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**Northeastern Forest
Experiment Station**

General Technical
Report NE-140

Is Forest Fragmentation a Management Issue in the Northeast?

FOREWORD

The term 'forest fragmentation' has been widely used to describe various removals of the forest overstory; removals have ranged from small to large, temporary to permanent. The importance of such removals to wildlife and fish habitats is directly related to their size and permanence. Forest fragments have been compared to oceanic islands, with rates of species extinction and recolonization related to woodlot "island" size and nearness to larger woodlands. This paradigm may have some utility in describing effects on forest lands where the landscape consists of scattered woodlots separated by non-forest land uses such as agriculture or urban development.

The resultant distribution of island woodlots affects the population of breeding birds, forest mammals, and plants within these woodlots.

The effects of forest fragmentation have been most intensively studied with respect to birds. In essentially nonforest landscape, small (<20 ha) isolated woodlots have few neotropical migrant species, but resident forest species are usually present. Isolated woodlots likely present dispersal barriers, lack suitable microhabitats or result in higher rates of nest predation or brood parasitism at woodland edges.

The effects of forest fragmentation on mammals have not been nearly as well studied as have effects on birds. Mammals, generally, are not as habitat-specific as birds, especially common small mammals of the Northeast. In New England, forests are increasing in extent and age. Consequently, species that were formerly rare or extirpated have become abundant during the last few decades--for example, moose, fisher, and black bear. Frequent human disturbance, rather than fragmentation, is likely the major factor limiting forest mammal populations. Most northeastern forests have well-developed road and trail networks which provide ready access for hunters and hikers. Frequent stand entries for forest management also produce access routes and disturbance.

But we must be careful when using evidence from isolated forests in suburban or agricultural landscapes and projecting potential effects of forest management on wildlife in heavily forested northeastern landscapes. In much of New England, early successional habitats are becoming less common as former agricultural land reverts to forest. Many privately owned woodlands are held for reasons other than timber products. The result is a landscape that is increasingly composed of mature forest.

In such a landscape, habitat alteration due to forest management is probably not analogous to that produced by suburban development or agriculture, where the forest is indeed fragmented and exists only as islands of various sizes.

Caution is also needed when considering migratory species, especially neotropical migrant birds whose local breeding populations are influenced by conditions existing in their specific winter habitats.

Last, we must distinguish species that have large home ranges from those that are sensitive to human disturbance, whether by forest management or recreation. To maintain habitats for species that require seclusion or large blocks of woodland, forest management that maximizes the intervals between stand entry and limits vehicular access must be found. The following papers offer ideas on forest management that can help maintain habitats for area-sensitive and shy species, both important components of northeastern forests.

Is Forest Fragmentation a Management Issue in the Northeast?

Papers from the technical session sponsored
by the Wildlife and Fish Ecology Working Group
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MANAGEMENT ISSUE IN THE EASTERN UNITED STATES[1]

David S. Wilcove[2]

Abstract. The impact of forest fragmentation on wildlife in the eastern United States has become an important and controversial issue among land managers, scientists, and environmental organizations. Numerous studies of small woodlots in rural and suburban settings have shown major declines in forest bird populations. Other taxa have not been studied as thoroughly, but evidence suggests that certain mammals, amphibians, reptiles, and plants are adversely affected by forest fragmentation. Because federal and state forests are among the few remaining large, relatively undisturbed tracts of land in the eastern United States, they are important population centers for species sensitive to forest fragmentation.

Introduction

One of the most significant developments in the application of conservation biology to land management has been the realization that virtually all natural areas are destined to resemble islands in that they will eventually become smaller, more isolated fragments of what was once a much larger natural landscape (Wilcox 1980). Restricted to small areas and surrounded by human- modified environments, fragmented landscapes can suffer a loss of biological diversity, most noticeably through the extinction of populations. In the eastern United States, forest fragmentation has become one of the most important and controversial topics in wildlife management — important because the long-term viability of many species may be at stake, and controversial because the deliberate fragmentation of large, contiguous forest patches is a time-honored principle of wildlife management.

In this paper I briefly review the empirical evidence that forest fragmentation is a threat to certain species of plants and animals in the East. I then discuss the extent to which we can (and should) apply the results of current studies to the management of large forest ecosystems, such as those that exist in our national forests.

[1]A paper presented at the Convention of the Society of American Foresters, Rochester, NY. October 16 – 19, 1988.

[2]The Wilderness Society, Washington, D.C. 20005

A Review of the Evidence

Birds

Birds are by far the most intensively studied taxa with respect to fragmentation. They also provide the most compelling evidence to date that forest fragmentation is a serious threat to certain wildlife species. This evidence falls into two categories: long-term studies and presence/absence studies.

Long-term studies. In a small number of parks and nature reserves, observers have monitored population changes in breeding birds by conducting intensive, long-term censuses (see Figure 1). These long-term studies show major population declines of certain species of forest-dwelling songbirds that breed in the United States and Canada but winter in Latin America and the Caribbean (neotropical migrants). In contrast, species that breed and winter within the U.S. — permanent residents and short-distance migrants — usually exhibit stable or even increasing populations within the same forest tracts.

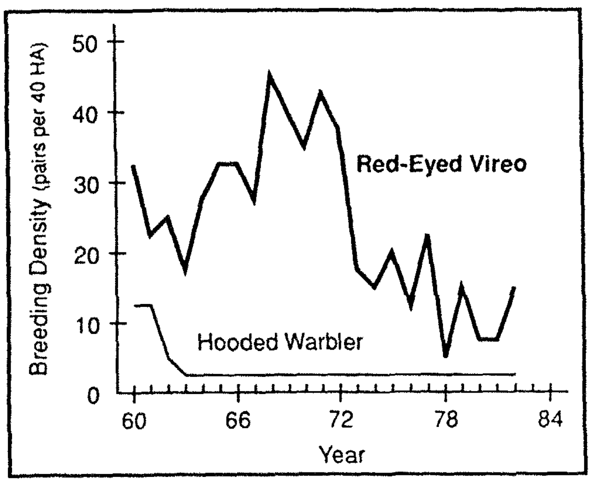

Figure 1. — Declines in breeding populations of two species of neotropical migrants in Glover-Archbold Park, a 14-ha forest reserve in Washington, D.C.

Presence/absence studies. Numerous studies have examined forest tracts of different sizes and noted the absence of certain species from all but the largest ones (Robbins 1979, Whitcomb et al. 1981, Askins et al. in prep.). Widespread neotropical migrants like the hooded warbler and yellow-throated vireo are consistently absent from small (< 20 ha), isolated woodlots, while permanent residents like the black-capped chickadee, northern cardinal, and blue jay are usually present.

We are slowly discovering the mechanism by which fragmentation causes these changes in forest bird communities. A partial list includes the following:

(1). Dispersal barriers. Neotropical migrants may have difficulty colonizing isolated woodlots when they return from their wintering grounds (Whitcomb et al. 1981). Dispersal barriers may be physical in nature (i.e., finding the woodlot is difficult because it is surrounded by nonforested lands) or psychological (i.e., the absence of conspecifics to serve as a cue that suitable breeding habitat is on hand; see Whitcomb et al. 1981).

(2). Absence of suitable microhabitats. When an extensive forest tract is fragmented, individual woodlots may lack the full range of microhabitats that existed in the original tract. Species that require the missing microhabitat(s) may be unable to survive in the woodlots (see Lynch and Whigham 1984, Bond 1957). In east-central Maryland, for example, northern parulas usually occur in bottomland forests and along streams. Fragments lacking either a bottomland or riparian component are unlikely to be suitable habitat for them. Changes in forest structure due to natural succession can make particular woodlots unsuitable for neotropical migrants that are partial to younger forests. However, succession alone cannot explain most of the population changes. The population declines have been too severe, too rapid, and too widespread to reflect gradual changes in forest vegetation. Also, many of the forest-dwelling neotropical migrants are able to use a wide variety of forest types and ages (Whitcomb et al. 1981).

(3). Small populations. Songbirds in isolated fragments are subject to the same problems that plague all small populations, including demographic fluctuations, genetic deterioration, and environmental perturbations (see Soule 1987).

(4). Edge effects. Field studies by Gates and Gysel (1978), Chasko and Gates (1982), and Brittingham and Temple (1983) have shown that the nesting success of songbirds is lower near forest edges than in the interior. This is because many nest predators (blue jay, American crow, common grackle, eastern chipmunk, short-tailed weasel, raccoon) and brood parasites (brown-headed cowbird) occur in higher densities around forest edges. Brittingham and Temple (1983) have also shown that rates of cowbird parasitism increase near openings within large forest tracts, a finding with obvious implications for forest management. Since an increased ratio of edge to interior is an inevitable byproduct of fragmentation, one might predict that forest birds would suffer higher rates of nest predation and parasitism in small woodlots compared to large tracts. Experimental studies (Wilcove 1985) support this hypothesis. Temple (1986) has shown that irregularly shaped forest fragments with high ratios of edge to interior harbor fewer area-sensitive songbirds than more compact fragments of similar size.

Mammals

Studies of the impact of forest fragmentation on eastern mammals have suffered from two handicaps. First, throughout much of eastern North America, the species that were probably most sensitive to forest fragmentation disappeared long before anyone could study them. For example, in their study of the impacts of forest fragmentation on the mammals of southern Wisconsin, Matthiae and Stearns (1981) noted that the woodland bison, elk, wolverine, black bear and lynx had vanished from the region as long ago as 1850. Almost by definition, the species that persist today in heavily developed areas like southern Wisconsin are those most adept at surviving in fragmented, human- dominated landscapes.

Second, few studies have disentangled the effects of forest fragmentation per se from simply the presence of people in once-wild areas. Consider, for example, the ongoing controversy over management of black bear habitat in the southern Appalachians. The black bear now occupies only five to ten percent of its original range in the southeastern U.S., where it survives primarily on federally-owned lands containing designated or de facto wilderness (Pelton 1985). In April 1986, the U.S. Forest Service released a management plan for the Cherokee National Forest in Tennessee. The plan called for increased logging levels and the construction of up to 2,600 miles of new roads through the forest over the course of 50 years.

Several conservation organizations appealed the plan on the grounds that logging and road construction would jeopardize the bear's survival by: (1) reducing the amount of available mast, especially during the fall months when the bears must store energy in preparation for hibernation; (2) displacing bears; and (3) making the forest more accessible to poachers. Of these three reasons, only the first one is directly related to forest loss. The other two are simply consequences of bringing more people in contact with bears. Were it possible to remove trees without deploying people and building miles of roads, the impact on black bears would probably be relatively minor. Black bears, like many other large mammals, use a variety of habitats and seral stages, but fare poorly in close proximity to humans.

These two handicaps notwithstanding, studies by Matthiae and Stearns (1981) and Fahrig and Merriam (1985) have shown that certain mammals are indeed more common in large forest tracts compared to small, isolated woodlots.

Thus, the impact of forest fragmentation on eastern mammals falls into two categories: the actual reduction and isolation of suitable habitat for forest-dwelling species and the loss of "wildness" for species that do not adapt well to the presence of people

Other Animals

Non-feathered, non-furred animals, such as reptiles, amphibians, and most invertebrates, have received very little attention in studies of forest fragmentation in the East. I predict that forest-dwelling species requiring two or more habitat types or a range of microhabitats will prove to be quite sensitive to fragmentation (Wilcove et al 1986). Examples would include salamanders and tree frogs that require ponds for breeding and woodlands for food and shelter, and snakes that require hibernacula in addition to foraging and breeding habitat.

Plants

Two studies from Wisconsin have shown that forest fragmentation changes patterns of seed dispersal and herbivory, with potentially large declines in populations of certain plant species. Ranney et al (1981) believe that the seed rain into the cores of small woodlots in Wisconsin is dominated by the seeds of edge species. This rain may ultimately change the species composition of woodlots, as the shade tolerant plants of the interior (e.g., sugar maple, American beech) are replaced by shade intolerant forms from the edge (e.g., hickories, hawthorns, basswood). Alien plants such as kudzu and Japanese honeysuckle will colonize openings and edges and gradually expand into the forest interior.

Alverson et al (1988) believe that overbrowsing by white-tailed deer has severely affected the abundance and population structure of several woody and herbaceous plant species in Wisconsin's Chequamegon National Forest. Regeneration of Canada yew, eastern hemlock, and white cedar, in particular, may no longer occur in many areas due to deer depredation.

The authors point out that prior to the arrival of European settlers, deer were relatively sparse in northern Wisconsin, with densities averaging less than four individuals per square kilometer, and probably as low as two per square kilometer. Extensive logging, coupled with restrictive hunting laws has allowed deer numbers to build, with densities reaching as high as nine individuals per square kilometer in some parts of the Chequamegon. Current management practices, such as dispersed clearcuts and wildlife openings, are designed to maintain or enhance these high densities of deer. Alverson and colleagues recommend the establishment of large (200-400 km2) contiguous blocks of mature forest as a way to create areas of low deer density in which the declining plant species could grow. This recommendation was the basis for their appeal of the Final Land and Resource Management Plan for the Chequamegon National Forest, which is now pending before the Chief of the Forest Service.

Lessons for Large Landscapes

Many of the seminal studies of forest fragmentation were conducted in small woodlots in suburban or rural areas. This has led some people to question whether such studies are applicable to the management of large forested landscapes, such as eastern national forests, where logging practices are not creating isolated stands of trees surrounded by barren land, but rather an interconnected matrix of forest at different stages of succession. However, studies of deleterious edge effects are clearly applicable to the management of large forest ecosystems, because edges are precisely what clearcuts and wildlife openings create.

Studies by Ranney (1977) and Wales (1972) have shown that the major vegetation changes caused by edges extend only 10-30 m inside the forest, depending on exposure. The edge-related increase in nest predation, on the other hand, extends much farther. Based on some preliminary studies, Wilcove et al (1986) suggest it may extend as far as 300-600 m inside the forest. If these values are more or less accurate, they have important management implications, because a small number of openings dispersed throughout a forest could have a profound impact over a vast area (see Figure 2).

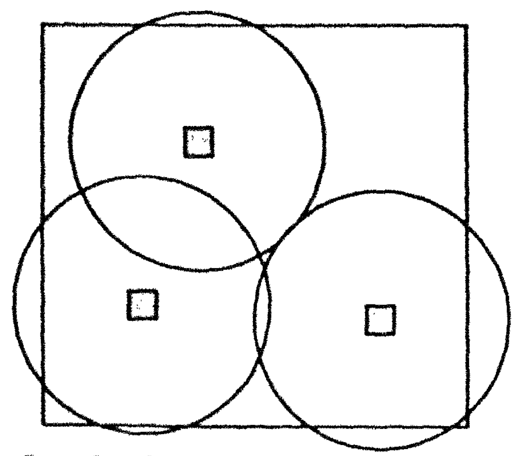

Figure 2 — The square (with stippling) represents a 400-ha block within a forest. Three 1-ha openings (hatched areas) have been created in this block. Rates of nest predation and cowbird parasitism are higher around the edges. This edge-related increase in predation and parasitism may extend as far as 600 m into the forest. If so, most of the 400-ha block is subject to higher nest predation rates as a result of just three openings, as shown by the three circles with radii equal to 600 m.

Although widespread, the high rates of nest predation around forest edges may not be a universal phenomenon. Experiments with artificial nests in Florida and Idaho forests (R. Noss, pers. comm.; Ratti and Reese 1988), for example, have not shown significant differences in predation rates between edge habitats and forest interior habitats. The explanation may lie in the nature of the landscape surrounding the forests and openings (Angelstam 1986). If the forest abuts an area that is highly productive for nest predators and sustains large populations of them (i.e., a suburban neighborhood with lots of raccoons, dogs, cats, and blue jays), then predation rates along the edges and well into the woods will be high. If the surrounding lands do not support high densities of nest predators, nest losses along edges will be less severe. (This argument may not apply to cowbirds, which are capable of flying long distances into the forest [Rothstein et al. 1984] and which use clearings as vantage points for spotting potential hosts.).

Sufficient data now exist to demonstrate the importance of large forest tracts for certain species of plants and animals in the eastern United States and to lead us to rethink the conventional wisdom of dispersing clearcuts and wildlife openings throughout contiguous forest tracts. But beyond this general conclusion— when it comes time to choose among different timber cutting practices and configurations— there is little to guide us in the way of empirical research. Unfortunately, only a handful of studies have focused on the impacts of actual clearcuts, and these have yielded inconclusive results. For example, authors sometimes assume that because area-sensitive bird species still occupy a forest that is riddled with openings, the openings are having no impact on them. Without data on the reproductive success of these birds, such conclusions are premature (see Yahner 1986).

I suggest the following as important research topics in the East: a comparison of different silvicultural methods (even-aged versus uneven-aged) with respect to impacts on the breeding success of forest songbirds; similar studies of human-made openings versus natural tree-fall gaps; studies of the relationship between clearings of different sizes and shapes and the spread of exotic plants; and more surveys of small mammals, reptiles, and amphibians in forests of different sizes, shapes, and degrees of isolation.

The Special Role of Public Lands

Federal and state forests serve a special function in the East, where they are among the few remaining large, undeveloped tracts of land. As such, they are important population reservoirs for wildlife sensitive to forest fragmentation. For example, the fate of gray wolves and black bears over much of the eastern United States will depend on the way public lands such as national and state forests and national parks are managed. The private land base is simply too developed or too small to sustain such species. If Illinois and Indiana are to maintain large, healthy populations of forest songbirds, it will be in places like the Shawnee and Hoosier National Forests, where extensive forest tracts still occur. Lands this important deserve our close attention.

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LANDSCAPE ECOLOGY OF FOREST BIRDS IN THE NORTHEAST[1]

Kathryn E. Freemark[2]

Abstract. Studies of forest birds in agricultural landscapes near Ottawa, Canada are presented to illustrate the need to incorporate the landscape ecology of wildlife into forest management plans. Spatial and temporal characteristics of landscape structure important to wildlife include forest stand size, habitat heterogeneity among stands, temporal dynamics in wildlife-habitat relationships, and the regional context of forest stands in the landscape. Research needed to improve our understanding of the relationship between landscape structure and the distribution and survival of wildlife is discussed.

Introduction

Forests cover about 45 percent of Canada's total land area (Forestry Canada 1989). About half is inventoried, productive forest (i.e. commercially viable) of which 80% is provincially owned, 11% is federally owned and 9% is privately owned.

Legislation, in at least some provinces, requires that forest management plans for provincial lands be developed and assessed with respect to maintenance of wildlife populations. To meet this requirement in New Brunswick for example, the Department of Natural Resources and Energy (DNRE) is developing a model for predicting the impact of different forest management plans on wildlife populations in relation to forecasted changes for existing forest stand types. To accomplish this, DNRE requires information on population levels in existing stand types for the 36 mammalian and 106 avian species dependent upon N.B. forests.

Because of our research expertise and legislative mandate for managing migratory birds, the Canadian Wildlife Service was approached by DNRE with a proposal for censusing birds in forest stands in N.B. In its proposal, DNRE had recognized the relationship between plant species composition and vegetation structure of stands and avian use, and the need for spatial replicates to measure within-stand variation. However, other potentially important factors related to newly-emerging ideas in landscape ecology (Risser et al. 1984, Forman and Godron 1986) were not considered. Spatial and temporal characteristics of landscape structure potentially important to forest wildlife include (1) forest stand size, (2) habitat heterogeneity (i.e. variability in habitat conditions) among stands, (3) temporal dynamics in avian use of forest stands, and (4) the regional context (e.g. extent and configuration) of forest stands in the landscape.

To illustrate the importance of landscape structure to wildlife, and to provide a basis for discussing their relevance to the development of forest management plans, I will present data for birds in forest fragments in agricultural landscapes near Ottawa, Canada.

Forest Size and Habitat Heterogeneity

Freemark and Merriam (1986) demonstrated the importance of forest size and habitat heterogeneity by examining breeding birds in a size range of forests near Ottawa, Canada. Habitat heterogeneity within forests was measured for plant species (tree, shrub and ground), and for forest structure (tree density/diameter, canopy height/closure, understory/ground cover) by an index of habitat heterogeneity (HH) derived from the Shannon information index.

The number of bird species increased significantly with forest area (Fig. 1). Forest size explained half or more of the variation among forests in the number of bird species, number of bird pairs, and number of pairs per species (Table 1). Components of habitat heterogeneity were secondarily important.

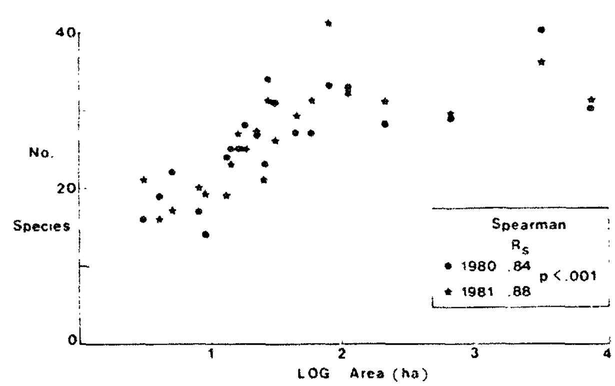

Figure 1 — Species-area patterns in forest birds near Ottawa, Canada

The importance of forest size and habitat heterogeneity varied among ecological classes of birds (Fig. 2). Habitat heterogeneity was particularly important to edge

[1]A paper presented at the Convention of the Society of American Foresters, Rochester, NY. October 16-19, 1988.

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Table 1 — Multiple linear regressions for birds in 21 forests (3- 7620 ha) near Ottawa, Canada, 1980-81. NS indicates nonsignificance.

		Partial Regression Coefficient and (% Variance Explained)				
Bird Variable	Y intercept	Log Area	HH Tree Spp.	HH Shrub Spp.	HH Ground Spp.	HH Forest Structure
No. spp.	14.1	4.8(50)	—	1.0(5)	- 10.0(4)	8.5(8)
No. pairs	-2.2	3.8(66)	—	8.5(7)	- 4.6(3)	—
No. pairs/spp.	0.7	0.9(62)	—	2.4(8)	- 1.2(4)	—

species. The edge-related classes accounted for the inverse relationships with ground plant heterogeneity (Table 1) because more of these species used more open-canopied forests with lower ground plant heterogeneity. In contrast, forest size was particularly important to forest-interior species and long-distance (neotropical) migrants, although habitat heterogeneity was secondarily important to some of these classes (Fig. 2). Some ecological classes of birds (e.g. forest-interior, species with large territories) were absent or rare in smaller forests as indicated by very low or negative y- intercepts (Table 2).

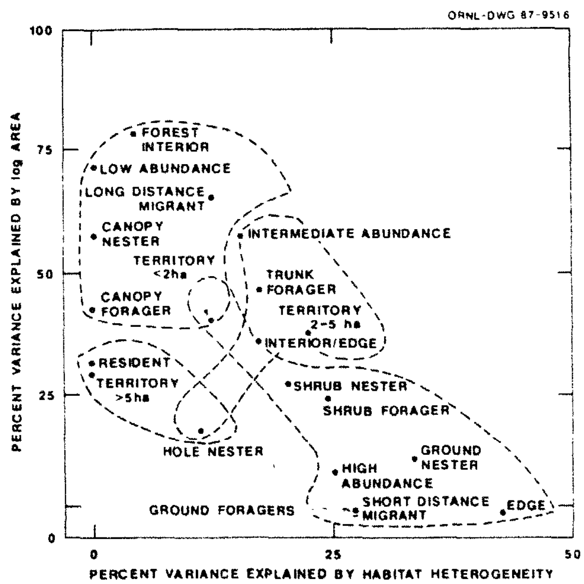

Figure 2 — Importance of forest size (log area) and habitat heterogeneity (HH) to numbers of species in ecological classes of birds. Delineated classes share a significant number of species. (Redrafted from Freemark and Merriam 1986).

Temporal Dynamics in Habitat Use

Temporal patterns in bird species use were analyzed for the forests studied by Freemark and Merriam (1986) to investigate variability in habitat use by birds between years. Species classified as utilizing only forest edges were removed from the analyses because they were less likely to be entirely resident in a forest and therefore could artificially inflate species turnovers (cf. McCoy 1982). The total number of bird species within forests was very similar between years (Table 3). Turnover in species composition between years averaged about 5 species per forest, or 18% of the total species number for both years combined.

Table 2 — Multiple regressions for ecological classes of birds underrepresented in the smaller of 21 forests (3-7620 ha) near Ottawa, Canada, 1980-81. NS indicates nonsignificance. (Abstracted from Freemark and Merriam 1986)

		Partial Regression Coefficient and (% Variance Explained)				
Bird Class	Y intercept	Log Area	HH Tree Spp.	HH Shrub Spp.	HH Ground Spp.	HH Forest Structure
Forest Interior Habitat	-4.7	3.7(78)	NS	4.6(4)	NS	NS
Low Regional Abundance	- 0.4	2.9(71)	NS	NS	NS	NS
Territory >5 ha	0.4	0.7(29)	NS	NS	NS	NS
Trunk Foragers	- 1.3	1.1(46)	NS	2.9(11)	NS	1.9(6)

Table 3 — Summary of annual turnovers in forest interior and interior/edge bird species within 21 forests (3-7620 ha) near Ottawa, Canada, 1980-81[a]

Bird Variable	Mean	SD	Range
Species Number			
$\lvert S1 - S2 \rvert$	1.7	1.1	0 – 4
Species Composition			
SE + SI	4.9	2.2	2 – 9
100 (SE + SI) / (S1 + S2)	18.1	8.2	8 – 36

a/ S1 = No. of species in year I

S2 = No. of species in year 2

SE = No. of species present in year 1 only i.e. local extinctions within forests

SI = No. of species present in year 2 only i.e. local immigrations within forests

Regional Context of Forests

As noted above, some ecological classes of birds were absent or uncommon in the smaller forest fragments studied above. Various factors could explain these patterns (see reviews in Askins et al. 1987, Freemark 1988, Whitcomb et al. 1981). Of greatest significance to the development of forest management plans is the potential relationship between the presence of wildlife species in smaller fragments and the regional context (i.e. extent and configuration) of forests.

Regression analyses for the forests studied by Freemark and Merriam (1986) indicated that annual turnovers in number and composition of bird species were not significantly related to either forest size (log area) or habitat heterogeneity within forests, despite the inverse relationship between forest size and number of pairs per species (Table 1), which could have resulted in more "local extinctions" due to stochastic changes in population size (cf. Wright and Hubbell 1983). For birds in these forests, high immigration rates each spring may counterbalance greater extinction rates of small populations within smaller and/or less heterogeneous forests by the "rescue effect" of demographic and genetic contributions from conspecifics (sensu Brown and Kodric-Brown 1977). In that case, populations of many species in these smaller forests are not self-sufficient but are part of a larger regional "metapopulation" (cf. Shaffer 1985). Their persistence depends on overwinter survival of individuals, regional availability of enough forest habitat to ensure sufficient production of new individuals each year, and dispersal of individuals among fragments each spring (Askins and Philbrick 1987, Askins et al. 1987, Whitcomb et al. 1981, and models by Fahrig and Merriam 1985, Urban and Shugart 1986).

To investigate the importance of the regional context of forests further, bird species patterns were compared for two agricultural landscapes near Ottawa. The landscapes differed in the extent and configuration of their forests (Table 4). One landscape had more farmland, less forest, more isolated forests, and greater distances between extensive forests. This less-forested landscape contained 16 of the 21 forests studied by Freemark and Merriam (1986). In contrast, the second landscape had less farmland, more forest, fewer isolated forests, and shorter distances between extensive forests. Because the range of forest sizes was replicated between landscapes, and bird species composition was very similar (Table 5), differences in bird species patterns among forests were assumed to reflect differences in the regional context of forests rather than effects of forest size or geographical differences in the bird species pool.

Table 4 — Landscape patterns near Ottawa, Canada, interpretated from Landsat TM imagery. (Abstracted from Muchoki 1988)

	ARNPRIOR	RENFREW
Study Area (km^2)	450	400
Percent Cover		
Agriculture	67	50
Forest	19	30
Wetlands	5	9
Residential	2	1
Other	7	11
No. Isolated Woodlots	54	17
Distance Between Extensive Forests (km)	16	3

In both landscapes, the total number of bird species increased with greater forest size (Fig. 3). The most rapid increase in total species number occurred among forests less than 100 ha. Further analyses were restricted to this size range because differences in the regional context of forests are most likely to affect bird species patterns in small forests.

Patterns in bird species number among small forests differed between landscapes (Table 6). The difference in intercepts indicates that the smallest forests (particularly those <10 ha) in the less-forested landscape had significantly more species than the smallest forests in the more-forested landscape. The difference in slopes indicates that forests in the more- forested landscape accumulated species more rapidly as forest size increased than forests in the less-forested landscape.

Table 5 — Patterns in forest birds for two different landscapes near Ottawa, Canada

Variable	Landscape		
	Less-forested		More-forested
	1980	1981	1984
No. forests	16	16	13
Forest size (ha)	3-7620	3-7620	3-8600
Total no. bird species	64	63	65
No. Species by Ecological Class:			
Habitat Use			
Forest-interior	18	19	25
Interior/edge	16	17	16
Edge	30	27	24
Migratory Status			
Long-distance	29	31	30
Short-distance	20	18	20
Resident	15	14	15
Territory Size			
<2 ha	31	32	31
2-5 ha	26	25	26
>5 ha	7	6	8
Nesting Stratum			
Canopy	22	21	25
Shrub	14	15	13
Ground	15	14	16
Hole	11	11	9
Parasitic/buildings	2	2	2
Foraging Stratum			
Canopy	11	12	12
Shrub	23	23	22
Ground	19	18	20
Trunk	8	8	8
Raptors	3	2	3

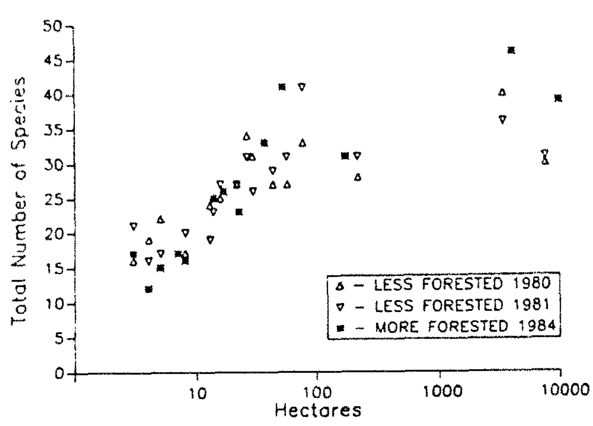

Figure 3 — Species-area patterns in forest birds for two different landscapes near Ottawa, Canada

Patterns in species number between landscapes varied among ecological classes of birds. Few species with territories larger than 5 ha, or that nest only in forest interiors, were found in forests under 10 ha in either landscape. Regressions for the less-forested landscape had significantly higher intercepts for 4 classes of bird species (Table 6). For at least some species (e.g. those using edge/interior habitats), small forests were particularly important when few large forests were available in the landscape (cf. Arnold 1983, Blake and Karr 1987).

Table 6 — Significant differences (p>.05) in regression parameters between landscapes near Ottawa, Canada, for birds species number vs. log(area) of forests <100 ha. NS indicates nonsignificance.

Ecological Class	Landscape with Higher Intercept	Higher Slope
[a] Edge/Interior	Less-forested	NS
[ac] Cavity-nesting	Less-forested	NS
[b] Forest-interior	NS	More-forested
[c] Large-territory	NS	More-forested
[c] Resident	Less-forested	More-forested
[b] Canopy-nesting	Less-forested	More-forested
[abc] Total Species	Less-forested	More-forested

[abc]Classes with same letters share a significant number of species

Regressions for the more-forested landscape had significantly higher slopes for 4 classes of bird species (Table 6). The dispersal of species (such as those restricted to forest interiors) into smaller forests appeared to be enhanced in the landscape in which forests were less isolated and in which there was a greater amount of forest to provide immigrants to maintain and replenish populations in individual forests. Since most bird species breeding in these forests are migrants that effectively recolonize the local region annually, it is more likely that distribution of birds among forests is limited more by the total amount and size distribution of forests rather than the ability of species to disperse among forests (cf. van Dorp and Opdam 1987).

Implications for Forest Management

Management plans aimed at maintaining forest wildlife should take into account spatial and temporal characteristics of landscape structure other than just plant species composition and vegetation structure within stands. Forest stand size can be a primary determinant of bird species composition. Habitat heterogeneity among forest stands could also be secondarily important. In order to maintain a diverse forest avifauna, both forest stand size and habitat heterogeneity among stands should likely be maximized in the landscape. Greater habitat heterogeneity may provide a more complete and more flexible range of necessary resources in a smaller area for at least some wildlife species.

Populations of forest birds are regional (i.e. populations within individual forest stands are part of a larger "metapopulation"). The persistence of some species within stands is related to the regional configuration of stands, through effects on the flow of individuals among stands. In particular, the presence/persistence of wildlife species which are most sensitive to forest fragmentation (e.g. birds restricted to forest interiors or with large territories) can be enhanced by increasing the total amount and interconnectivity of forests within landscapes.

Forest management plans based on wildlife-habitat relationships from single- season surveys may be misleading given the temporal dynamics in habitat use by birds evident in species turnover within forest fragments (cf. Karr and Freemark 1983). The assumption that local density of a species during a single breeding season is positively correlated with habitat quality often breaks down under intensive study, particularly when habitat use in winter is critical, local conditions (e.g. food resources, predation pressure, abiotic factors) vary among years, or individuals build up to high densities in lower- quality habitats during peak population years (cf. van Horne 1983).

Research Needs

Little research has yet been done on the relationship between spatial and temporal patterns in landscape structure and the distribution and survival of wildlife (but see Merriam 1988). A better understanding of the landscape ecology of wildlife is needed in order to develop better management strategies to minimize potential impacts of natural and human-induced disturbance, and to enhance the persistence of the entire complement of wildlife species and habitats.

Temple and Wilcox (1986) contend that habitat fragmentation looms as one of the most significant challenges to wildlife management in the future. Given the increasing public interest in recreational use of forests (Rose 1988, Willeke 1988), the relationships between habitat fragmentation, landscape structure and wildlife need to be determined for forested landscapes.

Harris (1984) proposed a planning and management strategy for the maintenance of old-growth forest in the U.S. Pacific Northwest based on size-frequency distribution, spatial distribution and connectivity of old-growth stands. Some of these principles are currently being applied to the management of the spotted owl (Strix occidentalis) in the the Pacific Northwest (USDA Forest Service 1985). Franklin and Forman (1987) investigated the ecological consequences of forest fragmentation from clearcutting by using a model of the dispersed-patch or checkerboard system currently practiced on federal forest lands in the western United States. Biotic components (e.g. diversity of forest-interior species, game populations) and probability of subsequent disturbance (e.g. windthrow, wildfire) were highly sensitive to changes in landscape structure associated with progressive cutover.

In the Northeast, field studies suggest that forest-interior birds in extensively-forested landscapes in Vermont have not been adversely affected by clearcutting (D.E. Capen, personal communication). Additional research is needed to investigate the apparent differences in response of forest wildlife to landscape structure along the gradient of habitat fragmentation from extensive-forest to agricultural landscape. Research efforts should focus on the following:

- Effects of forest size distribution, interconnectivity and regional availability of forest,
- Importance of habitat heterogeneity within the landscape including changes associated with forest management practices such as reforesting of mixed species stands with monoculture conifers, and
- Effects of different intervening matrices (e.g. clearcuts, regrowth, croplands).

Research at the landscape scale requires interdisciplinary research teams. Progress is likely to remain slow because of the logistics and substantial funding commitments required.

Acknowledgments

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A FOREST MANAGEMENT SCHEME MITIGATING IMPACT OF ROAD NETWORKS ON SENSITIVE WILDLIFE SPECIES[1]

R. H. Brocke, J. P. O'Pezio, and K. A. Gustafson[2]

Abstract. High road densities are associated with a variety of negative human effects on some wildlife species. These effects include excessive legal and illegal kill, and human disturbance. Black bear (Ursus americanus) legal kill for Adirondack counties, a measure of population density (Black Bear Density Index) was regressed against road density. The Black Bear Density Index shows a ten-fold decrease with a ten-fold increase in road density ($r^2 = 0.69$; $p \leq 0.01$). Similar sensitivity to vehicular road access has been reported for other large predators and ungulates. The presence of unusual wildlife species, trophy hunting and wilderness type recreation are salable products that can be economically combined with wood production. To mitigate the impact of road access networks on sensitive and desirable wildlife species in the Northeast, we propose the Wild Forest Management Scheme including even-aged hardwood management, closure of roads to vehicular access between cutting cycles, fees charged for recreation, and negotiation of conservation easements with appropriate government units.

The theory of island biogeography (McArthur and Wilson 1967) led to important research on the negative biotic effects of forest fragmentation (Burgess and Sharpe 1981). A number of recent publications have addressed the design and minimum size of nature reserves with the goal of enhancing species survival and diversity (Harris 1984, Soule Simberloff 1986, Rapoport et al. 1986, Boecklen 1986, Woolhouse 1987, Miller and Bratton 1987). Not surprisingly, habitat preservation through public acquisition is implicit in a number of papers. Indeed, the role of public lands in preservation is reflected in current Federal statutes that mandate preservation of old growth forests on Federal lands (Thomas et al. 1988).

Preservation of potential natural areas by public acquisition is not always economically feasible, practical or desirable, especially where land must meet many needs. Private lands can play an important role in biotic conservation (Metzger 1983, Teer et al. 1983, Taber 1983). In the northeastern U.S., private lands held by timber companies and other landowners compliment public lands in meeting recreational needs while contributing economic returns to state and local economies. These private lands also contribute much to wildlife diversity. However, under traditional forest management measures (e.g. selective cutting), wide-ranging wildlife species such as the black bear, moose, bobcat and large predators, are restricted in their distribution or are absent because of frequent human disturbance. Again, in highly accessible forest lands, deer rarely attain trophy size. In this paper, we propose a forest management scheme providing economic returns from wood production and recreation, while potentially enhancing the survival of sensitive wildlife species.

Data on black bear Ursusamericanus sensitivity to forest roads are presented for Adirondack Park where approximately 60% of the forest lands are in private ownership. Black bear harvest densities were collected from mandatory hunter report cards by the New York State Department of Environmental Conservation. Human population density and road density values (municipally maintained roads) are from reports of the New York State Department of Transportation. We thank R. Sage, R. Nyland, and D. Garner of SUNY College of Environmental Science and Forestry, Syracuse, New York, for their helpful suggestions.

Black Bear Survival And Road Density

Increasing patchiness of forest habitat is associated with increasing agricultural and urban development in a pattern continuum (Burgess and Sharpe 1981). As the degree of road density is often directly proportional to the degree of human presence and disturbance, road density can serve as an index to a wide spectrum of man-induced pressures on wildlife. For the black bear, most mortality in North America is apparently man-induced. In Minnesota, Rogers (1987) found that 91% of 35 deaths of radio-collared black bears were from legal and illegal gunshot. Other man-induced deaths (eight bears) included collisions with autos and a train, and electrocution. Hunter harvests of black bears ranging up to 42% have been recorded in Montana (Jonkel and Cowan 1971). In Virginia, 33% of the bears trapped and marked by Stickley (1961) were killed during the subsequent hunting season.

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The localized impact of human access on Adirondack black bear survival is indicated by data in Table 1 and in figure 1. The Bear Density Index (legal hunter kill, reflecting the bear population level) was regressed against road density, percent forest cover and human density. The best of the three relationships is for Bear Density Index regressed against road density for 12 counties where forest cover exceeded 75% ($Y = 7.10 - 3.22 \times r^2 = 0.69$, $p \geq 0.01$). We excluded counties that were less than 75% forested because they included areas of disproportionately high bear kill clustered along the border of agricultural lands. Representative values calculated from the regression equation are 6.46 bears harvested/100 mi²/yr (2.49 bears/100 km²/yr) at a road density of 0.2 mi/mi² (0.12 km/km²), versus 0.66 bears harvested/100mi²/yr (0.25 bears/100 km²/yr) at a road density of 2 mi/mi² (1.24 km/km²). These values show a ten-fold decrease in Bear Density index with a ten-fold increase in road density. It should be noted that road densities include highways, graveled roads and other municipally maintained forest roads. They do not include all roads in private road networks. However, the regression does illustrate the general effect of black bear vulnerability to vehicular road access. The other parameters, namely forest cover and human density (Table 1) were less sensitive indicators of bear vulnerability and population density. We have used these data to illustrate local vulnerability of black bears to human presence. We do not suggest that the Adirondack black bear population is over-exploited. Under state management, the bear population and hunter kill are closely monitored; the bear population has remained stable in the Adirondacks for the past 20 years.

Table 1. — Regressions of Bear Density Index (black bear harvest/100 mi²/yr) against human density, percent forest and highway density.

Parameter (X)	Bear density index (Y) (bear harvest/100 mi²/yr)	R^2
Human density (humans/mi²)	Y = 4.83 - 0.04X*	0.36
Percent forest	Y = 1.02 - 0.05X*	0.24
Road Density (miles/mi²)	Y = 6.52 - 2.75X*	0.50
Road density (miles/mi²) for counties ≥ 75% forested	Y = 7.10 - 3.22X**	0.69

*Significant at 0.05 level.
**Significant at 0.01 level.

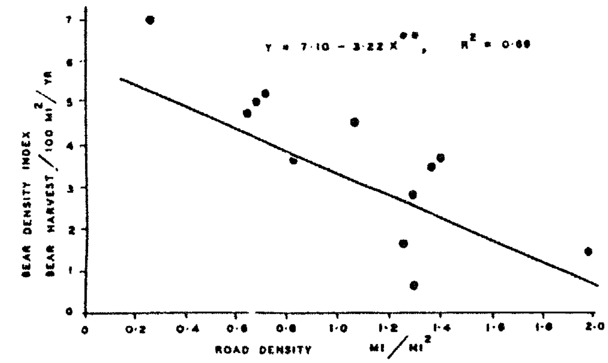

FIGURE 1.— Regression of bear density index (bear harvest/100 mi²/yr) on road density in Adirondack Park.

Sensitivity of large mammal species to road access has been reported in other studies. Such sensitivity apparently reflects behavioral avoidance of human disturbance as well as decreased species survival near roads open to vehicular access. In Norway, Elgmork (1978) found that observations of brown bears Ursus arctos declined five-fold from 100 to 20 observations/1000 km² when road density increased seven-fold from 0.16mi/mi² (0.1 km/km²) to 1.2 mi/mi²). In Wisconsin and Minnesota wolf Canis lupus populations tend to be absent where road densities exceed 0.9 mi/mi² (0.6 km/km²) and most populations are found at lower forest road densities (Thiel 1985, Mech 1988). In southern Utah, Van Dyke et al. (1986) found that mountain lion Felis concolor tended to establish residence outside logged areas with road densities less than 1 mi/mi² (0.6 km/km²). This reaction was due to the additional disturbance contributed by human access rather than habitat change. Also mountain lions shifted their activity to the night time in response to human disturbance.

Vulnerability of moose Alces alces to hunter harvest has been found to be significantly higher in areas accessible by logging roads than in roadless areas (Fraser 1976, Crete et al. 1981, Timmermann and Gollath 1982). In roadless areas newly opened up by logging road networks, the normal pattern is an initial reduction in local moose density followed by a later stabilization at a lower level (Timmermann and Gollath 1982, quoting Crete). In Ontario, locations of hunter-killed moose are closely associated with forest roads and water access (Judd 1972, Bidder and Pimlott 1973, Timmermann and Gollath 1982). In the Adirondacks, Sage et al. (1983) studied legal and illegal kill of white-tailed deer Odocoileus virginianus in relation to road access networks. They found that marked deer were most prone to be removed where individual deer maintained activity areas adjacent to forest roads, versus deer with activity areas distant from roads. The implication is that survival of whitetails would be increased by decreased road access, a point of interest where production of large bucks and trophy-sized antlers is a game management objective.

Even-Aged Veresus Uneven-Aged Forest Management

The preceding results indicate that the presence of desirable wildlife species as well as the availability of trophy sized game can be enhanced by locally limiting forest road access. However, closure of local access road networks may be impractical and uneconomical where uneven-aged management (e.g. selection cutting) is commonly practiced. We believe that an economically viable alternative is even-aged forest management, with long intervals between cutting cycles. A comparison of even-aged versus uneven-aged management schemes is shown in Table 2. Under the hypothetical shelterwood (even-aged) cutting scheme for northern hardwoods (Kelty and Nyland 1981), each logged stand is penetrated four times within a 120 year rotation period. Assuming that logging activities occur over a period of one year or less for each cutting cycle, there are four periods of non-disturbance of 7, 56, 14 and 39 years respectively (Table 2). The length of the latter three periods is substantial enough to benefit sensitive wildlife and two of them (39 and 56 years) may produce effects very similar to those in an unlogged forest. In contrast, the selection cut stand (Table 2) penetrated 10 times in a 120 year rotation, with 10 periods of non-disturbance, each of only 11 years duration. Closure of forest roads for such short periods would have only minimally positive effects on wildlife. Similar effects are illustrated in Table 3 comparing two selection cutting systems. In this case, System A is preferable, with 24 year periods of no disturbance.

Table 2.—Comparison of logging disturbance in shelterwood versus selection cutting systems over 120 year rotation periods.

Cutting system and description	Year of cut	Subsequent period of no disturbance (Yrs)
Shelterwood Cutting System		
Seed cut	0	7
Removal cut	8	56
Thinning cut I	65	14
Thinning cut II	80	39
Seed cut	120	—
Selection Cutting System		
Selection cut	0	11
" "	12	11
" "	24	11
" "	36	11
" "	48	11
" "	60	11
" "	72	11
" "	84	11
" "	96	11
" "	108	11
" "	120	—

Table 3.—Comparison of logging disturbance in two alternative selection cutting systems over 100 year rotation periods.

Cutting system and description	Year of cut	Subsequent period of no disturbance (Yrs)
Selection Cutting System A		
Selection Cut	0	24
" "	25	24
" "	50	24
" "	75	24
" "	100	—
Selection Cutting System B		
Selection Cut	0	9
" "	10	9
" "	20	9
" "	30	9
" "	40	9
" "	50	9
" "	60	9
" "	70	9
" "	80	9
" "	90	9
" "	100	—

One significant benefit of even-aged hardwood management using fewer cutting cycles is reduced soil erosion. In the examples given (Tables 2 and 3), operation time and effects of logging machinery are reduced by about one half over one rotation period. Currently, clearcuts or near-clearcuts are opposed by the public because they are unsightly. We believe that the positive environmental (and wildlife) effects of even-aged management must be carefully weighted against short-term esthetic liabilities. Much of the temporary unsightliness of clearcuts can be screened from the public by buffered strips and landscape planning. In most cases, the benefits from decreased erosion alone may justify even-aged hardwood management.

Proposed Management Scheme

The presence of unusual wildlife species, the opportunity for outstanding trophy hunts and the chance for solitude are highly salable products in a crowded world. We believe that these recreational objectives can be economically combined with wood production in the Northeast by what we term the Wild Forest Management Scheme, including the following measures:

1. Even-aged hardwood management (or selection cutting with long intervals between cutting cycles) implemented on selected blocks 100-500 acres in size. Particularly suitable are remote tracts adjacent to public

land with low vehicular access.

2. Closure of road networks to motorized traffic between cutting cycles and redistribution of vehicular traffic, permanent cabins and equivalent facilities to areas where road networks are continuously maintained.

3. Closed access roads are made available to pedestrians, backpackers, hunters, horse and non-motorized traffic (e.g. bicycles). This area may be open to temporary tent camping.

4. Fees charged for long-term, seasonal or day use of management units.

5. Tax relief (e.g. conservation easements) negotiated with appropriate government sectors to offset income foregone from alternative uses or development.

A hypothetical example of the Wild Forest Management Scheme is illustrated in Figure 2. In Area A, the road network is closed to motorized traffic for the long periods between required cutting cycles. These roads are open to fee-paying pedestrians (hikers, hunters, backpackers, etc.). Equestrian and bicycle traffic and wilderness style camping may be permitted, as appropriate. Area users park their vehicles at gated entrances. In Area B, south of the highway, permanent vehicular access in a traditional forest management setting is shown.

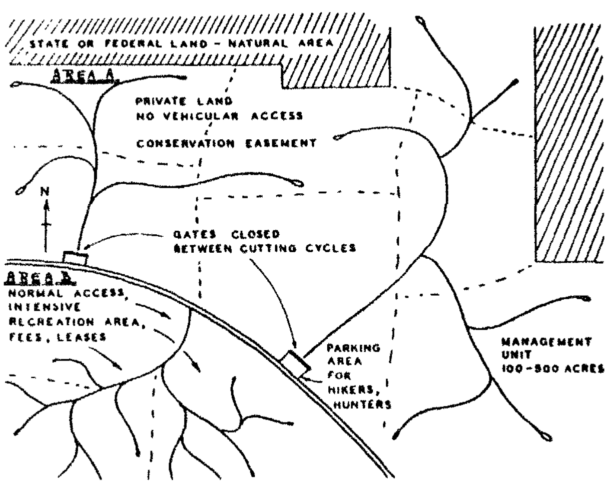

FIGURE 2.—Hypothetical example of the proposed Wild Forest Management Scheme, in practice north of the main road. Traditional forest management with maintained vehicular access is practiced south of the road.

Effectiveness of the proposed scheme will be enhanced when privately maintained tracts lie adjacent to public natural areas, as illustrated in Figure 3. In this example, private and public lands complement each other. Together, they increase the effective size of wildlife refugia and form habitat corridors mitigating the effects of human access. In combination, they also benefit rare forest birds and other wildlife (Robbins 1979, Harris 1984) by extending old growth forest conditions into managed tracts during the latter stages of stand rotation. The proposed scheme will be most effective where it is practiced in cooperation with government agencies on a regional scale.

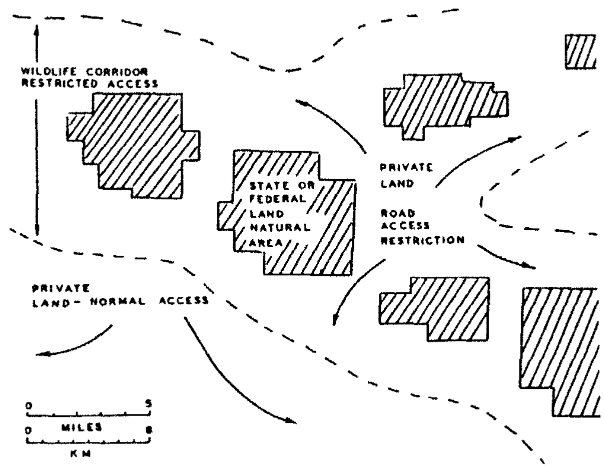

FIGURE 3.—The proposed Wild Forest Management Scheme on private lands, forming a "wildlife corridor" in conjunction with public lands. Traditional management with normal access is practiced outside the corridor.

Conclusion

Currently there are strong economic pressures on Northeastern timberland owners to sell their lands to developers (Blackmer 1989). To counter this problem, public land acquisition is often the solution of choice. But public land acquisition has drawbacks, particularly the loss of forest industry and tax base. The proposed Wild Forest Management Scheme may provide a viable alternative to public land acquisition. Its potential benefits, namely enhanced biotic diversity, preservation of open space, provision of low-intensity recreation and maintenance of forest industry, are all in the public interest. It seems to us that the time has come for state agencies and legislators to cooperate with the forest industry in developing economically viable management schemes to preserve open space and biotic diversity. The proposed scheme may offer a starting point for discussion.

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FISH HABITAT AND FOREST FRAGMENTATION[1]

Robert W. Hollingsworth[2]

Abstract. Large blocks of public land such as National forests present unique fish management opportunities. Aquatic systems, especially small streams, are tied to terrestrial systems for energy flow and fish food abundance. Management of riparian lands can be critical to stream temperature, fish habitat diversity and sedimentation. Fisheries scientists began to understand the role of large woody debris in fish habitat quality only about a decade ago. It is increasingly evident that fish need trees, not only for shade and bank stability, but dead and down in stream channels and lake basins, as well. Fisheries biologists must enlist the aid of foresters to assure the natural accrual of large woody debris to aquatic systems in the future.

Introduction

Sport fishing is a unique outdoor recreation. It has crossed all social and economic structure for centuries. Fishing equipment can be as simple and inexpensive or as sophisticated and costly as the fisherman chooses. His or her quarry can be as common as carp or as elusive as Atlantic salmon.

Fishing is especially appealing to young people. It is one of the few "grown-up" forms of outdoor recreation in which youngsters can participate on a more-or-less equal footing with adults.

Fishing's popularity is growing as our nation becomes increasingly urbanized. The 1985 National Survey of Fishing, Hunting, and Wildlife Associated Recreation identified nearly 60 million fishermen in the United States (USDI 1987). About 27 percent of all U.S. citizens age six and older went fishing in 1985. Fishing is predicted to increase 100 percent by 2010 (Sport Fishing Institute 1988).

The Forest Service has a key role in assuring the quality of fishing in the future. There are over 2.2 million acres of lakes and reservoirs and over 128,000 miles of fishable streams on National Forests (Everest and Summers, 1982). Land management is a critical element in protecting and improving fish habitat quality in these waters. What National Forest managers do, or don't do, especially in riparian areas, can positively or negatively affect fish habitat, sometimes far downstream from National Forests.

In summarizing the "Wild Trout II" Symposium in 1979, the late Starker Leopold made these comments to an audience consisting mostly of biologists and administrators charged with managing a public resource (fish) surrounded by private lands:

"...Most of us are in positions that call for managing or studying fish or the water in which they live. We are not responsible for managing the whole landscape. Someone else decides how many cows to run in a given watershed, where and how many trees to cut, and what sort of road system should be built, where towns and subdivisions should be situated, and what to do with sewage effluent or mine tailings or the drainage from dairy barns. Yet, these decisions are crucial in the maintenance of productive trout streams. The management of the trout resource cannot be dissociated from the management of the watershed."

In the context of Leopold's remarks, National Forests offer fish management opportunities unique to large blocks of public land. National Forest managers do decide "how many cows to run in a given watershed, where and how many trees to cut, and what sort of road system should be built..." National Forest managers are in the land management business. They can treat the watersheds as well as the trout!

Land management directly influences fish food abundance, energy flow and sediment flow from terrestrial to aquatic systems. Riparian land management is especially important to stream temperature and to physical habitat quality in lakes and streams.

Food Abundance And Nutrient Input

Headwater streams are described by Karr and Schlosser (1978) as the maximum interface between the aquatic and terrestrial systems. When covered by forest canopies, especially of deciduous species, small streams serve as organic matter collectors. Organic material of terrestrial origin may account for 70 to 80 percent of the food energy for the aquatic community (Hynes 1970). As shredders and collectors process organic material in headwaters, it is transported downstream as drift. Organic drift is the aquatic community's primary energy source until a stream widens enough to absorb sufficient sunlight through the canopy that photosynthesis becomes significant.

Leaf drop is a primary component of organic matter in small streams. It follows that maintaining near-stream trees is sound riparian area/fish management.

[1]A paper presented at the Convention of the Society of American Foresters at Rochester, NY. October 16 – 19, 1988.

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Terrestrial insects are a more important small stream fish food source than is generally realized. While their contribution is seasonal, it may account for 40 to 50 percent or even more of the summertime trout diet (Hynes 1970). Over 70 percent of the volume of food organisms consumed by brook trout in a White Mountain National Forest stream were terrestrial insects (Randy Ferrin, Forest Hydrologist, personal communication). This high percentage may be a reflection of the Forest's infertile, granitic watersheds and a relatively greater importance of terrestrial insects in such circumstances.

Water Temerature

The relationship between stream shade and trout production has long been noted. The Oregon/Washington Interagency Wildlife Committee (1979) determined that potential trout production is sacrificed rapidly as the percentage of a stream surface shaded between 10 A.M. and 2 P.M. declines from 80 percent. At 35 percent surface shade, only about 40 percent of a stream's trout production potential remains.

Brook trout, at least in Michigan's Upper Peninsula, appear to be much more shade dependent. This is consistent with the brook trout's optimum temperature range which is considerably lower than that of other trout. Edde (1985) found maximum brook trout biomass (trout flesh per unit area) in Ottawa National Forest streams which had low groundwater input to be associated with 100 percent shade. When stream surface shade declined to about 35 percent, nearly 85 percent of a stream's trout production potential was lost. The implication for riparian vegetation management and forest fragmentation is clear. Viable populations of some fish species are directly related to shade producing riparian tree stands.

Sediment

Sediment is likely the oldest, yet most common, fish habitat degrader. It sterilizes aquatic systems from a fish habitat perspective. Sediment fills in pools, critical habitats for large fish. It buries essential spawning and fish food producing substrates. Large amounts of sediment, such as those encountered as sand bedload, severely reduce habitat diversity by covering logs and boulders.

Sand bedloads result in drastic changes in stream morphology (Alexander and Hansen 1983). Stream bottoms are elevated, producing wider, shallower channels. Vulnerability to warming is greater by virtue of more sunlight reaching stream substrates.

Unfortunately, heavy sand bedloads are common in Lake States National Forest streams. It is estimated that streams on the Hiawatha National Forest in Michigan's Upper Peninsula receive a cubic yard of sand from every ten lineal feet of actively eroding bank, annually. As much as 18,000 feet of such bank has been inventoried in a single river system in that National Forest (Charles Bassett, Forest Fisheries Biologist, personal communication).

For years, fisheries biologists have been telling each other and anyone else who would listen that sediment is bad for fish. However, it was not until Alexander and Hansen (1983) quantified the effects of sand bedload on a brook trout population that we began to understand how damaging even small amounts of sediment can be. These researchers determined that 17 parts per million (ppm) sand as bedload in Michigan streams depresses brook trout biomass by 10 pounds per stream acre. This is especially significant since many National Forest streams in Michigan commonly carry sand bedloads of 30 to 80 ppm, and trout biomass is frequently less than 20 pounds per acre (Bassett 1987). While other limiting factors could prevent achieving the implied doubling or even quadrupling of trout biomass, significant increases can be expected from effective bedload control/prevention.

The damaging effect of even small amounts of sediment is cause to critically review many practices and facilities common to forest management. It may be most condemning of stream crossings. Bridges, culverts and fords previously accepted as having little or no impact on aquatic communities should be reevaluated. Virtually any stream crossing located at the low point in the grade of an unsurfaced road should be regarded as a potentially significant sediment source.

Physical Habitat

Prior to the last decade, fisheries managers had little appreciation for the role of large woody debris in fish habitat quality. We were prone to view streamside blow downs with upturned rootwads as potential sediment sources, despite the fact that rootwads frequently "sod over", at least along low gradient streams, and remain relatively stable. The functions of large limbs and boles as stable overhead cover and pool forming agents went largely ignored.

The fisheries profession, until recently, viewed debris jams as barriers to fish movement. Aside from the fact that very few jams are complete barriers, they have beneficial features which were overlooked. Among these were the habitat diversity and large pools usually associated with jams. Meanwhile, biologists worked diligently to make fishing better, ignoring a natural process that could help them.

Ironically, the fishing public got ahead of many fisheries biologists in appreciating the function of large woody debris in fish habitat. Evidence of this abounds in the 150 or so currently published magazines devoted wholly or in part to fishing (USDI 1982).

These magazines routinely highlight "how to" articles featuring tactics for fishing in and around "structure". The two most common forms of "structure" are boulders and large woody debris. Page after page of fishing articles, complete with high quality photos and sophisticated artwork, display various techniques for fishing large woody debris.

A presumed goal of publishers and authors is to show a profit. It follows that fishing "structure" boosts catch rates. If it didn't, fishermen would fish elsewhere and buy other publications. People catch more fish (of most species) in and around "structure" because that's where most of the fish are most of the time. It is better habitat than elsewhere in the same waterbody.

Dramatic results have been achieved by placing large brushpiles in otherwise relatively barren or "structure-less" lakes and reservoirs. In cooperation with the Tennessee Department of Wildlife Resources Agency, the Tennessee Valley Authority evaluated the effect of brushpiles on the distribution of fish in Norris Reservoir. The fish populations of five coves with brushpiles were compared to those of five similar coves without brushpiles with striking evidence that brushpiles attract fish. The coves containing brush held nearly twelve times more crappies, eight times more walleyes and five times more bluegills than the five control coves (Sport Fishing Institute 1980).

Lacking abundant evidence that structure actually produces more fish in a lake or stream rather than simply relocating them, fisheries biologists are wont to call such structures fish "attractors" or "concentrators". While there is at least one study which measured an actual increase in primary productivity resulting from artificial structure (Prince et al. 1985), I am aware of none which shows a long-term decline in fish biomass in adjacent control areas. Such evidence is prerequisite to relegating "structure" to a mere attracting or relocating function.

While there is not broad agreement that "structure", such as large woody debris, increases fish biomass, calling a large brushpile in a lake a fish "concentrator" seems analogous to calling an acre of brush in a fall plowed field a wildlife "concentrator". Both seem more appropriately described as the only, or best, available habitat.

While our understanding of the role of large woody debris in fish habitat began only about a decade ago, one point seems clear - fish need trees. Fish need trees on riparian areas to provide stability and leaf drop; fish need trees on streambanks and lakeshores for shade and bank stability, and fish need trees dead and down in stream channels and lake basins for habitat diversity.

None of this is new. In his "History of Artificial Reef Use in the United States", Richard Stone (1985) cites this quote:

"They (sheepshead) were formerly taken in considerable numbers among our various inlets, into which large trees had fallen to which the barnacles soon became attached; but as the lands have been cleared for the cultivation of sea-island cotton, the trees have disappeared, and with them the fish..."

These are the words of one William Elliot as they appeared in "Ichthyology of South Carolina" by John Holbrook, published in 1860. The Hon. Mr. Elliot went on to explain how oak and pine logs were "formed into a sort of hut without a roof". This structure was towed into place, sunk with stones and, in some weeks, the fish "began to resort to the ground".

How much large woody debris is enough? We don't know. Researchers feel that they have not seen an upper limit (Andrew Dolloff, Southeastern Forest Experiment Station, personal communication). Since many rivers in their pristine condition held debris jams up to five miles long (Sedell et al. 1982), it seems likely that the upper limit for large woody debris will be determined by social factors, not by fish habitat objectives. Power boating, water skiing, canoeing, and flood control are only a few of the interests with the potential to be adversely affected by high woody debris densities.

Society has interrupted the natural accrual of large woody debris to aquatic systems. On large blocks of public land such as those found on the National Forests, there are opportunities to reverse that trend and to recover at least some of the fish habitat quality lost decades ago. However, fisheries biologists cannot do it alone. They need help from professional foresters. As Brouha and Parsons (1985) point out, "Foresters are fish habitat managers. They just haven't recognized it, yet."

Fisheries biologists need help from a previously unrecognized kind of forester, the "fisheries forester". "Fisheries foresters" will accept the challenge to develop prescriptions for specific vegetative types to facilitate the natural accrual of large woody debris to aquatic systems.

Over time, "fisheries foresters" will provide down and stable large boles which studies show will function as fish habitat for well over 100 years (David Gibbons, Forest Service Alaska Region, personal communication). "Fisheries foresters" will manipulate riparian vegetation to produce habitat diversity now lacking in stream channels and lake basins, and they will do that at very little direct cost.

"Fisheries foresters" will do all this while recognizing the difference between large, stable debris which diversifies habitat, and the smaller slash which smothers it.

Tops, small branches and other by-products of timber harvest constitute organic overload when disposed of in stream channels. Large woody debris, as used here, is the material which usually leaves a sale area on the bed of a logging truck. It is not the smaller tops, brush and branches left behind.

Fish habitat across much of the U.S. was broadly degraded by past land use/abuse (Bassett 1985). Foresters have made remarkable progress in restoring healthy terrestrial systems on National Forests. Through careful manipulation of riparian vegetation, they can also restore much of the productivity that our aquatic systems once had.

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FOREST FRAGMENTATION IN THE NORTHEAST — AN INDUSTRY PERSPECTIVE[1]

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Abstract. Industrial forestland owners manage more than 12 million acres of forestland in the Northeast. The silvicultural practices that are used affect habitat conditions and have a temporary impact on the wildlife species that live there. Many of these companies incorporate wildlife management considerations into their forest management plans. Some species of wildlife are increased, others decreased, and some are not affected by forest management activities. Forest management improves the overall wildlife diversity of forests in the northeast by increasing spatial diversity, vertical diversity and structural diversity of the habitat. There are large expanses of continuous forested land remaining in the northeast with a diversity of stand types, habitat conditions and wildlife species. Responsible management should maintain forest and wildlife habitat diversity for the foreseeable future.

Forest industry owns and manages approximately 12.6 million acres of the 80.1 million acres of forestland in the Northeast (U.S. Forest Service 1987). Most of this land is managed primarily for the production of forest products to produce an income for the companies and their shareholders. Because of the economic concerns inherent in industrial ownership, most lands are intensively managed for forest products. Many of the major forest types in the Northeast, from hardwood in PA to the spruce-fir forests in Maine, are managed by the even-aged system which includes clearcutting for the final harvest.

This intensive management creates a mosaic of successional stages that provides habitat for many species of wildlife. In addition many industrial forest landowners also incorporate wildlife considerations into their forest management plans.

[1]A paper presented at the 1988 Convention of the Society of American Foresters at Rochester, NY. October 16 – 19, 1988.

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Industry Management

The policies of International Paper will be used as an example of industry management in the Northeast. Wildlife habitat management on company lands is integrated into our forest management plans. Guidelines have been developed that serve as a framework for our foresters as they make daily decisions about harvest locations, size, etc. We manage lands in a variety of forest types. Forest management and the things that can be done to benefit wildlife vary between these types. Following are some examples of wildlife habitat considerations that are included in our guidelines.

In some forest types we manage on a stand basis, so clearcuts have irregular boundaries because stand boundaries are usually irregular. This provides an abundance of edge habitat and makes clearcuts more aesthetically pleasing. To provide wildlife species with habitat diversity a size limitation on clearcuts and the location of these stands throughout the forest is important. The standard within industry seems to be a variation of either 5-10 years between cuts or a height differential of up to 12 feet between adjoining stands. Clearcut size varies from 100 acres or less up to 250 acres.

In forested habitat there are often few open, herbaceous areas. We attempt to maintain a portion of our land in permanent herbaceous openings. These openings are used by many species of wildlife including white-tailed deer (Odocoileus virginianus), wild turkey (Meleagris gallopavo), and bluebirds (Sialia sialis).

Some forest types or individual tree species that are very valuable to wildlife and make up a small percentage of stands in certain geographic locations are given special management consideration. For example, aspen (Populus spp.) stands cover less than 2 percent of company land in Pennsylvania and southwestern New York. Aspen stands, however, are important to some species of wildlife including beaver (Castor canadensis), woodcock (Scolopax minor), songbirds, and particularly ruffed grouse (Bonasa umbellus). Good ruffed grouse populations are almost always associated with aspen. Aspen requires specific management techniques in order to maintain it as a component of the forest. Where aspen is a minor component of the forest, these stands are managed to maintain aspen in a variety of age classes. Where clearcuts are large we consider leaving some clones of large uncut male aspen.

Conifer cover is an important habitat component for many species during periods of inclement weather, and other species like the sharp-shinned hawk (Accipiter striatus) rely on it for nesting habitat. In areas where conifer habitat makes up a small percentage of the forest we attempt to maintain conifer stands and small groups of trees.

Wildlife corridors and streamside management zones provide a diversity of habitat for wildlife. Corridors are retained both along streams and in appropriate locations in upland habitats. Corridors provide edge, habitat diversity, travel lanes and protected areas for wildlife, and a link between various habitat components in a managed forest. For example, a corridor can provide a travel lane for white-tailed deer between upland sites and wintering areas and for furbearers such as pine marten (Martes americana). As a landowner our policy is to use corridors to break up forest stands of similar age to provide those benefits mentioned above.

Streamside management zones provide the same benefits as corridors plus maintain lower water temperature for fisheries and serve as a filter strip to catch sediments from upland sites to maintain water quality. Riparian areas along streams and lakes are considered one of the most valuable habitats for wildlife species. The width of streamside zones varies depending on forest type, general stand conditions and state regulations.

According to Gutierrez et al. (1979) more than 29 species of mammals and 38 species of birds use snags or cavity trees in the Northeast. Even-aged management can eliminate many of the suitable cavity trees and snags if efforts are not made to leave some of them. Our foresters routinely mark some of these trees to be left standing in cutting areas.

Various species of trees and shrubs that produce food for wildlife or are uncommon in occurrence are often left standing during harvesting operations. Some of these include serviceberry (Amelanchier arborea), apple (Malus spp.), and hickory (Carya spp.).

Spring seeps occur extensively in many of the mountainous areas of the Northeast. They are used as feeding areas for wildlife, particularly during the winter. They are especially important to turkeys, and studies in the mountains of West Virginia (Healy 1977) have shown that when snow depth exceeded 4 inches, 86 percent of the feeding sites were in seeps. Healy's study also showed that certain seeps are used more often than others. We try to protect the integrity of the most valuable seeps by keeping equipment from running through them, not allowing any slash to be left in the seeps and leaving some trees standing around the seeps.

Endangered and threatened species and other species of concern are given special consideration on company land. Our management for great blue herons (Ardea herodias) is one example. Great blue herons, which are colonial nesters, often nest in hardwood stands where from a few to more than 1OO nests may be found in a rookery. No trees containing a heron nest are cut. We maintain a 500 foot protection zone around the nest trees. Normal logging operations are deferred within this zone from March 1 through June 30. Only selective harvesting is practiced within this zone. A11 roads coming within 1/2 mile of the protection zone are closed to public vehicular traffic use from March 1 through June 30, and the establishment of new roads inside this zone is discouraged.

Many species of hawks and owls also nest on company land, and the nests are often used in successive years. Trees containing a nest are left uncut in most cases. If logging is occurring in the vicinity of a nest during the period of January through May, the forester uses discretion in scheduling any activity in the immediate nest area until the young are fledged.

In order to economically remove timber it is necessary to have a fairly extensive logging road system. Many of these roads in Pennsylvania and New York are gated and closed to unauthorized vehicular traffic to prevent road damage as well as unnecessary disturbance to wildlife.

Seeding of roadsides and log landings provide stabilization of the soil, a food source for wildlife and improved aesthetics of the roadside. Plantings in northern Maine have been used by black bear as the first source of green food after coming out of the winter den. Herbaceous plantings adjacent to deer wintering areas will provide an immediate, high energy food source for deer coming off the wintering area.

Forest Fragmentation

We have discussed some of the steps taken by International Paper to integrate forest and wildlife management on the lands we manage in the Northeast. Now we need to focus on the question "is forest fragmentation a wildlife and fish habitat issue in the Northeast" on industrial land.

We know for certain that forest management has a temporary impact on wildlife habitat and the wildlife that are present in the area. All species of wildlife are dependant upon suitable habitat to survive, and each species has distinct habitat needs. All silvicultural practices alter habitat conditions and affect the wildlife species that live there. The numbers of some species of wildlife are increased by even-aged forest management, others are decreased, and some are not affected. Many game species, white-tailed deer, ruffed grouse, snowshoe hare (Lepus americanus), and moose (Alces alces) are benefitted by the early successional stages following clearcutting. Some non-game species also thrive in this brushy habitat such as chestnut-sided warblers (Dendroica pensylvanica), mourning warblers (Oporornis philadelphia), and white-throated sparrows (Zonotrichia albicollis). Other species like gray squirrels (Sciurus carolinensis), pileated woodpeckers (Dryocopus pileatus), and ovenbirds (Seiurus aurocapillus) will generally avoid these areas and use other adjacent suitable habitat. This scenario is not very different from large stands of old growth forest where certain groups of species are benefitted and others find this habitat undesirable. No single silvicultural practice or lack of it will provide optimum habitat for all species of wildlife.

Many wildlife species adapt to changing habitat conditions created by forest management. Steventon and Major's (1982) work with pine marten illustrates this point. They found that although marten relied on the uncut and partially cut stands within the commercially clearcut forest, they were apparently able to tolerate or make seasonal use of extensive areas of regenerating clearcuts within their home ranges.

There are other factors affecting forests in the Northeast that have had a more extensive and long term impact on wildlife habitat and wildlife than forest management. One example is the affect of overbrowsing by white-tailed deer, which has changed habitat conditions on hundreds of thousands of acres of forestland. For example, over the past 40 to 50 years deer have eliminated much of the understory in the forests of northern Pennsylvania resulting in a one layered forest with very little habitat complexity and correspondingly low wildlife diversity (Marquis and Brenneman 1981).

Forest management in the Northeast is changing habitat on a relatively localized basis. New clearcuts are usually not adjacent to other newly clearcut areas, so there is continuous forest cover around them. Niemi and Hanowski (1984) reported that as habitat complexity increases in logged areas more habitat conditions are created that will have a higher probability of satisfying more bird species. Some wildlife species may be temporarily displaced by clearcutting, but even this impact can be minimized by incorporating certain practices, as discussed in this paper, into forest management plans. Mannon and Meslow (1984) stated that old growth forests are necessary for some species but that the effect of the loss of these stands could be minimized by providing some components of old growth forests (ie. snags) in managed stands.

Crawford et al. (1981), looking at songbird response to silvicultural practice in the central Appalachian hardwoods, stated that silvicultural practices cannot be categorically described as beneficial or detrimental to birds. Each habitat has a characteristic group of bird species. We feel this statement can be expanded to describe the effect of forest management practices on most wildlife populations. Forest management improves the overall wildlife diversity of forests in the Northeast by increasing spatial diversity, vertical diversity and structural diversity of the habitat.

From an industrial perspective forest fragmentation is not an issue on managed industrial lands in the Northeast. It is something, however, we need to be continually aware of as forest management planning takes place. We still have large expanses of continuous forested land with a diversity of stand types, habitat conditions and wildlife species. Responsible management should maintain forest and wildlife habitat diversity for the foreseeable future.

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LANDSCAPE ECOLOGY PLANS FOR MANAGING FORESTS[1]

Richard T. T. Forman[2]

Abstract. To plan sustainably for more than a century the major elements of a landscape ecology plan are outlined. Sustainability requires maintaining or achieving ecological integrity together with human aspirations, and the landscape ecology approach focuses on the spatial configuration and consequent fluxes through large land mosaics. Management options are illustrated for a forest boundary plus the edges on each side. Like a semipermeable membrane, this regulates fluxes of objects in and out of the forest. Within the forest five key spatially fixed characteristics are first delineated (uncommon features, existing large patches, stream corridors, steep slopes, and links with other forests). Three additional characteristics requiring more decision-making (additional large patches, major natural land corridors, and primary people routes) tie this together into a basic spatial framework, within which fine scale patterning is addressed. A landscape ecological plan should be developed for every forest and other natural resource area.

Sustainable Environments

Current interest in developing sustainable environments is mushrooming. Most approaches focus on the planet and use a time frame of several human generations (more than a century) (Repetto 1985, Clark and Munn 1986, Jacobs and Munro 1987). In designing a sustainable environment it is essential both to maintain or attain ecological integrity, and to maintain or achieve human aspirations (Forman 1989).

Foresters have pioneered in one dimension of sustainability, i.e., sustained yield of wood products. This capitalizes on the productive life of many trees that continues over several human generations. We must be as effective in adding the other dimensions of sustainability, including soil, biological diversity, fresh water, cultural cohesion, and basic human needs of food, health, and housing (Regier and Baskerville 1986, Forman 1979, 1989).

The individual local ecosystem may change rapidly and markedly, and appears to be a poor candidate for planning sustainably. At the broadest scale, the planet must be tended for sustainability, but few of us will directly plan or manage that. An intermediate spatial scale is needed where humankind's planning, managing, and decision-making talents coalesce. The large landscape as a mosaic of local ecosystems, and usually containing people and their activities, appears promising as a sustainable environment.

The objective of this paper is to consider the applicability of principles emerging in landscape ecology and other disciplines to sustainably planning any natural resource area, including a forest. Thus, after introducing the elements of landscape ecology, I will illustrate general principles underlying a landscape ecology plan, including: (1) its essential aerial extent; (2) the role of boundaries and edges in management; and (3) the spatial configuration within a natural resource area, separating spatially fixed characteristics from construction of a spatial framework.

The Landscape Ecology Approach

Landscapes, such as a coniferous forest landscape, a corn-and-bean landscape, and a suburban landscape, are mosaics extending for kilometers with local ecosystems or land uses repeated in similar form. Landscape ecology focuses on the spatial relationships, fluxes, and changes in species, energy, and materials across large land mosaics (Forman and Godron 1981, 1986, Risser et al. 1984, Naveh and Liebermann 1984, Brandt and Agger 1984, Preobrazhensky 1984, Forman 1986, Turner 1987, Li and Franklin 1988).

A structural approach to landscape ecology elucidates how these objects (species, energy, and materials) are distributed in relation to the sizes, shapes, numbers, kinds, and configuration of the ecosystems or landscape elements present. Patch, corridor, and background matrix analyses have been particularly fruitful.

A functional approach builds on this and explores the interactions among the landscape elements, that is, the flows of objects between adjacent ecosystems or through the mosaic. Edge and stream corridor studies, forest-field interactions, and vertebrate radiotracking studies have provided especially rich insights.

A dynamic or change approach focuses on the alteration in structure and function of the ecological mosaic over time. Geographic information system and satellite image technology, landscape logging patterns, and quantitative modeling have contributed significantly here.

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The rapidly growing body of theory and application cuts across and is closely linked with a number of disciplines from forestry to wildlife management, landscape architecture, and ecology (table 1). Virtually all the principles and theory emerging at the landscape scale are applicable to any spatially heterogeneous ecological system. In essence, the landscape ecology approach changes our focus from the relatively-homogeneous ecosystem to the role of spatial configuration in determining fluxes and change in large mosaics (Harris 1984, Forman and Godron 1986, Saunders et al. 1987, Turner 1987, Meentemeyer and Box 1987, Franklin and Forman 1987).

Table 1.— Some rapidly developing landscape ecology research areas with recent references.

Landscape fragmentation effects	**Connectivity**
Burgess & Sharpe 1981	Merriam 1984
Temple 1986	Forman & Godron 1984
Sharpe et al. 1987	Fahrig & Merriam 1985
Saunders et al. 1987	Salwasser et al. 1986
Johnson 1988	Bridgewater 1987
Mosaic change	**Network structure and function**
Wilcove et al. 1986	Baudry 1984
Turner 1987a	Forman & Baudry 1984
Sharpe et al. 1987	Noss & Harris 1986
Turner & Ruscher 1988	Forman & Godron 1986
Agger & Brandt 1988	Van Dorp & Opdam 1987
Configuration effects of landscape cutting	**Boundaries and edges**
Harris 1984	Ranney et al. 1981
Shugart 1984	Wiens et al. 1986
Pickett & White 1985	Schonewald-Cox &- 1986
Milne 1987	Forman & Godron 1986
Franklin & Forman 1987	Buechner 1987
Landscape heterogeneity and disturbance	**Fractal geometry and other indices**
Romme & Knight 1982	Burrough 1981
Pickett & White 1985	Gardner et al. 1987
Wiens 1985	Turner 1987a
Turner 1987b	Milne 1988
Knight 1987	O'Neill et al. 1988
Energy and nutrient flow in mosaics	**Scale and hierarchy relationships**
Shelton 1987	O'Neill et al. 1986
Naveh 1987	Urban et al. 1987
Johnston & Naiman 1987	Bridgewater 1987
Ryszkowski &- 1987	Meentemeyer & Box 1987
Swanson et al. 1988	Milne et al. 1989

The Aerial Extent of a Landscape Ecology Plan

Where a natural resource area extends over parts of two or more landscapes, such as an extensive grassland area and an extensive coniferous forest, the landscape ecology plan must include those landscapes in toto. To simplify for a spatial model here, we use the case of a natural resource area within a single more extensive landscape (Salwasser et al. 1986). The natural resource area may be, for example, a national forest, provincial or state park, wildlife refuge, or natural area.

The landscape usually has boundaries that are ecologically relatively distinct, due to geomorphology, natural disturbance regimes, and human land uses (Forman and Godron 1986). In contrast, the natural resource area almost always has administrative boundaries based on previous land ownership, that do not correspond well with natural ecological boundaries (Schonewald-Cox and Bayless 1986).

Protection against human overuse is a major objective of all natural resource areas. Linkages with the surroundings are rampant, and managers must deal increasingly with the effects and costs of these linkages. Numerous effects of the surroundings, including people themselves, on the forest, and numerous effects of the forest on the surroundings must be considered and ultimately paid for by society. Therefore, the boundary of a natural resource area is an inappropriate boundary for sustainability; the landscape ecology plan must be of the larger landscape mosaic.

Managing Boundaries and Edges

A sustainable plan of, say, a forest must include management in five spatial areas, i.e., the (1) forest interior, (2) forest edge area, (3) boundary area, (4) edge area of the surrounding matrix, and (5) surrounding matrix interior. Here we will omit discussion of the last since the manager has least control here, though clearly the distribution of land uses, human populations, and other forest areas in the surroundings has major impacts on the natural resource area. Rather we will first focus on the boundary, plus the forest and matrix edges on each side, followed by a spatial analysis of the forest interior.

The boundary might be considered analogous to a semipermeable membrane through which species, energy and materials are filtered at different rates and different times (Wiens et al. 1985, Schonewald-Cox and Bayless 1986, Buechner 1987). How can the structure of this membrane be altered to enhance or inhibit the crossing rates of objects (fig. 1)? Basically we can alter the boundary height, width, and curvilinearity. The average dimension of each of these is important, but just as critical to membrane permeability is the variability in these three boundary dimensions.

Matrix Edge	Boundary	Forest Edge
Parallel roads and paths	Abrupt	Concentrate roads and paths (maximal road density)
Created wetland	Gradient	Concentrate edge animals for dispersal to matrix
Unambiguous single land use to enhance protection	Mosaic	Concentrate small patch cutting and other fine-grain activity
Decoy woods to absorb most impacts	Convoluted	Wildlife viewing platforms by rivers and wetlands
Natural corridors and filters	Cove	Firebreaks
Distinct abrupt boundary by houses and villages	Peninsula	Parking areas and buildings
Funnel effect of peninsulas for wildlife	Created wetland	Openings for wildlife and hunting
Wide corridor spokes to other natural resource areas	Corridor along outside	Wildlife plantings of native species
Wide stream and river corridors	Corridor along inside	Concentrate fish management and fishing
	Pores	Orient axes of land uses parallel to boundary
	Predator dens and nests	
	Decoys, repellents, attractants	
	Entrance for people	
	Controlled burn	
	Plantings/fences to alter wind-blown materials	
	Ditch, berm, fence, wood pile	
	Stream corridor with water quality change	
	Impenetrable thorn and vine planting	
	Thinning to produce dense shrub strip	

Figure 1 — Examples of management options for a boundary and adjacent edges. Here the boundary separates a forest (as an administrative unit) on the right from its surrounding matrix on the left. Only the edge portions of the forest and matrix are portrayed.

The matrix edge area on one side of the boundary and the forest edge area on the other also significantly affect flux rates between forest and matrix, and are amenable to management. The edges are often of considerable width (Ranney et al. 1981, Temple 1986, Wilcove et al. 1986), and many of the management options involve linear features generally parallel to the boundary. In the matrix edge area most options are designed to minimize the flow of people and human effects toward the forest (fig. 1). In the forest edge area many options involve concentrating those people and human effects that do enter the forest, in order to protect the forest interior (fig. 1).

Spatial Configuration within Natural Resource Areas

Spatially Fixed Characteristics

Nature provides resources as well as constraints on their use. Identification of the spatial configuration of natural characteristics requiring special protection against degradation is the first priority of a plan. Four types of these top priority characteristics are recognized (Merriam 1984, Noss and Harris 1986, Forman 1987):

1. Uncommon, Unusual or Rare-Features. Such as species, ecosystems, archaeological remains, and geological formations.

2. Large Natural Patches. (Discussed below).

3. Flux Centers. Where the movement of objects is concentrated, including major stream corridors, major upland natural corridors, steep slopes, and primary people routes.

4. Effective Links with Other Natural Resource Areas.

Generally the locations of several of these characteristics are relatively fixed, for which management options other than size are limited. Typically these spatially fixed characteristics are the (1) uncommon features, (2) existing large natural patches, (3) stream corridors, and (4) steep slopes (fig. 2). In addition, the options for (5) links with other natural resource areas are usually limited.

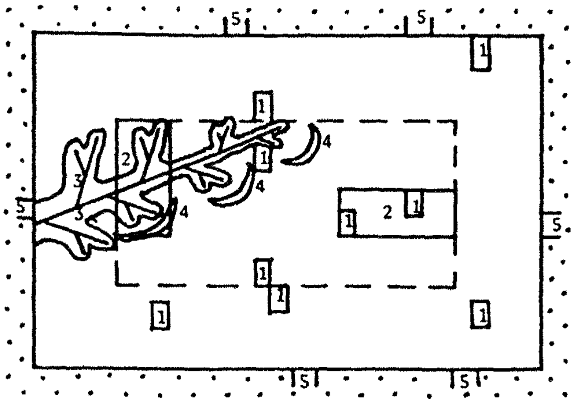

Figure 2. — Spatially fixed characteristics that require special protection within a natural resource area such as a forest. Dotted area indicates the surrounding matrix; dashes separate the forest edge area from the forest interior.
1 = Uncommon features; 2 = Large patches (existing);
3 = Stream/river corridors; 4 = Steep slopes;
5 = Links with other natural resource areas.

Constructing the Spatial Framework

The second major step of the landscape ecology plan is to tie the above fixed characteristics together with three remaining key characteristics, i.e., (6) additional large patches, (7) major upland natural corridors, and (8) primary people routes (fig. 3). More options and decision-making are required here.

We should note the particular significance of large protected natural patches. These provide at least four unique major functions, including linking headwaters or low-order stream networks together, habitat for interior or remoteness requiring species, habitat for wide-ranging or large home range species, and enhancing the natural disturbance regimes in which most species evolved. Surprisingly, the number of large protected natural patches required is perhaps the least certain of the planning decisions to be made. One study based on maximizing avian richness in the landscape indicated that more than three large patches were required (Forman et al. 1976). In this study the number of species found only in medium and large patches decreased sharply if large patches were subdivided into equal areas of smaller patches. Clearly many more studies are needed to establish the optimum and minimum numbers of large patches required.

In the spatial model used (fig. 3) an arbitrary 67% of the area is forest edge and 33% interior. Approximately 32% of this natural resource area requires special protection (4% uncommon features, 9% stream corridors and steep slopes, 10% large patches, and 9% upland corridors). One percent is allocated to roads, paths, etc. for people. The remaining two-thirds (55% in the forest edge and 12% in the forest interior) is available for various more intensive land management uses such as frequent cutting of wood products, wildlife enhancement, recreation, etc. For example, short cutting rotations might be concentrated in the forest edge area and long rotations in the interior. The percentages here are illustrative only and will vary somewhat according to forest size, width of edge, and areas of individual features.

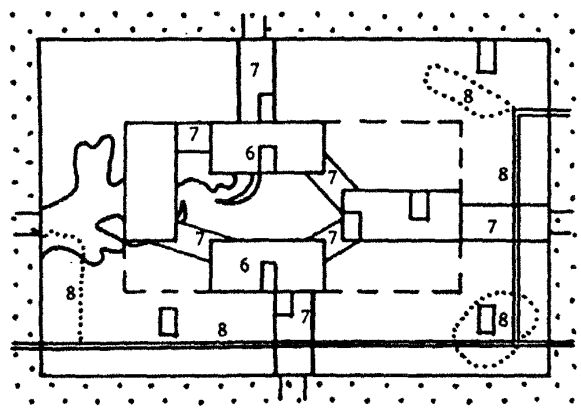

Figure 3. — Construction of the basic spatial framework that delimits areas requiring special protection and areas appropriate for more intensive uses. Two characteristics, i.e., 6 = Large patches (additional) and 7 = Upland natural corridors (major), are added to the spatially fixed characteristics 1 to 5 (fig. 2), to delimit the area requiring special protection. 8 = primary roads and paths for people.

Fine-scale Spatial Planning

The third major priority focuses on smaller areas within the basic spatial framework. Here numerous landscape ecology issues such as adjacency effects, interdigitation of habitats, locations of patches, curvilinearity of narrow corridors, connectivity patterns, routes of hiking trails, and wildlife using two or more ecosystems in proximity are keys in planning (Leopold 1933, Romme and Knight 1982, Fahrig and Merriam 1985, Pickett and White 1985, Forman and Godron 1986, Turner 1987b, Van Dorp and Opdam 1987, Johnson 1988, Agger and Brandt 1988, Milne et al, 1989).

Conclusion

Ecologically sustainable landscapes are critical for our future, and foresters and landscape ecologists should be in the forefront of this developing area of thought and planning. Landscape ecology, focusing on mosaic structure, function, and change, is developing rapidly, and shifts our thinking from relatively-homogeneous ecosystems to large heterogeneous land areas usually containing people. Developing a landscape ecology plan that concurrently optimizes wood production, biological diversity, clean water, cultural cohesion, human health, housing, and other societal goals, should be a high priority for every forest and other natural resource area.

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