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THE IMPACT OF ASPEN HARVESTING ON SITE PRODUCTIVITY

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ABSTRACT

Aspen management can affect site productivity in two major ways: First, aspen accumulates large amounts of nutrients (especially Ca) in its biomass. Harvesting removes these nutrients from the site and, in the long run, site quality will decline if these nutrients are not replenished. Second, the harvesting operation itself can cause site quality loss through soil physical disturbance or through accelerated soil organic matter decomposition and nutrient leaching losses. Our understanding of the processes controlling site productivity is very weak, therefore our ability to predict the consequences of management activities on site productivity is very limited. Current research will help correct this weakness.

SITE PRODUCTIVITY

Site productivity can be defined in terms such as plant biomass, wildlife, water, and aesthetics. For this paper, site productivity refers to the inherent ability of a site to grow vegetation. This is largely determined by soil and climatic factors. The best measure of site productivity is net primary production (Grier et al. 1989). Stand productivity, the actual production of a given stand, is controlled by inherent site productivity and by insect, disease, thinning, fertilization, and other factors. Site and stand productivity are not necessarily related; to distinguish between them is crucial in evaluating management activities. For example, severe scalping may improve survival and growth of planted trees by controlling the competing vegetation. In such a case, stand productivity might be enhanced but site productivity diminished. Management practices affect site productivity primarily through their effects on the soil, and it is by soil monitoring that the implications of management practices on long-term site productivity can best be evaluated.

HARVESTING IMPACTS

Forest harvesting can affect site productivity in two major ways. First, it takes with it organic matter and nutrients in the harvested biomass. These materials have accumulated over the life of the stand and may have caused slow soil changes over time. Secondly, it directly affects the soil, for example, by accelerated leaching of nutrients, increased oxidation of soil organic matter, and physical disturbance of the site, i.e., soil displacement, erosion, or compaction.

Monitoring soil properties will help evaluate management practices, but for deeper understanding, extrapolating to new situations, and designing ameliorative treatments, the actual processes controlling site productivity, such as moisture and nutrient dynamics, must be quantified.

Biomass Removal

Aspen accumulates more of most nutrients, particularly Ca, than its common associates (Table 1). Aspen also has a much greater fraction of nutrients in the stem bark than other species (Table 2). The amounts of Ca annually accumulated in aspen stands are greater than the uptake by many agricultural crops. This suggests the possibility of significant soil changes due to the growth of aspen. If the Ca accumulated in the aspen biomass is not replaced by precipitation inputs or soil weathering, soil Ca will decline and soil pH will decrease. Such an effect was noted on two sites in Minnesota where soil pH declined about 0.5 pH units (Alban 1982). Soil pH also declined in Tennessee under oak, another Ca accumulator. The soil changes there were accentuated by acidic precipitation (Johnson and Todd 1987). If a site that has had soil Ca and pH lowered by aspen growth is harvested, soil changes should continue during the second rotation. But the rate of change is unknown and may be mitigated by feedback mechanisms. For example, the lowered pH may increase the rate of mineral weathering.

Nutrient accumulation by aspen stands can clearly affect soil characteristics at least on some sites. This should alert us to the possibility of site productivity changes. For example, radiata pine (Pinus radiata D. Don) and Norway spruce (Picea abies [L.] Karst.) grew less when logging slash was removed than when it was left on the site (Squire et al. 1985; Sterba 1988).

For aspen we have only a few case studies showing soil changes. Our knowledge of the relation between soil properties or processes and tree growth is too limited to draw firm conclusions, either in general or on a specific

Table 1. Aboveground biomass nutrient accumulations

<table>
<thead>
<tr>
<th>Species</th>
<th>Age</th>
<th>Location</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspen</td>
<td>40</td>
<td>Minnesota</td>
<td>368</td>
<td>47</td>
<td>287</td>
<td>858</td>
<td>58</td>
<td>Perala and Alban 1982</td>
</tr>
<tr>
<td>White spruce</td>
<td>39</td>
<td>Minnesota</td>
<td>389</td>
<td>59</td>
<td>234</td>
<td>734</td>
<td>41</td>
<td>Perala and Alban 1982</td>
</tr>
<tr>
<td>Red pine</td>
<td>39</td>
<td>Minnesota</td>
<td>356</td>
<td>43</td>
<td>180</td>
<td>302</td>
<td>59</td>
<td>Perala and Alban 1982</td>
</tr>
<tr>
<td>Jack pine</td>
<td>39</td>
<td>Minnesota</td>
<td>264</td>
<td>25</td>
<td>99</td>
<td>203</td>
<td>38</td>
<td>Perala and Alban 1982</td>
</tr>
<tr>
<td>Aspen</td>
<td>66</td>
<td>Minnesota</td>
<td>439</td>
<td>55</td>
<td>354</td>
<td>1589</td>
<td>112</td>
<td>Alban (unpublished)²</td>
</tr>
<tr>
<td>Aspen</td>
<td>47</td>
<td>Michigan</td>
<td>249</td>
<td>30</td>
<td>179</td>
<td>729</td>
<td>62</td>
<td>Alban (unpublished)²</td>
</tr>
<tr>
<td>Aspen</td>
<td>45</td>
<td>Wisconsin</td>
<td>207</td>
<td>21</td>
<td>107</td>
<td>441</td>
<td>43</td>
<td>Boyle et al. 1972</td>
</tr>
<tr>
<td>Aspen</td>
<td>65</td>
<td>Wisconsin</td>
<td>620</td>
<td>64</td>
<td>460</td>
<td>1100</td>
<td>90</td>
<td>Pastor and Bockhein 1984</td>
</tr>
<tr>
<td>Mixedwood b</td>
<td>60-95</td>
<td>Ontario</td>
<td>362</td>
<td>42</td>
<td>188</td>
<td>596</td>
<td>73</td>
<td>Hendrickson et al. 1987</td>
</tr>
</tbody>
</table>

²Aspen comprises 32% of the biomass of this stand. Red and white pine contribute most of the remainder.
Table 2. Percentage of nutrients in tree tissues

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Nitrogen (%)</th>
<th>Calcium (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jack Aspen</td>
<td>Jack Aspen</td>
</tr>
<tr>
<td>Foliage</td>
<td>24 25</td>
<td>4 10</td>
</tr>
<tr>
<td>Branches</td>
<td>22 30</td>
<td>25 26</td>
</tr>
<tr>
<td>Bole wood</td>
<td>23 32</td>
<td>20 36</td>
</tr>
</tbody>
</table>

*Perala and Alban 1982.

site. Leaving limbs, tops, and especially the bark on sensitive sites will minimize nutrient withdrawals and likely will not cause nutrient deficiencies.

Leaching Losses

Timber harvesting generally results in lessened evapotranspiration and increased water-flow through the soil. For most species and soils, harvesting will result in a flux of some nutrients through the soil for a few years, but the loss is generally small relative to that removed in the harvested timber (Mann et al. 1988). In aspen, stream flow increased 42% the first year after clear-cutting in Minnesota, and returned to precut levels in 9 years (Verry 1987). Clear-cutting aspen stands on a wide range of sites in Minnesota, Michigan, and Ontario caused essentially no leaching losses of N and P and just a few kilograms per hectare of K and Mg (Hendrickson et al. 1989; Silkworth and Grigal 1982; Richardson and Lund 1975). Only Ca loss was statistically significant, but even for Ca the loss was small and unlikely to have an impact on subsequent growth. The evidence is thus quite strong that aspen harvesting is unlikely to accelerate leaching loss of nutrients sufficiently to affect site productivity.

Organic Matter Loss

Loss of soil organic matter has been identified as one way that forestry operations might lower site productivity (Powers et al. 1990). A classic case occurred in New England, where clear-cutting caused a large decrease in forest floor weight (Covington 1981), but it was not clear whether the decreases represented actual losses from the site or simply a redistribution to deeper soil horizons. More intensive sampling showed that total carbon pools before and after harvest did not differ (Huntington and Ryan 1990). Neither were soil carbon changes found after clear-cutting a mixed hardwood forest in Tennessee (Edwards and Ross-Todd 1983). In an Ontario forest stand containing aspen, soil organic matter to a depth of 20 cm was not significantly different 3 years after harvesting (Hendrickson et al. 1989).

In a study of three sites having sand, loam, and clay soils, whole-tree harvesting of aspen did not change the soil carbon content (Table 3; Alban and Perala 1990). The increased oxidation of organic matter following harvesting is compensated for by the addition of logging slash and decaying root systems. Any accelerated organic matter loss would be short-lived because regeneration is usually rapid, the site is fully occupied quickly, and annual litterfall returns to pre-harvest levels within 5 years (Alban and Perala 1990). It seems that for most sites,

Table 3. Soil carbon content before and after harvesting

<table>
<thead>
<tr>
<th>Sandy soil (Minnesota)</th>
<th>Loam soil (Minnesota)</th>
<th>Clay soil (Michigan)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-harvest</td>
<td>Post-harvest</td>
<td>Pre-harvest</td>
</tr>
<tr>
<td>Uncut</td>
<td>57</td>
<td>55</td>
</tr>
<tr>
<td>Clear-cut</td>
<td>58</td>
<td>62</td>
</tr>
</tbody>
</table>

*Forest floor plus top 25 cm of mineral soil.

bPost-harvest is the mean value for all years since harvesting (7 years for the sandy and clay soils and 4 years for the loam soil).
whole-tree aspen harvesting will not result in loss of soil organic matter by accelerated decomposition.

**Soil Physical Disturbance**

Soil displacement by root raking or erosion generally lowers productivity and often has detrimental off-site effects. It also creates adverse public reaction. For these reasons, most land managers attempt to keep soil displacement to a minimum, and good guidelines are available for doing so (Perry et al. 1989). Because factors other than site productivity largely determine how soil displacement is managed, it will not be discussed further in this review.

Soil compaction is perhaps the single most important site impact of forest management. Heavy machinery in both agriculture and forestry can, under some conditions, compact soils. This results in changes in soil strength, aeration, infiltration rate, and moisture and nutrient regimes. These changes can have dramatic effects on plant growth. Excellent reviews of forest soil compaction are available (Froehlich and McNabb 1984; Greacen and Sands 1980; Standish et al. 1988). Unfortunately, few unconfounded data are available on the impact of soil compaction on forest growth and there is virtually none for aspen. Froehlich and McNabb (1984) showed that decreased height growth in several conifers was directly related to an increased soil bulk density. When soil bulk density was increased by 70%, height growth was reduced by about 45%. Application of this relationship to other species on other areas is subject to gross errors. It is known from agriculture experience, for example, that soil compaction, by increasing fine pore spaces, can increase soil moisture-holding capacity, resulting in increased plant growth, particularly in dry years (Raghavan et al. 1981).

The complex interaction of plant species, soils, and climate make predictions of compaction effects on tree growth and the rate of soil recovery marginal at best. For aspen the information is equally meager. I am aware of only two studies in aspen that examine how harvesting affects soil compaction. In a study on two Minnesota sites and one Michigan site, harvesting was on snow-covered, frozen ground, in a purposeful attempt to avoid compaction. Not surprisingly, soil bulk density was not affected (Alban and Perala 1990). In an earlier study in north-central Minnesota, a 50-year-old aspen stand on a silty clay loam soil was tree-length harvested, and surface soil bulk density was increased from 1.15 g/cm³ to 1.47 g/cm³ on heavily disturbed areas with little recovery after one year (Mace 1971). Unfortunately, the effects of the compaction on tree growth were not reported. We are unable (on a site-specific basis) to reliably predict the impact of aspen harvesting on soil compaction or how it affects tree growth.

To address this lack of knowledge, the literature was reviewed comprehensively to evaluate the factors responsible for site productivity decline (Powers et al. 1990). Organic matter removal and soil compaction were the factors most often associated with productivity decline. A U.S. nationwide study was proposed to evaluate these two factors. Research plots have since been installed in Louisiana, California, and Minnesota. Three levels of compaction and three levels of organic matter removal are applied to a wide range of soils and forest types. The objective is to quantify the relationship between site productivity and the soil properties and processes controlling plant growth. Climate will be measured on each site because, even though management practices are unlikely to have an effect on climate, the impacts of compaction and organic matter removal on site productivity will be affected by climate and must be accounted for.

In the Lake States, the study will examine the aspen forest type. It is anticipated that the results will be applicable over a wide range of sites. Extension of the study to sites throughout the range of aspen would encompass a wide range of soils and climate and could provide powerful means to quantify the impacts of harvesting on site productivity.

**SUMMARY AND CONCLUSIONS**

If aspen harvesting affects site productivity, it does so by changing soil properties. Long-term nutrient accumulation by aspen can lower soil nutrients, particularly Ca. Such effects can be augmented by acid precipitation or increased precipitation. The impacts of such effects will be quite site-specific, and we currently have no
reliable method to assess the magnitude of the effect on site productivity.

Some harvesting impacts appear to be minor for many sites. Leaching loss of nutrients and accelerated organic matter loss appear to be small; however, such generalization must be tempered by the knowledge that aspen grows over a wide range of soils and climates.

Soil compaction is likely to alter site productivity in some cases, but our predictive ability is limited. The effects of soil compaction can be avoided on the most susceptible sites by harvesting when the soil is dry or frozen. Nevertheless, these mitigating practices would be put on a sounder and more rational basis if the impacts could be reliably quantified.

In general, our knowledge of management impacts on site productivity is based on case studies, most of which are retrospective. Extrapolation of results to new areas and new situations is risky. Therefore, in most cases the implications of a given forest management practice on long-term site productivity cannot be accurately assessed. What are needed to correct this deficiency are designed and replicated studies to manipulate the soil and to develop the relationship between site productivity and soil properties and processes. Such studies will quantify the key soil factors that can be monitored to assess the management impacts on site productivity.

Soil monitoring should be an integral part of forest management activities in the 21st century. That information, fed back to research, will suggest areas requiring further study, which will in turn refine and improve the monitoring guidelines. The complex problem of assessing harvesting impacts on site productivity can best be resolved by such a joint partnership between researchers and people directly involved in the management of forest lands.

LITERATURE CITED


