REVEGETATION AFTER WHOLE-TREE CLEARCUTTING OF HARDWOODS IN CONNECTICUT[1/]

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Abstract.--A 6-ha watershed in the hardwood forest of Connecticut was whole-tree harvested. Prior to cutting, the density of trees and shrubs was 1,163 stems ha^{-1}, and the above-ground living biomass was 168,400 kg ha^{-1}. By the end of the third growing season after cutting, density was 965,400 stems ha^{-1}, and biomass was 7,830 kg ha^{-1}. Postharvest biomass contained approximately 21 percent of the nitrogen, 6 percent of the calcium, and 22 percent of the potassium of the preharvest forest. Data from the Connecticut site are compared to revegetation after intensive harvests in other locations within the central hardwood forest.

Keywords: biomass, calcium, nitrogen, nutrients, harvesting.

More than 50 percent of Connecticut is classified as commercial forest land; 40 percent, or about 295,500 ha, is in the hardwood type (Dickson and Bowers 1976). Forest managers are increasingly pressured to produce wood for industrial, commercial, and domestic fuel. To meet this demand, clearcutting with whole-tree removal by mechanized equipment was introduced in the early 1980's. Such intensive management raised concerns about the combined effects on site productivity of the removal of nutrients in wood products and in leaching losses to streamwater. A major concern of forest managers continues to be species composition and growth rate of the regeneration expected on these sites, and the role of this regeneration in conserving nutrients.

To address these concerns, we initiated a study of nutrient dynamics following clearcutting with whole-tree removal, in cooperation with the Connecticut Department of Environmental Protection, on the Cockaponset State Forest in Chester, CT. The objectives of the study reported in this paper were: (1) to evaluate the roles of herbs and shrubs as well as tree species in the revegetation of the site following whole-tree clearcutting; (2) to evaluate the role of the regrowing vegetation, including herbs and shrubs, in sequestering nutrients and conserving them on the site; and (3) to evaluate whether regeneration following whole-tree clearcutting would reproduce the preharvest forest. This paper addresses these objectives by presenting an analysis of the first 3 years of revegetation including estimates of the density, biomass, and nutrient content of the regrowth.

The overall study also included the following objectives: (4) to estimate the quantities of the major nutrients removed from the site by whole-tree clearcutting in forest products and dissolved in streamwater; (5) to assess the chemical changes in the soil and soil solutions following whole-tree clearcutting; and (6) to evaluate nutrient removals, changes in the chemistry of the soil solution, and nutrient uptake by revegetation in terms of the total nutrient capital of the site, site productivity, and rotation length.

THE STUDY SITE

A forested watershed, approximately 6 ha in area and drained by a first-order stream, was selected for study. Elevation ranged from 121 to 152 m above mean sea level, with an average slope of 6 percent and a SSE aspect. The frost-free season is about 200 days, and annual precipitation is about 110 cm (Kingsley 1985).

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The terrain in the upper reaches of the watershed is gently rolling, while the lower sections are steep with exposed bedrock cliffs. The bedrock geology is of the upper Middletown formation, an assemblage of gneisses and schists with inclusions of sillimanite quartz and pegmatite.

The soils were formed on a mantle of glacial till. The soils on the ridge tops generally are of the Hollis-Chatfield-Rock association, loamy, mixed, mesic Lithic Dystrochrepts, which consists of shallow, somewhat excessively drained soils and exposed bedrock. The soils on the slopes of the watershed are deep, well-drained soils of the Chatfield-Canton association, coarse, loamy, mixed, mesic Typic Dystrochrepts. The soils in the valley floor near the stream channel generally are of the poorly drained, acidic, Leicester series, coarse-loamy, mixed, mesic Aeric Haplaquepts (USDA Soil Conservation Service 1981).

We have no specific land-use history for our 6-ha study site. But the history of Connecticut's forests is a series of disturbances and recoveries. The presettlement forest was cleared for agriculture. As early as 150 years ago, the fields and pastures began to revert to forests. Forest fires and selective logging often were factors in the developing Connecticut forests (Stephens and Waggoner 1980). The invasion of the chestnut blight (Endothia parasitica {Muss.} A.+A.) from 1914 to 1925 changed the species composition of the forest. Since the 1960's, the gypsy moth (Lymantria dispar L.) has repeatedly defoliated the forest, causing mortality and decline (Stephens 1981). It is likely that most, if not all, of these agents have been at work on our site. Our baseline data indicate that the geology, soils, forest cover, and land-use history of the site are representative of Connecticut. The forest on our 6-ha site probably was partially cleared and possibly burned in places for grazing during the 19th century, but abandoned more than 80 years ago. The soils show no evidence of having been plowed.

Prior to whole-tree clearcutting, our watershed supported an 80- to 110-year-old oak-birch-maple forest. The basal area of the trees and shrubs larger than 2 cm dbh was 23 m^2 ha^{-1}, with a density of 1,163 stems ha^{-1}. The above-ground living biomass was 168 Mg ha^{-1}, which contained 316 kg ha^{-1} of total N (Tritton et al. 1982). In terms of density and basal area, our stand was typical of Connecticut and southern New England (Stephens and Waggoner 1980). There are no biomass and nutrient data from the area for comparison.

METHODS

In the winter of 1981-82, the watershed was whole-tree clearcut by commercial loggers. All living and standing dead stems greater than approximately 5 cm dbh were cut. Trees less than 30 cm diameter at the stump were cut with a rubber-tired feller buncher; larger trees were cut by chain saw. Whole trees of all diameters were skidded to the landing outside the watershed by rubber-tired, articulated skidder. Sawlogs were separated, and the remainder, including tops and branches, were chipped on site. The majority of the smaller trees and shrubs, including the Kalmia latifolia, were broken during skidding.

In this paper, regeneration is defined as regrowth of commercial tree species, and revegetation is defined as regrowth of all trees, shrubs, and herbs.

Harvesting was completed in March 1982, and was confined to the dormant season. In August of 1982, the first growing season, and again in August of 1984, the third growing season, estimates were made of the density, biomass, and nutrient content of the revegetation. By mid-August, woody plants had not quite completed their growing season, but many herbs were senescent. Since the entire plant community was to be evaluated and two sampling periods per year were not possible, August was selected as a compromise. A 25 x 25-m grid was established on the watershed. Sample plots were selected randomly from this grid. To allow for sampling of herbaceous and woody plants, seedlings, saplings, and sprouts, a stratified random design was chosen. First the population was stratified by seedlings and stump sprouts. Then these groups were further stratified by size classes. Seedlings of trees, shrubs, and herbs less than 1.3 m tall were inventoried on fifty 1 x 1-m plots by height class. Seedlings taller than 1.3 m were inventoried on sixteen 1 x 25-m transects by dbh class. Stump sprouts were inventoried on four 25 x 25-m plots by height and diameter class. Large size plots were required to adequately sample stumps. The four plots equalled 4 percent of the watershed.

Biomass of seedlings of trees, shrubs, and herbs was estimated by harvesting twenty-one 1 x 1-m plots selected using a ranked-set sampling technique developed by McIntyre (1952) and tested by Halls and Dell (1966) and Dell and Clutter (1972). Biomass of sprouts was estimated by harvesting three stems of each height and diameter class by species. The mean oven-dry weight of the three harvested stems for each size and species was then multiplied by the estimated number of stems of that size and species per hectare. Estimates of all size classes were then summed to estimate total biomass per hectare.

Nutrient analyses were performed on each biomass sample and were reported as a percent per

unit biomass. The average of the three samples for each species and size class was multiplied by the estimated biomass for that species and size and summed. All samples were dried to a constant weight at 65°C, weighed, and chemically analyzed.

Total Kjeldahl nitrogen and total phosphorus in the plant tissue were determined with the Technicon BD-20[3/] block digestor, with colorimetric analyses performed on the Technicon Autoanalyzer. Cation concentrations were determined by flame atomic absorption spectroscopy (American Public Health Assoc. 1975).

RESULTS

The first growing season after harvest at least 49 genera of plants were identified. Eleven genera and 14 species of trees were inventoried with 10 genera and about 12 species of shrubs, and at least 28 genera of herbs. Because of the difficulty in differentiating between species of very small seedlings of grasses, rushes, and sedges, these plants were identified only by genera. By the third growing season, 51 genera were identified on the watershed, with 13 genera and 19 species of trees, 10 genera and 13 species of shrubs, and at least 28 genera of herbs (Appendix 1).

Density

Near the end of the first growing season there were more than 787,000 stems per hectare on the watershed. All of these plants were less than 130 cm tall, and all but about 15,000 were less than 50 cm tall. Tree species, especially Betula lenta, accounted for 41 percent of the stems; shrubs, especially Viburnum acerifolium, for 28 percent; and herbs, especially Lysimachia sp., for 31 percent (Table 1).

Near the end of the third growing season there were about 965,000 stems per hectare. Of these, only 18 percent were tree species, especially Betula lenta; 30 percent were shrubs, especially Vaccinium sp.; and 52 percent were herbs, especially Aster sp. Of the tree species, 8 percent were taller than 130 cm, predominately Acer rubrum, and about 100 trees per hectare had reached a dbh of 3 to 4 cm, exclusively Castanea dentata and Cornus florida (Table 1).

Biomass and Nutrient Content

By the end of the first growing season after harvest, above-ground living biomass of all species averaged 1,540 kg ha^{-1}. Biomass samples had an average concentration of 29 kg-N ha^{-1}, 2 kg-P ha^{-1}, 9 kg-Ca ha^{-1}, 3 kg-Mg ha^{-1}, and 17 kg-K ha^{-1} (Table 2). Acer rubrum had accumulated more biomass and nutrients than any other single species.

By the end of the third growing season, the total average above-ground living biomass had increased to 7,830 kg ha^{-1}, with 55 percent in stems taller than 130 cm. Nitrogen content of the biomass had more than doubled since the first

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Table 1. Density of revegetation during the first and third growing seasons after whole-tree harvesting in Connecticut.

Item	Growing season: First	Growing season: Third
	stems ha^{-1}	
Trees:		
<130 cm tall	322,100	155,000
0-1 cm dbh	0	10,600
1-2 cm dbh	0	2,900
2-3 cm dbh	0	400
3-4 cm dbh	0	100
Shrubs:		
<130 cm tall	220,800	288,800
0-1 cm dbh	0	3,100
1-2 cm dbh	0	100
Herbs:	244,600	504,400
Total:	787,500	965,400

Table 2. Biomass and nutrient content of revegetation during the first and third growing seasons after whole-tree harvesting in Connecticut.

Item	Biomass	N	P	Ca	K	Mg
	kg ha^{-1}					
Trees, shrubs, herbs:			FIRST YEAR			
<130 cm tall	1540	29	2	9	17	3
>130 cm tall	0	0	0	0	0	0
Total	1540	29	2	9	17	3
Trees, shrubs, herbs:			THIRD YEAR			
<130 cm tall	3540	32	3	19	22	5
Trees and shrubs:						
0-1 cm dbh	1550	10	1	6	5	1
1-2 cm dbh	2080	16	1	7	9	2
2-3 cm dbh	510	5	<.5	2	2	<.5
3-4 cm dbh	150	2	<.5	1	1	<.5
Total	7830	65	5	35	39	8

year after cutting; phosphorus had nearly tripled; calcium increased nearly fourfold; potassium and magnesium doubled (Table 2).

Emerging Dominants

In the third year, more than 17,000 woody stems per hectare had exceeded 130 cm in height (Table 3). These trees and shrubs represented only 2 percent of all of the stems per hectare on the watershed, but they accounted for 55 percent of the above-ground living biomass. They also had sequestered 50 percent of the nitrogen, 48 percent of the phosphorus, 44 percent of the calcium, 44 percent of the potassium, and 44 percent of the magnesium. Commercial tree species of the genera *Acer*, *Betula*, *Carya*, *Fagus*, *Fraxinus*, and *Quercus* represented slightly more than 1 percent of all plants on the watershed, 34 percent of the biomass, 30 percent of the nitrogen, 30 percent of the phosphorus, 23 percent of the calcium, 28 percent of the potassium, and 24 percent of the magnesium sequestered in above-ground living biomass.

Of the woody stems taller than 130 cm, *Acer rubrum* accounted for 37 percent of the stems and 37 percent of the biomass. All of the *Acer rubrum* taller than 130 cm were sprouts. *Betula lenta* represented 19 percent of the stems taller than 130 cm, but only 5 percent of the biomass.

Acer represented 53 percent of the commercial tree species taller than 130 cm, and 60 percent of the biomass. Of the commercial tree species, *Betula* represented 28 percent of the stems taller than 130 cm, and 9 percent of the biomass. *Quercus* sp. are the most valuable commercial species in Connecticut, and the four species represented 12 percent of the stems of commercial species more than 130 cm tall, and 26 percent of the biomass, with *Q. Prinus* predominant.

The following genera are in order of importance in terms of numbers of stems taller than 130 cm: *Acer* > *Betula* > *Hamamelis* > *Castanea* > *Quercus* (Table 3). The following are in order of importance in terms of biomass in stems taller than 130 cm: *Acer* > *Castanea* > *Quercus* > *Hamamelis* > *Betula*. The following are in order of importance in terms of sequestering nutrients in stems taller than 130 cm: *Acer* > *Castanea* > *Quercus* (Table 3).

Noncommercial trees and shrubs more than 130 cm tall represent less than 1 percent of all of the plants of all sizes on the watershed, but they account for 21 percent of the biomass, 20 percent of the nitrogen in above-ground living biomass, 16 percent of the phosphorus,, 21 percent of the calcium, 17 percent of the potassium, and 20 percent of the magnesium (Tables 2-3). Of these noncommercial species, the most prominant is *Castanea dentata*, which, in spite of 60 years of chestnut blight, still accounts for more than 12 percent of the above-ground biomass on the watershed and more than 13 percent of the nitrogen, 10 percent of the phosphorus, 9 percent of the calcium, 9 percent of the potassium, and 13 percent of the magnesium sequestered in above-ground living biomass the third year after harvesting.

DISCUSSION

Prior to the harvest in 1981, density of living trees and shrubs greater than 2 cm dbh was 1,163 stems per hectare. The above-ground living

Table 3. Stems, biomass, and nutrient content of saplings and sprouts of trees and shrubs taller than 130 cm near the end of the third year after whole-tree harvesting.

Species	Density	Biomass	N	P	Ca	K	Mg
	stems ha^{-1}	kg ha^{-1}					
Acer rubrum	6330	1590	9.8	0.8	4.4	5.6	0.9
Betula lenta	3300	230	2.1	0.1	0.7	0.9	0.2
Carya sp.	420	90	1.1	0.1	0.5	0.6	0.2
Castanea dentata	1480	910	8.6	0.5	3.2	3.6	1.0
Cornus florida	450	190	1.5	0.1	1.7	1.1	0.3
Fagus grandifolia	400	50	0.4	t	0.1	0.2	t
Fraxinus americana	40	10	t	t	t	t	t
Hamamelis virginiana	3200	460	2.3	0.2	2.2	1.6	0.3
Kalmia latifolia	40	40	0.2	t	0.2	0.1	t
Ostrya virginiana	80	20	0.2	t	0.1	0.1	t
Prunus pensylvanica	40	10	t	t	t	t	t
Quercus sp.[a]	1380	690	6.2	0.5	2.4	3.5	0.6
Total	17160	4290	32.5	2.4	15.5	17.3	3.5

[a] *Quercus alba*, *Q. Prinus*, *Q. rubra*, *Q. velutina*.
t = <0.05 kg ha^{-1}.

Table 4. Density, biomass, and nutrient content of the major tree species ≥ 2 cm dbh prior to harvest.

Species	Density	Biomass	N	P	Ca	K	Mg
	stems ha^{-1}	Mg ha^{-1}	kg ha^{-1}				
Quercus sp.	202	94.1	176.0	11.9	399.3	113.1	17.2
Betula sp.	174	40.9	65.7	4.4	89.2	27.2	9.9
Acer sp.	305	18.8	29.8	2.5	51.0	18.1	4.4
Carya sp.	58	5.0	9.1	0.5	18.6	7.1	3.0
Cornus florida	339	3.6	7.3	0.7	9.6	6.3	2.3
Other trees	85	6.0	14.8	1.3	20.8	8.5	2.4
Total	1163	168.4	302.7	21.3	588.5	180.3	39.2

biomass of these trees and shrubs was 168 Mg ha^{-1} (Tritton et al. 1982). This biomass contained 303 kg-N ha^{-1}, 21 kg-P ha^{-1}, 589 kg-Ca ha^{-1}, 180 kg-K ha^{-1}, and 39 kg-Mg ha^{-1} (Table 4). These data did not include herbs, shrubs, and seedings less than 2 cm dbh. These small plants, while numerous, are ins ignificant in terms of biomass and nutrient content in a mature forest.

By the end of the third growing season, we estimated 500 stems ha^{-1} larger than 2 cm, or 43 percent of the value for a mature forest (Table 1). Biomass of stems larger than 2 cm dbh was 660 kg ha^{-1} or less than 1 percent of that in the mature forest (Table 2). However, all of the biomass accumulated during the first 3 years, 7,830 kg ha^{-1}, is nearly 5 percent of that in the mature forest. Compared to the mature forest, the 3-year-old forest has 21 percent of the nitrogen, 24 percent of the phosphorus, 6 percent of the calcium, 22 percent of the potassium, and 21 percent of the magnesium (Table 2).

Forest Development

The "initial floristic composition" theory states that for abandoned agricultural pastures, 95 percent of the species of the mature forest are present at time of abandonment (Egler 1954). The relative importance of individual species as expressed by height, biomass, or nutrient content will change as the forest matures (Leopold et al. 1985).

The theory of "initial floristic composition" seems to be true for the clearcut at Cockaponset. The first year after harvesting, 14 species of trees, 12 species of shrubs, and 28

genera of herbs were identified. By the third year, tree species had increased by five; shrubs increased by one; and herbs remained the same. This regrowth is the result of a variety of reproductive methods. The tree species reproduced by stump or root sprouting, except for Betula lenta, B. alleghaniensis, Ostrya virginiana, and Populus tremuloides which occurred mainly as seedlings. Prunus pensylvanica occurred as seedlings, but from seeds that may have been buried for decades (Bormann and Likens 1979). The shrubs were more evenly divided between sprouts and seedlings, but the two that emerged as important contributors to the biomass (Table 3) of the watershed, Hamamelis virginiana, and Kalmia latifolia reproduced almost exclusively by sprouts. Nearly all of the herbs were seedlings the first year after harvest.

Prior to harvesting (Table 4), the order of density of trees larger than 2 cm dbh was: Cornus > Acer > Quercus > Betula > Carya (Tritton et al. 1982). The order of density of saplings taller than 130 cm at 3 years after cutting was Acer > Betula > Hamamelis > Castanea > Quercus. Hamamelis is a shrub and Castanea will lose importance because of the chestnut blight. The three most dense commercial tree species before cutting already have emerged as dominants in 3 years. Biomass prior to harvesting was distributed with Quercus > Betula > Acer > Carya > Cornus. At year 3, Acer, Quercus, and Betula were the dominant commercial species in terms of biomass. On the basis of 3 years of regrowth, this site seems to be producing a forest similar to the preharvest forest, but, because of the dynamics of competition at this age it seems premature to speculate on whether or not the shift of dominance from Quercus to Acer is permanent (Oliver 1981). Hamamelis and Kalmia were badly damaged during harvest to the point where there was no advanced regeneration. The emerging sprouts do not seem to be a competitive threat to commercial species.

Early regrowth on our site seems to be similar in numbers of species to central hardwood sites. Trimble (1973) found 20 tree species 5 years after clearcutting in West Virginia. Leopold et al. (1985) reported about 21 genera and about 30 species 8 years after the first cut of a watershed in North Carolina in 1939-40. About 24 genera and about 32 species were reported 7 years after the same watershed was clearcut again in 1962. They did not report shrubs and herbs. Boring et al. (1981) reported 21 genera of trees and shrubs with about 30 species, 3 genera and 6 species of vines, and 23 genera of herbs the first year after clearcutting another watershed in North Carolina.

Wendel and Trimble (1968) reported that commercial tree reproduction on nine areas in West Virginia averaged 30,560 stems per hectare (15,760 to 45,450) of commercial tree species from 30 cm tall to 2.5 cm dbh 3 years after clearcutting. By August in the third year after cutting, the Connecticut site had 65,536 stems ha^{-1} of commercial tree species.

Mann (1984) reported that 1,765 kg ha^{-1} accumulated on a watershed in central Tennessee the first year after clearcutting with whole-tree removal; 433 kg ha^{-1} was in sprouts, 129 kg ha^{-1} in seedlings and shrubs, and 1,203 kg ha^{-1} in herbs. Boring et al. (1981) reported that 1,725 kg ha^{-1} accumulated on a clearcut watershed in North Carolina the first year after cutting, with 63 percent in sprouts, 25 percent in herbs, 9 percent in vines, and 3 percent in woody seedlings. Our site was slightly less productive, with only 1,540 kg ha^{-1} the first year. Only 50 percent of our biomass was sprouts; 18 percent was herbs, 18 percent was seedlings, and 14 was percent shrubs. There were virtually no vines.

Boring et al. (1981) reported that first-year biomass on their watersheds in North Carolina accumulated 29.2 kg-N ha^{-1}, 2.5 kg-P ha^{-1}, 19.5 kg-Ca ha^{-1}, 24.5 kg-K ha^{-1}, and 4.8 kg-Mg ha^{-1} in above-ground living biomass. The biomass on our site sequestered 29 kg-N ha^{-1}, 2 kg-P ha^{-1}, 9 kg-Ca ha^{-1}, 17 kg-K ha^{-1}, and 3 kg-Mg ha^{-1}. Boring et al. (1981) and Mann (1984) were the only comparative biomass and nutrient content data sets we could locate.

SUMMARY

1. The revegetation of the Connecticut watershed was rapid, with nearly equal numbers of trees, shrubs, and herbs the first year after cutting. The density and allocation by trees, shrubs, and herbs were similar to data from Tennessee and North Carolina. By the third year, relative density of trees decreased, but revegetation remained adequate based on comparisons with data from West Virginia.

2. Biomass, the first year after cutting in Connecticut, was similar to that on sites in Tennessee and North Carolina. Data were unavailable for third-year comparisons.

3. For the first year after cutting, the biomass in Connecticut accumulated the same amount of nitrogen as the site in North Carolina, similar quantities of phosphorus, much less calcium, less potassium, and similar magnesium. This difference may be the result of differences in species mix because various species accumulate nutrients preferentially (Johnson et al. 1982).

4. The watershed seems to be adequately stocked with species similar to those in the preharvest forest. Rapid revegetation, particularly of the shrub and herb layers, is conserving substantial quantities of nutrients and beginning the process of intrasystem cycling of nutrients. Noncommercial herbs and shrubs, and trees such as Castanea, play a vital role in this nutrient conservation.

5. On the basis of dominant vegetation 3 years after cutting and the "initial floristic composition" theory, the mature forest that emerges from this clearcut should be similar to the preharvest forest in species composition.

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APPENDIX I

Cockaponset Revegetation, Third Year After Cutting.

Species List

Trees:

- Acer rubrum L.
- Betula alleghaniensis Britt.
- B. lenta L.
- Carya glabra (Mill.) Sweet
- C. ovata (Mills) K. Koch
- C. tomentosa Nutt.
- Castanea dentata (Marsh.) Borkh.
- Cornus florida L.
- Fagus grandifolia Ehrh.
- Fraxinus americana L.
- Nyssa sylvatica Marsh.
- Ostrya virginiana (Mill.) K. Koch
- Populus tremuloides Michx.
- Prunus pensylvanica L.
- Quercus alba L.
- Q. Prinus L.
- Q. rubra L.
- Q. velutina Lan.
- Sassafrass albidum (Nutt.) Ness

Shrubs:

- Clethra alnifolia L.
- Comptonia peregrina (L.) Coult
- Hamamelis virginiana L.
- Kalmia latifolia L.
- Lindera Benzoin L. Blume
- Prunus virginiana L.
- Rhus glabra L.
- R. radicans L.
- Rubus allegheniensis Porter
- R. hispidus L.
- R. idaeus L.
- Vaccinium sp.
- Viburnum acerifolium L.
- Vitis sp.

Herbs:

- Aralia
- Aster
- Cirsium
- Desmodium
- Erechtites
- Eupatorium
- Ferns
- Fragaria
- Grasses
- Hypericum
- Lobelia
- Lycopodium
- Lysimachia
- Maianthemum
- Mitchella
- Mosses
- Parthenocissus
- Potentilla
- Rumex
- Rushes
- Sedges
- Solidago
- Trifolium
- Uvularia
- Viola
- 2 unknowns

APPENDIX 2

1 hectare (ha) = 2.471 acres
1 acre = 0.4047 ha
1 meter (m) = 3.281 feet
1 foot = 0.3048 m
1 centimeter (cm) = 0.3937 inches
1 inch = 2.540 cm
1 square meter per hectare ($m^2 ha^{-1}$) = 4.3561 square feet per acre ($ft^2 ac^{-1}$)
1 $ft^2 ac^{-1}$ = 0.2296 $m^2 ha^{-1}$
1 kilogram per hectare (kg ha^{-1}) = 1.0843 pounds per acre (lbs ac^{-1})
1 lb ac^{-1} = 0.9223 kg ha^{-1}
1 megagram per hectare (Mg ha^{-1}) = 891.1 lbs ac^{-1} or 0.446 tons per acre
1 ton per acre = 2.2422 Mg ha^{-1}