ROLE OF SPROUTS IN REGENERATION OF A WHOLE-TREE CLEARCUT

IN CENTRAL HARDWOODS OF CONNECTICUT

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Abstract: Stump sprouts were the single most important type of regeneration in a central hardwood forest in Connecticut during the first 5 years after whole-tree clearcutting. Herbs, shrubs, tree seedlings, and stump sprouts were inventoried using stratified permanent plots on a 6-ha watershed during the first, third, and fifth years after harvest. The first year after cutting 1,540 kg ha^{-1} of living biomass, including herbs, shrubs, and tree seedlings and sprouts, accumulated on the watershed. Of that, 54% was in tree seedlings and sprouts from stumps < 10 cm, and 13% in sprouts from stumps ≥ 10 cm. Oaks produced the most sprout biomass from large stumps, followed by maples and chestnut. By the fifth year, 17,990 kg ha^{-1} of living biomass had accumulated with 56% in tree seedlings and sprouts from small stumps, and 15% in sprouts from large stumps. Approximately 28% of the initial number of sprouts from large stumps had survived through year 5, and sprout biomass of oaks was still greater than that of maples and chestnut. Our study indicates that sprouts are highly active in the initial accumulation of biomass and nutrients after harvest.

INTRODUCTION

Rapid revegetation of sites following clearcutting can reduce soil erosion, conserve nutrients, and promote the development of a new forest. Stump sprouts are one means for rapidly establishing many hardwood species (Smith 1986). Their prevalence has been documented after clearcutting in Tennessee (Mann 1984), North Carolina (Boring et al. 1981), West Virginia (Wendel 1975), Georgia (Miller and Phillips 1984), and Michigan (Mroz et al. 1984). Factors that influence the potential contribution of sprouts to development of a commercially desirable forest include rate of growth and quality of sprouts (Wendel 1975); species, diameter, and height of parent stumps (Miller and Phillips 1984, Solomon and Blum 1967); mortality and long-term survival of sprouts (Johnson 1977, McIntyre 1936); and susceptibility of sprouts to decay (Jones and Raynal 1987, Roth and Hepting 1943). A better understanding of the role of sprouts in revegetation of hardwood sites is needed to guide logging practices and forest management.

As part of long-term research on the effects of whole-tree harvesting on a Connecticut hardwood forest ecosystem (Hornbeck et al. 1990, Tritton et al. 1987), we are following the

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species composition, biomass, and nutrient content of revegetation on the site (Martin et al. 1987). This paper summarizes data from the first, third, and fifth years after cutting in order to evaluate: 1) Whether stump sprouts are a viable means for regenerating a commercially desirable Connecticut hardwood forest, 2) The importance of stump sprouts in conserving nutrients on the site immediately after cutting, thereby acting to maintain site fertility; and 3) How management practices influence the importance of stump sprouts.

THE STUDY SITE

The study site is a 6 ha forested watershed located on the Cockaponset State Forest in Chester, CT. The soils of the upper slopes generally are of the Hollis-Chatfield-Rock association, loamy, mixed, mesic Lithic Dystrochrepts, which consist of shallow, somewhat excessively drained soils with occasional outcrops of exposed bedrock. The bedrock is of the upper Middletown formation, an assemblage of gneisses and schists with inclusions of sillimanite quartz and pegmatite. The soils of the lower slopes are deep, well-drained, coarse, loamy, mixed, mesic Typic Dystrochrepts of the Chatfield-Canton association. The soils of the valley floor are poorly drained, acidic, coarse-loamy, mixed, mesic Aeric Haplaquepts of the Leicester series (USDA Soil Conserv. Serv. 1981).

Prior to whole-tree clearcutting, the watershed supported an 80- to 110-year-old mixed age oak-birch-maple forest typical of Connecticut and southern New England (Martin et al. 1987, Stephens and Waggoner 1980). 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 aboveground living biomass was 168 metric tons ha^{-1}, with 303 kg ha^{-1} of total nitrogen, 589 kg ha^{-1} of calcium, and 180 kg ha^{-1} of potassium (Hornbeck et al. 1990, Tritton et al. 1982).

In the winter of 1981-82, the watershed was whole-tree clearcut. All living and standing dead trees greater than 5 cm dbh were cut. Trees less than 30 cm stump diameter 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, skidders. Sawlogs were separated and the remaining stems, tops, and branches were chipped on site. Harvesting was completed in March 1982, and was confined to the dormant season.

METHODS

Sample plots were selected randomly from a 25 X 25-m grid established on the watershed. A stratified, nested design was chosen for sampling of herbaceous and woody plants, including seedlings and sprouts. Seedlings of trees, shrubs, and herbs < 1.3 m tall were inventoried on fifty 1 X 1-m plots by 0.5-m height classes. Seedlings and sprouts taller than 1.3 m from stumps < 10 cm in diameter were measured on sixteen 1 X 25-m transects by 1-cm dbh classes. Sprouts of all heights from stumps ≥ 10 cm in diameter were inventoried on four 25 X 25-m plots. One plot was placed at random on the grid within each of four strata: dry ridge top, midslope westerly aspect, midslope easterly aspect, and poorly drained Leicester soils. The four plots were equal in area to 4% of the watershed.

Inventories of all three types of plots were made in August of 1982, the first growing season, in August of 1984, the third growing season, and in August and November of 1986, the fifth growing season. By mid-August, woody plants had not yet completed the growing season, though many herbs were senescent. Because of the density of the stump sprout clusters at year 5, the 25 X 25-m plots of stumps ≥ 10 cm diameter were inventoried in November after leaf fall.

Biomass of tree seedlings, shrubs, and herbs was estimated by harvesting twenty-one 1 X 1-m plots selected using a ranked-set sampling technique (McIntyre 1952). Biomass of sprouts was estimated by harvesting three stems of each 0.5-m height class for sprouts < 1.3 m tall, and for each 1-cm diameter class for the larger sprouts, 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 collected from the twenty-one 1 X 1-m plots and from each sprout and seedling. Nutrient data were reported as a percent per unit of 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. The tissues were digested in a Technicon BD-20[2] block digestor. Total Kjeldahl nitrogen was measured on the digested samples with colorimetric analyses performed on the Technicon Autoanalyzer. Cation concentrations of the digested samples were determined by flame atomic absorption spectroscopy (Franson 1975).

RESULTS

Whole-tree clearcutting removed 91% of the aboveground biomass, including some sound dead wood. In the process, all of the trees were cut, and nearly all advance regeneration and shrubs were crushed by the equipment. The vegetative cover quickly reestablished after this treatment. By the end of the first growing season, there were nearly 800,000 living plants ha^{-1} on the area, of which 60% were herbs and shrubs, and 40% were tree seedlings and sprouts (Fig. 1). By the end of the fifth growing season, there were more than one million plants ha^{-1}, of which 90% were herbs and shrubs and only 10% were tree seedlings and sprouts. There was a systematic increase in the total number of stems of all vegetation ha^{-1} over the 5 years, but a consistent decrease in the numbers of stems of tree species. *Betula* represented nearly

[2]The use of trade, firm, or corporation names does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that might be suitable.

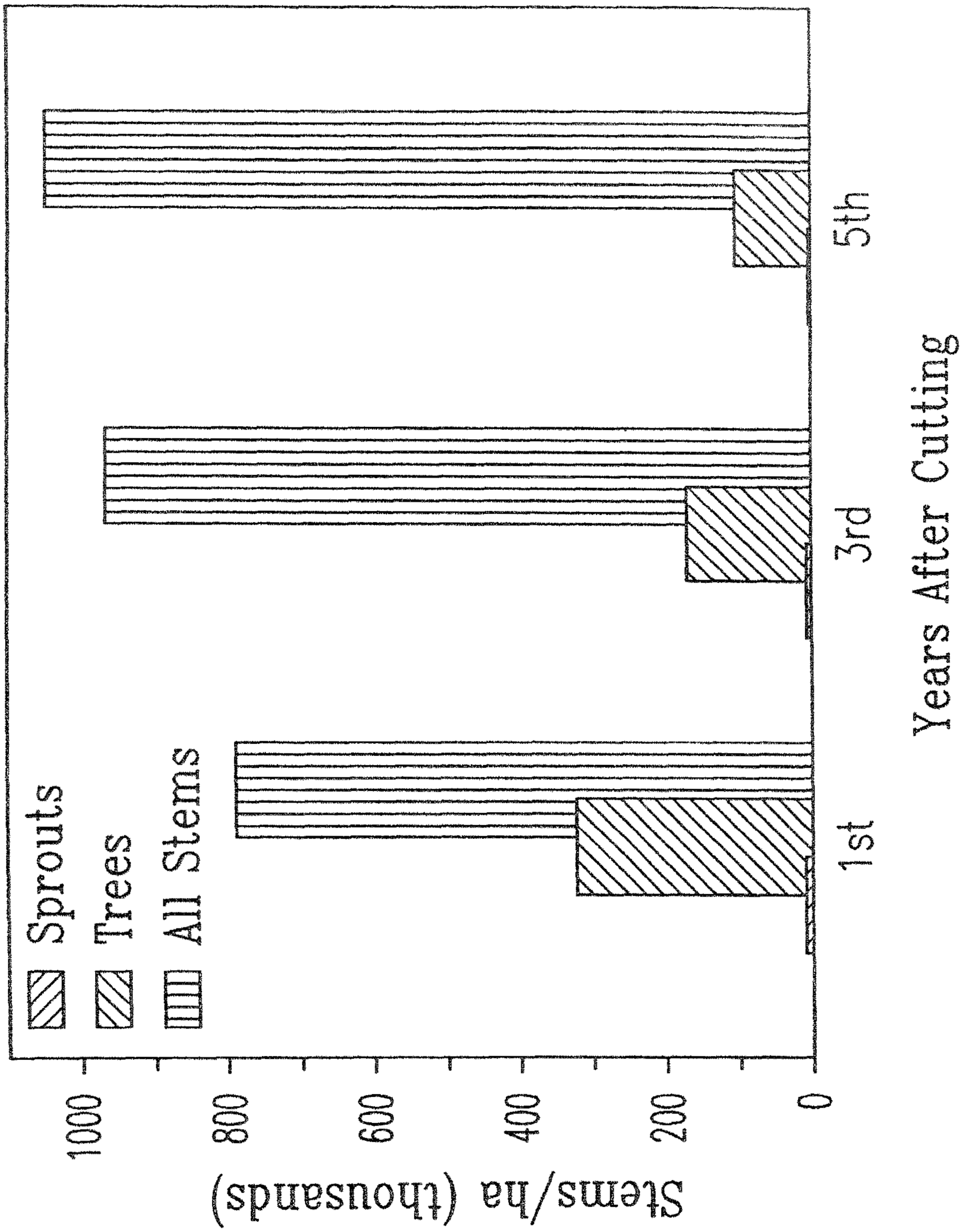

Figure 1. Stems per hectare, in thousands, by year after cutting. The tallest bars include herbs, shrubs, tree seedlings, and sprouts; the bars labeled trees include seedlings and sprouts.

75% of the tree seedlings and sprouts the first year after cutting, and nearly 60% at year 5. *Betula*, *Acer*, *Quercus*, and *Castanea* represented 90% of all the stems of tree seedlings and sprouts on the site the first year after cutting, and 95% in the fifth year.

By the end of the first growing season, plants had produced more than 1,500 kg ha^{-1} of aboveground living biomass. Tree seedlings and sprouts accounted for about 65% of this biomass with herbs and shrubs accounting for the remainder. By the end of the fifth growing season, there were nearly 18,000 kg ha^{-1} of aboveground living biomass on the watershed with tree seedlings and sprouts accounting for more than 70% (Fig. 2). While the number of stems of tree species continued to decline, tree species clearly dominated the site in terms of biomass by year 5. *Acer* accumulated biomass more rapidly than any other genus throughout the 5 years. By year 5, *Acer* accounted for nearly one-third of the biomass of tree species on the site, followed by *Quercus*, *Betula*, and *Castanea*. These four genera comprised nearly 90% of the biomass of tree species at year 5.

By the end of the first growing season, nearly 30 kg ha^{-1} of nitrogen was stored in aboveground living biomass; this increased to more than 130 kg ha^{-1} by the end of the fifth growing season. Trees, including both seedlings and sprouts, accounted for more than 60% of this nitrogen accumulation the first year, and more than 70% by the fifth year (Fig. 3). Aboveground living biomass accumulated nearly 10 kg ha^{-1} of calcium and nearly 20 kg ha^{-1} of potassium the first growing season. Calcium and potassium in the biomass had increased to nearly 80 kg ha^{-1} for both elements by the fifth year, with tree seedlings and sprouts accounting for more than 60% in both cases.

Sprouts from stumps $\geq$ 10 cm in diameter at time of cutting were a major component of the regeneration on the clearcut watershed. They represented only about 3% of the total numbers of stems of tree species during the first 5 years after cutting (Fig. 1). But they represented 20 to 25% of the biomass of tree species throughout that period (Fig. 2). And by the fifth year after cutting, about 20% of the nitrogen, calcium, and potassium sequestered by tree species, including both seedlings and sprouts, was stored in sprouts from stumps $\geq$ 10 cm in diameter. These sprouts had accumulated about 13% of the nitrogen, calcium, and potassium stored in all aboveground vegetation on the watershed (Fig. 3).

During the first year after cutting, more than 55% of the sprouts on the watershed were *Quercus*, followed by *Acer*, *Betula*, and *Castanea*. By the fifth year, more than 40% of the sprouts were *Acer*, followed by *Quercus*, *Betula*, and *Castanea* (Fig. 4). Throughout the 5 years, *Quercus* sprouts accumulated the most biomass followed by *Acer* and *Castanea*, with *Betula* a distant fourth (Fig. 5).

At the time of cutting, there were an average of 424 live trees per hectare with stump diameters $\geq$ 10 cm. By the end of the first growing season, an average of 252 stumps ha^{-1} had sprouted to produce about 9,400 sprouts, an average of 37 live sprouts per live stump. By the end of year 5, an average of 212 stumps ha^{-1} remained alive with about 2,540 live sprouts, an average of 12 live sprouts per live stump.

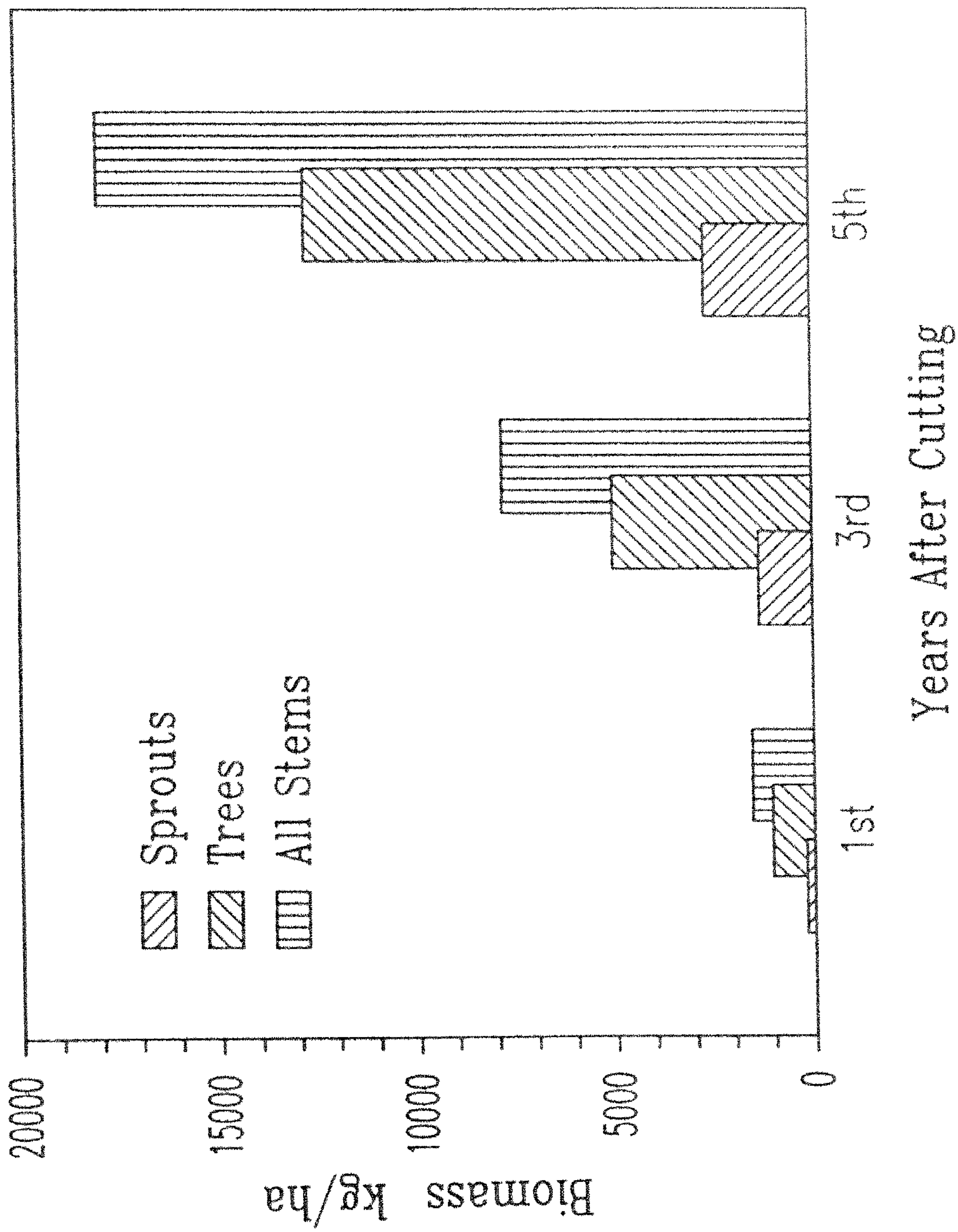

Figure 2. Biomass of revegetation in kg ha^{-1} by year after cutting. The tallest bars include herbs, shrubs, tree seedlings, and sprouts; the bars labeled trees include seedlings and sprouts.

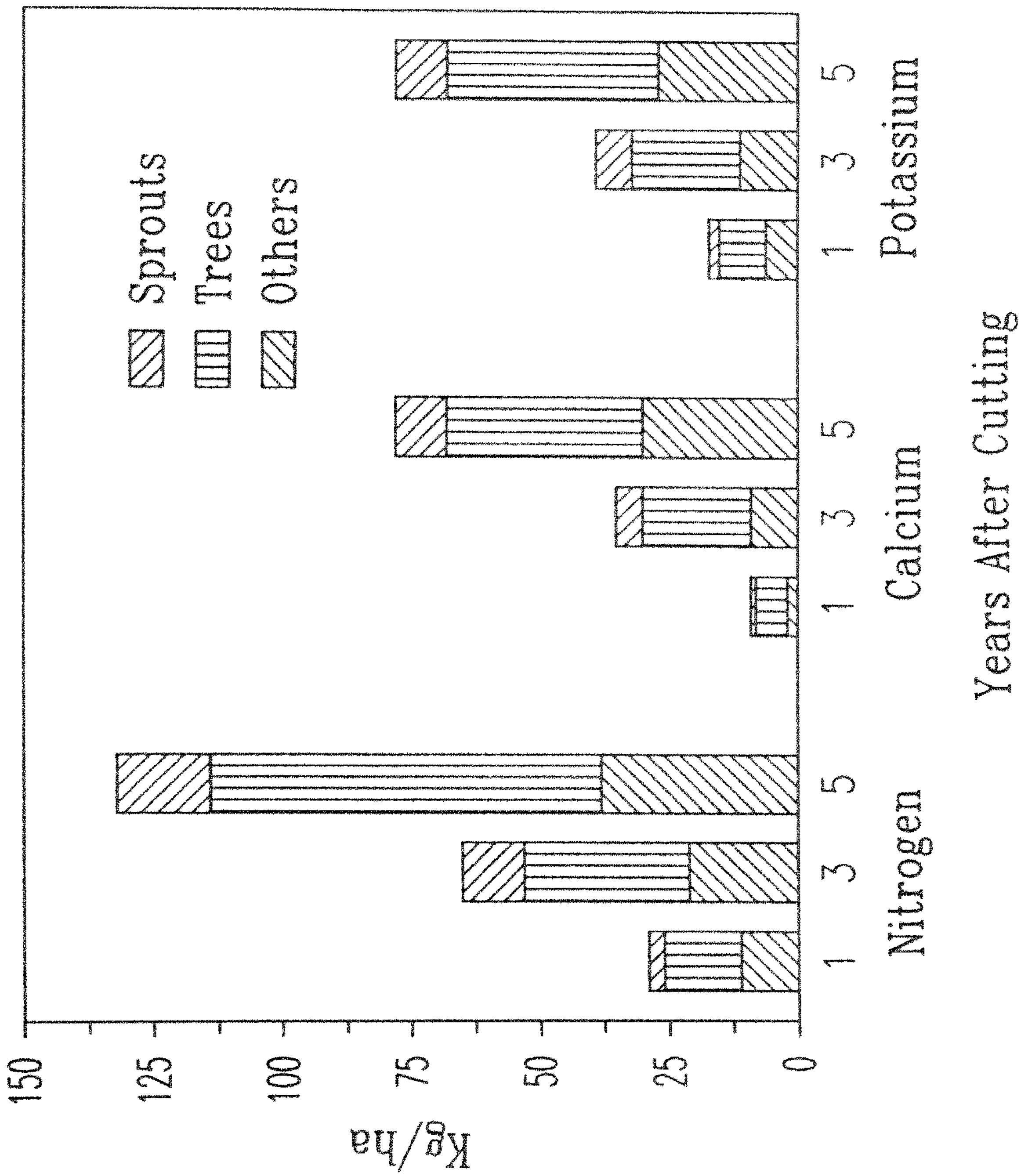

Figure 3. Mass of nutrients accumulated in the aboveground living biomass by years after cutting.

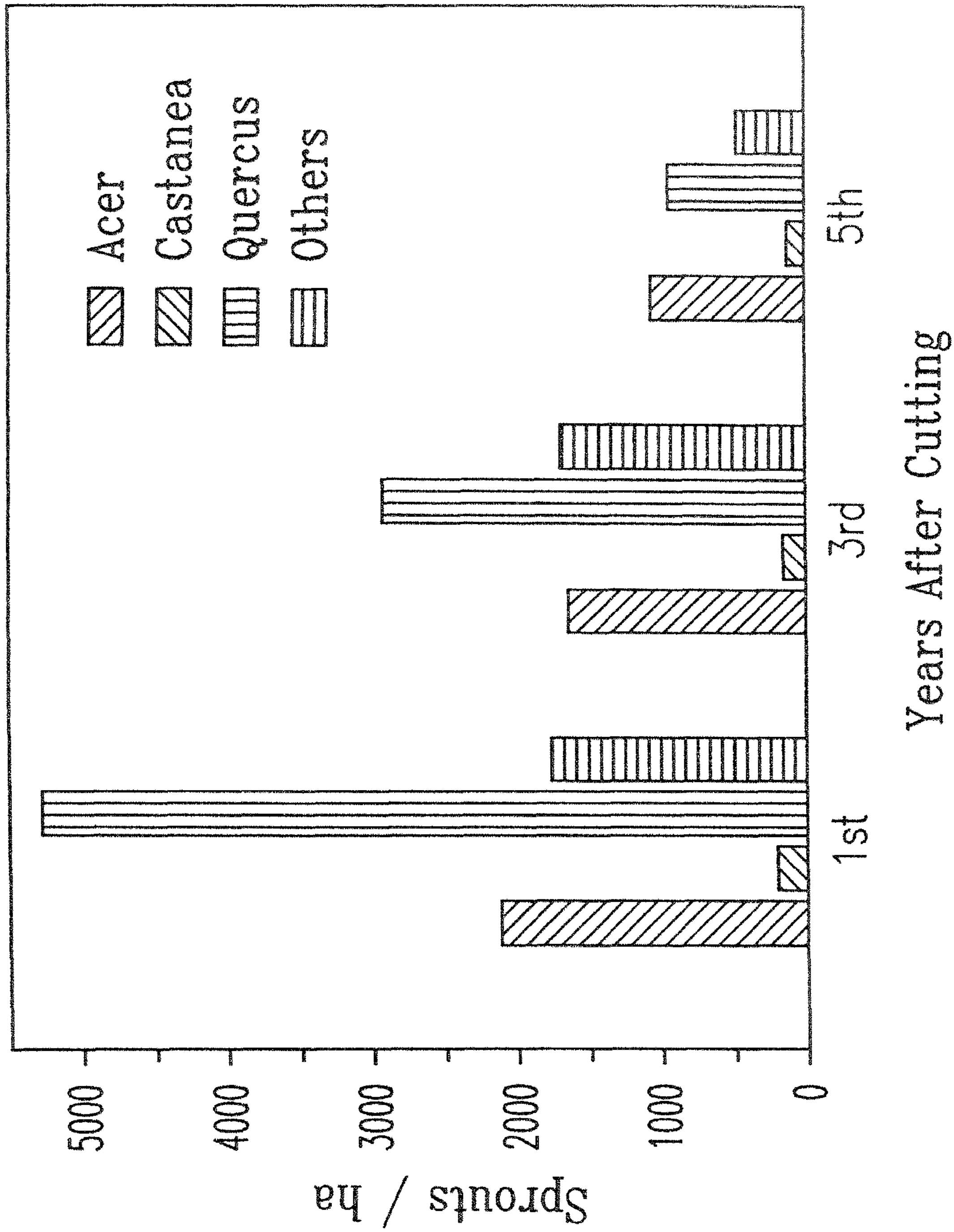

Figure 4. Numbers of sprouts per hectare by species and years after cutting.

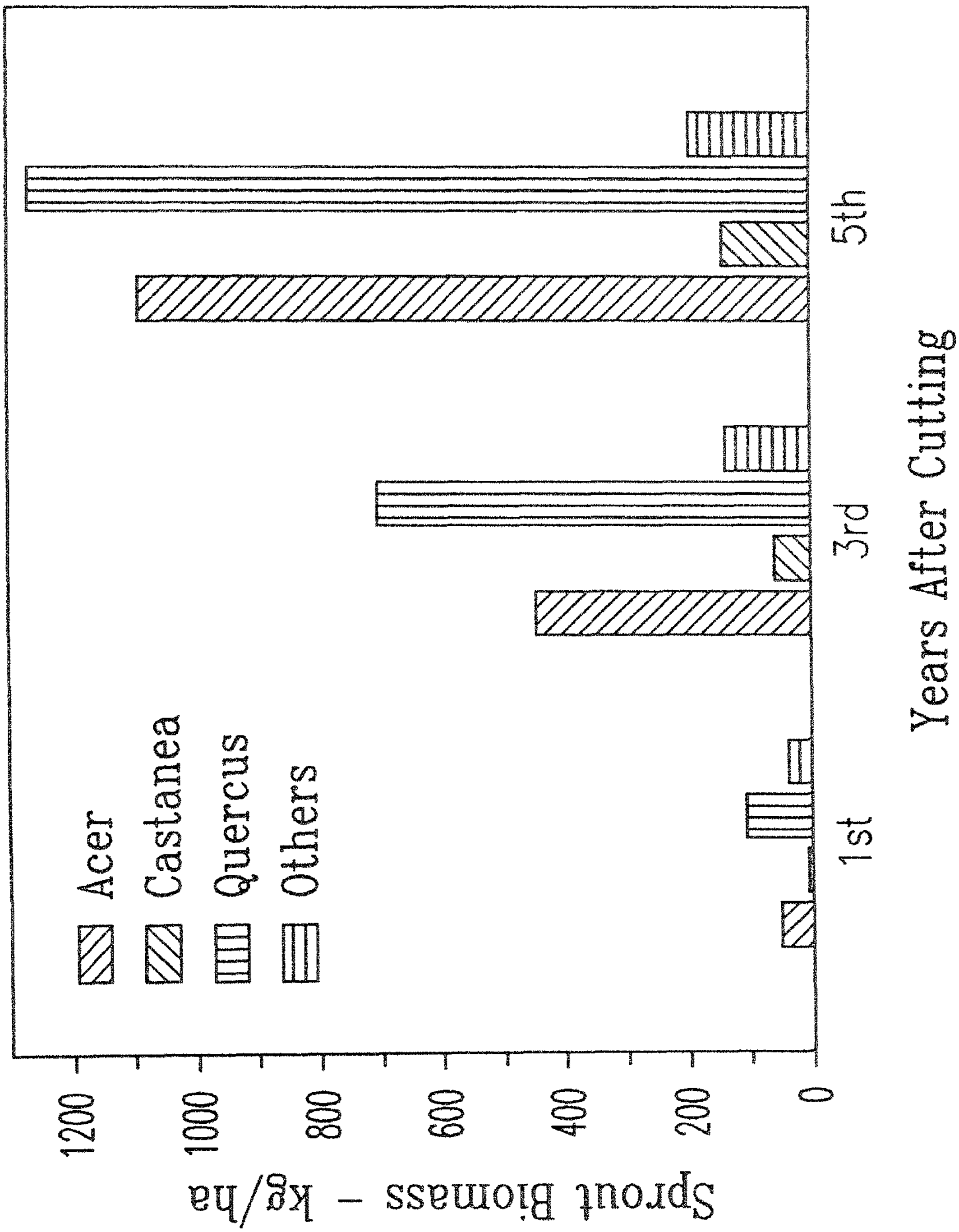

Figure 5. Aboveground living biomass of sprouts per hectare by species and years after cutting.

More than 80% of the *Acer* stumps on the four sample plots sprouted the first year after cutting, and all continued to have live sprouts throughout the 5 years. About 75% of the *Quercus* stumps sprouted but that percentage dropped to about 60% by year 5. Only about 25% of the *Betula* stumps sprouted (Table 1).

Table 1.--Number of live stumps by genus on the four 25 x 25 m sample plots.

	Years after cutting		
Genus	0	1	5
Acer	12	10	10
Betula	35	9	8
Quercus	37	28	22
Others	22	16	13

Of all the genera, *Acer* produced the most sprouts per stump and retained the greatest number of live sprouts over the 5 years. Approximately 50% of the *Acer* sprouts and 75% of the *Quercus* sprouts died over the 5-year period. (Table 2).

Table 2.--Average number of sprouts per live stump by genus. (Standard errors).

	Years after cutting	
Genus	1	5
Acer	53 (7)	26 (6)
Betula	21 (9)	4 (2)
Quercus	47 (8)	11 (1)
Others	19 (6)	9 (3)

DISCUSSION

The importance of sprouts in a regenerating forest can be evaluated in terms of biomass, density, and species represented. Density is an indicator of stand age and structure; biomass reflects dominance; species indicates future worth. Together, we used these three variables to characterize revegetation on our study area.

Sprouts as a Component of Regeneration

Beginning with the first growing season after cutting, tree seedlings and sprouts had the greatest amount of aboveground living biomass on the site. Stump sprouts represented 19% of that biomass and, on average, accumulated 10 times more biomass than seedlings. However, sprouts accounted for only 3% of the total stems of tree species on the site. Other studies have reported larger numbers of sprouts than were tallied in our study. Boring et al. (1981) found that both density and biomass of sprouts exceeded density and biomass of tree seedlings following cable logging of a watershed in North Carolina. Mann (1984) reported that sprouts dominated whole-tree and saw-log clearcut sites in Tennessee, both in terms of numbers of stems of tree species and biomass.

Betula seedlings and sprouts far exceeded the total number of seedlings and sprouts for other genera of tree species in the first growing season. Initially, scarified soil conditions following whole-tree harvest probably favored the establishment of *Betula* seedlings. Although the total numbers of *Quercus* stems were less than either *Betula* or *Acer*, a far greater proportion (72%) of *Quercus* stems were sprouts. In addition, almost all (97%) *Quercus* biomass was in sprouts, compared with 16% for Acer and 4% for *Betula*. Thus, sprouts were a more important form of regeneration for *Quercus* than for other genera in the first growing season.

Dynamics of Sprouts over the First Five Years

Sprouts continued to account for a small proportion of the total numbers of stems per hectare of all plants over the 5 years studied (Fig. 1). Whereas the total number of plant stems increased, both the total number of stems of all tree species and the total number of sprouts decreased. These data suggest that initiation of sprouts occurred largely in the first (and second) growing season after harvest. Roth and Hepting (1943) reported that there was rarely further sprouting of oaks beyond the second year after cutting.

By contrast, herbaceous plants and tree seedlings apparently continued to fill in open spaces on the forest floor for several years after cutting. Skid trails and other severely disturbed areas may take several years to stabilize before plants can become established. Light and moisture conditions at the soil surface are rapidly changing at this time (Bormann and Likens 1979), resulting in changes in species dominance (Hornbeck et al. 1987). Our study suggests that although species dominance may shift, the tree species present in the first and fifth growing seasons will be the components of the future forest, as discussed by Martin et al. (1987).

It is not possible to predict the long-term survival of sprouts with certainty. At our site, more than three quarters of the *Quercus* sprouts had died by the fifth year. McIntyre (1936) reported that mortality of oak sprouts continued to be high during the first 10 years following cutting but slowed thereafter. McIntyre also found that the basal area of sprouts decreased with stand age. Therefore, clearcut sites may be characterized by dominant, rapidly growing sprouts only in the first one or two decades after clearcutting.

Although we did not carry out a systematic study of causes of sprout mortality, we found evidence of several diseases which probably contributed to mortality. Fruiting bodies of *Armillaria* spp. were observed on numerous stumps over the entire site. This root disease reduces not only sprouting capability of stumps but also sprout survival (P.M. Wargo, USDA For. Serv. pers. comm.). By the fifth year, some of the largest sprouts apparently were too heavy to be supported by the thin living cambial layer of the stump, and whole clusters of these sprouts peeled away from the stump, fell over, and died. *Castanea*, which had been a very minor component of the precut forest, demonstrated extensive sprouting after harvest. These sprouts grew rapidly in diameter and height and rapidly accumulated biomass. But by year 5, the majority of sprouts showed evidence of chestnut blight (*Cryphonectria parasitica* (Murr.) Barr) and died.

Quercus stumps sprouted quickly and prolifically, accounting for nearly twice as much biomass as the other species in the first growing season and retaining that dominance through year 5. However, *Acer* accumulated biomass more slowly but nearly equalled *Quercus* by the fifth year. Mroz et al. (1985) similarly found that red maple biomass accumulated slowly during the first 3 years after cutting and then increased dramatically in the fourth year.

Sprouts Relative to Precut Forest

Prior to harvest, *Acer* was the most numerous tree genus and *Quercus* accounted for the most biomass at the Connecticut site (Martin et al. 1987). Since Mann (1984) found a greater average number of sprouts per live stump for red maple than for oak in Tennessee, we expected *Acer* to dominate the site immediately. However, this was not the case, and there was no clear relationship between species and sprouting at the Connecticut site. Nor was there an obvious effect of stump diameter on sprouting. Roth and Hepting (1943) showed that for *Quercus*, sprout initiation increases up to a stump diameter of around 12 inches (30 cm) and then decreases. Dominant *Quercus* trees on the Connecticut site were 80 to 100 years old and averaged 20 to 30 cm dbh. Allowing for the difference between dbh and stump diameter, these trees fell well within the range of stump diameters capable of producing large numbers of sprouts. However, approximately half of all stumps ≥ 10 cm at the Connecticut site failed to sprout.

Intensive use of mechanized equipment may partially explain the small percentage of stumps sprouting and the small number of sprouts measured in Connecticut relative to findings from studies by Mann (1984) and Boring et al. (1981). Mann (1984) found a lower number of sprouts on a whole-tree-harvested site compared with a sawlog-harvested site. She reported that skidding of whole trees tended to increase mechanical damage to stumps and soil, and removal of nonmerchantable residues reduced protection of soil surface and stumps afforded by leaving these materials in conventional harvests. Miller and Phillips (1984) demonstrated that shearing by fellers damaged stumps and resulted in lower numbers of sprouts. Whole-tree harvesting disturbed approximately 70% of the soil surface of our site in Connecticut (Martin 1988). Although we did not assess associated damage to stumps, we observed that shearing tended to shatter stumps, especially birch. It is likely that mechanical harvesting reduced the number of stumps that sprouted as well as the number of sprouts per stump to some degree. Site quality is another factor that may have influenced sprouting. Mroz et al. (1985) concluded that sprout numbers for northern hardwoods were independent of site quality, but similar studies have not been reported for central hardwoods.

Importance of Sprouts in Conserving Nutrients

One of the major concerns with clearcutting in general and with whole-tree clearcutting in particular is the potential for a substantial loss of nutrients from the site both by the removal of wood products and leaching losses. Rapid revegetation of the site will reduce these losses in several ways (Bormann and Likens 1979, Hornbeck 1986). The first is by the sequestering of available nutrients from the soil into long-term storage in aboveground biomass. The second is by covering the watershed with vegetation which shades the site, increases transpiration, slows the velocity of raindrops which reduces erosion and increases infiltration, and works toward restoring the microclimate of the site. Sprouts play a major role in both processes since they have rapid initial growth rates.

Throughout the first 5 years after cutting at our site, sprouts stored about 13% (11 to 18%) of the nitrogen, calcium, and potassium accumulated on the watershed by all aboveground living biomass, and about 20% of those elements stored in tree species. The first year after cutting, this represented 1 to 3 kg ha^{-1}, but by year 5 had increased to 10 kg ha^{-1} of potassium and calcium and 18 kg ha^{-1} of nitrogen. These fifth-year values represented 6% of the nitrogen stored in aboveground living biomass of the precutting forest, 2% of the precutting calcium, and 6% of the precutting potassium.

Boring et al. (1981) reported biomass from a 1-year-old clearcut in the southern Appalachians that was similar to ours. They reported 1,725 kg ha^{-1} to our 1,540 kg ha^{-1} for all living biomass. Accumulations of nitrogen and potassium were similar on both sites, but nearly twice the calcium accumulated at the North Carolina site. However, they reported 63% of their biomass was sprout biomass, with 57% of the nitrogen, 35% of the potassium, and 61% of the calcium occurring in sprouts.

The southern Appalachian site may represent one extreme in the amounts of nutrients that may be sequestered by 1-year-old biomass because of the lack of soil disturbance and stump damage and the longer growing season of North Carolina. Our site may represent the other extreme due to the more northern climate and the severe site disturbance and stump damage caused by mechanical whole-tree clearcutting.

SUMMARY

1. Stump sprouts are an important component in the revegetation of a central hardwood forest after whole-tree clearcutting. They are especially important in the early stages of forest development. They play an important role initially in reestablishing the microclimate of the site; then they play a transitional role in forest development. However, stump sprouts alone may not regenerate a viable forest.

2. Competitive thinning and root diseases change the dynamics of the sprout population too rapidly to predict, at year 5, whether trees of sprout origin will be a major component of the future forest.

3. Revegetation of all types, including herbs, shrubs, and tree seedlings and sprouts, play a vital role in conserving nutrient elements on the site.

4. Whole-tree clearcutting does not seem to have radically changed the species composition of the site. The composition of the regeneration on the whole-tree clearcut is similar to that of the preharvest forest. Before cutting, *Acer* was the most common genus followed by *Quercus* and *Betula*. At year 5, *Betula* is the most common, followed by *Acer* and *Quercus*. Prior to harvesting, *Quercus* contained the most biomass, followed by *Betula* and *Acer*. At year 5, *Acer* had accumulated the most biomass, followed by *Quercus* and *Betula*.

5. *Quercus* is the most commercially valuable genus in the region. Therefore, forest managers are likely to encourage oak regeneration in this region. If so, it is important for them to consider the sprouting potential of the site before cutting, including:

a. species,
b. stump diameters,
c. season of cutting,
d. stump- and root-disease potential,
e. soil-disturbance potential,
f. stump damage during logging.

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