight projections for the same trees.

Tissue Mineral Analysis Procedures

Leaf, branch, and stem samples for each of the three tree species were collected, ashed, and extracted using 0.1 N nitric acid in accordance with established procedures (Likens and Bormann 1970). All solutions were analyzed for Ca, Mg, K, Na, Fe, Mn, and Zn using a model 306 Perkin-Elmer digital atomic absorption spectrophotometer equipped with a recorder output. Ca and Mg were read in the presence of lanthanum and Na and K were read using emission techniques. All other elements were measured using absorbance methods.

N and P were determined by performing standard Kjeldahl extractions on each of the tissues. All samples were read on a Technicon Autoanalyzer II set up to read N and P content of each sample simultaneously.

RESULTS

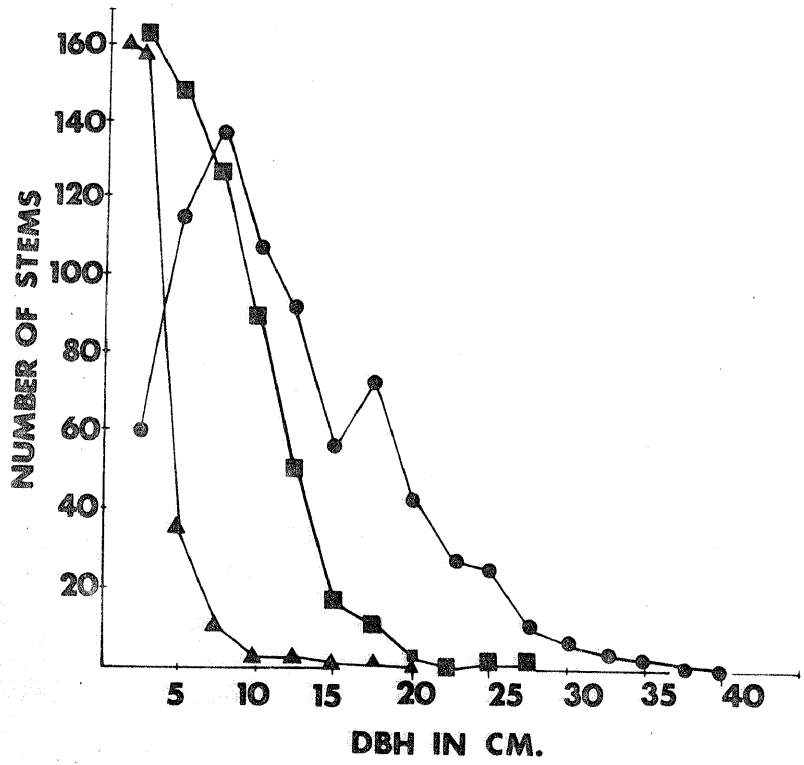
Community Structure and Phytosociology

Red maple is the dominant tree species present in the hardwood swamp in terms of population density, frequency, and basal area. Tupelo is the codominant tree species having the second greatest density and basal area. Sweetbay magnolia is co-codominant. This species and tupelo have approximately equal frequencies, but their spatial distributions are quite different. The tupelos occur on the drier edges of the swamp, whereas the magnolias and large maples occur primarily in the center of the swamp. The magnolias appear to be replacing many of the older maples which are dying.

Red maple has a stand density of 756 stems/ha. and a basal area of 11.85 M^2/ha. A few trees range up to 40.6 cm. diameter, although most are under 30.5 cm. and are not more than 16.9 meters tall (Figure 1). These trees range in age (87 years for a 20.3 cm. tree, 119 years for a 30.5 cm. tree, and 148 years for a 40.6 cm. tree). Red maple trees occur in 88% of the study plots. Codominant tupelo trees occur in about two-thirds of the study plots, have a density of 511 stems/ha., and a combined basal area of 3.17 M^2/ha. Most of these trees range up to 15.2 cm. diameter, are less than 14.7 meters tall, and are between 50-70 years old. The co-codominant magnolia trees also occur in about two-thirds of the study plots, have a density of 361 stems/ha., and a combined basal area of 0.41 M^2/ha. Most of these trees range up to 7.6 cm. dbh, are less than 13.2 meters tall, and are between 16-82 years old.

Individual Tree Biomass and Productivity

Total above-ground biomass for individual trees cut, and representative of the three species ranged from 222.3 to 1,112.8 kg. for maple (7.1 to 23.5 cm. dbh), from 7.1 to 114.3 kg. for tupelo (5.6 to 16.8 cm. dbh), and from 5.5 to 452.7 kg. for magnolia (2.5 to 19.3 cm. dbh). Computations of productivity based upon dividing individual tree stem weights by individual tree ages, indicate that mean annual productivity for the three species ranges from 1.06 to 5.6 kg./yr. Maple is the most productive, and tupelo is the least productive. Magnolia is intermediate at 2.1 kg./yr.



Population structure of the hardwood swamp. Numbers of red maple (●), tupelo (■), and sweetbay magnolia (▲) stems, broken down according to diameter class, are shown.

Community Biomass Characteristics

Regression coefficients used for predicting stem, branch, or leaf biomass for each of the three tree species are presented in Table 1. Estimates of community weight for this hardwood swamp forest are 253,823 kg./ha. for red maple stems (trunks); 40,268 kg./ha. for maple branches; and 1,444 kg./ha. for maple leaves. Total stem, branch, and leaf biomass values for all tupelo trees growing in the swamp are 10,418; 2,387; and 582 kg./ha. Values for magnolia are 6,477; 628; and 77 kg./ha.

Tissue Mineral Contents

Large individual differences among the three species for elemental accumulation exist (Table 2). Concentrations of N, P, Mg, and K were highest in the leaves, and lowest in the stems. Concentrations of these elements were intermediate for the branches. A reverse pattern of accumulation occurred for Mn and Zn. Concentrations of these elements were generally lowest in the leaves, highest in the stems, and intermediate in the branches. As an exception to the rule, high levels of Mn (81.7 ppm/gm.) were found to accumulate in magnolia branches. For the elements Fe and Na, no clear patterns of tissue accumulation occurred. Concentrations of Ca were generally highest in the branches. Of all the elements measured, N concentrations were highest. For the five macronutrients studied, concentrations of P were lowest. For the micronutrients Fe, Mn, and Zn, tissue concentrations were lowest for Zn and greatest for Mn.

Individual Tree and Community Mineral Biomass

Estimates of mineral content for individual red maple, tupelo, and magnolia trees of differing diameters are presented in Table 3. An examination of magnolia values for the five macronutrients shows that total amounts of N are highest and total amounts of P are lowest. For red maple, total amounts of Ca are highest and total amounts of Mg are lowest. For tupelo, total amounts of Ca are highest and total amounts of P are lowest. With regard to the three micronutrients, total amounts of Mn are highest and total amounts of Zn are lowest for all three tree species. The three most abundant elements found in all tree species tissues are N, Ca, and K.

Information pertaining to community mineral biomass for the tree stratum is presented in Table 4. It should be noted that Fe, Mn, Zn, and Na biomass for all magnolia tissues added together exceeds that for all tupelo tissues added together. In addition, N and K biomass for magnolia stems exceeds that for tupelo stems.

TABLE 1

Regression coefficients used to estimate above-ground standing biomass. The equations are of the form Y = A + BX, with Y = Log 10 oven dry weight and X = Log 10 d.b.h. in cm.

TISSUE	A	B	R
		Red Maple	
stem	-0.2375	2.3151	0.988
branch	0.2294	1.3100	0.763
leaf	-1.9475	1.8989	0.952
		Tupelo	
stem	-1.3806	2.7279	0.999
branch	-1.1225	1.8908	0.993
leaf	-1.7257	1.8819	0.999
		Sweetbay Magnolia	
stem	-0.1089	2.1340	0.999
branch	-1.8652	2.8795	0.961
leaf	-1.1202	0.9180	0.970

TABLE 2

Tissue mineral content (ppm/gm) for each of the three tree species occurring in the hardwood swamp.

TISSUE	N	K	Ca	Mg	P	Na	Mn	Fe	Zn
				Red Maple					
stem	1,680	978.0	2,469.5	199.4	220	41.3	21.2	18.8	4.0
branch	7,400	2,355.2	3,960.6	313.7	580	26.9	20.4	8.1	3.2
leaf	18,340	6,574.9	2,604.8	795.4	1,050	41.1	3.3	9.1	7.4
				Tupelo					
stem	1,380	737.8	3,488.0	549.0	220	28.9	17.6	8.0	4.0
branch	2,920	2,556.9	3,591.1	626.9	300	11.9	5.1	6.8	3.2
leaf	19,300	8,297.4	964.1	1,368.7	1,010	67.3	2.0	10.6	0.99
				Sweetbay Magnolia					
stem	4,130	1,594.8	1,686.9	472.3	300	89.3	41.8	16.0	9.2
branch	5,430	1,967.9	2,763.0	681.5	390	33.2	81.7	9.6	8.3
leaf	19,070	6,693.0	2,255.1	903.5	901	58.7	4.5	9.3	0.7

TABLE 3

Mineral content (grams) of above-ground biomass (stem + branch + leaf) for individual red maple, tupelo, and magnolia trees of differing diameter.

TREE SIZE	N	K	Ca	Mg	P	Na	Mn	Fe	Zn
				Red Maple					
10.2 cm.	484.0	209.3	446.9	36.4	48.6	6.1	3.3	2.6	0.61
20.3 cm.	1,747.4	833.5	1,883.0	153.4	190.6	28.0	14.9	12.3	2.8
30.5 cm.	3,890.8	1,943.1	4,509.4	367.3	441.4	69.5	36.4	31.0	6.8
				Tupelo					
10.2 cm.	77.8	44.6	102.9	18.4	8.4	0.83	0.43	0.24	0.11
20.3 cm.	383.5	215.9	624.9	106.4	46.2	5.1	2.8	1.4	0.7
				Sweetbay Magnolia					
10.2 cm.	530.1	202.8	219.0	60.5	38.2	10.3	5.5	1.9	1.1

TABLE 4

Mineral budget (kg./ha.) for each of the three tree species occurring in the hardwood swamp.

TISSUE	N	K	Ca	Mg	P	Na	Mn	Fe	Zn
					Red Maple				
stem	426.4	248.2	626.8	50.6	56.0	10.5	5.4	4.8	1.01
branch	298.0	94.8	159.5	12.6	23.0	1.1	0.82	0.33	0.13
leaf	26.0	9.5	3.8	1.15	1.5	0.059	0.005	0.013	0.011
					Tupelo				
stem	14.4	7.7	36.3	5.7	2.3	0.3	0.183	0.083	0.042
branch	7.0	6.1	8.6	1.5	0.7	0.028	0.012	0.016	0.008
leaf	11.2	4.8	0.56	0.8	0.59	0.039	0.001	0.006	0.0006
					Sweetbay Magnolia				
stem	27.0	10.3	10.9	3.06	1.9	0.58	0.27	0.103	0.06
branch	3.4	1.24	1.74	0.43	0.24	0.021	0.051	0.006	0.005
leaf	1.5	0.52	0.17	0.069	0.069	0.0045	0.00035	0.0007	0.000054

DISCUSSION

Community biomass for the hardwood swamp may be compared with biomass data for two other southern New Jersey lowland forests currently being studied (Reynolds et al. 1978b and c). These include the Atlantic white cedar swamp mentioned in the site description portion of this paper and an American holly swamp, located approximately 12 km. from the hardwood swamp at the Brigantine National Wildlife Refuge. The three swamp ecosystems vary widely in community biomass. However, the largest biomass for the three swamps occurs in the hardwood swamp. Although the density of cedars in the cedar swamp is nearly three times that of the maples in the hardwood swamp, the total above-ground biomass for all the cedars is only about 62% of that for all the maples in the hardwood swamp. For the hardwood and cedar swamps, red maple and cedar are dominant by virtue of biomass as well as density, frequency, and basal area. For the holly swamp, holly is dominant by virtue of density, frequency, and basal area, but is far from being dominant in terms of biomass. The codominant tree species, red maple, by virtue of basal area, is also the most dominant species in terms of total above-ground biomass. Compared with the present hardwood swamp, the total above-ground biomass for maple within the holly swamp amounts to only 56% of that for red maple in the hardwood swamp.

Individual tree biomass and productivity for maple, tupelo, and magnolia trees growing in the hardwood swamp may be compared with that for cedar and holly growing at the other two southern New Jersey lowland swamp sites. Compared with maple, tupelo, and magnolia, these species were determined to have mean annual stem productivity values of 0.44 kg./yr. for holly and 2.56 kg./yr. for cedar. Thus, when all five species are compared with regard to stem weight productivity, holly is least productive, maple is most productive, and magnolia is intermediate. Cedar is the second most productive species, and tupelo is the second least productive species.

Mineral biomass characteristics for the hardwood swamp may be compared with findings of previous researchers for other types of forest ecosystems or with similar results for the cedar or holly swamps. As reported upon in this study, high levels of Mn were found to accumulate in magnolia branches. Comparable accumulations of micronutrients in the tissues of other lowland swamp species have been observed (Reynolds et al. 1978b and c). Some of these include the accumulation of high levels of Zn in holly stems and of high levels of Fe in cedar dead branches. Accumulation of micronutrients in the tissues of these lowland swamp tree species is in good agreement with the findings of earlier investigators for other tree species (Fortescue and Marten 1970). Likens and Bormann (1970) reported high levels of Mn in the current twigs of several tree species at the Hubbard Brook Experimental Forest. These investigators also reported high concentrations of Zn in all tissues of yellow birch. Both Likens and Bormann and Safford and Young (1968) have observed high levels of Fe in the branches and current twigs of red spruce.

In the present study, concentrations of Mn and Zn were greatest in the stem tissues of the various swamp species, and least in the leaf tissues. Similar results were observed for these species growing at the other two swamps described above, and were also noted for holly, as has been partially noted already. Cedar trees growing on the Stockton campus showed the opposite trend, whereas cedar trees growing at the Wildlife Refuge behaved in a manner similar to maple, tupelo, magnolia, and holly. For the tree species at Hubbard Brook, Likens and Bormann observed that concentrations of these elements were generally greatest in leaves and least in stems. These differences in pattern between Hubbard Brook and southern New Jersey may be accountable in terms of soil differences, and warrant closer attention.

In addition to the various micronutrient accumulation patterns discussed above, relatively high levels of Na (89.3 ppm/gm.) were observed in magnolia stems when compared with other magnolia tissues or with red maple or tupelo tissues. Higher levels of Na have been observed in holly leaves and stems and in cedar needles as well. This lack of a clear pattern of tissue accumulation for Na is in substantial agreement with the work of earlier investigators, in particular Likens and Bormann (1970) and Hoyle (1965), who observed Na concentration to be especially variable in several species, the most noteworthy being yellow birch.

For the hardwood swamp reported on in this paper, the three most abundant elements found in all tree species were N, K, and Ca. P levels were generally quite low. The most abundant elements in trees at the Hubbard Brook Experimental Forest are N, Ca, and K (Likens and Bormann 1970). The generally low levels of P found in the tissues of the present hardwood swamp species may account for the low productivity of these forest species.

The three species reported upon in this paper exhibit differing patterns of nutrient control which characterize their individual level of importance in over-all nutrient cycling. These differences in pattern are the result of differences in whole tree mineral biomass, and are the direct result of individual species differences in mineral accumulation coupled with individual species differences in biomass. Various patterns of nutrient control exhibited by the three species include: (1) total amounts of N, K, Mg, P, Mn, and Zn found in whole magnolia trees are greater than those found in whole red maple trees of comparable size, (2) total amounts of these elements found in whole red maple trees are greater than those found in whole tupelo trees of comparable size, (3) total amounts of Ca and Fe found in whole red maple trees are greater than those found in whole magnolia trees of comparable size, and (4) total amounts of these two elements found in whole magnolia trees are greater than those found in whole tupelo trees of comparable size. The ability for a given size magnolia tree to cycle more N than an equivalent size maple (as suggested in the first of these patterns) is probably attributable to superior mechanisms for N uptake and accumulation by magnolia, since biomass for this species is less than that for maple, when trees equal size are compared.

In the present study, total community weight biomass for magnolia was found to be less than that for tupelo. Despite this weight biomass difference, community biomass for Fe, Mn, Zn, and Na for all magnolia tissues added together exceeds that for all tupelo tissues added together. This reverse in weight and mineral biomass relationships is attributable to the generally higher levels of accumulation of these elements in magnolia tissues. Thus, magnolia trees are less important than tupelos in terms of weight biomass for the hardwood swamp, but more important than tupelos in terms of mineral biomass for certain elements.

Individual species differences in mineral accumulation and biomass coupled with differences in species dominance within the hardwood swamp have resulted in differences in community mineral biomass for the tree stratum. When community mineral biomass for the hardwood swamp is compared with that for other swamp types, significant differences in pattern are notable. When compared with either of the two previously mentioned swamp types, community mineral biomass for N is greatest in the hardwood swamp. By contrast, the largest mineral biomass for Zn occurs in the holly swamp, primarily due to the accumulation of Zn by holly stems as previously cited. And the largest mineral biomass for Fe occurs in the cedar swamp, due primarily to the accumulation of Fe by cedar branches and trunks.

In summary, the present paper provides new information pertaining to community structure, weight biomass, species productivity, and mineral biomass for the tree stratum of a southern New Jersey hardwood swamp. The most important of these characteristics have been compared with similar characteristics for two other differing, but commonly occurring Pine Barrens swamps, in order to facilitate a better understanding of how these characteristics for a hardwood swamp compare with other important forested swamp types. Hopefully, a better understanding of these characteristics for this particular forest type will ultimately better enable us to increase its overall productivity if desired.

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