Applying Principles of Landscape Design and Management to Integrate Old-Growth Forest Enhancement and Commodity Use

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Abstract: Using geographic information systems (GIS) and spatial analysis techniques, we developed 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 clearcutting practices are modified to partial cutting 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 also by the management strategy used to integrate commodity production.
tem, but by modifying the management of the majority commodity lands matrix as well.

Introduction

Background

Demands for land managers to produce commodities and conserve biological diversity concurrently are increasing (Probst & Crow 1991). As a result, greater attention is being given to the role that the vast areas under some form of active management for food and fiber can play in maintaining biological diversity (Franklin 1993). Clearly, there is a need for greater integration of biodiversity enhancement and commodity production on managed landscapes (Wilcove 1989; Crow 1991; Hansen et al. 1991; Probst & Crow 1991).

Biological diversity maintenance must be accomplished at a multitude of spatial scales in order to meet all needs (Noss & Harris 1986; Noss 1987; Crow 1991). Reserve areas, both large and small, remain essential for many ecological processes, and to provide protection and isolation from human influences for many species. For some processes and for wide-ranging species, effective reserves must generally be larger and more numerous than has typically been the case (Diamond & May 1976; Pickett & Thompson 1978; Baker 1989; Noss 1991). At the same time improved management and planning are needed on commodity lands to ensure future productive potential as well as to contribute to diversity maintenance through more integrated and ecologically based land-use practices (Probst & Crow 1991; Mladenoff & Pastor 1993). Throughout eastern North America—and indeed much of the world's temperate climatic zone—past and current land uses have created an extensively and intensively altered landscape with few remaining natural areas. Biodiversity maintenance in these landscapes poses significant challenges for enhancing the value and functioning of remaining natural fragments.

Objectives

We approached this situation on a forested Wisconsin landscape in the northern Great Lakes region (Fig. 1, inset). Because of the complex mixed ownership of this landscape, simply delineating a large reserve area surrounding the old-growth patches is not a management option. This is increasingly the case elsewhere as competition between land uses increases even under public ownership forests. The objective of our study, old-growth enhancement in a commodity landscape, is limited to addressing a specific portion of biodiversity maintenance needs based on the opportunities provided by a real world example. Yet maintaining old growth as functional ecosystems and for the habitat values they provide is important in this region (Tyrrell & Crow 1989). Forests once characteristic of the region, largely old growth (Frellich & Lorimer 1991), are now reduced to less than 0.5% of their former extent (Eckstein 1980). Late-successional forests, particularly with large conifers, are important as forest bird habitat because of their more diverse structure and composition (Jaako Pöyry Consulting, Inc. 1992; Howe et al. 1993). In the Border Lakes landscape, much of the remaining old growth contains eastern hemlock (Tsuga canadensis), which has been nearly eliminated regionally by past logging and land-use practices (Mladenoff & Stearns 1993).

Given this importance, our goal is to develop a landscape design that enhances the value of remaining natural old-growth forest by restoring characteristic landscape-scale features. To do so we used geographic information systems (GIS) and a hierarchical approach to develop our design. Our task here is to develop a design that protects and enhances the current old-growth ecosystems both judiciously and effectively. A requirement of the design is to integrate harvesting with the protection and enhancement of old-growth forest. The landscape contains scattered, small remnants of old-growth forest within a matrix of managed second growth in mixed ownership (mostly private with some public land).

Integration of Previous Work

Results of previous work are key to our design and include a comparison of landscape pattern in the Border Lakes, characteristic of managed second-growth landscapes, with that of the Sylvania Wilderness, a nearby, reference old-growth landscape (Mladenoff et al. 1993). We also verified that the Sylvania landscape was comparable to Border Lakes through a reconstruction of the pre-European landscape and historical vegetation. These data were used to analyze temporal landscape transitions to the present and to project future conditions (White & Mladenoff 1994). We previously found that
the pre-European landscape, as reflected by Sylvania, had important characteristics that are now lacking on Border Lakes and in much of the region (Mladenoff & Pastor 1993). (1) The natural old-growth landscape has a greater range of forest patch sizes (ranging from less than 1 to more than 1000 ha) compared to Border Lakes (ranging from less than 1 to 200 ha), resulting in greater edge-interior ratios on Border Lakes. (2) Patch complexity, as measured by fractal dimension (Mandelbrot 1977) is significantly greater on the natural landscape, providing for greater interspersion of ecosystems and habitats. (3) Characteristic adjacency relationships, where particular ecosystems typically occur next to certain other ecosystems, no longer occur on the managed landscape. This adjacency relationship may be important for complex, multiple habitat requirements, or for seed dispersal and stand regeneration. The strongest adjacency relationship found on the Sylvania landscape occurred between old-growth hemlock and lowland conifer ecosystems.

We examined the scales at which important landscape features are expressed in the natural landscape (Mladenoff et al. 1993) to decide what might realistically be restored or managed at the scale of the Border Lakes landscape. We determined that several key objectives might be met, based on our previous analysis (Mladenoff et al. 1993). These objectives were (1) to restore significant ecosystem spatial adjacency relationships that exist in the natural landscape, and (2) to enhance the integrity of the interior of remaining old-growth forest. We then developed techniques to incorporate those features in a landscape design using modifications of landscape patch structure, and by proposing modified and spatially segregated forest harvesting. These techniques include adding and—potentially, over time—restoring some old-growth forest. At the same time, we designed a plan where forest harvesting decreases in intensity from outer to core old-growth areas. Continued forest cutting is a given condition in this landscape.

Our purpose in this study has a limited scope. Using a real landscape, we seek to present an example of a conceptual approach and techniques for designing integrated forest landscapes using GIS. To illustrate, we compare our sample design with prior conditions and features found in a natural old-growth landscape through our previous work.

Study Landscape

Our study landscape, known as the Border Lakes area, is located in north-central Wisconsin, U.S.A. (46°12'N, 89°34'W), with Michigan's upper peninsula adjacent to the north (Fig. 1). Climate is continental, with mild summers and long, cold winters with snow cover from November to April. Mean temperatures are —10° C for January and 18° C for July, with approximate annual precipitation of 85 cm.

Our design encompasses the eastern two-thirds of the Border Lakes landscape (4415 ha), which contains all current old-growth forest remnants. Like much of the region, this morainal landscape contains many lakes and wetlands within an upland forest matrix that was formerly dominated by conifers such as eastern hemlock and northern hardwood species, predominantly sugar maple (Acer saccharum) and yellow birch (Betula alleghaniensis). White pine (Pinus strobus) was present as an admixture and locally abundant on sandy soils (Curtis 1959; White & Mladenoff 1994).

Today, only scattered remnants of the original old-growth hemlock and northern hardwood forest remain. Second-growth forests of successional hardwoods such as aspen-birch (Populus tremuloides–Betula papyrifera) and conifers such as spruce-fir (Picea glauca–Abies balsamea) predominate in pure stands and in a variety of mixtures, along with second-growth northern hardwoods dominated by sugar maple (Mladenoff et al. 1993). These second-growth forests are common to this boreal–northern hardwood transition region (Walter et al. 1995). Past human disturbance and the vagaries of site, climate, and stochastic events have produced a more complex and varied assemblage of types on the landscape than originally occurred (Pastor & Mladenoff 1992).

Methods

The original landscape map was derived from 1:24000 color infrared stereo photography. The photos were interpreted and forest and land cover mapped onto a rectified base map. The map was digitized into the ARC/INFO geographic information system software (ESRI, Inc. 1987). Data acquisition and GIS database creation methods are detailed in Mladenoff et al. (1993). All second-growth types delineated in Mladenoff et al. (1993) are mapped here as general upland and lowland categories. Old-growth forest contrasts markedly from the dominant younger forests on the site. Old growth was identified from air photos and historical information. In our discussion we refer to these mapped patches as vegetation types or ecosystems, as seems most appropriate in a given context. Ecosystems may be described at any scale, and different forest types in this region have different characteristic ecosystem processes (Pastor & Mladenoff 1992). Where we are discussing potential habitat value of these different patch types or ecosystems, we refer to them as habitats.

Our analysis methods here are techniques used to meet design objectives. We used GIS and several spatial analysis methods to develop and assess the landscape
structural changes in our proposed design. These structural changes were created by designing an old-growth restoration zone around the existing old-growth patches. Complementary management changes are incorporated into the design by aggregating harvesting methods into zones and assuming qualitative changes in their implementation. Thus a moderately harvested secondary zone was designated beyond the restoration zone, as well as a more intensively managed outer zone (Fig. 2).

Edge/Interior Analysis

We used the BUFFER procedure in ARC/INFO to evaluate edge/interior conditions of a habitat patch by generating a band of specified width around the interior of the polygon boundaries, to yield a map with habitat edge and interior differentiated (Fig. 1). We then calculated amounts and proportions of old-growth edge and interior, and edge/interior ratios for the original landscape and the designed landscape. In our example we used a 100-meter edge effect extending into old-growth patches adjacent to immature forest or wetlands (Franklin & Forman 1987). We also chose the 100-meter edge value as a guide in restoring old-growth buffers, assuming that many adjacent areas will eventually be cut, causing greater edge effects than occur now. Other specific edge-effect distances can be justified for specific objectives. For example, Brittingham and Temple (1983) found higher nest parasitism by cowbirds up to 300 meters into forest patches from agricultural edges. In our landscape, we are assuming microclimate effects that may influence tree reproduction or ecosystem processes as well as effects on habitat value (Franklin & Forman 1987; Chen et al. 1992).

Our main design objective is to insure the integrity of all existing old-growth forest. Based on our 100-meter edge effect assumption, we delineated a 100-meter-wide buffer around all existing old-growth polygons within upland areas, designating these areas as the old-growth restoration zone. We then compared the spatial effects of this change on the landscape with the prior condition. The width of the secondary zone (300 meters) was also chosen based on our 100-meter edge assumption. Any areas of the secondary zone will have some minimum habitat interior even if isolated by disturbance or serving as a corridor between larger patches.

Adjacency Analysis

We conducted an adjacency analysis using the electivity index of Jacobs (1974) and Jenkins (1979), and as applied previously (Pastor & Broschart 1990; Mladenoff et al. 1993) to evaluate how the juxtaposition of different
Figure 2. Border Lakes study landscape (4415 ha) with remnant old-growth hemlock and hardwood forest types. The diverse matrix of surrounding second-growth forest types (Mladenoff et al. 1993) are mapped as general upland or lowland forest types. Map includes landscape design with all zones: (1) current old-growth, (2) 100-meter restoration zone, (3) 300-meter secondary zone, (4) general commodity management outer zone.

Ecosystem types change due to the addition of the restoration zone to the landscape:

\[ E_{ij} = \ln\left(\frac{r_{ij}P_{ij}}{r_{ij}P_{ij}}\right) \]

where \( E_{ij} \) is the electivity index for the nearest neighbor probabilities of patch types \( i \) and \( j \), and \( r_{ij} \) is the proportion of shared boundary between type \( i \) and type \( j \). \( P_{ij} \) is the proportion of shared boundary of type \( i \) with all other patch types except type \( j \). These electivity index values are compared with the chi-square distribution for significance of positive or negative association between ecosystem types.

We mapped a band of specified width (here 20 m) around the outside of all polygons of a type to determine the type and relative perimeter proportion of the adjacent ecosystem patch types using the BUFFER procedure in ARC/INFO (Fig. 3). We applied this analysis to the existing landscape and compared it to an identical analysis of the proposed landscape design with hypothetically induced changes due to management.

We also used ARC/INFO to summarize patch types by number and area, to generate management-zone boundaries of specified width around the old-growth forest types, and to assess future changes in old-growth patch sizes and forest interior based on our design.

Results and Discussion

Edge/Interior Analysis

The total edge area in the current landscape, based on the 100-meter buffer, is 282.6 ha, or nearly 84% of the total old-growth area (Fig. 1, Table 1, upper values). The old-growth hemlock type is most affected by edge, because the complex, linear shapes leave little forest interior (Table 1, upper values, Fig. 1). Hemlock forests create a highly modified microclimate within stands compared to hardwoods (Godman & Lancaster 1990). They also differ significantly in ecosystem processes such as nitrogen cycling (Mladenoff 1987) and structural features such as coarse woody debris (Tyrrell & Crow 1989; Tyrrell 1991). Logically, edge contrast may affect forest processes most in these stands.

The remaining old-growth hardwoods are less affected by edge than hemlock, though still significantly reduced in interior (Fig. 1, Table 1, upper values). Hardwood patches retain proportionately nearly three times as much area in forest interior as hemlock (20.9% versus 7.1%), due both to larger patch size and simpler shape. Similarly, edge habitat surrounding interior hardwoods is proportionately less than that surrounding hemlock (7.0% versus 13.8%) (Fig. 1, Table 1, upper values).
Adding the 100-meter buffer as an old-growth restoration zone means that all existing old growth will become forest interior, thereby maximizing its integrity. By adding this relatively small but key area to the old-growth forest, reserved land area is increased by only 174.8 ha, but with substantial effective changes in the landscape. Besides maximizing old-growth interior, many formerly isolated old-growth patches now coalesce, thus increasing their potential habitat value for these ecosystems and better assuring their functional integrity (Fig. 2). The number of separate old-growth patches has been reduced from 19 to eight, and the

### Table 1. Edge/interior analysis of current old growth (upper values) and old growth plus 100-meter exterior restoration zone (lower values).

<table>
<thead>
<tr>
<th></th>
<th>Overall</th>
<th>Interior</th>
<th>Edge</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Area</td>
<td>%</td>
<td>n</td>
</tr>
<tr>
<td>HEMLOCK (original)</td>
<td>222.7</td>
<td>66.0</td>
<td>15</td>
</tr>
<tr>
<td>Restored</td>
<td>328.2</td>
<td>64.1</td>
<td>14</td>
</tr>
<tr>
<td>HARDWOOD (original)</td>
<td>114.6</td>
<td>34.0</td>
<td>13</td>
</tr>
<tr>
<td>Restored</td>
<td>183.9</td>
<td>35.9</td>
<td>10</td>
</tr>
<tr>
<td>COMBINED (original)</td>
<td>337.3</td>
<td>100.0</td>
<td>19</td>
</tr>
<tr>
<td>Restored</td>
<td>512.1</td>
<td>100.0</td>
<td>8</td>
</tr>
</tbody>
</table>

*Edge and interior classes are based on an assumption of 100 meters edge effect extending into old-growth adjacent to second-growth forest (see Methods). Data are for total area (ha), percentage of total, number of patches in each class, and mean patch area (ha).
mean patch size, possibly the most important factor, increased more than three-fold from 17.8 to 64.0 ha (Table 1).

Most of the added 100-meter restoration zone ends up under the edge category, not forest interior, and much of it serves as relatively narrow links between formerly isolated patches when a 100-meter edge is assumed (Table 1). Currently, less than 3.0% of the study landscape is in clearcuts and other openings (Table 2). However, nearly all of the second growth is at or approaching harvest age. Therefore, under conventional management, additional harvest patches would be expected soon to increase significantly. We therefore feel that our conservative approach to this design criterion is justified when planning for future management. Adjacent to new clearcuts, edge effects much greater than 100 meters may be created (Franklin & Forman 1987; Chen et al. 1992).

**Adjacency Analysis**

The adjacency analysis map with the "restored" old-growth hemlock polygons (original old-growth hemlock plus 100-meter restoration zone) shows old-growth neighbor associations (Fig. 3). In the current landscape, hemlock is not spatially associated with lowland conifers. In the restored landscape, old-growth hemlock is again positively associated with lowland conifers (Table 3). In addition, the negative relationship between old-growth hardwoods and lowland conifers, and the positive associations between old-growth hardwoods and hemlock, still remain (Fig. 2, Table 3). These associations were all important in the natural Sylvania landscape and the pre-European Border Lakes (Mladenoff et al. 1993; White & Mladenoff 1994).

**Discussion**

**Landscape Design**

Much is unknown about the relation between ecological processes and landscape patterns. Yet we have found that there are characteristic patterns that define both natural old growth and disturbed, managed landscapes (Mladenoff et al. 1993). In this context it is prudent to attempt to mimic natural landscape structure, restoring aspects that can be managed at different scales (Crow 1991). Habitat interior, old-growth patch size, and landscape linkage can be significantly increased at the scale of our landscape design (1000s of hectares), even where constrained by commodity management. A design using the fine-grained manipulations possible with GIS allows important ecosystem juxtapositions to be restored on the landscape while maintaining efficient land use. These improvements may benefit area-sensitive species requiring mature forest ecosystems, as well as restore a degree of connectivity for ecosystem processes and species dependent on greater landscape linkage.

The natural old-growth landscape had attributes of landscape structure that we could not restore at this scale (Mladenoff et al. 1993). The full range and distribution of old-growth patch sizes on Sylvania (less than 1 to more than 1000 ha) could not be replicated on the Border Lake landscape. The natural old-growth landscape also contained forest patches of more complex shape than those of the disturbed Border Lakes. More-complex patch shapes increase the relative amount of forest edge. In the natural landscape, however, the greater number and size of old-growth patches allows both forest interior (habitat) and patch interspersion (connectivity) to be maximized (Mladenoff et al. 1993). Also, in the natural landscape fewer patch edges are high-contrast, induced edges characteristic of heavily disturbed forest landscapes. These features cannot generally be restored at the limited spatial extent of our study landscape.

**Complementary Management Changes**

Our design to maintain the integrity of the old-growth forest remaining on the Border Lakes landscape reduces

<table>
<thead>
<tr>
<th>Area (ha)</th>
<th>Restored</th>
<th>Original</th>
<th>% Area</th>
<th>Restored</th>
<th>Original</th>
<th>Number of Patches</th>
<th>Restored</th>
<th>Original</th>
<th>Mean Patch (ha)</th>
<th>Restored</th>
<th>Original</th>
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<tr>
<td><strong>Old Growth</strong></td>
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<td></td>
</tr>
<tr>
<td>Hemlock</td>
<td>329.9</td>
<td>223.0</td>
<td>7.5</td>
<td>5.1</td>
<td>14</td>
<td>15</td>
<td>23.6</td>
<td>14.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardwood</td>
<td>183.9</td>
<td>114.6</td>
<td>4.2</td>
<td>2.6</td>
<td>10</td>
<td>13</td>
<td>18.4</td>
<td>8.8</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Second Growth</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>N. Hardwood</td>
<td>1301.1</td>
<td>1388.3</td>
<td>29.5</td>
<td>31.5</td>
<td>95</td>
<td>74</td>
<td>13.7</td>
<td>18.8</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Mixed Hardwood</td>
<td>540.6</td>
<td>549.5</td>
<td>12.2</td>
<td>12.5</td>
<td>42</td>
<td>39</td>
<td>12.9</td>
<td>14.1</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Hardwood and Conifer</td>
<td>375.9</td>
<td>387.0</td>
<td>8.5</td>
<td>8.8</td>
<td>33</td>
<td>32</td>
<td>11.4</td>
<td>12.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardwood over Conifer</td>
<td>1022.7</td>
<td>1052.0</td>
<td>23.2</td>
<td>23.8</td>
<td>131</td>
<td>107</td>
<td>7.8</td>
<td>9.8</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Mixed Conifer</td>
<td>549.3</td>
<td>585.4</td>
<td>12.4</td>
<td>13.3</td>
<td>155</td>
<td>126</td>
<td>3.5</td>
<td>4.7</td>
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</tr>
<tr>
<td>Upland Open</td>
<td>109.4</td>
<td>115.0</td>
<td>2.5</td>
<td>2.6</td>
<td>22</td>
<td>22</td>
<td>5.0</td>
<td>5.2</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Total</td>
<td>4414.7</td>
<td>4414.7</td>
<td>100.0</td>
<td>100.0</td>
<td>502</td>
<td>428</td>
<td>12.0</td>
<td>11.0</td>
<td></td>
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</tbody>
</table>

*Restored version has 100 meters added to perimeter of all old-growth patches.*
Table 3. Adjacency analysis of patch types in current landscape (upper symbols) and restored landscape (lower symbols).*

<table>
<thead>
<tr>
<th></th>
<th>Old Growth</th>
<th>Second Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LC</td>
<td>HE</td>
</tr>
<tr>
<td>Lowland Conifer</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Old-Growth Hemlock</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Old-Growth Hardwood</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Second-Growth</td>
<td></td>
<td></td>
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<tr>
<td>Northern Hardwood</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Mixed Hardwood</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Hardwood/Conifer</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Hardwood over Conifer</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Mixed Conifer</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

*Restored landscape has 100 meters buffer addition to old-growth patches. Associations shown for $X^2 > 7.78$, 1 df, $p < 0.005$.

the isolation and increases the size of the original old-growth patches, but the distribution of these ecosystems leaves a complex map with a large proportion of existing and potential old growth (restoration zone) in the edge category (Fig. 2). The secondary zone buffer of 300 meters surrounding the restoration zone and existing old-growth partly ameliorate this condition (Fig. 2). The proposed forest management within this zone is uneven-aged, with eventual creation of a mature forest that is structurally and compositionally similar to the adjacent old-growth. This will provide a secondary buffer to the entire design and particularly to the narrow old-growth linkages between larger old-growth patches (Fig. 2).

A combination of secondary buffering with a narrow restoration zone maximizes old-growth enhancement while still maintaining commodity production. This integration of harvesting and biodiversity protection can be further enhanced by matching spatial buffering with what is, in effect, temporal buffering through selection cutting. In selection harvesting, cutting of trees in a stand is spread over many years. Selection cutting includes a variety of harvesting intensities, and thus it is not necessarily a conservation panacea. Removing a large proportion of basal area (>30%) can result in inadequate intact canopy for some habitat needs (Lorimer 1989), and frequent entries can also require maintenance of large road networks. Existing guides provide the management flexibility to grow more trees into larger diameter classes while maintaining stand structure (Arbogast 1957; Crow et al. 1981). Retaining a greater number of trees in larger size classes, maintaining higher stand basal area, increasing the time between cuttings, and creating canopy gaps for regeneration all increase stand structural diversity (Crow et al. 1981; Mladenoff & Pastor 1993). Such an approach will provide higher-value products, thus providing some incentive for these changes (Tubbs 1977; Marquis 1978). The existing forest types within the secondary zone are largely suitable to this modified selection management. Over 75% of the uplands are dominated by northern hardwoods (largely sugar maple) or are succeeding to northern hardwoods and conifers (Table 4).

The outer zone of the landscape design, beyond the secondary buffer, can accommodate more intensive—but modified—even-aged management designed to maintain successional species such as aspen and birch, as well as uneven-aged management of northern hardwoods (Pastor & Mladenoff 1993). Successional types can be managed by partial cutting in mixed stands with conifers such as spruce/fir—for example, alternating harvests of aspen with rotations of fir (Graham et al. 1963). Selected species can be retained in clumps and large individuals for structural diversity that more resembles naturally regenerating stands (Hansen et al. 1991; Franklin 1993; Mladenoff & Pastor 1993). Over 50% of the uplands in this zone are mixed stands of aspen, birch, spruce, and fir that can be maintained using these modified silvicultural systems.

This tiered landscape design is in some respects a
Table 4. Summary of patch types within old-growth restoration zone (100 meters), 300-meter buffer zone, and outer zone.

<table>
<thead>
<tr>
<th>Area (ha)</th>
<th>Old Growth and (100 m) Restoration Zone</th>
<th>300-m Buffer Zone</th>
<th>Outer Zone</th>
<th>Old Growth and (100 m) Restoration Zone</th>
<th>300-m Buffer Zone</th>
<th>Outer Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowland Conifer</td>
<td>136.2</td>
<td>240.2</td>
<td>711.6</td>
<td>20.9</td>
<td>34.8</td>
<td>17.1</td>
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<tr>
<td>Hemlock</td>
<td>329.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Hardwood</td>
<td>183.9</td>
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<tr>
<td>Second Growth</td>
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</tr>
<tr>
<td>N. Hardwood</td>
<td></td>
<td>172.4</td>
<td>1130.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixed Hardwood</td>
<td></td>
<td>39.2</td>
<td>501.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardwood and Conifer</td>
<td>51.9</td>
<td>324.0</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Hardwood over Conifer</td>
<td>95.5</td>
<td>926.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixed Conifer</td>
<td></td>
<td>86.8</td>
<td>460.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upland Open</td>
<td></td>
<td>5.2</td>
<td>104.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>650.0</td>
<td>691.2</td>
<td>4157.8</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

modification of the multiple-use module (MUM) presented by Harris (1984) and Noss and Harris (1986). Their approach recognizes that reserve cores and corridors do not exist in isolation from the larger managed landscape context (Noss 1987; Franklin 1993). In our design, however, we place equal emphasis on modifying forest management practices within the zones beyond the old-growth core as well as on the spatial gradient of management intensity of the different zones per se. Harvests can be spread temporally through the use of modified selection harvesting, which is well suited to many forest types in this region. This provides a more finely-grained and lower contrast integration of harvesting and biodiversity protection than in the simplest application of the MUM concept. By necessity of ownership, the harvested matrix zones (secondary zone and outer zone) will continue to constitute 11.9% and 75.9% of the landscape design, making their dual purpose very important and providing incentive for finer integration of the dual management objectives (Table 4). In an integrated design, however, the landscape plan must be evaluated on the basis of changes in the management of the commodity forest matrix as well as the amount of buffers and corridors provided.

Summary

As applied here, integrated forest management landscape designs can increase the value of small, isolated ecosystem remnants for protection of certain biodiversity values, even in situations where forest harvesting will continue. Selected landscape structural attributes can be restored at characteristic scales while maintaining greater within-stand structure by combining spatial changes with qualitative management modifications.

The hierarchical management zones efficiently buffer the core area while allowing harvesting intensity to increase with distance from the core. Buffer zones are managed temporally as well as spatially. Innermost zones are managed as uneven-aged forest favoring retention into larger diameter sizes. Management of the outer zone includes even-age harvesting accomplished with partial cutting techniques (Mladenoff & Pastor 1993).

The constraints of our dual objectives meant that some characteristics of the old-growth landscape, such as the range of patch sizes, the shape complexity of large patches, and dominance by an old-growth matrix, could not be restored on the Border Lakes. Clearly, not all conservation objectives can be met at only one or several scales; context as well as content of reserves must be considered in their design, and a need remains for very large reserves if the full array of natural processes are to be maintained on the landscape. Our landscape design is an example of a concept and technique. Other landscapes and ownerships may provide opportunities for modifying the balance of commodity production and biodiversity protection in different ways.

Such designs, coupled with modified silvicultural techniques, can contribute to more ecologically sustainable forest management. Not only do such techniques directly benefit the ecological health of the system, but they increase biological diversity, provide a further ecological buffer and sources of colonization, and hedge against future change. In this way such landscape designs both extend biodiversity protection into the managed forest matrix and help to insure the future productive potential of managed forests.

Acknowledgments

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Literature Cited


