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Modeling the Effects of Management Approaches on
Forest and Wildlife Resources in Northern
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Christine Hanaburgh

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Major professor

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MODELING THE EFFECTS OF MANAGEMENT APPROACHES ON FOREST AND WILDLIFE RESOURCES IN NORTHERN HARDWOOD FORESTS

By

Christine Hanaburgh

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
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DOCTOR OF PHILOSOPHY

Department of Fisheries and Wildlife

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Professor Henry Campa, III

ABSTRACT

MODELING THE EFFECTS OF MANAGEMENT APPROACHES ON FOREST AND WILDLIFE RESOURCES IN NORTHERN HARDWOOD FORESTS

By

Christine Hanaburgh

I compared the effects of forest management regimes associated with 4 land ownerships in Michigan's Upper Peninsula on forest and wildlife resources in northern hardwood forests. Management ownerships investigated were the State of Michigan/Michigan Department of Natural Resources (MDNR) (management primarily for game species and timber products), Federal/USDA Forest Service (management for multiple use), private/industrial (management primarily for timber products), and private/non-industrial (minimal manipulations with the goal of preservation).

Twelve sites, 7-23 km^2 each, were evaluated in the Lake Superior State Forest, the Hiawatha National Forest, the Mead Company and Shelter Bay Forests property, and at the privately owned Huron Mountain Club. From 1996-1998, data were collected on 35 forest attributes, and on the relative abundance of red-backed salamanders, forest songbirds, barred owls, and fishers. Landscape characteristics were quantified from 1991 classified thematic mapper satellite imagery. Habitat suitability index models were developed for the red-backed salamander, yellow-rumped warbler, and northern flying squirrel, and wildlife habitat quality was evaluated with these models and with published models for other species.

Several forest structure characteristics differed among ownerships. Huron

Mountain Club stands had a more open understory, larger diameter trees, and more conifer cover ($p \leq 0.10$) than other ownerships. Timber industry stands had a larger proportion of beech and more midstory (0.5-5 m) canopy cover ($p \leq 0.10$), and Forest Service and MDNR sites tended to be more similar to each other in structure and composition than to other ownerships.

Salamander numbers were positively correlated with the density of trees >10 cm dbh, and negatively correlated with canopy cover 0.5-5 m in height. Relative abundance did not differ ($p > 0.10$) among ownerships, but tended to be greatest at the Huron Mountain Club. Relative abundance of American redstarts and veeries was greater ($p \leq 0.10$) on timber industry sites, and yellow-rumped warblers and pileated woodpeckers were most abundant on Huron Mountain Club sites. Habitat suitability index values for the red-backed salamander, yellow-rumped warbler, and pileated woodpecker were correlated ($p \leq 0.10$) with species population indices, indicating that these models performed well. The fisher and veery models did not predict the distribution and abundance of these species.

Landscape characteristics at the scales and resolution evaluated were primarily influenced by historical and physiographic factors, rather than management approaches within ownerships. Results indicated that the 4 land ownerships investigated represent a range of wildlife habitat conditions found in northern hardwood forests, reflecting the diversity of management goals across the eastern Upper Peninsula, as well as physiographic differences among ownerships.

ACKNOWLEDGMENTS

This project was made possible through funding from Michigan State University, the Michigan Nongame Wildlife Fund, the Huron Mountain Foundation, and the Federal Aid in Wildlife Restoration Act under Project W-127-R administered by the Michigan Department of Natural Resources, Wildlife Division. I would like to thank Terry Minzey and the staff of the Cusino Wildlife Research Area for being so accommodating to the field crew during our stay at Cusino. I am grateful to David Gosling, Arthur Turner, and the staff and members at the Huron Mountain Club for providing project support, beautiful accommodations, and the very rewarding experience of working on such an wondrous and majestic piece of property. I would also like to acknowledge the Mead Company and Shelter Bay Forests for permission to conduct research on their land, and for providing information on my study sites.

The expertise of my graduate committee has been invaluable in this undertaking. I am grateful to Dr. Doug Lantagne for his continued interest in this project, all the way from Vermont, and to Dr. Richard Groop for his time and helpful comments during the course of the project. Dr. Dean Beyer was instrumental in developing this project and provided a valuable management perspective. Special thanks are extended to Dr. Kelly Millenbah for generously filling a last minute committee opening. I have especially enjoyed working with Dr. Scott Winterstein, and I have learned he can always be counted on to give scientific advice that makes sense in "real life." Most of all, I am indebted to my advisor, Dr. Henry (Rique) Campa for his commitment to this project and to me, for

the wealth of professional opportunities he has brought to me, and for his hard work on behalf of his students.

I must also recognize the field assistants who worked with me and provided the companionship, suggestions, observations, and hard work that made it possible for me to complete the field work for this project. Most sincere thanks to Sarah Converse, Sarah Harris, Leah Trudgeon, April Woodward, and especially Tammy Giroux for her extra effort and leadership with this project.

There are others I would like to recognize for their support and contributions during my journey through graduate school. Delia Raymer and Meg Clark have been my office mates, teaching assistant colleagues, and graduate school comrades from the very beginning, and I thank them for sharing their experiences and friendship with me. I am also grateful to Dr. Bill Taylor for taking an interest in my graduate experience and for giving me advice and opportunities that have helped shape my professional and personal goals.

Certainly without my family this whole endeavor would not have the personal meaning that it does. I was truly fortunate to have the continual support, praise, and encouragement of my parents David and Johanna Hanaburgh, my grandparents, and my parents in-law. Finally, no words can express my gratitude to my wonderful husband Jeff, for never questioning my goals and for making this dissertation part of his life as well.

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INTRODUCTION

Among the challenges facing natural resource managers implementing ecosystem management is the integration of differing goals and objectives among land ownerships across a landscape (Allen 1994, Sample 1995). Often, the demands placed on individual pieces of property drive the land use decisions made by public and private landowners, rather than consideration for the role of that property in the landscape. However, the emergence of ecosystem management as the cornerstone of natural resources management has stimulated changes in the goals and management approaches of natural resource agencies. In managed forests, these changes have involved a greater emphasis on maintaining ecological integrity and biodiversity, integrating social perspectives into management plans, and providing nontimber forest products, such as recreational opportunities and nongame wildlife. Nonetheless, the administrative boundaries that separate land ownerships remain obstacles to coordinating natural resources management at the large scale necessary to encompass forest ecosystems and conserve many wildlife species (Allen 1994, Sample 1995).

In a landscape that spans political boundaries, such as the northern hardwood forests of Upper Michigan, the combined effects of differing management goals among land ownerships can impact the outcome of management in each area. Approximately 80% of Michigan's Upper Peninsula is forested, and forest resources have historically been one of the major social, economic, and environmental driving forces of the area (Leatherberry 1993, Schmidt 1993). This heavily forested region is divided among

multiple land ownerships whose individual management approaches reflect the diversity of values associated with the ecosystem, and the diversity of products that the system provides. One of the major factors that has shaped the forests that dominate Michigan's Upper Peninsula today has been the extensive logging that occurred throughout Michigan in the late 1800s and early 1900s. Prior to this time period, Upper Michigan was covered by expanses of forest dominated by sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*), and hemlock (*Tsuga canadensis*) in drier areas, and balsam fir (*Abies balsamea*), spruce (*Picea* spp.), and northern white cedar (*Thuja occidentalis*) in lowland areas. There were also areas of pine (*Pinus* spp.) dominated forests on the drier sandier soils, and a few pockets of mesic deciduous forest, composed of sugar maple and beech (*Fagus grandifolia*) (Frelich 1995).

Before 1870 there were over 4 million ha of forest in the Upper Peninsula; by 1941, 75% of the original forest had been subjected to logging or other types of development (Cunningham and White 1941). The Upper Peninsula logging industry was driven by white pine (*Pinus strobus*) and Norway pine (*Pinus resinosa*) harvest (Langhorne 1988), despite the fact that pine was the dominant species in only 15% of Upper Peninsula forests (Karamanski 1989). Pine was initially the most important tree in the logging industry because it was valued for its light weight and strength as a building material. It also occurred in relatively large, isolated stands (Langhorne 1988). Perhaps most importantly, it was buoyant enough to be transported to sawmills by water, which was the prevailing transportation medium for that era and region.

Between 1870 and 1900, cedar and hemlock began to be exploited as well. There were a

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were also approximately 1.9 million ha of hardwood forest in the Upper Peninsula, dominated by sugar maple, beech, and hemlock, with smaller amounts of yellow birch, basswood (*Tilia americana*), and green ash (*Fraxinus pennsylvanica*) (Karamanski 1989, Frelich 1995). However, hardwood species received little industrial attention until the late 1890s, when an extensive railroad transportation system had been established and supplies of pine were diminishing.

By 1920, timber supplies were greatly reduced, and the logging industry declined further under the effects of the Great Depression. Agriculture in the Upper Peninsula had coevolved with the logging industry, and it too, suffered a decline immediately after World War I, leading many farmers to abandon their farmland. Between 1921 and 1932, 800,000 ha of abandoned forest land reverted to the State of Michigan. In 1931, the National Forest Reservation Commission approved land purchases in the Upper Peninsula to create the Hiawatha National Forest. The lands returned to federal ownership were among those most severely impacted by previous logging activities. Much of the land had been logged and then burned over several times, and after clearing, the land was often maintained as agricultural plots. In addition, lumber companies whose land had been cut over and were no longer returning a profit offered large pieces of land for sale to the federal government. The Civilian Conservation Corps, established in 1933, greatly improved the condition of publicly owned land by aggressively planting trees and controlling fires on national and state forest land (Karamanski 1989). Thus, the Upper Peninsula logging that continued past 1920 represented a transition from an era of unregulated commercial timber harvest to one of managed forestry.

Today, although ecosystem management is an approach shared by many natural resources agencies and other land managers, the precise objectives and management strategies applied to a forest may be quite different. Current management of U.S. Forest Service (Forest Service) lands seeks to meet multiple use objectives, which includes managing for "outdoor recreation, range, timber, watershed, and wildlife and fish purposes" as mandated by the 1960 Multiple Use-Sustained Yield Act. The Forest Service has stated that an ecosystem approach to management is central to achieving its goals and objectives, and has recognized the necessity of landscape scale assessments (U.S. Department of Agriculture 1995). For example, in 1994, The Forest Service engaged in the Northern Lower Michigan Ecosystem Management Project, in collaboration with the Michigan Department of Natural Resources (MDNR), several other federal agencies, and state and local conservation groups (Michigan Department of Natural Resources 2000). The intention of the project was to evaluate and make recommendations on how public land in northern lower Michigan can be managed in consideration of the interactions among the social, economic, and ecological components of the region. Products of this project have included a Resource Conservation Guide, which explains the interrelationships between human and natural communities for public and private stakeholders in Michigan natural resources management, and a classification map of all ecosystems, grouped by climate, topography, soils, and vegetation, in northern lower Michigan.

While not bound by the same legislation as the Forest Service, the MDNR has also undertaken the task of initiating ecosystem management on their state forest lands

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(Begalle 1991). This approach contrasts with past management efforts which have focused more specifically on producing game wildlife and timber revenues. In addition to the MDNR's involvement in the northern lower Michigan ecosystem management project, another example of how the MDNR is moving in this direction is its draft of a comprehensive resource management plan for the Escanaba River State Forest in Michigan's Upper Peninsula (Michigan Department of Natural Resources 1991). One way in which this plan is different from past management efforts is that the focus of management is moved away from forest stands to larger scale ecological management units, in which classification is based on climate, physiography, soils, and vegetation types. The plan also provides criteria for designation of old-growth forests that allow more integrated management of current and future old-growth with the rest of the landscape (Begalle 1991, Michigan Department of Natural Resources 1991).

Though under much less public pressure to conform to the principles of ecosystem management, wood products industries are also making changes in their forest management practices. The timber industry has recognized that sustainably high timber production is not possible on all industry lands and that other objectives are compatible with intensive timber management (Wright 1991). Wood products companies are also aware that the industry can ultimately benefit from a more balanced management approach that integrates public values and generates a positive public perception of timber industry management practices. One example of timber company efforts to manage at the ecosystem level is the Total Ecosystem Management Strategies (TEMS) project. Total Ecosystem Management Strategies is a collaboration initiated in 1989 betwee

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between The Mead Corporation, a wood products company, and White Water Associates, a Michigan ecology consulting firm (Ticknor 1993). The project used White Water's technical expertise to evaluate the effects of Mead's management practices on ecosystem health within a 10,000 ha forested landscape owned primarily by Mead. Part of the TEMS approach was to assess songbird and mammal use of the area, to relate the results to specific timber harvesting practices, and to improve those practices to maintain the viability of native ecosystems where possible.

Objectives for management of nonindustrial private lands, owned by individual or private organizations such as the Huron Mountain Club or private hunt clubs, are perhaps the most diverse of all types of land ownership. Private land owners are a more numerous group, their lands range in size from less than a hectare to several thousand hectares, and, unlike institutionalized resource management organizations that are accountable to public and scientific opinion, private landowners are only accountable to governmental laws and regulations for their management decisions. Nonindustrial private land management objectives may include hunting, wildlife viewing, economic return from timber production, maintenance or restoration of ecological integrity, or any combination of these objectives. An additional example of private nonindustrial forest management is the Huron Mountain Club's goal of preserving the condition and natural processes of their forests, much of which have never been logged.

Managing to meet different ownership objectives can result in differences in the structure and composition of forests and landscapes. In addition to current management practices, other factors that may influence landscape characteristics include past

management activities, historical disturbances that occurred in the area, and inherent site attributes. These variables are also important to consider when planning management approaches to meet wildlife and ecosystem management objectives. For example, white-tailed deer (*Odocoileus virginianus*) in the Upper Peninsula travel an average of 9.7-14.5 km between summer and winter ranges (Verme 1973), and the spatial arrangement of summer and winter ranges has been found to influence the population structure of deer on their summer range (Van Deelen 1995). Patterns of silvicultural practices among ownerships can also determine the spatial diversity of the entire landscape (Mladenoff et al. 1993).

In the northern hardwood forests of Michigan's Upper Peninsula, the ultimate impacts of varying management approaches, past disturbances, and abiotic factors on forest and wildlife resources across ownership boundaries have not been rigorously documented. Therefore, the focus of this project was to evaluate and compare the impacts of management approaches guided by the goals and objectives of several different land ownerships on northern hardwood ecosystem characteristics. This information may be used for coordinating forest management that will meet individual agency and land owner objectives, yet will maintain biodiversity and ecological integrity across the landscape.

OBJECTIVES

Specific objectives of this project were to:

1.) Model and compare the effects of 4 different management approaches (management for multiple use [federal forest management agency], management for game species and timber products [state natural resources agency], management primarily for timber products [timber industry], and minimal management with the goal of preservation [private forest land that has never been manipulated]) on ecosystem conditions and forest and wildlife resources, at spatial scales ranging from the stand to the landscape level.

2.) Compare forest and landscape characteristics, and wildlife relative abundance in mesic hardwood forests that have been subjected to minimal human disturbance with areas last manipulated in the early 20th century.

3.) Develop recommendations for ecosystem management that will maintain biodiversity and ecological integrity across a landscape that is managed with different goals and objectives.

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STUDY AREA

In 1996, study sites were selected to fulfill 3 (Forest Service, MDNR, and private ownership) of the 4 management categories evaluated in this study. Three replicate study sites were located in the Hiawatha National Forest, representing the Forest Service ownership category, and 3 replicate sites were selected in the Lake Superior State Forest to represent the MDNR ownership category (Fig. 1). The private/non-industrial management category was represented by the Huron Mountain Club. Three additional sites were identified in 1997, 1 of which was on land owned by the Mead Company, and 2 of which were on land owned by Shelter Bay Forests. These sites were added to the study to fill the private industrial forest management category of study sites.

Of the 3 study sites located in the Hiawatha National Forest, 2 were in the western part of the forest in Alger County, and 1 was in the eastern part in Chippewa County (Table 1). The Mead site was also in Chippewa County and the 2 Shelter Bay sites were in Alger and west-central Luce Counties. In the Lake Superior State Forest, 1 site was located in Alger County, 1 was in northeastern Luce County, and 1 was across the border of Luce and Mackinac Counties. All study sites ranged from 12-19 km^2 and contained the largest proportion of contiguous northern hardwood forests available, based on GIS coverages, within each land ownership. There was a mix of successional stages and management intensities among the study sites, ranging from recently thinned mid-successional stands to unmanipulated old-growth forest.

Study sites in Alger, Luce, and Chippewa counties are in a region that is heavily

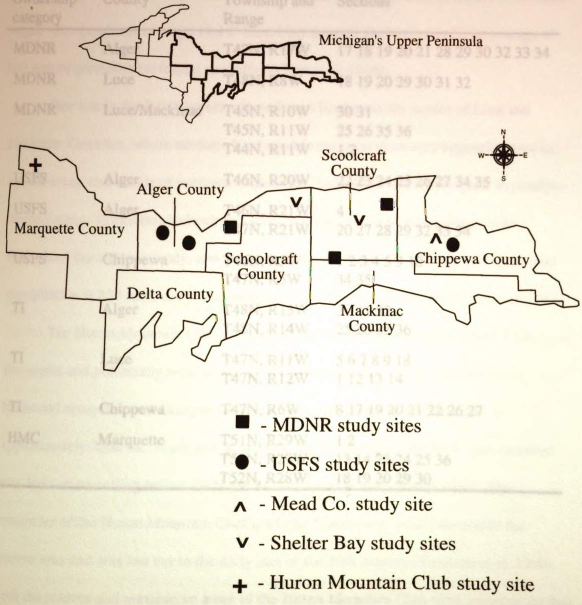

Figure 1. Approximate locations of 1996-1998 study sites on state (MDNR), federal (USFS), timber industry (Mead Company and Shelter Bay Forests), and Huron Mountain Club land in Alger, Chippewa, Luce, Mackinac, and Marquette counties in the Upper Peninsula of Michigan.

Table 1.
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Table 1. Legal descriptions of locations for Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) study sites in Michigan's Upper Peninsula.

Ownership category	County	Township and Range	Sections
MDNR	Alger	T47N, R17W	17 18 19 20 21 28 29 30 32 33 34
MDNR	Luce	T48N, R8W	18 19 20 29 30 31 32
MDNR	Luce/Mackinac	T45N, R10W	30 31
		T45N, R11W	25 26 35 36
		T44N, R11W	1 2
USFS	Alger	T46N, R20W	22 23 24 25 26 27 34 35
USFS	Alger	T46N, R21W	4
		T47N, R21W	20 27 28 29 32 33 34
USFS	Chippewa	T46N, R5W	1 2 3 4 5 9 10
		T47N, R5W	34 35
TI	Alger	T48N, R13W	30 31 32
		T48N, R14W	25 26 35 36
TI	Luce	T47N, R11W	5 6 7 8 9 18
		T47N, R12W	1 12 13 14
TI	Chippewa	T47N, R6W	8 17 19 20 21 22 26 27
HMC	Marquette	T51N, R29W	1 2
		T52N, R29W	13 14 23 24 25 36
		T52N, R28W	18 19 20 29 30

influenced by Lake Superior to the north, resulting in cold winters with heavy snowfall, and a cool growing season of about 114 days. Elevations range from 183-378 m, and the physiography includes poorly drained sand lakeplains and well drained sand end-moraine ridges. Temperatures average 14.4 C from May through September, with an average of 840 mm of precipitation falling annually (Albert et al. 1986).

One site in the Lake Superior State Forest lies across the border of Luce and Mackinac Counties, where northern hardwood forest is the dominant vegetation type in upland areas, and stands of northern white-cedar, balsam fir, and spruce grow in poorly-drained areas. Limestone bedrock and sand lake plain occur in this region. Soils throughout the area are sandy, and topography ranges from 178-317 m. Average annual precipitation is 810 mm, and temperatures average 14.9 C in summer (Albert et al. 1986).

The Huron Mountain Club property, located in northwestern Marquette County, is the largest and potentially most representative example of an old-growth northern hardwood ecosystem in Michigan. The land is privately owned and consists of approximately 7200 ha. A portion of the land, approximately 3300 ha in size, received only light or no cutting before 1900 and is designated as the "reserve area." The remainder of the Huron Mountain Club land (the "nonreserve area") surrounds the reserve area and was last cut in the early part of the 20th century (Simpson et al. 1990). Both the reserve and nonreserve areas of the Huron Mountain Club were sampled for this project. The physiographic region in which the Huron Mountain Club is located is characterized by steeper topography than other areas of Michigan, with elevations ranging from 183-604 m. Granitic bedrock lies near the surface of most of the region, and

outwash plains and ground moraines characterize smaller portions of the area. Soils consist of well drained to excessively well drained sands. Northern hardwood forests and hardwood-conifer or conifer swamps are the most prevalent habitat types. The average temperature in summer is 15.0 C, and the growing season typically lasts 89 days. An average of 900 mm of precipitation falls annually (Albert et al. 1986).

In 1996 and 1997, the average annual temperature for the eastern half of the Upper Peninsula was below the 20 year average, and in 1996 the average temperature (4.4 C) was lower than in any other year since 1980. Cumulative precipitation for the eastern Upper Peninsula was above average in 1996 and below average in 1997 and 1998 (Western Regional Climate Center 1999).

Prior to European settlement, most known disturbances in Michigan northern hardwoods occurred in the form of wind and ice storms, which removed <20% of the canopy in a stand. More severe disturbance events, which removed >60% of the canopy, were much less common, and occurred on a rotation of more than 1000 years in the Upper Peninsula (Frelich and Lorimer 1991). The result of the historical disturbance patterns was a mostly uneven aged forest structure, with as much as 90% of the presettlement northern hardwood forest in old growth condition (Frelich 1995).

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CHAPTER 1 - Assessment and Modeling of Wildlife Habitat

INTRODUCTION

Determination of wildlife habitat quality and quantity in relation to forest management practices is an important link between landscape-level habitat evaluation and effective wildlife management. This link can be established by implementing a fine-filter method of evaluation (Noss 1987) to describe important habitat elements and processes that occur on a relatively small spatial scale (Allen 1994, Roloff 1994), combined with a coarse filter approach (The Nature Conservancy 1982) to integrate information about the large scale habitat characteristics of a landscape.

At the stand level, a fine-filter evaluation can be applied by measuring vegetation characteristics and determining habitat conditions for individual wildlife species. Habitat suitability index (HSI) models are a widely used method of evaluating habitat quality for individual wildlife species on a local scale. The fundamental premise of HSI models is that species' abundances and distributions can be predicted from measurements of habitat parameters (Marcot et al. 1983). While many research studies have quantified key habitat attributes for particular wildlife species, HSI models offer the advantage of being a standardized, repeatable evaluation method. Assumptions associated with HSI models are that observed wildlife abundance is a function of habitat quality and that HSI model output is positively and linearly related to habitat quality for the species of interest (Schamberger and O'Neil 1986).

Habitat suitability index models are useful in a management context for

monitoring changes in habitat quality through time and in response to specific management practices without directly measuring population density (O'Neil and Schamberger 1983). This is an advantage when managers are interested in evaluating habitat for several species at once, or when a species is difficult to survey. However, use of HSI models has been criticized based on their lack of validation (Cole and Smith 1983, Bart et al. 1984). As use and development of HSI models has been scrutinized and refined, other researchers have identified additional considerations for using HSI models, including sample size adequacy (Cole and Smith 1983), the spatial scale of model applicability (Roloff 1994), and the amount of variance associated with model inputs (Bender et al. 1996). Other studies have demonstrated the accuracy and usefulness of HSI models for particular wildlife species (Thomasma et al. 1991, Roloff 1994, Negri 1995). Although there has been no established technique for consistently validating HSI models, Roloff and Kernohan (1999) recently proposed a protocol for validating HSI models and improving their reliability. These researchers concluded that, if used conscientiously, HSI models are a valuable and practical tool for habitat assessment.

This chapter addresses part of the first objective of this project, by comparing the effects of 4 different management approaches on forest and wildlife resources at the level of the forest stand. The fine filter evaluation in this study consisted of stand level analyses and habitat modeling to reveal habitat variables that may be driving species distributions and relative abundance, yet would be overlooked in a coarser, landscape-level analysis. This information on stand-level habitat characteristics and relationships to wildlife populations may then be blended with documented stand management histories

and larger scale assessments to explain how differing forest management approaches affect wildlife populations (Allen 1994).

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METHODS

Experimental design

The 4 land ownership categories evaluated for this project were represented by tracts of northern hardwood forest owned by the U.S. Forest Service, which manages for multiple use objectives; land managed by the Michigan Department of Natural Resources (MDNR), which emphasizes game species and timber production; land owned by the Mead Company and Shelter Bay Forests, which manage primarily for timber products; and property owned by the Huron Mountain Club, which has a goal of preserving the existing late successional stage northern hardwoods and minimizing human disturbance.

Nine wildlife species associated with northern hardwood forests were selected as indicators of the range of conditions and relative habitat quality of hardwood forests in each ownership category. These species were selected based on their use of northern hardwood forests to meet their life requisites, and on the range of spatial scales at which their habitat requirements occur (Table 2). Representation of wildlife with a variety of habitat requirements was important to understand the contributions each ownership is providing to wildlife habitat quality in the landscape. Species chosen were the red-backed salamander (*Plethodon cinereus*), pileated woodpecker (*Dryocopus pileatus*), American redstart (*Setophaga ruticilla*), ovenbird (*Seiurus aurocapillus*), veery (*Catharus fuscescens*), yellow-rumped warbler (*Dendroica coronata*), northern flying squirrel (*Glaucomys sabrinus*), barred owl (*Strix varia*), and fisher (*Martes pennanti*).

Red-backed salamanders were selected because they meet their life requisites within 3-5 m^2 of forest floor (Kleeberger and Werner 1982), while the male fisher's home

Table 3. Published home range estimates for species surveyed in Michigan's Upper Peninsula, 1996–1998.

Source	Location

Table 2. Published home range estimates for species surveyed in Michigan's Upper Peninsula, 1996-1998.

Species	Home range	Source	Location
Red-backed salamander	3.0-4.8 m^2	Kleeberger and Werner 1982	Michigan
American redstart	0.59 ha 2.45 ha	Sturm 1945 Samson 1979	Ohio New York
Ovenbird	0.27 ha 0.2-1.8 ha	Smith and Shugart 1987 Hann 1937	Tennessee Michigan
Yellow-rumped warbler	No data found		
Veery	0.04-1.10 ha	Martin 1960	Ontario
Pileated woodpecker	70 ha 130-243 ha	Kilham 1959 Bull and Meslow 1977	Georgia, Florida Oregon
Northern flying squirrel	3.1-12.5 ha 3.4-4.9 ha	Weigl and Osgood 1974 Witt 1992	Pennsylvania, N. Carolina Oregon
Barred owl	118-282 ha	Elody and Sloan 1985	Michigan
Fisher	3100 ha (males) 1600 ha (females)	Arthur et al. 1989	Maine

range may encompass approximately 31 km^2 (Arthur et al. 1989). Veeries are ground nesting birds that prefer moist forests with a dense understory (Winnett-Murray 1991), while ovenbirds are generally associated with mature hardwood forests with an open understory (Bourque and Villard 2001), and the American redstart prefers early successional forests with high stem densities (Bond 1957). Pileated woodpeckers and northern flying squirrels are both cavity nesters and depend on older forests to provide them with a supply of large dead trees (Cowan 1936, Weigl and Osgood 1974, Bull and Meslow 1977, Carey and Witt 1991). The yellow-rumped warbler was selected because, although it frequently occurs in Michigan northern hardwood forests (Eastman 1991), its association with northern hardwood forests is weaker than the other species chosen. The yellow-rumped warbler occurs regularly in conifer forests, and less often in northern hardwoods unless they have a conifer component (Hagan et al. 1997). Therefore, the yellow-rumped warbler represents a species which occurs at one end of the range of conditions that may occur in northern hardwood forests.

In 2 of the designated land ownerships (MDNR and Forest Service), 3 study areas were identified in each ownership and were sampled during the 1996, 1997, and 1998 field seasons. One site owned by Mead Co. was identified at the end of 1996 and was included in 1997 songbird, barred owl, and red-backed salamander data collection. Permission to work on 2 sites owned by Shelter Bay Forests was granted by Martin Wilk at the end of 1997, and these sites were sampled in 1998.

Replication of sites within the privately owned, low intensity management category was not possible within a reasonable travel distance from the other 9 study sites.

This ownership category was represented by the Huron Mountain Club, which was included in this study to provide information on habitat conditions in a forested landscape that is shaped by natural disturbances rather than silvicultural activities. For sampling purposes, the Huron Mountain Club was divided into 3 separate areas, approximately 2.5-7 km^2 each, based on ecological and geographic boundaries, such as the numerous lakes throughout the property and the borders of the reserve and nonreserve areas of the Club.

Vegetation sampling

Vegetation characteristics were measured in 104 stands. On MDNR, Forest Service, and timber industry land, 1 survey point was established in each of 7-12 hardwood stands throughout each site, based on the size of individual sites. Points were placed approximately every 1.6 km along permanent transects located 1.6 km apart to form a rough grid pattern across each study site. Locations of sampling points were recorded with a Global Positioning System (GPS) unit (Appendix A). This systematic sampling pattern was chosen to obtain data that would represent the range of conditions in the northern hardwood forest stands present on each site. The Huron Mountain Club was sampled more intensively to allow comparisons of areas logged early in this century with sections that have never been logged. In each of the 3 areas chosen for sampling at the Huron Mountain Club, 6-8 points, located approximately 0.6 km apart, were surveyed.

Within each stand selected for vegetation sampling, 3 sampling points were randomly located within a 200 m radius of the birding point associated with that stand. From 1996-1998, each stand was sampled once from summer to early fall. Attributes

sampled include those specified in published HSI models for the fisher (Allen 1983), barred owl (Allen 1987), pileated woodpecker (Schroeder 1982), American redstart (Minnis and Haufler 1994), ovenbird (Roloff 1994), and veery (Sousa 1982). Variables in these models include canopy cover of conifers, deciduous trees, shrubs, ground vegetation, and total canopy cover; density, height, and diameter of trees, shrubs, and saplings; and snag, stump, and log density (Table 3).

Published HSI models do not exist for the red-backed salamander, yellow-rumped warbler, and northern flying squirrel, so habitat sampling was based on important habitat attributes reported in the literature for these species. Vegetation features linked to red-backed salamander abundance include leaf litter depth (Pough et al. 1987, DeGraaf and Yamasaki 1992), soil pH and moisture, vegetation canopy cover (Heatwole 1962, Wyman and Hawksley-Lescault 1987), and the availability of cover objects such as decaying logs and rocks (Jaeger 1980, Pough et al. 1987, Mathis 1989).

Published information on the habitat requirements of the yellow-rumped warbler is scarce. The Michigan Breeding Bird Atlas survey indicated that the warbler is common throughout the Upper Peninsula, occurring most often in mesic forests consisting of mixed northern hardwoods. The yellow-rumped warbler also occurs in other forested areas, including dry coniferous forests and certain edge habitats (Eastman 1991). Therefore, the variables specified for other wildlife species in this study were considered inclusive of the characteristics that would be associated with a range of yellow-rumped warbler habitat quality.

Critical characteristics of flying squirrel habitat identified from the literature are

Table 3. Published HSI model variables and values associated with relatively good habitat quality. Dbh=diameter at breast height.

Variable / Species (Reference)	American redstart (Minnis and Haufler 1994)	Barred owl (Allen 1987)	Fisher (Allen 1983)	Ovenbird (Roloff 1994)	Pileated woodpecker (Schroeder 1982)	Veery (Sousa 1982)
% overstory canopy cover	60-80% (V1)	>60% (V3)	>80% (V1)		>75% (V1)	
% Shrub crown cover						>70% decid. (V3)
% Conifer cover in overstory	<40% (V2)					
% Herbaceous canopy cover						>90% (V5)
% Deciduous cover in overstory						
Tree density (stems/ha)	325-350 (V3)					
Sapling density (stems/ha)	>650 (V4)					
Shrub/sapling stem density				2000-4000/ha (V2)		
Density of trees >51 cm dbh		>2 trees/ .04ha (V1)			>30/.04 ha (V2)	
Mean dbh of overstory trees		>51cm (V2)	>38 cm (V2)			>38 cm (V2)

Table 3 (cont.) Table 3. Published HSI model variables and values associated with relatively good habitat quality. Dbh=diameter at breast height.

Species	American	Barred owl	Fisher	Ovenbird	Pileated	Veery

Table 3 (Cont). Table 3. Published HSI model variables and values associated with relatively good habitat quality. Dbh=diameter at breast height.

Variable	Species (Reference)	American redstart (Minnis and Haufler 1994)	Barred owl (Allen 1987)	Fisher (Allen 1983)	Ovenbird (Roloff 1994)	Pileated woodpecker (Schroeder 1982)	Veery (Sousa 1982)
Basal area					(V1) >10m²/ha		
Average ht. of deciduous shrubs							1.5-3.0m (V4)
Avg. height of herbaceous canopy							>30% (V6)
Average dbh of snags >38 cm dbh						>54 cm (V5)	
Density of snags >38 cm dbh						>.17/.4ha (V4)	
Density of stumps and logs						>10/0.4 ha (V3)	
% Cover type flooded							0% (V1)
Soil moisture regime							moist - saturated (V2)
Tree canopy diversity				≥3 layers (V3)			

snag and log abundance, which are important for nesting and foraging, respectively (Cowan 1936, Gilmore and Gates 1985), and overstory tree species composition (Payne et al. 1989).

Canopy cover was measured with the line intercept method (Canfield 1941) (Table 4). Intercepts were 20 m long and all woody cover was measured at strata of 0-50 cm above ground level (ground layer), 50 cm - 5 m (midstory), and >5 m above ground level (overstory), corresponding to variables in the HSI models (Table 3) and the dominant vegetation layers in the forest. In addition, conifer cover, deciduous cover, and canopy cover of hard mast producing trees (e.g., red oak [*Quercus rubra*], beech) >51 cm diameter at breast height (dbh) were measured in the overstory. Combined canopy cover of shrub species (e.g., serviceberry [*Amelanchier* spp.], yew [*Taxus* spp.]) was measured in the midstory, and the percent cover of woody debris and herbaceous vegetation in the ground layer was recorded (Table 4).

Nested plots were used to obtain densities of forest stand attributes. Density of each tree species, saplings (defined as trees 2.5-10.2 cm dbh [Bond 1957]), and snags were measured within 10x50 m plots (Table 4). A snag was defined as a dead or partly dead tree that had a dbh ≥10.2 cm and a height ≥1.8 m (Thomas et al. 1979). The density and diameter of logs >15 cm wide at their midpoint, and density, height, and diameter of stumps >15 cm wide were also measured within 10x50 m plots.

Within a 10x25 m subplot, dbh of individual trees ≥10.2 cm in diameter were measured with a dbh tape, and heights of trees were measured with a Haga altimeter (Table 4). The density and heights of woody stems <5 m tall and <2.5 cm in diameter

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Table 4. Forest stand variables and methods used to measure them in the Upper Peninsula of Michigan, 1996-1998.

Variable	Sampling method
Overstory tree species composition	10x50 m plots
Overstory tree diameter	10x25 m plots, dbh tape
Overstory tree height	10x25 m plots, Haga altimeter
Overstory tree density	10x50 m plots
Sapling density	10x50 m plots
Snag density	10x50 m plots
Snag height	10x50 m plots, Haga altimeter, meter stick
Snag diameter	10x50 m plots, dbh tape
Log density	10x50 m plots
Log length and diameter	10x50 m plots, meter tape, meter stick
Stump density	10x50 m plots
Stump height and diameter	10x50 m plots, measuring stick
Density of shrubs and seedlings	Variable sized plots
Height of shrubs and seedlings	Variable sized plots, meter stick
Herbaceous plant height	5 points along 3 50 m belt transects and at 15 salamander cover boards
Litter depth	5 points along 3 50 m belt transects and at 15 salamander cover boards
Canopy cover	20 m line intercepts
Woody debris	20 m line intercepts
Soil pH	Kelway soil tester at 6 points in each salamander survey grid
Soil moisture	Kelway soil tester at 6 points in each salamander survey grid
Number and size class of cover objects	3 1x50 m plots in each salamander survey grid

(shrubs and tree saplings) were measured in plots 10x25 m. Occasionally, shrub stems were counted and measured within smaller (2x2 m) plots in areas of exceptionally high shrub density.

Wildlife species surveys

Red-backed salamanders

In 1996, red-backed salamanders were surveyed in June using transect ground searches (Thomas 1983). During rainy nights, salamanders typically forage above ground (Heatwole 1962). During this time, the ground and tree trunks within 1x25 m transects were searched, and woody debris and rocks were overturned to locate salamanders. Salamander surveys were completed in 3-6 hardwood stands, located at least 1.6 km apart, in each study site. Although published literature had suggested that red-backed salamanders are relatively abundant in Michigan hardwood forests (Test and Bingham 1948), no more than 3 salamanders were found among all stands sampled at a site during rainy night surveys. Therefore, the nighttime search method was discontinued and 2 new survey methods were implemented during the second and third years of data collection.

In 1997 and 1998, 2 salamander survey methods were used concurrently to identify the most useful method for surveying red-backed salamanders. For 9 of the 12 hardwood forest study areas sampled during the project (3 in the Hiawatha National Forest, 3 in the Lake Superior State Forest, and 3 owned by private timber companies), salamander surveys were conducted in 5 stands selected randomly from a larger set of systematically located stands sampled for vegetation, forest birds, and barred owl. Selected stands were located throughout the study site and were separated by at least 1.6

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km. Three stands were randomly selected for salamander surveys at each of the 3 Huron Mountain Club sampling areas and were separated by intervals of 0.6-1.2 km.

One of the 2 survey methods used was daytime ground searches (Mathis 1989) within 2x50 m belt transects. Three 100 m^2 transects laid out parallel to each other and separated by 20 meters were searched in each stand. Within each transect, all movable cover objects such as logs and bark were overturned, and the underlying litter was examined for salamanders. When possible, ground cover and vegetation disturbed while searching were replaced after searching. The amount of time spent searching each transect was also recorded to standardize survey results to the amount of effort expended.

The other method used to survey salamanders was the cover board method, described by DeGraaf and Yamasaki (1992), in which wood boards were placed on the forest floor to simulate natural woody cover, and observations were made throughout the field season to find salamanders. Cover boards were untreated pine and were 90 cm long x 20 cm wide x 2.5 cm thick. In each stand, 3 rows of boards were placed parallel to the 2x50 m belt transects used for cover object searches. Rows were spaced 20 m apart, and each row had 5 boards placed at intervals of 10 m, resulting in a 3x5 grid of cover boards that covered approximately the same area as the belt transects (Fig. 2). Boards were distributed on MDNR, Forest Service, Huron Mountain Club, and 1 timber industry site in May and June 1997, and on the remaining 2 timber industry sites, boards were placed in November 1997. Surveys began in mid-June when salamanders are thought to have established territories (Jaeger 1979). Salamanders were located by carefully turning over each board and examining the underlying litter for salamanders, and after looking for

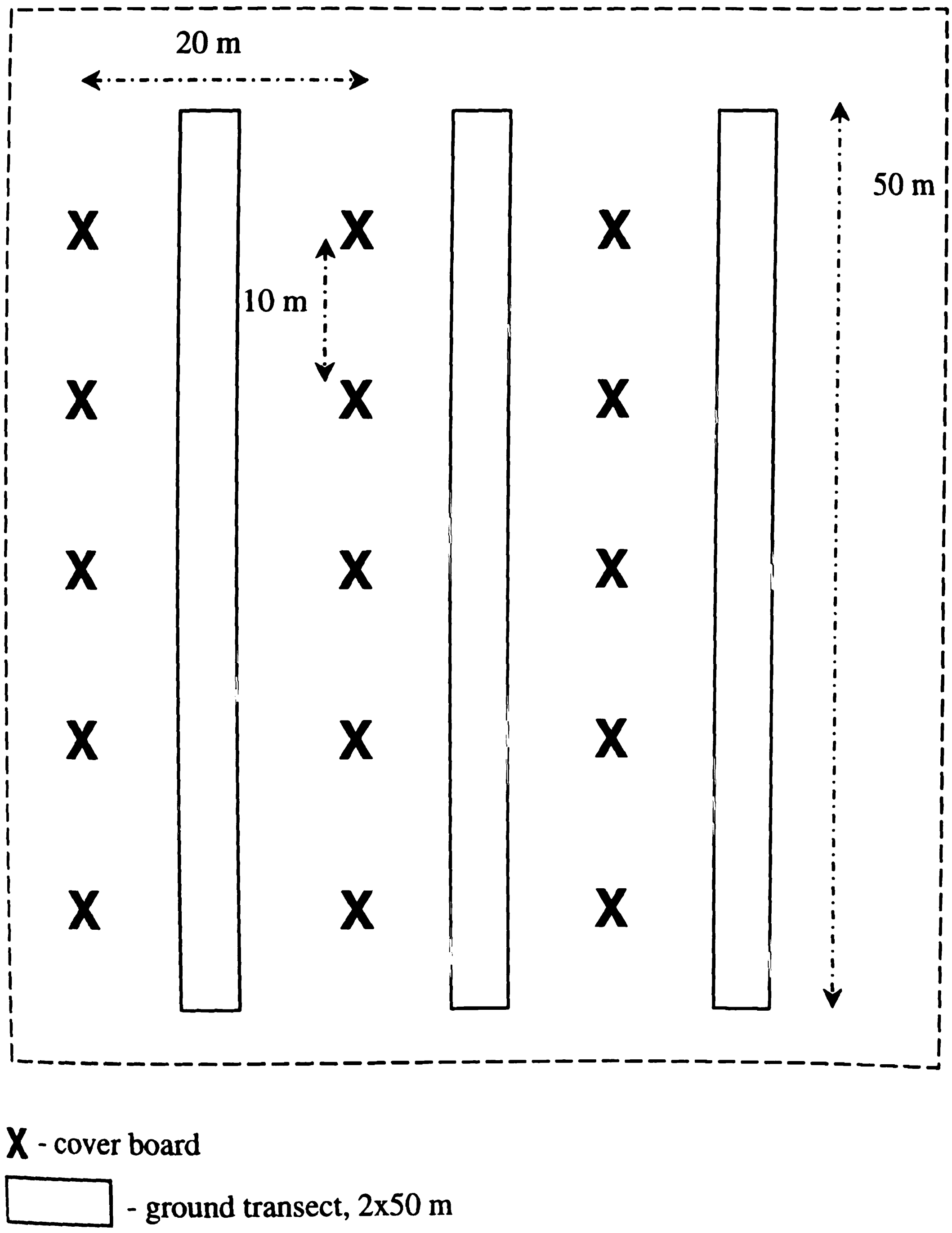

Figure 2. Arrangement of cover boards and ground transects used for salamander surveys in Michigan's Upper Peninsula, 1997 and 1998.

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salamanders, boards were put back into place.

During spring and summer salamander surveys, litter depth and height of vegetation below 50 cm were measured at every cover board and every 10 m along salamander search transects, for a total of 30 litter and vegetation height measurements per stand (Table 4). Soil moisture and pH were measured at 6 points in each stand with a Kelway Soil Tester (Kel Instruments Co., Wyckoff, NJ). During ground transect searches, the size and type of cover objects turned over were recorded, and the presence or absence of salamanders beneath each object was noted. Size of cover objects was recorded in width classes of 0-5 cm, 5-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, and >40 cm to determine if particular sizes of cover objects were used more often by salamanders on some sites than on others, and cover objects were classified as wood, bark, rock, or other (Table 4). Observations of herptile species other than red-backed salamanders were also recorded during surveys.

Cover board searches were conducted concurrently with ground transect searches. Both salamander survey methods were conducted once in each of the 54 selected forest stands during the period from June through early August. In September and October, 1997, before salamanders went below ground for the winter, ground transect searches and cover board searches were repeated in 20 of the stands that had been searched that summer. The purpose of these surveys was to assess seasonal population trends and obtain a population index before salamanders went below ground for the winter. In fall, 1998, cover board searches were conducted in every stand that had been sampled during summer. After the second cover board survey at the Huron Mountain Club in August,

1998, the boards were picked up from the sites and put into storage. Cover boards on all other sites were left in place after fall surveys so that researchers may start compiling a long-term data set on the relative abundance of red-backed salamanders in relation to habitat characteristics.

Forest bird species

Relative abundance of all forest birds, including the American redstart, ovenbird, veery, yellow-rumped warbler, and pileated woodpecker (i.e., the indicator species), was determined with point count surveys (Whitcomb et al. 1981) in 1996, 1997, and 1998 in all stands where vegetation sampling occurred. Each sampling point was surveyed once during May and June, during territory establishment and breeding, and once in July, after fledging. Surveying began at dawn and continued for 3 hours after dawn (Robbins 1981a). Bird surveys consisted of a 1-minute settling period followed by a 10-minute sampling period. The length of time used for each point count was determined from preliminary surveys, during which the number of species observed was plotted against time, and the point at which the number of new species began to level off was used as the count period. The species, gender, and relative location of all birds heard and seen from the survey station was recorded. To maintain fairly standard sampling conditions, surveys were not conducted in weather conditions such as rain, fog, winds over 20 kph (Robbins 1981b), or when water was dripping from the trees due to a recent rain. If possible, surveys conducted when there was >70% cloud cover were repeated when cloud cover was <70%, to minimize the inhibitory effects that cloud cover can have on bird vocalization (D. Beyer, Michigan Department of Natural Resources, pers. commun.)

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Northern flying squirrels

In 1996, during vegetation sampling, all snags within vegetation sampling plots were hit with a stick in an attempt to flush and observe flying squirrels that might have been in the tree. Because flying squirrels are nocturnal, they are expected to stay within their nest cavities during the day, and usually flee their nest cavity when their tree is disturbed, for instance by banging on the trunk of the tree (Sonenshine et al. 1973). However, no flying squirrels were observed with this method, so in 1997 larger transects were set up specifically to locate snags and observe flying squirrels that might be inhabiting the snags. Observers walked together through the forest stand, covering an area approximately 30 m wide and 200 m long, and knocked on each snag in the transect with a large stick to prompt flying squirrels inhabiting the snags to emerge. Again, no flying squirrels were located, either during formal sampling or during other field activities. Other potential methods for surveying northern flying squirrels, such as track plates (Carey and Witt 1991) or live trapping (Rosenberg and Anthony 1993) were not attempted because the amount of time they required would have prevented collection of other data needed for this project.

Barred owls

Taped playback surveys (McGarigal and Fraser 1985) were used to determine the relative abundance of barred owls throughout all study sites. Barred owl surveys were conducted once during July or August in 1996, 1997, and 1998. Surveys began after dusk and were completed by 0500. Barred owl survey stations were established at each point used for songbird surveys, spaced 1.6 km apart on MDNR, Forest Service, and timber

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industry land, and 0.6 km apart on Huron Mountain Club sites. At each survey point, a taped barred owl call was played through an amplifier for 2 3-minute periods, with 1 minute between each period. During the tape and for 10 minutes afterwards the number of barred owl responses to the taped call were recorded. The approximate distance and direction of responses were also estimated to determine if the same barred owl had been detected more than once. Stands in which barred owls were surveyed were not surveyed for songbirds the following morning.

Fisher

Fishers were surveyed by counting the frequency of fisher tracks in the snow (Powell 1994) during February and March of 1997 and 1998 on MDNR, Forest Service, and timber industry study sites, and in 1999 on 1 timber industry site and 1 MDNR site. Observers walked along transects through each study site and recorded the number and location of fisher tracks encountered. Between 2 and 4 transects, 1.6 km in length and spaced approximately 1.6 km apart, were used at each study site. Exact placement of transects depended on winter road accessibility in each study site.

Track count data were used to obtain an index of fisher use of study sites and to describe the intensity of activity on each site. The number of tracks per transect was divided by the total length of the transect to obtain an index of fisher activity in units of tracks/km for each study site. This approach was based on the assumption that an increase in the number of tracks per unit distance, even if left by one animal, corresponds to an increase in the suitability of the surrounding habitat for meeting that animal's life requisites.

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Because accessibility to the Huron Mountain Club is limited during winter, fisher track counts were not performed. Instead, scent post stations (Linhart and Knowlton 1975) were used during the summers of 1997 and 1998 as an alternate method for determining fisher relative abundance in stands at the Huron Mountain Club. Scent stations consisted of a circle of ground 1 m in diameter, cleared of vegetation, with a cotton swab with fermented egg and cod liver oil placed in the center. Placement of scent post stations followed the pattern of bird survey point locations, with stations located at approximately 600 m intervals in hardwood forest stands at the Huron Mountain Club. Each scent post station was checked for 3 consecutive days each in June and July.

Habitat modeling

For species without an existing HSI model (red-backed salamander, northern flying squirrel, and yellow-rumped warbler), preliminary models were developed using published information on habitat requirements in Michigan or in comparable habitats and geographic areas. The preliminary models guided field data collection, and analyses of ecological attributes measured in this study were used to finalize the red-backed salamander and yellow-rumped warbler models. For each variable included in the model, values thought to be indicative of high and low quality habitat conditions were used as the basis for determining an index of habitat quality for a sampled area.

For the red-backed salamander model, 35 vegetation and structural attributes were analyzed as independent variables in a multiple regression analysis of 30 of the 54 stands where salamanders were surveyed. The number of salamanders found per stand during summer cover board and ground transect surveys, averaged over all years of data

collection, was used as the dependent variable. Initially, the analysis was performed on data from 30 stands, randomly selected from the 54 stands where salamander surveys occurred, to preserve some data to use later for testing the validity of the model. The analysis began with forward and stepwise variable selection (Sokal and Rohlf 1981), and through this process, several variables that described little variability in the data (partial $R^2<0.05$) were eliminated. Based on the regression results using 30 data points, an intermediate model was developed. This model was tested on the remaining 24 data points, and the results were used to further evaluate and refine the salamander model.

Testing of the regression model against remaining data resulted in a poor model fit ($R^2=0.20$), suggesting that the model would not accurately predict salamander habitat quality. The next approach to improving the initial model was to divide data from the 54 stands into 2 groups. Stands with an average of ≤ 2 salamanders found during the summer, under boards and on transects combined, were considered to represent areas of unsuitable or very poor quality habitat, while the remaining stands represented varying degrees of better quality habitat, with the highest quality habitat occurring in stands where the maximum number of salamanders had been recorded. An independent t-test (Ott 1988) was used to identify habitat variables that differed significantly between the 2 groups. Final model variables were selected based on statistical results from field data (regression analysis and t-tests) and published research on red-backed salamander habitat use (Appendix B).

Field data for the yellow-rumped warbler were more limited than for the red-backed salamander, so model development differed slightly from that of the salamander.

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Potential model variables were first identified from a thorough literature review. In the next step, independent paired t-tests were used on field data to compare stands where yellow-rumped warblers were observed during data collection with stands where yellow-rumped warblers were not observed. These results were then used to corroborate and associate quantitative values with an index of habitat quality for each variable identified from the literature (Appendix C).

No northern flying squirrels were observed during field sampling, so population data were not available to use in model development. Instead, the model was derived from an intensive literature review (Appendix D).

Data analysis

The parametric assumption of normally distributed data was tested for each vegetation and soil attribute with the Shapiro-Wilk test. Many of the variables tested were nonnormal, so appropriate nonparametric tests were used for univariate data analyses. A limitation for conducting data analyses was the was the lack of replication, or pseudo-replication, of Huron Mountain Club study sites. While this may affect the strength of some conclusions about wildlife populations and habitat conditions at the Huron Mountain Club, the data that were collected provide an important reference point for the range of conditions that may occur in northern hardwood forests.

Comparisons of vegetation variables and species relative abundances among land ownerships and among sampling periods (years for all species, and seasons within a year for bird data) were made with the Kruskal-Wallis one-way analysis of variance or the Wilcoxon-Mann-Whitney test (Siegel and Castellan 1988). Significant differences

($p \leq 0.10$) detected with the Kruskal-Wallis test were further analyzed with the Kruskal-Wallis multiple comparison statistic (Siegel and Castellan 1988) to determine which pairs of ownerships were different. Songbird comparisons were based on the proportion of sampling points at which a species was detected.

Songbird data were compared across the 3 years of this study for each ownership category to determine if it would be appropriate to combine the data for further analysis. In this analysis, species which never occurred more than once in any of 6 possible sampling periods (spring and summer, 1996, 1997, and 1998) on any of the sites within an ownership were omitted from comparisons among years. The overall management approaches of each ownership remained constant during the study, so differences in species relative abundances among years were assumed to be related to local environmental conditions, rather than treatment effects. Therefore, data collected in multiple years were combined by calculating yearly values for each site, then averaging yearly values among sites within each ownership to obtain a value for each ownership by year, and finally by averaging values for all years of data collection within each ownership. Principal components analysis (PCA) (Morrison 1990) was also used to obtain a graphical representation and quantitative description of the multivariate relationships among vegetation variables in all 4 ownerships.

Patterns in bird species communities among ownerships were investigated by conducting PCA on a subset of all bird species that occurred at an average relative frequency >20% on any ownership. Additionally, forest birds with similar life history characteristics (e.g., cavity nesters, year round residents) were grouped together and a

Kruskal-Wallis one-way analysis of variance was used to test for differences among ownerships in the relative abundance of each group.

At each study site, an index of relative habitat quality was calculated using existing HSI models for the ovenbird, veery, American redstart, pileated woodpecker, barred owl, and fisher, and recently developed models for the red-backed salamander, northern flying squirrel, and yellow-rumped warbler. For the ovenbird, veery, American redstart, pileated woodpecker, barred owl, red-backed salamander, yellow-rumped warbler, and northern flying squirrel, model outputs between 0 and 1.0 were calculated from data collected at each stand survey point. For comparisons among ownerships, HSI values were averaged across stands to obtain a value for the entire study site. Based on the typical home range size of adult fishers, it was assumed for each study site that the entire area was included in the home range of any fishers whose tracks were observed on the site. Therefore, fisher habitat suitability indices were calculated by first averaging data for vegetation sampling locations across the whole study site, and using the average values as the model input, resulting in a single HSI value for each site. Comparisons of relative habitat quality (HSI values) among ownerships were made with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

Spearman-rank correlations (Siegel and Castellan 1988) between species average relative abundances and HSI values for all study sites were analyzed to test the validity of the models that are available for the ovenbird, American redstart, veery, pileated woodpecker, barred owl, and fisher, and for the red-backed salamander and yellow-rumped warbler models developed for this project.

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RESULTS

Vegetation and structural attributes

Vegetation variables were measured in 104 hardwood forest stands, and the majority of vegetation sampling was done in July and August of 1996 and 1998. Tests of univariate normality suggested a nonnormal data distribution for 12 of 27 vegetation variables, so nonparametric tests were used for univariate analyses. On the forest floor, differences among ownerships were found in the average height of ground vegetation ($p=0.034$), the size of logs measured (length, $p=0.075$; width, $p=0.052$), and the average diameter of tree stumps ($p=0.053$) (Table 5). Sites managed by the MDNR had taller herbaceous plants than the other 3 land ownership categories sampled, which corresponds to the significantly greater amount of vertical cover of herbaceous vegetation also measured on MDNR sites. Logs on MDNR and Forest Service sites were significantly smaller in width ($p=0.052$) than logs measured on other ownerships, and the largest diameter logs were at the Huron Mountain Club. Sites on timber industry and Forest Service land had the greatest density ($p=0.041$) of shrubs (defined as woody species 50 cm - 5 m tall with a dbh <10.2 cm), and on timber industry sites there was more vertical cover in the shrub layer of the forest (50 cm - 5 m) (0.038), while forests at the Huron Mountain Club have relatively few shrubs, resulting in a much more open understory. Approximately 98% of all stems classified structurally as shrubs were tree species; the remainder were shrub species.

The diameter and basal area of overstory trees was significantly different among the 4 ownership categories, with stands at the Huron Mountain Club having the largest

Table 5. Understory vegetation variables (means and standard errors) measured on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, July and August, 1996, 1997, and 1998.

Table 5. Understory vegetation variables (means and standard errors) measured on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, July and August, 1996, 1997, and 1998.

	Ownership category								
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)		Probability level[a]
Variable	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	
Saplings/ha*	**883.72**[b]	104.73	**1,066.58**[bc]	227.01	**1,263.81**[c]	171.00	**439.15**[d]	184.47	0.063
Shrubs/ha*	**6,389.96**[b]	1,622.64	**15,663.06**[c]	5,895.86	**16,967.74**[c]	3,657.55	**1,303.36**[d]	733.62	0.041
Shrub height (cm)	**103.20**	8.60	**109.54**	11.94	**108.42**	9.68	**95.94**	13.80	0.814
Stumps/ha	**169.30**	28.51	**172.88**	23.88	**178.69**	9.95	**102.55**	33.72	0.361
Stump height (cm)	**48.10**	1.39	**45.98**	4.20	**54.57**	8.92	**63.72**	5.40	0.264
Stump diameter (cm)*	**27.53**[b]	0.40	**25.15**[b]	2.54	**35.95**[c]	3.43	**39.10**[c]	3.54	0.053
Logs/ha	**174.03**	25.14	**122.53**	15.41	**264.34**	81.12	**183.30**	9.38	0.270
Log length (m)*	**5.80**[b]	0.32	**4.43**[c]	0.23	**4.62**[c]	0.67	**5.63**[b]	0.23	0.075
Log diameter (cm)*	**20.88**[b]	1.34	**22.25**[b]	0.74	**24.24**[c]	0.68	**27.79**[d]	2.25	0.052
Herbaceous height (cm)*	**19.05**[b]	1.20	**14.77**[c]	0.96	**15.01**[c]	2.07	**7.74**[d]	1.25	0.034
Litter depth (cm)	**3.47**	0.15	**3.54**	0.24	**3.81**	0.25	**3.20**	0.20	0.347
Vertical cover (%)									
0-0.5 m	**22.42**	3.65	**20.62**	3.04	**14.91**	1.28	**13.33**	1.94	0.192
0.5-5 m*	**27.79**[b]	0.76	**36.90**[b]	5.47	**50.83**[c]	5.41	**16.95**[d]	3.06	0.038
Herbaceous*	**11.84**[b]	1.82	**7.67**[c]	0.42	**6.63**[c]	0.92	**7.28**[c]	0.69	0.082
All shrub species*	**0.12**[b]	0.02	**0.41**[c]	0.10	**0.10**[b]	0.08	**0.08**[b]	0.07	0.084

Table 5 (Cont). Understory vegetation variables (means and standard errors) measured on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, July and August, 1996, 1997, and 1998.

Table 5 (Cont). Understory vegetation variables (means and standard errors) measured on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, July and August, 1996, 1997, and 1998.

	Ownership category								
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)		Probability level[a]
Variable	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	
Vertical cover (%)									
Deciduous shrub species*	**0.12**[b]	0.02	**0.41**[c]	0.10	**0.09**[b]	0.09	**0.08**[b]	0.07	0.083
Woody debris	**6.05**	0.84	**6.38**	0.54	**4.59**	0.48	**7.86**	1.45	0.270

[a] Probability levels reported were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

*Values on the same line with the same letter are not different (p>0.10) (Kruskal-Wallis multiple comparison statistic [Siegel and Castellan 1988]).

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dbh ($p=0.057$) and basal area ($p=0.031$) of the stands sampled (Table 6). The Huron Mountain Club also had the greatest amount of vertical cover of conifer species ($p=0.044$) and the least canopy cover of deciduous tree species ($p=0.063$), due to the large hemlock component and near absence of beech in forests at the Huron Mountain Club. The proportion of hard mast producing trees, primarily beech, >25.4 cm dbh was greatest ($p=0.029$) on timber industry sites (Table 6).

Principal components analysis

Conifer cover was one variable that exhibited a very nonnormal, skewed distribution, with especially high values in stands at the Huron Mountain Club (Table 6). This variable was arcsine transformed to more closely meet the assumption of multivariate normality associated with PCA, and the analysis was run on both transformed and untransformed data. Results of PCA on the untransformed data corresponded most closely with the ecological relationships (e.g., differences in canopy cover) that were evident in nonparametric tests and univariate statistical comparisons, and only these results are included here.

The first 3 principal components (PC's) of the analysis for 27 overstory and understory vegetation variables accounted for 66% of the variability in the data set, and with the fourth principal component, 76% of the variability was described. The first principal component explained 37% of the variance and describes a contrast between coniferous and deciduous overstory cover, and also between basal area and understory characteristics such as shrub stem densities, midstory canopy cover, and herbaceous vegetation height (Fig. 3). Specifically, stands at one end of the gradient had more

Table 6. Overstory vegetation variables (means and standard errors) measured on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper

Table 6. Overstory vegetation variables (means and standard errors) measured on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, July and August, 1996, 1997, and 1998.

	Ownership category								Probability level[a]
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)		
Variable	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	
Basal area (m^2/ha)*	**24.69**^{b}	2.39	**26.84**^{b}	2.25	**20.0**^{c}	1.47	**46.85**^{d}	6.03	0.031
Overstory trees/ha	**578.75**	70.75	**544.39**	62.38	**483.32**	33.42	**617.81**	95.54	0.376
Overstory tree DBH (cm)*	**23.72**^{bc}	1.82	**25.51**^{b}	1.54	**22.78**^{cd}	0.26	**32.40**^{e}	3.87	0.057
Overstory tree height (m)	**20.88**	0.28	**21.88**	0.79	**19.83**	1.03	**21.05**	0.56	0.433
Snags/ha	**69.09**	16.56	**53.86**	7.02	**32.17**	5.44	**46.90**	3.62	0.137
Snag height (m)	**10.11**	0.32	**10.86**	1.06	**10.41**	0.12	**10.43**	1.40	0.875
Snag diameter (cm)	**19.29**	2.30	**20.65**	0.72	**21.85**	2.72	**32.14**	5.16	0.248
Vertical cover (%)									
>5 m	**84.49**	1.01	**80.17**	1.76	**82.83**	4.34	**82.34**	1.87	0.516
Conifer trees*	**3.29**^{b}	2.06	**9.99**^{c}	1.97	**6.34**^{bc}	2.70	**47.45**^{d}	5.25	0.044
Deciduous trees*	**82.77**^{b}	2.04	**77.17**^{c}	2.87	**79.07**^{bc}	6.02	**58.66**^{d}	5.58	0.063
Hard mast trees >10 in (25.4 cm) DBH*	**2.01**^{b}	1.17	**5.31**^{c}	0.82	**9.67**^{d}	1.93	**0.67**^{be}	0.67	0.029

[a] Probability levels reported were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

*Values on the same line with the same letter are not different ($p>0.10$) (Kruskal-Wallis multiple comparison statistic [Siegel and Castellan 1988]).

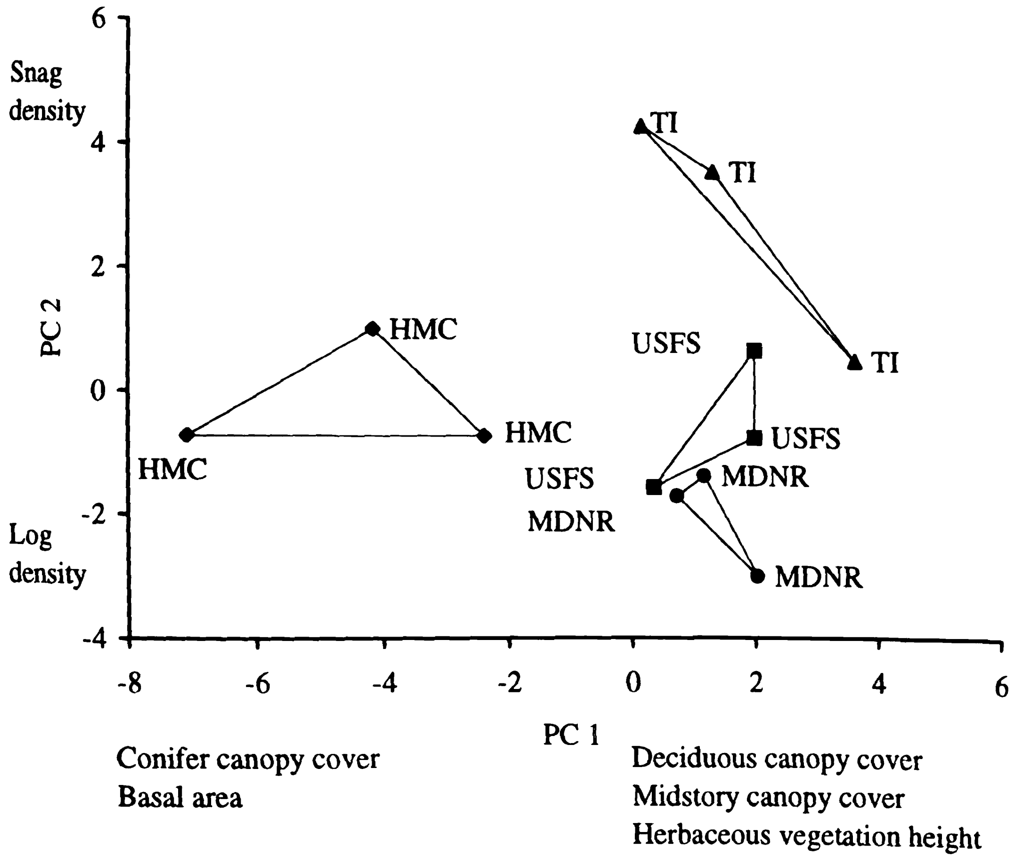

Figure 3. Scores for the first 2 principal components (PC) for vegetation variables measured on study sites on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, 1996, 1997, and 1998.

coniferous overstory cover, higher basal area, and relatively little midstory canopy cover, while stands at the opposite end of the range had more deciduous overstory cover, lower basal area, more midstory cover, and taller herbaceous vegetation. Sixteen percent of the variance was explained by PC2, which represents a gradient between stands with relatively larger numbers of fallen or cut logs and stands with higher snag densities. The third principal component accounted for 13% of the variability and describes a contrast between a combination of overstory canopy cover and overstory stem densities, and a combination of litter depth, shrub stem density, and ground cover.

Scores for PC1 were negative for all 3 Huron Mountain Club sites and positive for all other sites, reflecting the relatively high proportion of conifer cover and low proportion of deciduous cover in the overstory, along with the greater tree volume and open midstory on Huron Mountain Club sites. These characteristics distinguished Huron Mountain Club sites from forests managed by the MDNR, Forest Service, and private timber companies, which had higher proportions of deciduous canopy cover, denser midstories, and taller ground vegetation. Among sites on MDNR, Forest Service, and timber industry land, scores for PC1 varied substantially, and these 3 ownership categories are not graphically distinguishable along the first principal component axis (Fig. 3).

Michigan Department of Natural Resources sites and timber industry sites occupied opposite positions along the gradient described by PC2. This relationship corresponds to the relatively high number of logs and low number of snags on timber industry sites, and the high snag densities and somewhat lower log densities on MDNR as. T

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sites (Table 6). Huron Mountain Club and Forest Service sites fell in the middle of this gradient, indicating intermediate ratios of logs to snags on these sites (Fig. 3).

Overstory tree species composition

Eighteen overstory tree species occurred in vegetation sampling plots across the 4 ownerships (Table 7). Sugar maple was the most abundant species in the overstory of MDNR and Forest Service sites and accounted for 72% and 71%, respectively, of trees present on those sites. On timber industry sites, the dominant tree species was beech, which accounted for 40% of the trees sampled. Sugar maple and red maple together made up 45% of the overstory trees on these sites. Hemlock was the most prevalent tree species at the Huron Mountain Club (49%) and was significantly more abundant ($p=0.089$) there than on other sites. Of the 18 tree species identified during vegetation sampling, only 2, beech and balsam fir, did not occur in sampling plots at the Huron Mountain Club. Several tree species seen at the Huron Mountain Club, including bigtooth aspen (*Populus grandidentata*), red oak, striped maple (*Acer pensylvanicum*), and white ash (*Fraxinus americana*), were not recorded from sampling plots in any of the 3 other ownership categories (Table 7).

Table 7. Overstory tree species composition (stems/ha) on Michigan Department of Natural Resources (MDNR), U. S. Forest
Mountain Club (HMC) land in Michigan's Upper Peninsula, July and August,

Table 7. Overstory tree species composition (stems/ha) on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, July and August, 1996, 1997, and 1998.

Tree species (*Scientific name*)	Ownership category								Probability level[a]
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)		
	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	
American basswood *Tilia americana*	**9**	9	**0**	0	**0**	0	**14**	7	0.269
American beech* *Fagus grandifolia*	**17**[b]	4	**43**[b]	13	**195**[c]	18	**0**[d]	0	0.018
American elm* *Ulmus americana*	**5**[b]	3	**2**[bc]	2	**0**[cd]	0	**26**	11	0.042
Balsam fir *Abies balsamea*	**19**	19	**0**	0	**9**	4	**0**	0	0.266
Bigtooth aspen* *Populus grandidentata*	**0**[b]	0	**0**[b]	0	**0**[b]	0	**12**[c]	11	0.088
Black cherry *Prunus serotina*	**19**	14	**33**	16	**9**	9	**0**	<1	0.425
Eastern white pine *Pinus strobus*	**3**	3	**0**	0	**1**	1	**2**	1	0.577
Hemlock* *Tsuga canadensis*	**14**[b]	9	**24**[b]	6	**33**[b]	18	**305**[c]	38	0.089
Northern red oak* *Quercus rubra*	**0**[b]	0	**0**[b]	0	**0**[b]	0	**4**[c]	3	0.088

Table 7 (Cont). Overstory tree species composition (stems/ha) on Michigan Department of Natural Resources (MDNR), U.
... Michigan's Upper Peninsula, July

Table 7 (Cont). Overstory tree species composition (stems/ha) on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, July and August, 1996, 1997, and 1998.

	Ownership category								
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)		Probability
Tree species (*Scientific name*)	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	level[a]
Northern white cedar* *Thuja occidentalis*	**0[b]**	0	**0[b]**	0	**4[b]**	4	**19[c]**	15	0.060
Quaking aspen *Populus tremuloides*	**4**	2	**3**	3	**0**	0	**1**	1	0.427
Red maple *Acer rubrum*	**59**	37	**34**	21	**86**	11	**74**	73	0.681
Striped maple* *Acer pensylvanicum*	**0[b]**	0	**0[b]**	0	**0[b]**	0	**6[c]**	2	0.013
Sugar maple* *Acer saccharum*	**411[b]**	64	**379[b]**	71	**130[c]**	58	**124[c]**	35	0.040
White ash *Fraxinus americana*	**0**	0	**0**	0	**0**	0	**3**	3	0.392
White birch *Betula papyrifera*	**0**	0	**4**	4	**0**	0	**0**	0	0.530
White spruce *Picea glauca*	**3**	2	**0**	0	**11**	6	**1**	1	0.224

Table 3 (Cont). Overstory tree species composition (stems/ha) on Michigan Department of Natural Resources (MDNR), U
land in Michigan's Upper Peninsula, July

Table 7 (Cont). Overstory tree species composition (stems/ha) on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, July and August, 1996, 1997, and 1998.

	Ownership category								
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)		Probability
Tree species (*Scientific name*)	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	level[a]
Yellow birch* *Betula alleghaniensis*	**10**[b]	5	**9**[b]	3	**6**[b]	4	**34**[c]	7	0.090
All species combined	**573**	86	**532**	50	**485**	51	**623**	101	0.622

[a] Probability levels for tests of differences among ownerships were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

*Values on the same line with the same letter are not different ($p>0.10$) (Kruskal-Wallis multiple comparison statistic [Siegel and Castellan 1988]).

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Wildlife population survey results

Red-backed salamanders

During June, July, and August, 1997, an average of 3.8 salamanders per stand were located through ground searches on MDNR sites, 2.8 salamanders per stand were found on the Forest Service sites, an average of 1.6 were found in each of the 5 stands sampled at the Mead site, and 4.2 salamanders were found per stand at the Huron Mountain Club (Table 8). These numbers correspond to densities of 127 salamanders/ha on MDNR sites, 93 on Forest Service sites, 53 on timber industry land, and 140 salamanders/ha at the Huron Mountain Club, based on the 300 m^2 transect area used in each stand. In addition to red-backed salamanders, 3 central newts (*Notophthalmus viridescens louisianensis*) and 1 blue spotted salamander (*Ambystoma laterale*) were also found during ground searches. These results were very different from 1996 results when nighttime ground searches were used to survey salamanders, and salamanders were only rarely detected.

In summer 1998, an average of 144 salamanders/ha were located through ground searches on MDNR sites, 115/ha were found on Forest Service sites, 76/ha were found in stands managed by Mead Co. and Shelter Bay Forests, and an average of 189 salamanders/ha were found in stands at the Huron Mountain Club (Table 9). Two central newts (*Notophthalmus viridescens louisianensis*), 2 blue spotted salamanders (*Ambystoma laterale*), and 1 spotted salamander (*Ambystoma maculatum*) were also found during ground searches in 1998.

Table 8. Number of salamanders surveyed per hectare (means and standard errors) with ground transect searches, time spent ground searching, number of salamanders found per minute of ground searching, and number of salamanders found under

Table 8. Number of salamanders surveyed per hectare (means and standard errors) with ground transect searches, time spent ground searching, number of salamanders found per minute of ground searching, and number of salamanders found under cover boards in forest stands on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, June, July and August, 1997.

	Ownership category							
	MDNR (n=3)		USFS (n=3)		TI[a] (n=1)	HMC (n=3)		Probability
Variable	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	$\bar{x}$	S.E.	level[b]
Salamanders/ha found during ground searches by cover object size								
0-5 cm	**26.7**	16.7	**20.0**	7.7	**26.7**	**74.0**	41.7	0.857
5-10 cm	**51.0**	15.7	**46.7**	23.3	**20.0**	**40.7**	24.3	0.594
10-20 cm*	**37.7**[c]	4.3	**22.3**[d]	4.3	**0.0**[e]	**14.8**[df]	3.7	0.048
20-30 cm	**6.7**	3.8	**4.3**	2.3	**6.7**	**7.4**	7.4	0.950
30-40 cm	**0.0**	0.0	**0.0**	0.0	**0.0**	**3.7**	3.7	0.506
>40 cm	**4.4**	4.4	**0.0**	0.0	**0.0**	**0.0**	0.0	0.506
Total salamanders on transects (#/ha)	**126.7**	33.0	**93.3**	27.8	**53.3**	**140.3**	59.6	0.461
Minutes searched per stand	**67.3**	3.4	**71.3**	2.0	**68.6**	**81.9**	7.9	0.433
Salamanders found/minute searched	**0.06**	0.02	**0.04**	0.01	**0.02**	**0.05**	0.02	0.540
Mean of all salamanders under cover boards (#/ha)*	**2.3**[c]	2.3	**9.0**[c]	2.3	**20.0**[c]	**26.0**[d]	9.7	0.076

[a] Only 1 site surveyed; therefore, no standard error could be calculated.

[b] Probability levels for tests of differences among ownerships were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

*Values on the same line with the same letter are not different (p>0.10) (Kruskal-Wallis multiple comparison statistic [Siegel and Castellan 1988]).

Table 9. Number of salamanders surveyed per hectare (means and standard errors) with ground transect searches, time spent

Table 9. Number of salamanders surveyed per hectare (means and standard errors) with ground transect searches, time spent ground searching, number of salamanders found per minute of ground searching, and number of salamanders found under cover boards in forest stands on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, June, July and August, 1998.

	Ownership category								
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)		
Variable	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	Probability level[a]
Salamanders/ha found during ground searches by cover object size									
0-5 cm	**24.3**	11.7	**46.7**	6.7	**9.0**	2.3	**52.0**	29.0	0.338
5-10 cm*	**77.7**[b]	18.3	**44.3**[c]	6.0	**26.7**[d]	6.7	**74.0**[bc]	24.3	0.059
10-20 cm	**29.0**	6.0	**24.3**	2.3	**29.0**	12.3	**48.0**	26.7	0.930
20-30 cm	**13.3**	7.7	**0.0**	0.0	**6.7**	6.7	**11.0**	6.3	0.359
30-40 cm	**0.0**	0.0	**0.0**	0.0	**4.3**	4.3	**3.7**	3.7	0.530
>40 cm	**0.0**	0.0	**0.0**	0.0	**0.0**	0.0	**0.0**	0.0	1.000
Total salamanders on transects (#/ha)	**144.3**	43.7	**115.3**	15.0	**75.7**	32.3	**188.7**	90.0	0.270
Minutes searched per stand	**82.4**	3.6	**89.2**	5.0	**86.1**	1.0	**96.6**	8.5	0.238
Salamanders found/minute searched	**0.05**	0.21	**0.04**	0.07	**0.03**	0.25	**0.06**	0.24	0.182
Salamanders under cover boards (#/ha)	**11.0**	4.3	**33.3**	10.3	**13.3**	6.7	**37.0**	7.3	0.107

[a] Probability levels for tests of differences among ownerships were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

*Values on the same line with the same letter are not different ($p>0.10$) (Kruskal-Wallis multiple comparison statistic [Siegel 1988 and Castellan]).

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Although there were no significant differences among ownerships in the mean number of red-backed salamanders found during ground transect searches in 1997 or 1998, stands at the Huron Mountain Club showed a consistent trend of having more salamander observations than any of the other 3 ownership categories (Tables 8 and 9). Across all stands surveyed for salamanders, the number of salamanders found through ground transect searches remained fairly constant during both years of data collection. In 1997, an average of 110 salamanders/ha were found for all study sites combined, and in 1998, 123/hectare were recorded. However, the proportion of cover boards with salamanders beneath them more than doubled, from 2.3% in 1997 to 5.2% in 1998.

In the summer of 1997, the greatest numbers ($p=0.076$) of salamanders under cover boards were found at the Mead site and at the Huron Mountain Club (Table 8). During summer, 1998, the most salamanders, in terms of absolute numbers, were found under boards on Forest Service sites and at the Huron Mountain Club (Table 9).

Results of surveys conducted in September and October, 1997 were similar to the results of summer surveys. Again, there were no statistically significant differences among ownerships in the number of salamanders found during ground searches. Differences in numbers of salamanders located beneath cover boards were also nonsignificant (Table 10). However, it should be noted that during fall 1997, ground transect and cover board surveys were completed in only 20 of 54 stands surveyed during summer, and none were included from the Huron Mountain Club.

The most notable aspect of the fall surveys is that the number of salamanders found per ground transect search was slightly less than in the summer, but on MDNR and

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Table 10. Number of salamanders surveyed per hectare (means and standard errors) with ground transect searches, time spent ground searching, number of salamanders found per minute of ground searching, and number of salamanders found under cover boards in forest stands on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), and timber industry (TI) land in Michigan's Upper Peninsula, September and October, 1997. No significant differences (p>0.10) were detected.

	Ownership category					
	MDNR		USFS		TI[a]	Probability
Variable	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	level[b]
Salamanders found during ground searches						
Cover object size						
0-5 cm	**41.7**	24.0	**13.3**	13.3	**0.0**	0.368
5-10 cm	**33.3**	16.7	**41.0**	21.7	**0.0**	0.513
10-20 cm	**22.3**	11.0	**5.0**	2.7	**0.0**	0.422
20-30 cm	**0.0**	0.0	**2.3**	2.3	**0.0**	0.513
30-40 cm	**2.7**	2.7	**0.0**	0.0	**0.0**	0.513
>40 cm	**0.0**	0.0	**0.0**	0.0	**0.0**	1.000
Mean of all salamanders on transects	**100.0**	38.7	**61.7**	36.7	**0.0**	0.361
Minutes searched per stand	**56.7**	11.1	**58.7**	9.1	**49.0**	0.867
Salamanders/minute searched	**0.1**	0.0	**0.0**	0.0	**0.0**	0.260
Mean of all salamanders under cover boards	**14.0**	0.4	**20.0**	10.3	**0.0**	0.676

[a]Only 1 site surveyed; therefore, no standard error could be calculated.

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Forest Service sites, the proportion of cover boards with salamanders found beneath them more than doubled from summer to fall. However, the increase was not statistically significant (p=0.947) because of the relatively small sample size (7 sites sampled both seasons). This trend was not observed on the 1 timber industry site sampled in 1997, where no salamanders were found under cover boards (Table 10), most likely because sampling was completed in only 1 of the 5 stands where boards had been placed.

During late August, September, and October, 1998, a total of 58 red-backed salamanders (35.8 individuals/ha) were counted during fall cover board surveys, compared with 36 salamanders (22.2 individuals/ha) found under the same number of cover boards during the June through early August sampling period (Tables 9 and 11). The seasonal increase was evident on all 4 ownerships.

In 1997 and 1998, there were several statistical differences among ownerships in the number of cover objects examined while conducting salamander surveys (Table 12).

Table 11. Number of salamanders found per hectare (means and standard errors) under cover boards in forest stands on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, late August, September, and October, 1998.

Ownership category								
MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)		Probability
$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	level[a]
44	11	**40**	10	**18**	2	**60**	60	0.351

[a] Probability levels for tests of differences among ownerships were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

[illegible] Michigan Department of Natural Resources (MDNR), U.S. Forest Service (USFS), Timber Company (TC), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, June, July and August, 1997 and 1998.

Table 12. Mean values for soil and vegetation variables measured during red-backed salamander surveys in forest stands on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber company (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, June, July and August, 1997 and 1998.

	Ownership category								
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)		Probability
Variable	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	level[a]
Soil pH	**6.53**	0.11	**6.46**	0.02	**6.34**	0.07	**6.25**	0.10	0.187
Soil moisture (%)	**15.83**	1.58	**15.78**	3.28	**16.17**	5.62	**31.11**	2.23	0.141
Herbaceous height (cm)*	**17.35[b]**	0.94	**18.97[b]**	1.80	**17.74[b]**	2.09	**6.39[c]**	0.57	0.086
Litter depth (cm)	**4.15**	0.19	**4.03**	0.23	**4.21**	0.30	**3.76**	0.22	0.578
Number of cover objects per hectare									
0-5 cm*	**4710[b]**	534	**5153[b]**	628	**4758[b]**	326	**6552[c]**	230	0.086
5-10 cm*	**1959[b]**	86	**2212[c]**	31	**1510[d]**	227	**1891[b]**	108	0.031
10-20 cm	**519**	94	**477**	57	**513**	42	**561**	52	0.644
20-30 cm	**94**	28	**76**	14	**140**	44	**161**	55	0.243
30-40 cm	**26**	14	**12**	7	**34**	6	**46**	5	0.146
>40 cm	**30**	8	**28**	9	**47**	4	**39**	15	0.417

[a] Probability levels for tests of differences among ownerships were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

*Values on the same line with the same letter are not different ($p>0.10$) (Kruskal-Wallis multiple comparison statistic [Siegel and Castellan 1988]).

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In the smallest category of cover objects measured, 0-5 cm, stands at the Huron Mountain Club had more ($p=0.086$) cover objects than any of the other ownership categories investigated. In the 5-10 cm size class, the fewest cover objects were counted in stands on timber company sites and the most were counted during transect searches on Forest Service sites ($p=0.031$). The number of cover objects in the 20-30 cm and 30-40 cm size categories varied considerably among ownerships, with the fewest of each on Forest Service sites and the most on Huron Mountain Club sites, but differences were not significant (Table 12)

Despite differences in cover object abundance among ownerships, the number of salamanders associated with each size class of cover objects varied little among the 4 ownership types in 1997 or 1998 (Tables 8 and 9). The total number of salamanders found during ground searches was also divided by the amount of time spent ground searching to standardize differences in the amount of effort spent searching on each site, but differences in salamander abundance per unit effort among study sites were not statistically significant.

There were no statistical differences in soil moisture or soil acidity among study areas during the study (Table 12). Soil pH ranged from an average of 5.80 to 6.84 within a stand, and soil moisture averaged between 2% and 50% within a stand.

Among all the salamanders detected during ground searches, the size of cover objects was not related to the number of salamander observations. Relatively few salamanders were associated with cover objects ≤5 cm in width, while cover objects 30-40 cm wide had the highest proportion of salamanders found beneath them (Fig. 4). This

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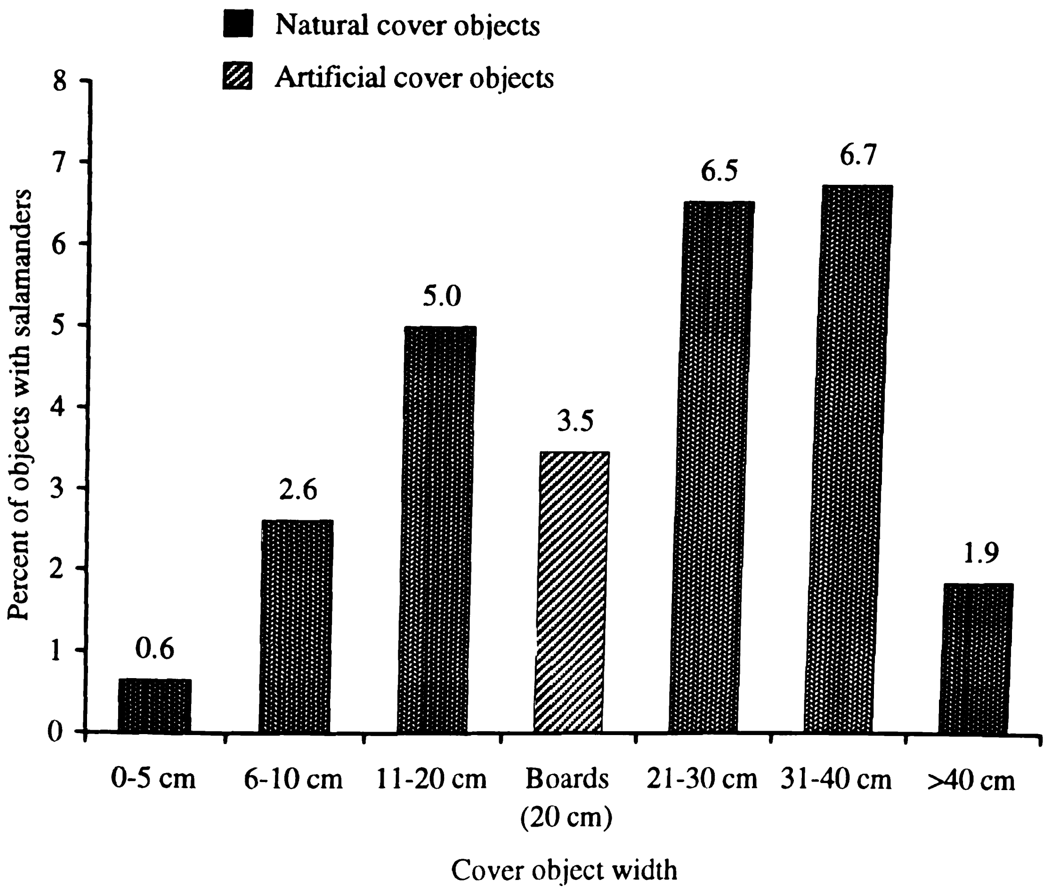

Figure 4. Proportion of natural cover objects and artificial cover boards with salamanders found beneath them, summer and fall, 1997 and summer, 1998 in Michigan's Upper Peninsula.

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suggests that certain size classes of woody debris may provide better habitat for salamanders than others.

Salamander relative abundance exhibited a strong ($p \leq 0.10$) positive association with the density of overstory trees ≥ 10.2 cm dbh (Table 13). Significant negative correlations were found between the number of salamanders observed and several midstory attributes, including midstory canopy cover (r_s=-0.325), canopy cover of shrub species (r_s=-0.430), and the density of shrubs and regenerating trees 50-5 m tall (r_s=-0.297). No correlations with woody debris were statistically documented.

Comparison of ground transect searches and cover boards for surveying salamanders

With ground transect searches, there were no statistical differences in salamander relative abundance among study sites in any sampling period, while use of cover boards resulted in differences (p=0.076) among ownerships in spring 1997 (Table 8). The relative differences among ownerships indicated by each method were somewhat different as well. For example, in summer, 1998 ground transect searches revealed more salamanders on MDNR sites than on Forest Service or timber industry sites, but with cover boards, fewer salamanders were found on MDNR sites than on sites in all other ownership categories (Table 9). However, results of both methods suggested that the relative abundance of salamanders was greatest in stands at the Huron Mountain Club.

In 1997, 14 out of 660 boards, or 2.1%, had salamanders under them during the summer survey period. This proportion increased to 4.6% in the fall of 1997, and in summer, 1998, 36 out of 810 cover boards, or 4.4% were observed with salamanders

Table 13. Spearman rank correlations (r_s) between the mean number of salamanders found (ground transect searches and cover board surveys) and 35 forest stand variables in Michigan's Upper Peninsula, 1997 and 1998.

Variable	r_s
Saplings/ha	-0.07
Shrubs/ha	-0.30*
Snags/ha	-0.01
Stumps/ha	-0.12
Logs/ha	0.04
Shrub height (cm)	-0.18
Snag height (m)	-0.07
Snag diameter (cm)	-0.13
Stump height (cm)	-0.03
Stump diameter (cm)	-0.13
Log length (m)	0.19
Log width (cm)	0.06
Herbaceous height (cm)	-0.14
Litter depth (cm)	0.02
Basal area (m^2/ha)	0.13
Overstory trees/ha	0.32*
Overstory tree DBH (cm)	-0.01
Overstory tree height (m)	0.02
Vertical cover (%)	
0-0.5 m	-0.03
0.5-5 m	-0.33*
Herbaceous	-0.05
All shrub species	-0.43*
Woody debris	0.10
>5 m	0.17
Conifer trees	0.10
Deciduous trees	0.07
Hard mast trees >10 in (25.4 cm) DBH	0.01
Soil pH	0.02

Table 13 (Cont). Spearman rank correlations (r_s) between the mean number of salamanders found (ground transect searches and cover board surveys) and 35 forest stand variables in Michigan's Upper Peninsula, 1997 and 1998.

Variable	r_s
Soil moisture (%)	0.14
Number of cover objects per hectare	
0-5 cm	0.16
5-10 cm	0.10
10-20 cm	0.00
20-30 cm	-0.11
30-40 cm	-0.09
≥40 cm	0.02

* Probability level ≤0.10.

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beneath them. In contrast, with ground transect searches 95 salamanders/ha were found in spring, 1997, 83 salamanders/ha were observed in fall 1997, and 125 salamanders/ha were found in spring, 1998. These results suggest that both seasonal increases and increases specific to the sampling methods were observed.

Correlations between the relative abundance of salamanders observed with both survey methods ranged from 0.15 to 0.23 among the 3 sampling periods (Table 14). The relationship between the number of salamanders under cover boards and the number of salamanders under natural cover objects 0-5 cm wide were consistently positive, but correlations with other cover object sizes (>5cm) fluctuated between positive and negative values for the 3 sampling periods (Table 14).

The proportion of artificial cover boards with salamanders beneath them and the proportion of similar sized natural cover objects may be the most direct comparison between the 2 methods. Although cover boards were 20 cm wide, they were used less than natural cover objects 11-20 cm and 21-30 cm wide in proportion to their availability (Fig. 4).

The time required to complete each type of survey is also an important consideration when evaluating the usefulness of each survey method. An average of 70 minutes was required to search all 3 ground transects in each stand surveyed, in addition to time used to set up the transects. Cover boards initially required a great deal of time and labor to put in place for the surveys, but once established, the 15 boards in a grid could be searched in approximately 8-10 minutes.

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Table 14. Spearman rank correlations (r_s) and probability levels (p) for the number of salamanders found per stand between artificial cover boards and natural cover objects grouped by size class.

	Sampling period					
	Spring 1997 (n=44)		Fall 1997 (n=20)		Spring 1998 (n=54)	
Cover object size	r_s	p	r_s	p	r_s	p
0-5 cm	**0.22**	0.157	**0.20**	0.402	**0.20**	0.142
5-10 cm	**0.10**	0.500	**0.24**	0.307	**0.19**	0.168
10-20 cm	**0.17**	0.256	**-0.31**	0.181	**0.20**	0.147
20-30 cm	**-0.04**	0.788	**0.35**	0.127	**-0.23**	0.098
30-40 cm	**0.22**	0.145	**-0.10**	0.671	**0.06**	0.654
>40 cm	**-0.09**	0.530	**-0.20**	0.295	**NP**	NP
All sizes combined	**0.23**	0.153	**0.39**	0.085	**0.15**	0.268

NP = Cover objects were not present.

Forest bird species

During the study, a total of 51 bird species were surveyed on study sites (Appendix E). Forty-two species were recorded on MDNR sites, Forest Service sites had 44 bird species, 38 species were observed on timber industry sites, and species richness at the Huron Mountain Club was 39 (Table 15). Twenty-seven of these species occurred on stands in all 4 ownership categories, and 8 were detected on only 1 ownership category. The brown-headed cowbird (*Molothrus ater*) and cerulean warbler (*Dendroica cerulea*) occurred during sampling only on MDNR sites, the mourning warbler (*Oporornis philadelphia*) was only observed on Forest Service sites, and the ruby throated at which species occurred) and standard errors (S.E.) on the means

Table 15. Mean absolute frequencies (percent of points at which species occurred) and standard errors (S.E.) on the means over 3 years of data collection of bird species surveyed on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, May-July, 1996, 1997, and 1998. Indicator species are in bold.

	Ownership category								
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)		Probability of difference among ownerships[a]
Common name	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	
American crow	**3.66**	0.79	**2.09**	2.09	**7.14**	7.14	**2.29**	0.31	0.914
American redstart*	**9.17**[b]	5.78	**16.29**[b]	0.12	**38.89**[c]	3.97	**8.56**[b]	5.47	0.084
American robin	**7.88**	4.93	**5.26**	3.31	**6.61**	6.61	**8.90**	6.05	0.599
Black and white warbler*	**5.85**[b]	5.85	**10.29**[b]	9.61	**2.12**[b]	2.12	**17.25**[c]	8.14	0.097
Black-billed cuckoo	**7.69**	4.39	**3.70**	3.04	**2.38**	2.38	**0.00**	0.00	0.226
Blackburnian warbler	**2.18**	2.18	**4.07**	1.92	**1.19**	1.19	**7.37**	2.87	0.704
Black-capped chickadee	**9.27**	1.43	**16.22**	2.87	**11.90**	4.76	**20.76**	7.36	0.392
Black-throated blue warbler*	**21.62**[bc]	3.20	**30.91**[b]	2.37	**27.25**[bc]	5.82	**4.84**[c]	2.46	0.075
Black-throated green warbler*	**75.25**[bc]	2.23	**65.57**[b]	5.37	**30.95**[d]	16.67	**83.66**[c]	4.22	0.057
Bluejay	**8.88**	0.30	**6.32**	0.83	**9.52**	2.38	**4.74**	1.10	0.789
Brown creeper*	**0.69**[bc]	0.69	**2.71**[be]	2.05	**0.00**[c]	0.00	**4.96**[de]	2.89	0.089
Brown-headed cowbird	**0.79**	0.79	**0.00**	0.00	**0.00**	0.00	**0.00**	0.00	0.392
Cerulean warbler	**0.69**	0.69	**0.00**	0.00	**0.00**	0.00	**0.00**	0.00	0.392
Chestnut-sided warbler	**1.49**	0.75	**3.24**	1.22	**4.50**	4.50	**0.69**	0.69	0.106
Common flicker	**0.00**	0.00	**0.46**	0.46	**7.14**	7.14	**0.00**	0.00	0.530
Common raven*	**1.39**[b]	1.39	**9.30**[c]	1.88	**9.39**[c]	9.39	**0.93**[b]	0.93	0.033
Downy woodpecker	**7.63**	3.18	**3.67**	2.38	**4.50**	4.50	**4.98**	2.72	0.691
Eastern wood pewee*	**15.75**[b]	3.93	**14.36**[b]	2.43	**10.45**[c]	3.84	**1.27**[d]	0.64	0.060

Table 15 (Cont). Mean absolute frequencies (percent of points at which species occurred) and standard errors (S.E.) on the means over 3 years of data collection of bird species surveyed on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, May-July, 1996, 1997, and 1998. Indicator species are in bold.

	Ownership category								Probability of difference among ownerships[a]
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)		
Common name	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	
Golden-crowned kinglet	**1.49**	0.75	**0.97**	0.49	**3.57**	3.57	**0.00**	0.00	0.577
Great crested flycatcher	**1.59**	0.79	**3.85**	1.71	**8.07**	0.93	**3.11**	1.56	0.202
Hairy woodpecker	**2.28**	1.38	**1.85**	1.22	**11.64**	9.79	**5.09**	4.10	0.548
Hawk spp.*	**0.00**[b]	0.00	**3.47**[c]	1.10	**1.19**[b]	1.19	**0.00**[b]	0.00	0.060
Hermit thrush*	**19.27**[b]	9.65	**32.06**[c]	9.89	**33.47**[c]	2.25	**14.28**[b]	5.58	0.078
Least flycatcher*	**23.41**[b]	19.14	**10.97**[c]	10.97	**5.95**[d]	1.19	**14.16**[c]	11.86	0.052
Magnolia warbler	**0.79**	0.79	**0.93**	0.46	**2.38**	2.38	**1.50**	0.81	0.953
Mourning warbler	**0.00**	0.00	**0.51**	0.51	**0.00**	0.00	**0.00**	0.00	0.392
Nashville warbler	**1.49**	0.75	**0.93**	0.46	**4.76**	2.38	**0.00**	0.00	0.365
Northern parula	**1.49**	1.49	**2.36**	1.66	**0.00**	0.00	**4.12**	2.71	0.352
Ovenbird*	**70.50**[b]	9.11	**59.93**[c]	12.01	**28.31**[d]	0.26	**58.91**[c]	11.77	0.047
Pileated woodpecker*	**0.00**[b]	0.00	**2.05**[c]	1.41	**3.57**[bc]	3.57	**7.61**[d]	4.41	0.056
Pine siskin	**0.00**	0.00	**0.00**	0.00	**0.00**	0.00	**1.39**	0.69	0.392
Pine warbler*	**0.00**[b]	0.00	**0.00**[b]	0.00	**0.00**[b]	0.00	**1.49**[c]	1.49	0.088
Red-breasted nuthatch*	**1.44**[b]	0.72	**1.98**[b]	1.34	**0.00**[c]	0.00	**12.96**[d]	9.70	0.042
Red-eyed vireo	**88.54**	0.65	**78.82**	3.03	**91.27**	1.59	**74.90**	3.13	0.542
Red-headed woodpecker	**0.69**	0.69	**0.46**	0.46	**0.00**	0.00	**0.00**	0.00	0.530

Table 15 (Cont). Mean absolute frequencies (percent of points at which species occurred) and standard errors (S.E.) on the

Table 15 (Cont). Mean absolute frequencies (percent of points at which species occurred) and standard errors (S.E.) on the means over 3 years of data collection of bird species surveyed on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, May-July, 1996, 1997, and 1998. Indicator species are in bold.

Common name	Ownership category								Probability of difference among ownerships[a]
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)		
	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	
Rose-breasted grosbeak*	**12.94**[b]	6.45	**4.89**[c]	3.02	**0.00**[d]	0.00	**1.27**[d]	0.64	0.017
Ruby-throated hummingbird	**0.00**	0.00	**0.00**	0.00	**3.57**	3.57	**0.00**	0.00	0.392
Sandhill crane	**3.17**	1.59	**2.18**	1.21	**1.19**	1.19	**0.00**	0.00	0.267
Scarlet tanager	**3.08**	1.54	**4.44**	1.85	**1.19**	1.19	**0.79**	0.79	0.351
Solitary vireo	**2.28**	1.38	**0.51**	0.51	**0.00**	0.00	**2.89**	0.12	0.243
Swainson's thrush	**12.30**	8.14	**13.60**	9.66	**7.80**	7.80	**13.71**	5.28	0.924
Tennessee warbler	**0.00**	0.00	**0.00**	0.00	**0.00**	0.00	**1.04**	1.04	0.392
Veery*	**14.13**[b]	2.21	**12.08**[b]	4.80	**22.49**[c]	15.34	**2.78**[d]	1.60	0.047
White-breasted nuthatch	**6.75**	2.66	**7.72**	3.62	**3.31**	3.31	**12.58**	7.73	0.789
White-throated sparrow*	**7.54**[b]	6.53	**11.05**[b]	6.56	**1.19**[c]	1.19	**1.04**[c]	1.04	0.051
Winter wren	**10.36**	2.76	**10.68**	3.15	**14.29**	0.00	**32.04**	2.76	0.264
Wood thrush	**6.45**	1.29	**1.01**	1.01	**7.14**	0.00	**3.34**	3.34	0.160
Yellow-bellied flycatcher	**0.69**	0.69	**1.01**	0.51	**0.93**	0.93	**0.93**	0.93	0.981
Yellow-bellied sapsucker	**3.67**	3.67	**2.69**	1.65	**6.61**	0.53	**0.00**	0.00	0.189

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Table 15 (Cont). Mean absolute frequencies (percent of points at which species occurred) and standard errors (S.E.) on the means over 3 years of data collection of bird species surveyed on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, May-July, 1996, 1997, and 1998. Indicator species are in bold.

	Ownership category								Probability of difference among ownerships[a]
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)		
Common name	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	
Yellow-rumped warbler*	**1.59**[b]	0.79	**0.51**[b]	0.51	**0.00**[b]	0.00	**6.65**[c]	3.59	0.065
Yellow warbler	**0.00**	0.00	**0.00**	0.00	**0.00**	0.00	**0.93**	0.93	0.392

[a] Probability levels for tests of differences among ownerships were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

*Values on the same line with the same letter are not different ($p>0.10$) (Kruskal-Wallis multiple comparison statistic [Siegel and Castellan 1988]).

hummingbird (*Archilochus colubris*) was only seen on 1 timber industry site. Species that were identified only at the Huron Mountain Club were the pine siskin (*Carduelis pinus*), pine warbler (*Dendroica pinus*), Tennessee warbler (*Vermivora peregrina*), and yellow warbler (*Dendroica petechia*). On all 4 ownerships, the red-eyed vireo (*Vireo olivaceus*) was one of the 3 most abundant species observed. The ovenbird and black-throated green warbler (*Dendroica virens*) were among the 3 most abundant species on MDNR, Forest Service, and Huron Mountain Club sites, while the hermit thrush (*Catharus guttatus*) and American redstart were some of the most common species on timber industry sites.

Of the 5 bird species identified at the beginning of the project as having associations with particular aspects of northern hardwood forests, all exhibited differences in relative abundance among ownerships when data were combined among sampling periods (Table 15). Specifically, American redstarts were more abundant ($p=0.084$) on timber industry sites than on other ownerships, and veeries were most common on timber industry and least common on Huron Mountain Club sites ($p=0.047$). The ovenbird occurred most frequently on MDNR sites, and least frequently on timber industry sites ($p=0.047$). Pileated woodpeckers and yellow-rumped warblers were more abundant ($p=0.056$, $p=0.065$) at the Huron Mountain Club than on all other ownerships (Table 15).

Other species that were more common at the Huron Mountain Club than on other ownerships were the black and white warbler (*Mniotilta varia*) ($p=0.097$), black-throated green warbler ($p=0.057$), brown creeper (*Certhia familiaris*) ($p=0.089$), and pine warbler (p=0.088). Relative abundances of the least flycatcher (*Empidonax minimus*) (p=0.052) and rose-breasted grosbeak (*Pheucticus ludovicianus*) (p=0.017) were greater on MDNR sites than on other ownerships, and the eastern wood pewee (*Contopus virens*) (p=0.060) and white-throated sparrow (*Zonotrichia leucophrys*) (p=0.051) were most abundant on MDNR and Forest Service sites. Finally, the black-throated blue warbler (*Dendroica caerulescens*) was more common (p=0.075) on Forest Service sites than MDNR sites (Table 15).

Several species varied in relative abundance among years, and many more did not. The black and white warbler was the one species which showed the greatest fluctuations in abundance during the study. At the Huron Mountain Club, the black and white warbler was observed more often (p=0.074) in 1998 than in 1997. On MDNR and Forest Service sites, abundance was greatest (p=0.022, p=0.035) in 1996. In general, this species was relatively less abundant in 1997 than in the other 2 years on all 4 ownerships (Tables 16, 17, and 18).

The least flycatcher also differed in abundance over time on Huron Mountain Club (p=0.061), MDNR (p=0.046), and Forest Service (p=0.022) sites. On each of these 3 ownership categories, this species was observed most frequently in 1996, and relatively less frequently in 1997 or 1998 (Tables 16, 17, and 18). It is not known if the same pattern occurred on Mead and Shelter Bay land, because songbirds were only surveyed in 1997 and 1998 on timber industry sites. On MDNR sites, differences in abundance over time were detected for the hermit thrush (p=0.031), ovenbird (p=0.062), and white-throated sparrow (p=0.034).

Table 16. Mean absolute frequencies (proportion of points at which species occurred) and standard errors (S.E.) of bird species surveyed on study sites on U. S. Forest Service (USFS), Michigan Department of Natural Resources (MDNR), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, May-July, 1996. Indicator species are in bold.

	Ownership category						Probability of difference among ownerships[a]
	MDNR (n=3)		USFS (n=3)		HMC (n=3)		
Common name	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	
American crow	**2.08**	2.08	**0.00**	0.00	**1.72**	1.41	0.498
American redstart*	**4.46**[b]	2.25	**16.24**[c]	0.43	**0.00**[d]	0.00	0.052
American robin	**0.00**	0.00	**0.00**	0.00	**6.25**	5.10	0.223
Black and white warbler	**17.56**	7.15	**29.49**	5.09	**19.72**	0.79	0.260
Black-billed cuckoo	**16.37**	13.37	**9.72**	5.01	**0.00**	0.00	0.365
Blackburnian warbler	**0.00**	0.00	**1.39**	1.39	**4.85**	1.14	0.121
Black-capped chickadee	**11.90**	6.30	**17.63**	8.49	**11.10**	6.25	0.757
Black-throated blue warbler	**26.19**	16.67	**29.70**	4.84	**7.97**	3.70	0.363
Black-throated green warbler	**79.46**	0.89	**67.95**	7.45	**76.19**	14.34	0.570
Bluejay	**8.93**	4.49	**7.91**	3.74	**6.57**	0.26	0.986
Brown creeper	**2.08**	2.08	**6.73**	3.64	**10.02**	3.08	0.260
Brown-headed cowbird	**2.38**	2.38	**0.00**	0.00	**0.00**	0.00	0.435
Chestnut-sided warbler	**2.08**	2.08	**5.56**	3.67	**0.00**	0.00	0.388
Common flicker	**0.00**	0.00	**1.39**	1.39	**0.00**	0.00	0.435
Common raven	**0.00**	0.00	**5.56**	5.56	**0.00**	0.00	0.435
Downy woodpecker	**13.99**	7.30	**8.12**	0.21	**9.38**	7.65	0.894
Eastern wood pewee*	**8.93**[b]	1.79	**18.80**[c]	3.22	**1.72**[d]	1.41	0.052
Golden-crowned kinglet	**2.38**	2.38	**0.00**	0.00	**0.00**	0.00	0.435

Table 16 (Cont). Mean absolute frequencies (proportion of points at which species occurred) and standard errors (S.E.) of bird species surveyed on study sites on U. S. Forest Service (USFS), Michigan Department of Natural Resources (MDNR), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, May-July, 1996. Indicator species are in bold.

	Ownership category						Probability of
	MDNR (n=3)		USFS (n=3)		HMC (n=3)		difference among
Common name	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	ownerships[a]
Great crested flycatcher	**2.38**	2.38	**1.39**	1.39	**0.00**	0.00	0.667
Hairy woodpecker	**4.76**	4.76	**4.17**	4.17	**0.00**	0.00	0.667
Hawk spp.	**0.00**	0.00	**5.13**	5.13	**0.00**	0.00	0.435
Hermit thrush*	**2.38**[b]	2.38	**12.29**[c]	4.28	**3.45**[b]	2.82	0.072
Least flycatcher*	**61.61**[b]	4.92	**32.91**[c]	9.08	**37.72**[c]	0.18	0.078
Magnolia warbler	**2.38**	2.38	**1.39**	1.39	**1.72**	1.41	0.982
Nashville warbler	**2.38**	2.38	**1.39**	1.39	**0.00**	0.00	0.667
Northern parula	**4.46**	2.25	**5.56**	5.56	**3.13**	2.55	0.880
Ovenbird*	**88.39**[b]	2.68	**83.76**[c]	0.43	**35.67**[d]	6.60	0.041
Pileated woodpecker	**0.00**	0.00	**1.39**	1.39	**0.00**	0.00	0.435
Red-eyed vireo*	**88.69**	2.15	**77.67**	11.97	**71.34**	13.20	0.694
Red-headed woodpecker	**0.00**	0.00	**1.39**	1.39	**0.00**	0.00	0.435
Rose-breasted grosbeak*	**25.60**[b]	12.21	**10.90**[c]	2.89	**1.72**[d]	1.41	0.096
Sandhill crane	**4.76**	2.38	**4.17**	2.41	**0.00**	0.00	0.364
Scarlet tanager	**4.46**	2.25	**4.17**	2.41	**0.00**	0.00	0.365
Solitary vireo	**0.00**	0.00	**0.00**	0.00	**3.13**	2.55	0.223
Swainson's thrush	**27.68**	4.92	**32.91**	9.99	**13.15**	0.53	0.133
Tennessee warbler	**0.00**	0.00	**0.00**	0.00	**3.13**	2.55	0.223
Veery	**13.39**	3.38	**12.07**	2.05	**0.00**	0.00	0.130

Table 16 (Cont). Mean absolute frequencies (proportion of points at which species occurred) and standard errors (S.E.) of bird species surveyed on study sites on U. S. Forest Service (USFS), Michigan Department of Natural Resources (MDNR), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, May-July, 1996. Indicator species are in bold.

	Ownership category						Probability of difference among ownerships[a]
	MDNR (n=3)		USFS (n=3)		HMC (n=3)		
Common name	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	
White-breasted nuthatch	**11.31**	2.15	**14.85**	6.02	**28.02**	2.46	0.154
White-throated sparrow	**20.54**	0.89	**24.15**	7.94	**3.13**	2.55	0.116
Winter wren	**15.77**	8.38	**6.52**	4.59	**31.14**	0.09	0.106
Wood thrush	**8.63**	5.46	**0.00**	0.00	**10.02**	3.08	0.158

[a] Probability levels for tests of differences among ownerships were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

*Values on the same line with the same letter are not different (p>0.10) (Kruskal-Wallis multiple comparison statistic [Siegel and Castellan 1988]).

Table 17. Mean absolute frequencies (percent of points at which species occurred) and standard errors (S.E.) of bird species surveyed on U. S. Forest Service (USFS) and Michigan Department of Natural Resources (MDNR) sites, 1 Mead Co. (MEAD) site and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, May-July, 1997. Indicator species are in bold.

	Ownership category							Probability of difference among ownerships[b]
	MDNR (n=3)		USFS (n=3)		TI[a] (n=1)	HMC (n=3)		
Common name	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	$\bar{x}$	S.E.	
American crow	**4.44**	4.44	**6.28**	4.21	**14.29**	**2.78**	2.78	0.401
American redstart	**20.65**	8.51	**16.52**	8.42	**42.86**	**18.75**	9.55	0.470
American robin	**6.67**	6.67	**4.42**	2.63	**0.00**	**0.00**	0.00	0.436
Black and white warbler	**0.00**	0.00	**0.00**	0.00	**0.00**	**2.08**	2.08	0.506
Black-billed cuckoo	**2.22**	2.22	**1.39**	1.39	**0.00**	**0.00**	0.00	0.678
Blackburnian warbler	**6.55**	3.62	**7.79**	4.17	**0.00**	**4.17**	4.17	0.682
Black-capped chickadee	**6.98**	4.13	**10.70**	3.27	**7.14**	**15.97**	5.42	0.625
Black-throated blue warbler*	**15.46**[b]	1.67	**27.54**[b]	8.76	**21.43**[c]	**0.00**[c]	0.00	0.091
Black-throated green warbler	**71.88**	14.70	**73.45**	5.51	**14.29**	**84.03**	9.03	0.364
Bluejay	**9.37**	6.33	**5.93**	4.03	**7.14**	**2.78**	2.78	0.828
Brown creeper	**0.00**	0.00	**0.00**	0.00	**0.00**	**4.86**	2.50	0.159
Cerulean warbler	**2.08**	2.08	**0.00**	0.00	**0.00**	**0.00**	0.00	0.506
Chestnut-sided warbler	**0.00**	0.00	**1.39**	1.39	**0.00**	**2.08**	2.08	0.678
Common flicker*	**0.00**[b]	0.00	**0.00**[b]	0.00	**14.29**[b]	**0.00**[b]	0.00	0.029
Common raven*	**0.00**[b]	0.00	**11.44**[c]	5.11	**0.00**[bd]	**0.00**[b]	0.00	0.034
Downy woodpecker	**4.44**	4.44	**0.00**	0.00	**0.00**	**0.00**	0.00	0.506
Eastern wood-pewee	**22.56**	9.76	**10.44**	2.99	**14.29**	**2.08**	2.08	0.154
Golden-crowned kinglet	**0.00**	0.00	**1.52**	1.52	**7.14**	**0.00**	0.00	0.112
Great crested flycatcher	**2.38**	2.38	**7.14**	7.14	**7.14**	**4.86**	2.50	0.806

Table 17 (Cont). Mean absolute frequencies (percent of points at which species occurred) and standard errors (S.E.) of bird species surveyed on U. S. Forest Service (USFS) and Michigan Department of Natural Resources (MDNR) sites, 1 timber industry (TI) site and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, May-July, 1997. Indicator species are in bold.

	Ownership category							Probability of difference among ownerships[b]
	MDNR (n=3)		USFS (n=3)		TI[a] (n=1)	HMC (n=3)		
Common name	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	$\bar{x}$	S.E.	
Hairy woodpecker*	**0.00**[b]	0.00	**0.00**[b]	0.00	**21.43**[b]	**13.19**[c]	5.93	0.039
Hawk spp.	**0.00**	0.00	**3.90**	2.09	**0.00**	**0.00**	0.00	0.159
Hermit thrush	**35.79**	6.25	**41.67**	8.33	**35.71**	**17.36**	4.86	0.153
Least flycatcher	**6.55**	3.62	**0.00**	0.00	**7.14**	**0.00**	0.00	0.124
Mourning warbler	**0.00**	0.00	**1.52**	1.52	**0.00**	**0.00**	0.00	0.506
Nashville warbler	**2.08**	2.08	**1.39**	1.39	**7.14**	**0.00**	0.00	0.214
Ovenbird	**64.46**	7.77	**45.45**	4.55	**28.57**	**67.36**	12.05	0.159
Pileated woodpecker	**0.00**	0.00	**4.76**	4.76	**7.14**	**15.28**	5.01	0.142
Pine siskin	**0.00**	0.00	**0.00**	0.00	**0.00**	**2.08**	2.08	0.506
Red-breasted nuthatch*	**2.22**[b]	2.22	**4.55**[b]	4.55	**0.00**[c]	**31.94**[d]	7.73	0.083
Red-eyed vireo	**87.36**	9.50	**84.54**	7.10	**92.86**	**72.22**	12.11	0.615
Rose-breasted grosbeak	**8.77**	1.87	**2.38**	2.38	**0.00**	**0.00**	0.00	0.109
Ruby-throated hummingbird*	**0.00**[b]	0.00	**0.00**[b]	0.00	**7.14**[b]	**0.00**[b]	0.00	0.029
Sandhill crane	**4.76**	4.76	**2.38**	2.38	**0.00**	**0.00**	0.00	0.678
Scarlet tanager	**0.00**	0.00	**1.39**	1.39	**0.00**	**0.00**	0.00	0.506
Solitary vireo	**2.08**	2.08	**0.00**	0.00	**0.00**	**2.78**	2.78	0.678
Swainson's thrush	**0.00**	0.00	**4.29**	2.41	**0.00**	**4.86**	2.50	0.290
Veery	**18.27**	6.50	**3.77**	2.07	**7.14**	**5.56**	5.56	0.310

Table 17 (Cont). Mean absolute frequencies (percent of points at which species occurred) and standard errors (S.E.) of bird species surveyed on U. S. Forest Service (USFS) and Michigan Department of Natural Resources (MDNR) sites, 1 timber industry (TI) site and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, May-July, 1997. Indicator species are in bold.

	Ownership category							Probability of difference among ownerships[b]
	MDNR (n=3)		USFS (n=3)		TI[a] (n=1)	HMC (n=3)		
Common name	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	$\bar{x}$	S.E.	
White-breasted nuthatch	**2.08**	2.08	**5.28**	0.94	**0.00**	**5.56**	5.56	0.513
White-throated sparrow	**0.00**	0.00	**3.90**	2.09	**0.00**	**0.00**	0.00	0.159
Winter wren	**6.69**	0.26	**8.66**	6.52	**14.29**	**27.78**	12.11	0.194
Wood thrush	**4.17**	4.17	**3.03**	3.03	**7.14**	**0.00**	0.00	0.516
Yellow-bellied flycatcher	**0.00**	0.00	**1.52**	1.52	**0.00**	**2.78**	2.78	0.678
Yellow-bellied sapsucker*	**0.00**	0.00	**2.38**	2.38	**7.14**	**0.00**	0.00	0.154
Yellow-rumped warbler	**2.38**	2.38	**0.00**	0.00	**0.00**	**7.64**	0.69	0.088

[a] Only 1 site surveyed; therefore, no standard error could be calculated.

[b] Probability levels for tests of differences among ownerships were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

*Values on the same line with the same letter are not different (p>0.10) (Kruskal-Wallis multiple comparison statistic [Siegel and Castellan 1988]).

Table 18. Mean absolute frequencies (percent of points at which species occurred) and standard errors (S.E.) of bird species surveyed on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, May-July, 1998. Indicator species are in bold.

	Ownership category								Probability of difference among ownerships[a]
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)		
Common name	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	
American crow	**4.46**	2.25	**0.00**	0.00	**0.00**	0.00	**2.38**	2.38	0.245
American redstart*	**2.38**[b]	2.38	**16.10**[c]	6.05	**34.92**[d]	4.20	**6.94**[bc]	3.67	0.042
American robin	**16.96**	5.23	**11.36**	7.31	**13.23**	4.26	**20.44**	10.73	0.905
Black and white warbler*	**0.00**[b]	0.00	**1.39**[bc]	1.39	**4.23**[c]	2.17	**29.96**[d]	6.67	0.035
Black-billed cuckoo	**4.46**	2.25	**0.00**	0.00	**4.76**	4.76	**0.00**	0.00	0.269
Blackburnian warbler	**0.00**	0.00	**3.03**	3.03	**2.38**	2.38	**13.10**	7.24	0.293
Black-capped chickadee	**8.93**	4.49	**20.33**	5.87	**16.67**	10.38	**35.22**	4.48	0.171
Black-throated blue warbler	**23.21**	8.81	**35.48**	7.28	**33.07**	8.66	**6.55**	3.62	0.110
Black-throated green warbler	**74.40**	15.50	**55.30**	10.19	**47.62**	6.30	**90.77**	6.36	0.115
Bluejay	**8.33**	8.33	**5.11**	2.69	**11.90**	11.90	**4.86**	2.50	0.986
Brown creeper	**0.00**	0.00	**1.39**	1.39	**0.00**	0.00	**0.00**	0.00	0.392
Chestnut-sided warbler	**2.38**	2.38	**2.78**	2.78	**8.99**	2.68	**0.00**	0.00	0.162
Common raven*	**4.17**[b]	4.17	**10.92**[c]	3.68	**18.78**[d]	4.50	**2.78**[b]	2.78	0.085
Downy woodpecker	**4.46**	2.25	**2.90**	1.46	**8.99**	2.68	**5.56**	5.56	0.417
Eastern wood pewee*	**15.77**[b]	6.75	**13.83**[b]	4.80	**6.61**[c]	4.16	**0.00**[d]	0.00	0.086
Golden-crowned kinglet	**2.08**	2.08	**1.39**	1.39	**0.00**	0.00	**0.00**	0.00	0.530
Great crested flycatcher	**0.00**	0.00	**3.03**	3.03	**8.99**	6.42	**4.46**	2.25	0.417
Hairy woodpecker	**2.08**	2.08	**1.39**	1.39	**1.85**	1.85	**2.08**	2.08	0.983
Hawk spp.	**0.00**	0.00	**1.39**	1.39	**2.38**	2.38	**0.00**	0.00	0.530

Table 18 (Cont). Mean absolute frequencies (percent of points at which species occurred) and standard errors (S.E.) of bird species surveyed on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, May-July, 1998. Indicator species are in bold.

	Ownership category								Probability of difference among ownerships[a]
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)		
Common name	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	
Hermit thrush	**19.64**	3.72	**42.23**	16.32	**31.22**	6.10	**22.02**	11.31	0.470
Least flycatcher	**2.08**	2.08	**0.00**	0.00	**4.76**	4.76	**4.76**	4.76	0.737
Magnolia warbler	**0.00**	0.00	**1.39**	1.39	**4.76**	4.76	**2.78**	2.78	0.734
Nashville warbler	**0.00**	0.00	**0.00**	0.00	**2.38**	2.38	**0.00**	0.00	0.392
Northern parula	**0.00**	0.00	**1.52**	1.52	**0.00**	0.00	**9.23**	6.36	0.172
Ovenbird*	**58.63[b]**	1.95	**50.57[b]**	5.99	**28.04[c]**	12.83	**73.71[d]**	6.03	0.035
Pileated woodpecker*	**0.00[b]**	0.00	**0.00[b]**	0.00	**0.00[b]**	0.00	**7.54[c]**	4.14	0.088
Pine siskin	**0.00**	0.00	**0.00**	0.00	**0.00**	0.00	**2.08**	2.08	0.392
Pine warbler*	**0.00[b]**	0.00	**0.00[b]**	0.00	**0.00[b]**	0.00	**4.46[c]**	2.25	0.088
Red-breasted nuthatch	**2.08**	2.08	**1.39**	1.39	**0.00**	0.00	**6.94**	3.67	0.293
Red-eyed vireo	**89.58**	5.51	**74.24**	7.26	**89.68**	5.20	**81.15**	8.52	0.546
Red-headed woodpecker	**2.08**	2.08	**0.00**	0.00	**0.00**	0.00	**0.00**	0.00	0.392
Rose-breasted grosbeak	**4.46**	2.25	**1.39**	1.39	**0.00**	0.00	**2.08**	2.08	0.328
Sandhill crane	**0.00**	0.00	**0.00**	0.00	**2.38**	2.38	**0.00**	0.00	0.392
Scarlet tanager	**4.76**	4.76	**7.77**	2.42	**2.38**	2.38	**2.38**	2.38	0.620
Solitary vireo	**4.76**	4.76	**1.52**	1.52	**0.00**	0.00	**2.78**	2.78	0.734
Swainson's thrush*	**9.23[b]**	6.36	**3.60[b]**	1.87	**15.61[c]**	6.58	**23.12[c]**	4.29	0.094
Veery*	**10.71[b]**	7.43	**20.39[c]**	6.40	**37.83[d]**	5.03	**2.78[b]**	2.78	0.045
White-breasted nuthatch	**6.85**	4.13	**3.03**	3.03	**6.61**	0.53	**4.17**	4.17	0.795

Table 18 (Cont). Mean absolute frequencies (percent of points at which species occurred) and standard errors (S.E.) of bird species surveyed on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, May-July, 1998. Indicator species are in bold.

	Ownership category								Probability of difference among ownerships[a]
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)		
Common name	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	
White-throated sparrow	**2.08**	2.08	**5.11**	2.69	**2.38**	2.38	**0.00**	0.00	0.407
Winter wren	**8.63**	5.46	**16.86**	9.23	**14.29**	14.29	**37.20**	6.11	0.209
Wood thrush	**6.55**	3.62	**0.00**	0.00	**7.14**	4.12	**0.00**	0.00	0.153
Yellow-bellied flycatcher	**2.08**	2.08	**1.52**	1.52	**1.85**	1.85	**0.00**	0.00	0.734
Yellow-bellied sapsucker	**11.01**	2.44	**5.68**	3.65	**6.08**	3.25	**0.00**	0.00	0.120
Yellow-rumped warbler	**2.38**	2.38	**1.52**	1.52	**0.00**	0.00	**12.30**	8.48	0.293
Yellow warbler	**0.00**	0.00	**0.00**	0.00	**0.00**	0.00	**2.78**	2.78	0.392

[a] Probability levels for tests of differences among ownerships were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

*Values on the same line with the same letter are not different (p>0.10) (Kruskal-Wallis multiple comparison statistic [Siegel and Castellan 1988]).

On both MDNR and Forest Service sites, the rose-breasted grosbeak and Swainson's thrush (*Catharus ustulatus*) were most abundant in 1996, and less abundant in 1997 or 1998. The veery was also recorded more frequently (p=0.051) in 1998 than in 1996 on Forest Service sites. On timber industry sites, where data were collected on 1 site in 1997 and 3 sites in 1998, the American crow (*Corvus brachyrhynchos*) was the only species for which a difference (p=0.083) was observed among years (Tables 16, 17, and 18).

Other species which differed in abundance across years at the Huron Mountain Club were the black-capped chickadee (*Parus atricapillus*), which was detected most frequently in 1998 and least frequently in 1996 (p=0.077); brown creeper, which was significantly less abundant in 1998 than in the other 2 years (p=0.095); and the American robin (*Turdus migratorius*), which was more abundant (p=0.100) in 1998 than in the other 2 years (Tables 16, 17, and 18). The frequency of red-breasted nuthatch (*Sitta canadensis*) observations at the Huron Mountain Club was also statistically different among years, but it is likely that some red-breasted nuthatch vocalizations were confused with those of white-breasted nuthatches (*Sitta carolinensis*) in the field. When the abundance data for these 2 species were combined and tested again across years, the difference was not significant.

Principal components analysis of forest birds

The absolute frequencies (% of points where species occurred) of the 17 forest bird species that occurred at a frequency ≥20% on at least 1 of the study sites were analyzed with principal components analysis to describe the dominant bird communities on each ownership. The first 3 PCs of this analysis explained 71% of the variability in the data set, and the first 4 PC's explained 84% of the variability. Principal component 1 accounted for 36% of the total variance and represents a contrast between a bird community dominated by the black-throated green warbler and ovenbird and a community dominated by the raven and veery (Fig. 5). The second PC, which accounted for 18% of the variance in the data set, describes a gradient between a bird community composed of robins, red-breasted nuthatches, black-capped chickadees, and 9 other species, and another community consisting of black-throated blue warblers, least flycatchers, and rose-breasted grosbeaks. Twelve species, including the robin, red-breasted nuthatch, and black-capped chickadee had a positive component loading for PC2, but only five had negative loadings, suggesting a gradient between a very diverse bird community, and a less diverse community dominated by black-throated blue warblers, least flycatchers, and rose-breasted grosbeaks. The third principal component was dominated by the red-eyed vireo and robin in one direction and the black and white warbler and winter wren in another.

Huron Mountain Club and MDNR sites were grouped similarly along the first principal component, while Forest Service sites fell in the middle, and timber industry sites were grouped at the end opposite the Huron Mountain Club and MDNR sites (Fig. 5). Along PC2, Huron Mountain Club sites occupied the positive range of the gradient, while Forest Service and MDNR sites were grouped together at the opposite end of the gradient. Timber industry sites occupied an intermediate position along the axis, suggesting that they cannot be characterized by either of the bird communities

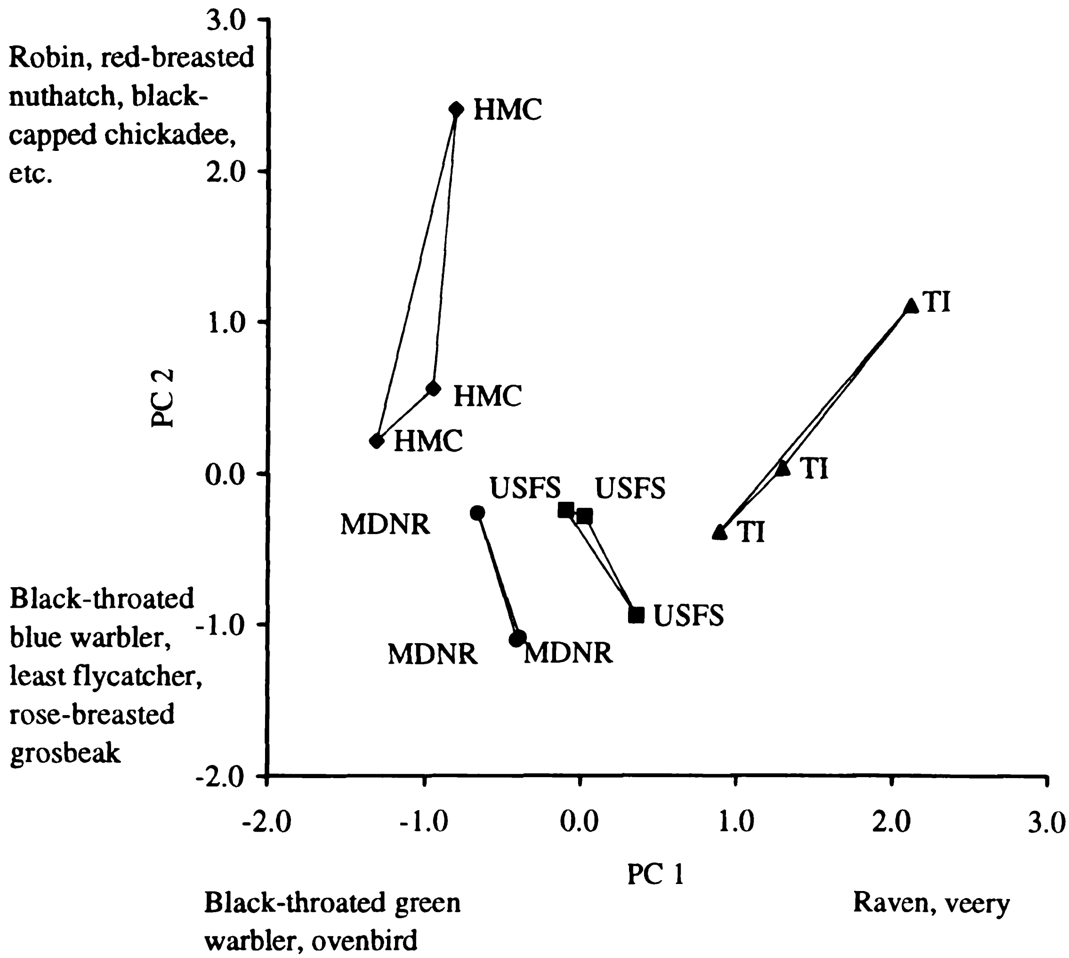


Figure 5. Scores for the first 2 principal components (PC) for songbirds which occurred at a frequency ≥20% on at least 1 study site on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, 1996, 1997, and 1998.

represented by PC2. Principal component 3 was less useful for characterizing the bird communities of the 4 ownership categories because sites in all ownerships ranged widely in their scores for PC3 (Fig. 5).

Forest bird communities

Eight of the 51 species encountered on study sites were cavity nesters. As a group, cavity nesting birds occurred more often on Huron Mountain Club sites and least often on MDNR sites. These differences, however, were not statistically significant (Fig. 6). Black-capped chickadees were the most numerous species in the cavity nesting bird community.

There were no differences ($p>0.010$) among ownerships in a comparison of bird species grouped by migratory status (year-round resident, short distance migrant, and neotropical migrant), but several trends were noticeable. Neotropical migrants tended to be most abundant on MDNR sites and least abundant on Huron Mountain Club sites (Fig. 7). Short distance migrants, defined as species that winter south of the study area, but north of the tropics (Blake et al. 1994), were slightly more common on timber industry sites, and resident species were seen most frequently on Huron Mountain Club sites.

The proportion of each species group out of the total of all species observed on an ownership followed a very similar pattern as the numbers of observations per sampling point. On MDNR sites, a larger proportion of the total species observations were of neotropical migrants, and Huron Mountain Club sites tended to have a smaller proportion of neotropical migrant species and a larger proportion of cavity nesters than other ownerships. Of the 27 neotropical migrant species observed, the 3 most abundant were

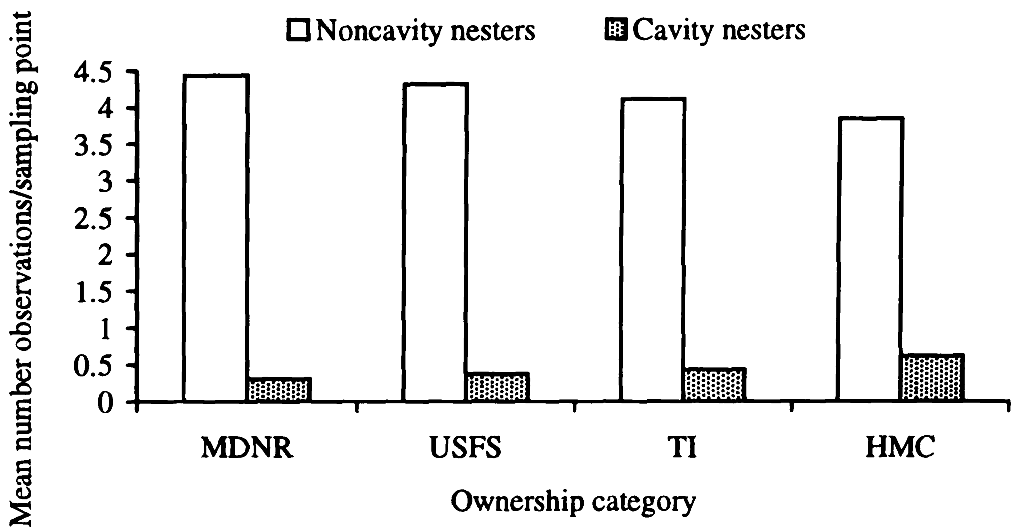


Figure 6. Mean number of cavity nesting and noncavity nesting birds per sampling point on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, 1996, 1997, and 1998.

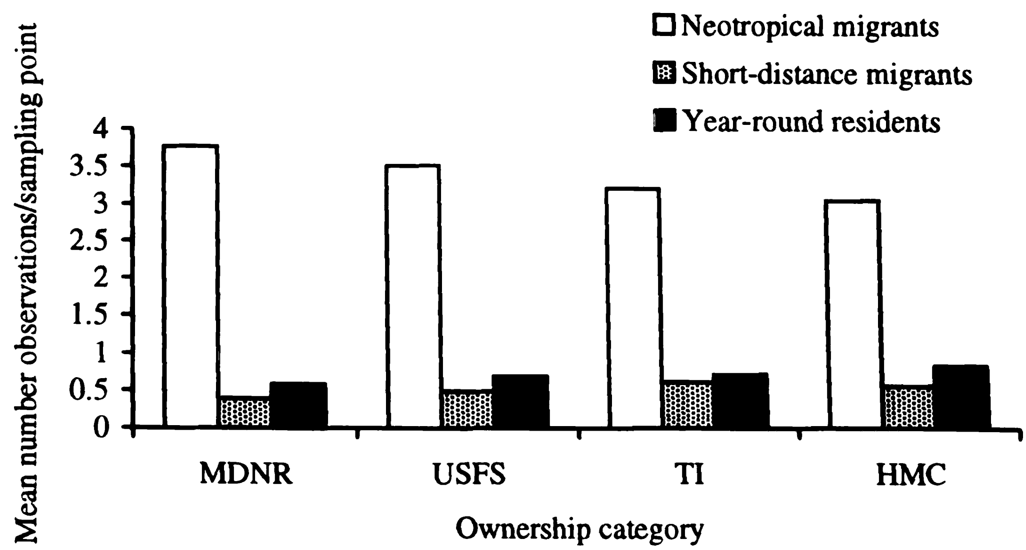


Figure 7. Mean number of birds per sampling point by migratory status on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, 1996, 1997, and 1998.

the red-eyed vireo, black-throated green warbler, and ovenbird. The most abundant short distance migrant was the hermit thrush, and the most common resident species was the black-capped chickadee.

Barred owls

Barred owl responses varied widely among the 3 summers during which data were collected. When average response rates for each site within an ownership were compared among 1996, 1997, and 1998, there were no significant differences within an ownership category (Table 19). The highest average response rate for a site within a year was 45% on MDNR sites in 1998, and the lowest, 0%, occurred on timber industry sites in 1997 when only one site in the timber industry category was surveyed. The second lowest response rate for a year was 5%, which occurred in 1996 when barred owls were detected on only 1 of 3 Huron Mountain Club sites sampled. Response rates were slightly higher on MDNR sites than on the other 3 ownerships in 1997 and 1998, but differences were not significant in any year (Table 19).

Fishers

Combined over the 2 years in which fisher track count data were collected on Forest Service and MDNR sites, and for the one year of data collected on timber industry sites, the average proportion of transects on which at least 1 set of fisher tracks was observed ranged from 33-80%. The sample size of fisher track count transects was not sufficient for statistical comparisons of fisher relative abundance; descriptively, however, the data indicate that portions of all sites in the study were used by fishers in the winter. Activity indices obtained were 0.55 tracks/km on MDNR sites, 0.63 tracks/km on Forest

Table 19. Frequency of barred owl responses (% of points sampled) and standard errors among years (S.E.) on study sites on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, 1996, 1997, and 1998.

	Ownership category								Probability of difference among ownerships[a]
	MDNR		USFS		TI		HMC		
	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	
1996	**26.3**	6.7	**31.8**	9.7	----	----	**4.2**	4.2	**0.133**
1997	**42.9**	21.8	**39.1**	19.3	**0.0**	----	**37.8**	23.2	**0.665**
1998	**44.6**	13.9	**20.5**	10.7	**22.8**	10.1	**22.2**	22.2	**0.525**
Mean % response for all years combined	**37.9**	4.8	**30.5**	4.4	**11.4**	6.6	**28.8**	3.1	**0.313**
Probability of difference among years[a]	**0.722**		**0.715**		**0.296**		**0.730**		

[a] Probability levels for tests of differences among ownerships were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

---- Sample size too small to calculate value.

*Values on the same line with the same letter are not different (p>0.10) (Kruskal-Wallis multiple comparison statistic [Siegel and Castellan 1988]).

Service sites, and 0.63 tracks/km on timber industry sites. The statistical probability of a difference in fisher activity among the 3 ownership categories was not significant ($p=0.640$).

On Huron Mountain Club sites, where fishers were surveyed with summer scent post stations, fisher visitations occurred at 4 out of 105 active station nights. The 4 visitations occurred on 2 of the 3 Huron Mountain Club study areas.

Habitat Suitability Analysis

Red-backed salamander

In developing the HSI model for the red-backed salamander, data on stand structure and composition, and indices of salamander relative abundance collected on study sites were used to identify the specific variables that are potentially important in determining the quality of red-backed salamander habitat. The preliminary model that was developed from literature information and a subset of field data included density of trees ≥ 10.2 cm dbh, average log width, shrub density, and the number of cover objects measured in width classes of 5-10 cm, 10-20 cm, and 20-30 cm present on the ground as potential determinants of red-backed salamander habitat suitability. After a statistical comparison of stands where ≤ 2 salamanders were found and stands where >2 salamanders were found during the course of field work (Table 20), overstory tree stem density and percent canopy cover of shrubs and regenerating trees (0.5-5.0 m tall) were chosen as components of the final HSI model (Appendix B).

Salamander HSI values ranged from an average of 0.33 on timber industry sites to 0.68 on Huron Mountain Club sites (Table 21). Habitat suitability index values differed

Table 20. Ranges and mean values for habitat variables in stands where ≤2 salamanders were found and in stands where >2 salamanders were recorded, and probability of statistical difference in the means of the 2 groups based on independent t-tests.

	Mean number of salamanders/stand				
	≤2 (n=22)		>2 (n=32)		Probability of
Variable	Range of stand values	**Average stand value**	Range of stand values	**Average stand value**	difference between means
Basal area (m^2/ha)	6.76-45.85	**23.93**	9.54-56.16	**27.66**	0.327
Overstory trees/ha	267-720	**481**	280-1093	**599**	0.025
Saplings/ha	60-2,120	**883**	47-5160	**991**	0.694
Shrubs/ha	107-60,000	**17,389**	13-34,770	**8841**	0.029
Snags/ha	0-140	**49**	0-193	**53**	0.608
Stumps/ha	33-340	**157**	40-340	**155**	0.811
Logs/ha	0-460	**170**	60-393	**180**	0.603
Overstory tree DBH (cm)	16.40-40.52	**25.20**	16.50-32.48	**24.38**	0.692
Overstory tree height (m)	14.69-26.99	**20.70**	17.41-25.75	**20.62**	0.817
Shrub height (cm)	60-166	**108**	50-185	**105**	0.744
Snag height (m)	2.0-18.0	**10.86**	4.0-17.5	**10.55**	0.762
Snag diameter (cm)	12.49-40.99	**22.59**	10.16-35.30	**21.20**	0.563
Stump height (cm)	25.35-115.5	**50.91**	30.27-66.28	**48.70**	0.758
Stump diameter (cm)	14.50-61.11	**30.64**	18.64-48.53	**30.72**	0.911
Log length (m)	2.33-7.48	**4.49**	2.79-8.51	**5.22**	0.015
Log width (cm)	17.00-31.53	**23.40**	16.12-31.79	**23.39**	0.459
Log area (m^2)	0.00-7.94	**2.07**	5.09-6.69	**2.21**	0.583
Herbaceous height (cm)	4.71-26.27	**16.41**	1.60-26.74	**16.05**	0.608

Table 20 (Cont). Ranges and mean values for habitat variables in stands where and average of ≤2 salamanders were found and in stands where >2 salamanders were recorded, and probability of statistical difference in the means of the 2 groups based on independent t-tests.

	Mean number of salamanders/stand				
	≤2 (n=22)		>2 (n=32)		
Variable	Range of stand values	**Average stand value**	Range of stand values	**Average stand value**	Probability of difference between means
Litter depth (cm)	3.12-5.28	**4.05**	2.17-5.23	**4.11**	0.948
Soil pH	5.80-6.80	**6.41**	5.85-6.84	**6.41**	0.839
Soil moisture (%)	2.17-37.67	**16.04**	2.00-50.20	**20.12**	0.195
Vertical cover (%)					
0-0.5 m	4.58-39.83	**17.68**	1.28-46.33	**16.72**	0.771
0.5-5 m	5.17-75.50	**44.03**	8.17-73.00	**34.73**	0.048
>5 m	62.00-92.17	**80.15**	56.67-94.33	**82.59**	0.484
Herbaceous	0.58-22.92	**7.47**	0.58-30.83	**8.19**	0.672
All shrub species	0.00-2.67	**0.64**	0.00-1.83	**0.09**	0.007
Conifer trees	0.00-67.83	**14.01**	0.00-64.00	**12.70**	0.961
Deciduous trees	43.83-92.17	**74.81**	54.92-94.33	**77.16**	0.720
Woody debris	1.17-8.92	**4.91**	1.28-10.75	**5.53**	0.226
Number of cover objects per stand					
0-5 cm	86-276	**151.57**	75-249	**156.70**	0.562
5-10 cm	26-121	**56.77**	24-92	**56.81**	0.934
10-20 cm	2-22	**14.48**	3-36	**16.00**	0.288
20-30 cm	0-12	**3.73**	0-11	**3.16**	0.656
30-40 cm	0-5	**0.86**	0-4	**0.81**	0.968

Table 20 (Cont). Ranges and mean values for habitat variables in stands where and average of ≤2 salamanders were found and in stands where >2 salamanders were recorded, and probability of statistical difference in the means of the 2 groups based on independent t-tests.

	Mean number of salamanders/stand				
	≤2 (n=22)		>2 (n=32)		
Variable	Range of stand values	**Average stand value**	Range of stand values	**Average stand value**	Probability of difference between means
Number of cover objects per stand					
>40 cm	0.00-4.00	**1.02**	0.00-4.00	**1.09**	0.788
All sizes of cover objects combined	160.00-360.00	**228.43**	148.00-325.50	**234.58**	0.486

Table 21. Mean suitability index values for each HSI model variable, and means and standard errors of final HSI values for the red-backed salamander on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula.

HSI variables	Ownership category				Probability level[a]
	MDNR	USFS	TI	HMC	
V1 (tree stem density)	0.52	0.48	0.44	0.62	0.433
V2 (midstory canopy cover)*	0.68[b]	0.46[c]	0.28[c]	0.75[bd]	0.026
V3 (cover object abundance)	1.00	1.00	1.00	1.00	1.000
Final HSI value*	**0.59[b]**	**0.46[c]**	**0.33[d]**	**0.68[b]**	**0.052**
S.E. of the mean of the HSI values	0.056	0.062	0.030	0.061	

[a] Probability levels for tests of differences among ownerships were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

*Values on the same line with the same letter are not different (p>0.10) (Kruskal-Wallis multiple comparison statistic [Siegel and Castellan 1988]).

significantly among sites, with the greatest values on Huron Mountain Club and MDNR sites, and the lowest values for timber industry sites (Table 21). The overall lower scores on timber industry sites were primarily influenced by the relatively greater amounts of midstory canopy cover (V2), which resulted in low scores for the second model variable.

Huron Mountain Club sites received higher scores ($p=0.026$) for the second model variable than timber industry sites. Habitat quality on MDNR and Forest Service sites was limited by tree stem density (V1), for which values were lower than that considered optimal, and the amount of midstory canopy cover, which was generally greater than the optimal range. The third model variable, which refers to the abundance of ground objects which may be used by salamanders for cover, was above the minimum value required for high quality habitat on all study sites. Therefore, the amount of ground cover objects was not a limiting factor for red-backed salamanders on any of the 4 ownerships.

Ovenbird

The 2 variables used to calculate the suitability of ovenbird habitat in a given forest stand are mean basal area and the density of shrubs and saplings. Nearly all stands had basal areas very near or much above the minimum values considered to provide suitable habitat (Table 22). Optimum values for shrub and sapling density are defined in a very narrow range by the model; stands with <2000 stems/ha are assigned a suitability index (SI) value between 0.75 and 1.0, and above 4000 stems/ha, suitability index values decline, reaching 0 for stands with >10,000 stems/ha. Timber industry and Forest Service sites tended to have too many shrubs and saplings to be considered suitable habitat by the model, while Huron Mountain Club and MDNR sites had more suitable shrub and sapling

Table 22. Mean suitability index values for each HSI model variable, and means and standard errors of final HSI values for the ovenbird on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula.

HSI variables	Ownership category				Probability level[a]
	MDNR	USFS	TI	HMC	
V1 (basal area)*	1.00[b]	1.00[b]	0.98[c]	1.00[b]	0.088
V2 (shrub/sapling stem density)*	0.70[b]	0.32[c]	0.12[b]	0.81[d]	0.048
Final HSI value*	**0.75[b]**	**0.37[c]**	**0.18[c]**	**0.89[d]**	**0.057**
S.E. of the mean of the HSI values	0.123	0.141	0.069	0.014	

[a] Probability levels for tests of differences among ownerships were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

*Values on the same line with the same letter are not different (p>0.10) (Kruskal-Wallis multiple comparison statistic [Siegel and Castellan 1988]).

stem densities. Final HSI scores were higher (p=0.057) for the Huron Mountain Club than for other ownerships (Table 22).

American redstart

For the American redstart HSI model, the variables related to the percent overstory canopy cover (V1) and tree stem density (V3) were near 1.0 on most stands sampled (Table 23). Habitat quality for some stands at the Huron Mountain Club was limited by a relatively high proportion of coniferous canopy cover (V2) and by a relatively low density of saplings (V4) compared to MDNR, Forest Service, and timber industry sites. The resulting HSI values were significantly lower for stands at the Huron Mountain Club than for stands on other sites, and higher for MDNR and timber industry sites than Forest Service sites (p=0.041) (Table 23).

Veery

The first variable in the veery HSI model, the percent of cover type flooded, is not applicable to the HSI calculation for nonwetland cover types (Sousa 1982). Values for the second variable, the soil moisture regime, were based on observations made during data collection in the spring of 1998. Sites were classified as falling into 1 of 3 moisture regime categories and assigned a corresponding suitability index value. Because all sites were comprised primarily of upland forest, most stands had relatively dry soils and were assigned to the lowest of the 3 suitability categories. However, several upland forest stands had noticeably moister soils, particularly stands located near streams, and these were subjectively assigned to the intermediate suitability category. No stands occurred in floodplain forest, therefore none were assigned the highest suitability value for the soil

Table 23. Mean suitability index values for each HSI model variable, and means and standard errors of final HSI values for the American redstart on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula.

	Ownership category				Probability level[a]
HSI variables	MDNR	USFS	TI	HMC	
V1 (percent tree canopy closure)	0.90	0.95	0.92	0.95	0.228
V2 (percent coniferous canopy cover)*	1.00[b]	0.99[b]	1.00[b]	0.64[c]	0.025
V3 (tree stem density)	0.95	0.88	0.90	0.92	0.658
V4 (sapling density)*	0.74[c]	0.70[b]	0.95[c]	0.30[d]	0.023
Final HSI value*	**0.78[b]**	**0.64[c]**	**0.84[b]**	**0.31[d]**	**0.041**
S.E. of the mean of the HSI values	0.081	0.041	0.084	0.154	

[a] Probability levels for tests of differences among ownerships were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

*Values on the same line with the same letter are not different (p>0.10) (Kruskal-Wallis multiple comparison statistic [Siegel and Castellan 1988]).

Table 24. Mean suitability index values for each HSI model variable, and means and standard errors of final HSI values for the veery on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula.

	Ownership category				Probability level[a]
HSI variables	MDNR	USFS	TI	HMC	
V1 (Percent of cover type flooded)	NA	NA	NA	NA	NA
V2 (soil moisture regime)	0.12	0.11	0.16	0.24	0.392
V3 (percent deciduous shrub cover)*	0.18[b]	0.35[b]	0.60[c]	0.08[d]	0.070
V4 (height of deciduous shrubs)	0.52	0.58	0.58	0.39	0.516
V5 (percent herbaceous canopy cover)	0.00	0.00	0.00	0.00	0.392
V6 (height of herbaceous canopy)*	0.64[b]	0.49[c]	0.49[c]	0.23[d]	0.034
Final HSI value	**0.07**	**0.10**	**0.16**	**0.08**	**0.192**
S.E. of the mean of the HSI values	0.003	0.021	0.032	0.054	

NA - Variable is not applicable in the habitat evaluated.

[a] Probability levels for tests of differences among ownerships were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

*Values on the same line with the same letter are not different (p>0.10) (Kruskal-Wallis multiple comparison statistic [Siegel and Castellan 1988]).

moisture variable (Table 24).

The third veery HSI model variable (V3) considers the amount of cover provided by deciduous shrubs and regenerating deciduous trees. Values for this variable were indicative of moderately suitable habitat on timber industry sites and Forest Service sites, which had intermediate amounts of midstory canopy cover (Table 5). Huron Mountain Club and MDNR sites received somewhat lower values for this variable because they had average shrub cover values below those considered suitable by the model. Values for variable 4, (the average height of deciduous shrubs) and variable 6 (average height of herbaceous vegetation), were moderately suitable for most stands in all 4 ownership categories, although stands at the Huron Mountain Club had slightly lower SI values than stands at other sites.

The final HSI values for all stands and the average HSI's for all ownerships were limited more by the percent of herbaceous canopy cover than by any other variables. Nearly all stands had too little herbaceous canopy cover to provide suitable habitat, as defined by the model. Final HSI scores averaged near 0 for all ownerships, and differences among ownerships were not significant.

Yellow-rumped warbler

Although data on the relative abundance of songbirds were collected from 104 forest stands, yellow-rumped warblers were positively identified in only 8% of those stands, so model development was based on a combination of field data and published literature. As with the red-backed salamander, the species data was divided into 2 groups. One group consisted of stands in which there was at least 1 yellow-rumped warbler observation during the 3 years of data collection, and the other was made up of stands in which no yellow-rumped warblers were recorded. Independent t-tests of these 2 groups indicated significant differences in shrub densities (p=0.040), height of herbaceous vegetation (p=0.071), average log width (p=0.039), and log densities (p=0.049) (Table 25).

An initial review of the literature suggested that the percent overstory conifer cover and the amount of shrub cover might be important habitat variables to consider in developing an HSI model for the yellow-rumped warbler. Although not statistically significant in this data set, the proportion of conifer cover also differed between the 2 groups with a probability of 0.11 (Table 25), giving moderate support to the previous hypothesis that conifer cover may be an important habitat variable. The final yellow-rumped warbler model based on these data analyses consists of 4 variables: percent overstory (≥5 m) conifer cover, average height of mature trees (defined as trees ≥5 m tall and ≥10.2 cm dbh), percent overstory (conifer and deciduous) canopy cover, and shrub stem density (Appendix C).

Suitability index values for the first model variable (overstory conifer cover) were greater (p=0.042) on Huron Mountain Club sites than on MDNR sites, due to the high proportion of hemlock in the overstory at the Huron Mountain Club (Table 26). The percent overstory conifer cover was the most limiting variable on MDNR and Forest Service, and was also very low on timber industry sites, all of which had much less conifer cover than optimal model values. The most limiting variable on timber industry sites was the density of shrubs and saplings <5 m tall (V4) because understory stem

Table 25. Ranges and mean values for habitat variables in stands where no yellow-rumped warblers were recorded and in stands where at least 1 yellow-rumped warbler was observed in 1996, 1997, or 1998, and probability of statistical difference in the means of the 2 groups based on independent t-tests.

	Mean number of yellow-rumped warblers per stand				
	0 (n=95)		≥1 (n=8)		Probability of difference between means
Variable	Range of stand values	**Average stand value**	Range of stand values	**Average stand value**	
Basal area	6.76-103.75	**29.23**	21.27-56.16	**36.35**	0.154
Overstory trees/ha	187-1093	**546.67**	400-840	**620.00**	0.225
Saplings/ha	40-5160	**906.32**	167-1840	**800.83**	0.672
Shrubs/ha	0-60,000	**11067.00**	67-4253	**2111.13**	0.040
Snags/ha	0-193	**51.37**	27-87	**49.17**	0.827
Stumps/ha	13-420	**158.04**	67-207	**132.50**	0.223
Logs/ha	0-460	**184.84**	40-193	**135.00**	0.049
Overstory tree DBH (cm)	16.40-60.59	**26.23**	19.22-34.88	**27.36**	0.545
Overstory tree height (m)	14.69-28.77	**20.99**	20.13-21.50	**20.88**	0.705
Shrub height (cm)	50-185	**101.65**	88.09-230.50	**118.60**	0.347
Snag height (m)	1.95-21.72	**10.82**	5.87-12.99	**9.25**	0.141
Snag diameter (cm)	10.16-66.33	**24.08**	13.91-30.16	**22.85**	0.624
Stump height (cm)	25.35-115.50	**52.16**	44.84-71.43	**57.68**	0.146
Stump diameter (cm)	14.5- 67.89	**31.23**	18.77-40.88	**31.67**	0.896
Log length (m)	2.43-8.51	**5.06**	3.89-8.17	**5.36**	0.564
Log width (cm)	16.12-49.11	**24.11**	17.00-27.96	**21.22**	0.039
Herbaceous height (cm)	1.20-27.40	**14.29**	3.27-16.11	**11.00**	0.071

Table 25 (Cont). Ranges and mean values for habitat variables in stands where no yellow-rumped warblers were recorded and in stands where at least 1 yellow-rumped warbler was observed in 1996, 1997, or 1998, and probability of statistical difference in the means of the 2 groups based on independent t-tests.

	Mean number of yellow-rumped warblers per stand				
	0 (n=95)		≥1 (n=8)		Probability of difference between means
Variable	Range of stand values	**Average stand value**	Range of stand values	**Average stand value**	
Litter depth (cm)	1.67-5.80	**3.51**	2.00-4.80	**3.32**	0.588
Vertical cover (%)					
0-0.5 m	1.28-46.33	**18.59**	3.33-30.75	**14.43**	0.212
0.5-5 m	2.17-75.5	**32.68**	9.33-58.33	**29.50**	0.366
>5 m	56.67-94.33	**82.22**	73.33-93.25	**84.58**	0.612
Herbaceous	0.58-30.83	**8.55**	1.75-11.75	**6.53**	0.227
All shrub species	0.00-2.67	**0.20**	0.00-0.67	**0.15**	0.636
Deciduous shrub species	0.00-2.67	**0.20**	0.00-0.67	**0.15**	0.647
Conifer trees	0.00-70.33	**15.64**	0.00-63.67	**31.13**	0.111
Deciduous trees	33.75-94.33	**74.38**	53.00-93.25	**73.54**	0.874
Hard mast trees >10 in (25.4 cm) DBH	0.00-41.83	**4.66**	0.00-14.17	**2.15**	0.230
Woody debris	1.17-23.25	**6.40**	3.62-10.22	**6.59**	0.814

Table 26. Mean suitability index values for each HSI model variable, and means and standard errors of final HSI values for the yellow-rumped warbler on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula.

	Ownership category				Probability level[a]
HSI variables	MDNR	USFS	TI	HMC	
V1 (percent overstory conifer cover)*	0.11^{b}	0.30^{c}	0.21^{bc}	0.95^{d}	0.042
V2 (height of mature trees)	0.98	1.00	0.96	0.99	1.000
V3 (% overstory canopy cover)	0.99	0.98	1.00	1.00	0.392
V4 (density of shrubs/saplings <5 m tall)*	0.63^{b}	0.31^{c}	0.12^{c}	0.95^{d}	0.028
Final HSI value*	**0.10^{b}**	**0.25^{c}**	**0.15^{c}**	**0.93^{d}**	**0.041**
S.E. of the mean of the HSI values	0.058	0.037	0.055	0.037	

[a] Probability levels for tests of differences among ownerships were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

*Values on the same line with the same letter are not different (p>0.10) (Kruskal-Wallis multiple comparison statistic [Siegel and Castellan 1988]).

densities on these sites were generally much higher than the HSI model's optimal range. Values for the second and third model variables (height of mature trees and percent overstory canopy cover) were consistently high on all study sites, indicating that the yellow rumped warbler's minimum requirements for these features are being provided within all ownerships.

Final HSI values strongly reflect the SI values for the conifer cover variable because it is given more weight than the other 3 variables in the final HSI equation. Consequently, habitat suitability indices were highest at Huron Mountain Club sites, and lowest on MDNR sites (p=0.041). Forest Service and timber industry sites also had relatively low values for yellow-rumped warbler habitat suitability (Table 26).

Pileated woodpecker

The first variable, tree canopy cover, considered in the habitat model for the pileated woodpecker was optimal or near optimal for all stands sampled (Table 27). The density of trees ≥51 cm dbh and snags ≥38 cm dbh (V2 and V4) were the most limiting variables on MDNR, Forest Service, and timber industry sites. Stands at the Huron Mountain Club had more suitably sized trees and snags, and therefore had higher values for these model components. Variable 3, the density of suitably sized logs and stumps, was not limiting to pileated woodpecker habitat quality on any of the sites sampled. Values for this variable in each stand were far above the minimum values required for suitable habitat, with the exception of 1 stand. This stand occurred on a Forest Service site, and had relatively few stumps and logs, although all other stands sampled at the site had sufficient number of stumps and logs to provide suitable foraging habitat for the

Table 27. Mean suitability index values for each HSI model variable, and means and standard errors of final HSI values for the pileated woodpecker on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula.

	Ownership category				Probability level[a]
HSI variables	MDNR	USFS	TI	HMC	
V1 (percent tree canopy closure)	0.98	0.96	0.99	0.99	0.663
V2 (density of trees >51 cm dbh)*	0.12[b]	0.06[b]	0.00[c]	0.56[d]	0.021
V3 (density of tree stumps and logs)	1.00	0.99	1.00	1.00	0.392
V4 (density of snags >38 cm dbh)*	0.04[bc]	0.03[b]	0.17[c]	0.56[d]	0.052
V5 (mean dbh of snags >38 cm in diameter)*	0.03[b]	0.01[b]	0.08[b]	0.49[c]	0.060
Final HSI value*	**0.01[b]**	**0.10[b]**	**0.01[b]**	**0.36[c]**	**0.067**
S.E. of the mean of the HSI values	0.012	0.009	0.013	0.102	

[a] Probability levels for tests of differences among ownerships were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

*Values on the same line with the same letter are not different (p>0.10) (Kruskal-Wallis multiple comparison statistic [Siegel and Castellan 1988]).

woodpecker.

Although some stands met the model requirements for the minimum number of large snags (V3) needed by woodpeckers for foraging and nesting, habitat quality was limited in a subset of these stands because the average diameter of large snags was below values associated with high quality pileated woodpecker habitat. Again, differences in this model component were most evident between the Huron Mountain Club and the other 3 ownership categories. Final HSI values were near 0 for MDNR, Forest Service, and timber industry sites, primarily due to the lack of very large trees and snags. Habitat suitability index values for stands at the Huron Mountain Club averaged 0.31 (Table 27), although the number and size of large trees and snags were still the primary factors that drove HSI values below 1.0.

Northern flying squirrel

The most limiting habitat variable for northern flying squirrel habitat quality for all 4 ownership categories was the density of snags $\geq$30 cm dbh (V3). Even though this variable was the most limiting factor on Huron Mountain Club sites, it was higher ($p=0.067$) on Huron Mountain Club sites than on other ownerships (Table 28). Variable 1, the density of overstory trees, was moderately suitable (0.58-0.68) for all 4 ownerships, with no significant differences observed. Values for the second model variable, the density of trees $\geq$30 cm dbh, were higher on Huron Mountain Club sites than on all other sites and lowest on Forest Service and timber industry sites ($p=0.024$). Although differences were not statistically significant, overstory canopy cover on MDNR sites was generally much lower than optimal model variables, slightly higher on Forest Service and

Table 28. Mean suitability index values for each HSI model variable, and means and standard errors of final HSI values for the northern flying squirrel on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula.

	Ownership category				Probability level[a]
HSI variables	MDNR	USFS	TI	HMC	
V1 (density of overstory trees)	0.68	0.64	0.58	0.69	0.376
V2 (density of trees >30 cm dbh)*	0.50^{b}	0.37^{c}	0.32^{c}	0.85^{d}	0.024
V3 (density of snags >30 cm dbh)*	0.11^{bc}	0.06^{b}	0.21^{c}	0.70^{d}	0.067
V4 (overstory conifer cover)*	0.28^{b}	0.47^{b}	0.41^{b}	0.99^{c}	0.093
Final HSI value*	**0.39^{b}**	**0.39^{b}**	**0.38^{b}**	**0.81^{c}**	**0.099**
S.E. of the mean of the HSI values	0.058	0.016	0.048	0.029	

[a] Probability levels for tests of differences among ownerships were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

*Values on the same line with the same letter are not different (p>0.10) (Kruskal-Wallis multiple comparison statistic [Siegel and Castellan 1988]).

timber industry sites, and near optimal at the Huron Mountain Club (Table 28). Final HSI values were determined to be different among sites ($p=0.099$), and a Kruskal-Wallis multiple comparison test showed that calculated habitat suitability was highest at the Huron Mountain Club (Table 28).

Barred owl

The first variable considered in the barred owl HSI model is the density of trees with a dbh ≥51 cm. Stands in which no such trees are present receive an SI value of 0.10, stands with an average of ≥5 trees/ha ≥51 cm dbh receive an SI of 1, and stands with >0 but <5 trees/ha are assigned an intermediate SI value. Tree diameter data in this study was collected from 3 250 m^2 plots per stand, or a total of 750 m^2 per stand. Any stand in which 1 tree ≥51 cm in diameter was recorded would be estimated to have a density of 13 such trees per hectare. Therefore, because of the plot sizes and sampling methods used, any stand in which at least 1 51 cm tree was recorded received an SI of 1.0 for that model component, and all others received an SI of 0.1 (Table 29).

Another of the barred owl model variables is the average diameter of all overstory trees. This parameter varied among study sites, with SI values ranging from 0.14-0.50. Most stands on Forest Service, MDNR, and timber industry sites were at the lower end of the range and several Huron Mountain Club stands were at the upper end (Table 29).

The third component of the barred owl HSI model is the percent overstory cover, with stands having ≥60% assigned a value of 1.0. All stands sampled had ≥60% overstory canopy cover, with the exception of one recently thinned stand on a Forest Service site in which the overstory canopy cover averaged 57%. As a result, this HSI

Table 29. Mean suitability index values for each HSI model variable, and means and standard errors of final HSI values for the barred owl on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula.

	Ownership category				Probability level[a]
HSI variables	MDNR	USFS	TI	HMC	
V1 (density of trees >51 cm dbh)*	0.44[b]	0.35[b]	0.14[c]	0.90[d]	0.023
V2 (dbh of overstory trees)*	0.28[bc]	0.33[b]	0.26[c]	0.50[d]	0.057
V3 (percent canopy cover of overstory trees)	1.00	1.00	1.00	1.00	0.392
Final HSI value*	**0.31[b]**	**0.29[b]**	**0.18[c]**	**0.65[d]**	**0.024**
S.E. of the mean of the HSI values	0.048	0.029	0.016	0.096	

[a] Probability levels for tests of differences among ownerships were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

*Values on the same line with the same letter are not different (p>0.10) (Kruskal-Wallis multiple comparison statistic [Siegel and Castellan 1988]).

model variable was optimal or very nearly optimal in all stands surveyed. Final HSI values ranged from an average of 0.18 on timber industry sites to 0.65 at the Huron Mountain Club, with significant differences (p=0.024) among study sites (Table 29).

Fisher

For each ownership category, the lowest SI values determined by the fisher HSI model occurred for variable 4, the proportion of the overstory canopy cover comprised of deciduous trees. Suitability index values on MDNR, Forest Service, and timber industry sites ranged between 0.22 and 0.24 (Table 30), because they had more deciduous canopy cover than that considered to occur in high quality fisher habitat. In addition, the average size of overstory trees contributed to the lower HSI values on MDNR, Forest Service, and timber industry sites than at the Huron Mountain Club.

Relationships between population indices and HSI model output

Spearman rank correlations between population indices for 8 selected indicator species ranged from -0.559 to 0.594 (Table 31). The fisher was the only species with a negative correlation between the population index (# tracks/km) and HSI values. Correlations between relative abundance and HSI scores were rather low for the barred owl and for the American redstart, a moderately positive correlation was found for the veery. For the pileated woodpecker, there was a significantly positive correlation between relative abundance and HSI model output.

The 2 species for which HSI models were developed from project field data had the highest correlations, indicating that the models are fairly good predictors of habitat quality on the sites examined in this study. In the 6 of the 8 stands where yellow-rumped

Table 30. Mean suitability index values for each HSI model variable, and means and standard errors of final HSI values for the fisher on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula. Probability levels for tests of differences among ownerships were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

HSI variables	Ownership category				Probability level[a]
	MDNR	USFS	TI	HMC	
V1 (percent tree canopy closure)	1.00	0.98	0.96	0.99	0.734
V2 (average dbh of overstory trees)*	0.53[bc]	0.59[b]	0.50[c]	0.80[d]	0.057
V3 (tree canopy diversity)	1.00	0.83	0.92	0.83	0.326
V4 (percent of overstory with deciduous trees)*	0.22[b]	0.23[b]	0.24[b]	0.53[c]	0.075
Final HSI value*	**0.18[b]**	**0.18[b]**	**0.18[b]**	**0.46[c]**	**0.099**
S.E. of the mean of the HSI values	0.013	0.018	0.015	0.141	

[a] Probability levels for tests of differences among ownerships were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

*Values on the same line with the same letter are not different ($p>0.10$) (Kruskal-Wallis multiple comparison statistic [Siegel and Castellan 1988]).

Table 31. Spearman rank correlations between mean relative abundances per study site and mean HSI values for species surveyed on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land.

Species	Correlation coefficient (r_s)	2-tailed probability level
Red-backed salamander*	0.594	0.042
Ovenbird	0.448	0.144
American redstart	0.168	0.602
Veery	0.347	0.269
Yellow-rumped warbler*	0.569	0.053
Pileated woodpecker*	0.498	0.099
Barred owl	0.294	0.354
Fisher[a]	-0.559	0.117

* Relationship is statistically significant ($p \leq 0.10$).

[a] Correlation calculated between fisher activity indices (tracks/km) on MDNR, USFS, and TI stands and HSI values.

warblers were observed, the SI value for the conifer cover variable was >0.75, which contributed strongly to the significant positive correlation (r_s=.569, p=0.053) between relative abundance and HSI values.

DISCUSSION

Vegetation and structural attributes

The divergent management goals of private timber companies and the Huron Mountain Club are reflected in several forest stand characteristics that varied most widely between Huron Mountain Club and timber industry sites. In contrast, attributes on MDNR and Forest Service sites tended to fall in the middle of the range of values measured. These relationships are evident in the statistical comparisons and in the principal components representation of the 4 ownerships (Tables 5 and 6, Fig. 3). For example, the significantly lower basal area on timber industry sites is an expected result of the timber industry's management goals of producing and harvesting timber. Conversely, many of the differences that distinguish the Huron Mountain Club from other ownerships, such as larger tree diameters and a sparse understory, are the result of the relatively unmanipulated condition of the land and the unique management history of the area. Logs at the Huron Mountain Club consist almost entirely of trees that have fallen over naturally, and the larger width of logs there reflects the greater size to which trees are able to grow in the absence of timber harvesting.

The proportion of hard mast producing trees in the overstory was another disparity between timber industry and Huron Mountain Club sites. Beech was the dominant hard mast producing tree observed, and it was significantly more abundant on timber industry sites than on Huron Mountain Club sites (Table 7). As a tree species with low commercial value, beech is generally not removed during sawlog thinning on timber industry sites, and therefore beech trees continue growing until being clearcut. The

Huron Mountain Club is located beyond the western front of beech's geographic range, and therefore beech does not occur at the Huron Mountain Club (Davis et al. 1991). The only hard mast producing trees observed at the Huron Mountain Club were oaks (*Quercus* spp.), which occurred in some drier, higher elevation northern hardwood stands.

For other vegetation characteristics, Huron Mountain Club and timber industry sites had similar values, and MDNR and Forest Service sites were at the other end of the range of values observed. Examples are the larger stump sizes and log diameters on both private ownerships (Table 5). Similarities between Forest Service and MDNR sites are also evident in the principal components analysis, which shows the clustering of these sites in terms of basal area, and standing and fallen dead material (Fig. 3). Another interesting result was that bigtooth aspen was recorded only at the Huron Mountain Club and not on any other ownerships. This was a result of treefall gaps at the Huron Mountain Club, where the death of a large tree initiates a gap in the overstory, forming a pocket in the forest that exists in an earlier successional stage than the surrounding forest. On other ownerships, aspen was most likely eliminated through succession as forest stands matured, and opportunities for aspen regeneration were rare.

Forest stand conditions in this study should not be viewed solely in terms of their current management. Although land on MDNR and Forest Service study sites has generally been under the same ownership since the 1920s, 3 timber industry stands sampled were purchased from a private owner by Shelter Bay Forests in the 1970s. Timber management activities on stands sampled on MDNR, Forest Service, and timber industry sites have consisted primarily of intermediate thinnings during the last 60 years.

Several MDNR stands had not been cut since the stand was established, and 4 stands on Shelter Bay and Mead sites have not been cut in the last 40 years. In a forest type that is generally managed as uneven-aged, the concept of "stand age" is generally less relevant than in other forest stands (Frelich and Lorimer 1991), and most stands were of indeterminate age beyond the fact that they were established after early 20th century logging.

Wildlife habitat relationships

Red-backed salamanders

Although statistically significant differences in salamander relative abundance among ownerships were not documented (Tables 8, 9, 10, and 11), the vegetation conditions associated with each ownership can help explain the relative differences in salamander relative abundance that were observed. The relationship between the density of overstory trees (≥ 10.2 cm dbh) emerged as one of the strongest indicators of salamander relative abundance on our study sites (Appendix B). This result has strong support from red-backed salamander research conducted in other hardwood forest ecosystems. Monti (1997) found a positive relationship between salamander relative abundance and tree stem density in an oak-pine forest in Maine, and suggested that the association may be related to the amount of litter that is produced, with stands that have a high density of growing trees producing more litter than fewer large trees would produce in a stand. Numbers of red-backed salamander were also positively associated with tree stem densities in Pennsylvania hardwood forests (Rodewald and Yahner 1999) and in New England oak forests (Brooks 1999). Interestingly, all 3 studies used artificial cover objects to survey amphibian populations.

Despite relatively low tree stem densities at the Huron Mountain Club, slightly greater numbers of salamanders were observed on those sites. Among all stands sampled, understory canopy cover and shrub stem densities were negatively related to salamander abundance, and the lack of understory canopy cover at the Huron Mountain Club may partially explain the slightly greater relative abundance of salamanders observed there. The negative relationship between salamander relative abundance and the amount of midstory canopy cover may be because less moisture is retained by the litter and soil on sites where there is an abundance of herbaceous and shrub cover, which may result in a less favorable habitat for salamanders (Welsh and Droege 2001). Midstory canopy cover may also be correlated with microhabitat characteristics that were not measured, such as nutrient ratios in the soil or daily soil moisture fluctuations.

The positive relationship between numbers of salamanders detected and high tree stem densities suggests that younger or regenerating forest stands may provide suitable salamander habitat. However, several studies have found that terrestrial salamanders, including *Plethodon cinereus*, are negatively impacted by intensive silvicultural treatments such as clearcutting, and have attributed the results to the drier surface conditions caused by the removal of canopy cover and litter (Pough et al. 1987, Herbeck and Larsen 1999, Howard and Caschetta 1999, Rodewald and Yahner 1999).

Because salamanders only used a very small proportion (1.6%) of all cover objects turned over during surveys, it was assumed that cover objects were not limiting to salamanders in the habitats examined. Although the importance of woody debris to terrestrial salamanders has been documented and widely acknowledged (Test and Heatwole 1962, Jaeger 1980, Grialou et al. 2000), some studies (Rodewald and Yahner 1999, Aubry 2000) have failed to find an association between salamander numbers and the amount of woody debris in their habitat. However, it is possible that certain forest activities where large amounts of dead woody debris may be removed from a stand, such as collection of dead and downed woody material for firewood, could reduce the amount of woody debris below a critical threshold. Thus, it should not be assumed that habitat quality is entirely independent of the amount of woody debris in a stand, but rather that woody debris was not limiting to red-backed salamanders in the habitats sampled.

Comparison of ground transect searches and cover boards for surveying salamanders

Ground transect searches and the artificial cover boards were useful methods for measuring the relative abundance of red-backed salamanders in northern hardwood forests in the Upper Peninsula of Michigan. Salamander relative abundance for both methods combined ranged from 73 salamanders/ha to 229 salamanders/ha during summer surveys on the 4 ownerships investigated. In comparison, Heatwole (1962) attempted a complete count of red-backed salamanders and measured 8900 salamanders/ha in a Michigan northern hardwood forest. Test and Bingham (1948) recorded 496 salamanders/ha during a surface census in a Michigan hardwood forest.

Although each method used in this study produced somewhat different results, they were in agreement in that the Huron Mountain Club showed a trend of having more salamanders than the other ownerships. The results of both methods should be viewed with caution in 1997 when only 1 timber industry site was represented, and especially in the fall, when only 20 stands were sampled before the first snowfall.

It appears that the boards may require an acclimatization period on a site before they reach their full potential as a survey tool. When cover board searches were conducted during summer, 1997, none of the boards had been in place more than 8 weeks, which may account for the comparatively low number of salamanders observed under boards (Table 8). One reason for this may be that it takes many weeks for the boards and the litter beneath them to decay to the point that they provide a suitable microhabitat for red-backed salamanders. Some time may also be needed for salamanders to locate the boards within their territories and to begin using them for cover. Therefore, cover board survey results may have been biased during the first summer the boards were out. By the time fall surveys began, cover boards had been in place for at least 14 weeks, and boards placed on the Shelter Bay sites, which were added to the study after fall data collection, had been in place for 7 months when the first surveys took place on those sites in 1998.

The relative abundance of salamanders determined with each survey method fluctuated among the spring 1997, fall 1997, and spring 1998 sampling periods (Tables 8, 9, and 10). Although it may appear that there was an overall increase in red-backed salamander populations between 1997 and 1998, the increase is most likely due to the fact that boards had only been in place for approximately 6 weeks when the first surveys took place, and probably became much more attractive to salamanders as the litter beneath them decayed during the first year the boards were on the ground.

There were generally low correlations between number of salamanders observed with artificial cover board and ground transect search methods. One reason may be that relatively few salamanders were observed under cover boards; thus, there was little variation (1-4 salamanders/stand) among stands, resulting in relatively weak correlations. In addition, salamander use of cover boards was generally lowest during the first year boards were used and increased after the boards had been in place for a few months, while ground transect search results were not subject to the same bias. Ground searches of cover objects revealed more salamanders than the cover board method, however, the time required to perform the ground searches according to the protocol used was also substantially greater. For studies of red-backed salamander populations where data will only be collected one time from a particular study site, ground transect searches like the ones used in this project are a more efficient method than cover boards. However, when population surveys will be repeated over time, the cover board method offers the advantage of requiring less time than ground transect searches. A second advantage of using artificial cover objects is that it allows researchers to standardize the amount of effort used to survey each site since the number and size of objects searched does not vary from site to site as it does when ground transect searches are used. Finally, cover boards searches can be accomplished with minimal habitat disturbance compared to other available survey methods.

Forest birds

Forest bird communities on Forest Service and MDNR sites were relatively similar, while timber industry and Huron Mountain Club land were structured very differently, based on principal components analysis and nonparametric comparisons (Table 15, Figs. 5-7). Forest Service and MDNR sites were characterized by a bird community that included the black-throated blue warbler, least flycatcher, rose-breasted grosbeak, black-throated green warbler, and ovenbird, but was not strongly dominated by any 1 or 2 species. The Huron Mountain Club bird community included 2 of the most abundant birds surveyed, the ovenbird and the black-throated green warbler, and a secondary assemblage of cavity nesting birds. On timber industry sites, the American redstart and veery, species with preferences for younger stands, and the raven, a habitat generalist, were important species.

Although black-throated blue warblers are expected to inhabit more mature forests, they prefer sites dominated by sugar maple and with a dense shrub layer (Binford 1991, Bourque and Villard 2001), which explains the small role they play in the Huron Mountain Club forest bird community. The blackburnian warbler is a species facing expected declines in Michigan, due to harvesting of uneven aged mature coniferous forests (Doepker et al. 1992). Although blackburnian warblers (*Dendroica fusca*) were encountered infrequently during field sampling, they were generally more common at the Huron Mountain Club than other study sites, where they were presumably attracted to the conifer component of the hardwood forests (Tables 6 and 7). This is a potentially important finding, as it indicates the potential of unique areas such as the Huron Mountain Club to provide a refuge for species whose primary habitat is threatened.

The distribution of birds grouped by migratory status among ownerships was slightly skewed in favor of neotropical migrant bird species on MDNR and Forest Service sites, and resident and short distance migrant species were relatively more important on timber industry and Huron Mountain Club sites. This result is most likely due to the influence of a few very abundant species, such as the black-throated green warbler, ovenbird, and red-eyed vireo, that accounted for the majority of individuals in the neotropical migrant group. In addition, 5 of the 8 birds classified as year round residents are also cavity nesters, which tended to be more prevalent in the older forests found at the Huron Mountain Club. Thus, neotropical migrants as a group may not exhibit associations with forest characteristics that reflect overall management approaches. However, Noon et al. (1979) determined that mature and undisturbed forested habitats contained more regionally rare species, in terms of absolute numbers and proportion of species present, that did not occur in early successional or disturbed forests.

Barred owls

The index of barred owl population used in this study was highly variable among years and among locations within a year. Barred owl responses may have been more influenced by weather conditions and time of night than had been expected, and sampling may not have been intensive enough to accurately describe the population. Barred owl responses to taped broadcast calls have been found to vary with weather, environmental conditions, and time of night; they are particularly influenced by moon phase, occurring most frequently when the moon is visible (i.e., a full moon with no cloud cover) (Takats and Holroyd 1997). In this study, however, barred owl surveys were not controlled for conditions other than precipitation.

No strong conclusions can be drawn about the effects of management approaches on barred owl populations other than the fact that barred owls were distributed among all study sites. These results might also be a function of the resolution of the data analyzed, which may have been too fine to demonstrate the true variability in the population.

Fisher

There was not sufficient population data to determine if fisher habitat use differed among ownerships. However, observations of fisher tracks necessarily indicate that the fishers were moving, and because fishers are generally solitary in the winter (Powell 1982), fishers whose tracks were observed were either foraging on the study sites or moving through the study sites en route to another part of their home range. As with the barred owl, the scale of the analysis may have obscured some population characteristics that would be apparent in a broader scale of analysis.

HSI model performance

The model developed for the red-backed salamander exhibited a good fit to the data used to develop the model, based on the significant correlation with salamander relative abundance. Possible sources of error in the red-backed salamander model include population variation due to the effects of stochastic events (e.g., weather conditions) during the 2 years of population monitoring, potential bias in population sampling methods (e.g., differential use of cover objects in response to moisture conditions), and unidentified multivariate relationships in the data. Also, HSI models are driven by measures of habitat structure and composition, and do not consider the impact of interspecific relationships or density-dependent factors on a population (Schamberger and O'Neil 1986).

In New Brunswick, Canada, ovenbird densities and reproductive success were lower in selection cuts than in uncut stands (Bourque and Villard 2001). In this study, the lowest ovenbird numbers occurred on timber industry sites (Table 15) which presumably have had more intensive cutting. Leaf litter depth and biomass of invertebrates in the litter have also been positively associated with ovenbird territory establishment (Burke and Nol 1998). Although not significant, the correlation between ovenbird relative abundance and HSI values was more positive than for other species, and as a model with 2 simply measured variables, it may be especially useful to forest managers.

As might be expected for an early successional species, calculated habitat quality for the American redstart was highest for timber industry sites and lowest for the Huron Mountain Club (Table 23). There was a positive but weak correlation between redstart numbers and HSI values, although average HSI values followed the trend for redstart relative abundance (Table 15) for all ownerships except Forest Service sites. Discrepancies between model output and redstart abundance may be due to the fact that there are contradictions in the published literature regarding redstart habitat requirements (Minnis and Haufler 1994), and the model was not empirically based. Also, the model was developed for deciduous, coniferous, and mixed forests, but the parameters that define high quality habitat may not be the same in each forest type.

Although there was a small positive correlation between veery observations and calculated HSI values, all ownerships had HSI values <0.2, indicating poor habitat quality (Table 24). Nonetheless, the veery was not as uncommon on any of the ownerships as might be expected from such low HSI values. Thus, the existing veery model may not be a very useful tool for evaluating veery habitat quality in northern Michigan hardwood forests. The one model variable that most strongly contributed to the low HSI values on all study sites was the herbaceous canopy cover component. The model specifies at least 90% herbaceous cover for a site to receive an overall HSI of 1.0, but none of the sites sampled even approached that. The definition for this variable is perhaps too restrictive, and might be expanded to include woody canopy cover on the forest floor (i.e., tree seedlings) as a contributor to veery habitat quality.

Because the yellow-rumped warbler model results were based on the same data used to develop the model, the significant positive correlation between yellow-rumped warbler observations and HSI values only indicates how well the model fits the data. The high HSI values for yellow-rumped warblers at the Huron Mountain Club were mainly driven by the strong influence of conifer cover in the warbler model (Table 26). Generally, mature hardwoods and immature hardwoods are avoided by the yellow-rumped warbler (Howe et al. 1995), but yellow-rumped warblers in Michigan have also been reported to use northern hardwoods more often than is commonly believed (Eastman 1991). Even though the Huron Mountain Club forests where most yellow-rumped warbler observations occurred do have a significant conifer component, there may be other factors unique to that area, understory vegetation species composition, that are important to yellow-rumped warblers and should be built into the model.

Four species associated with mature forest (pileated woodpecker, northern flying squirrel, barred owl, and fisher) had significantly higher HSI values on Huron Mountain Club sites than on other ownerships (Tables 27, 28, 29, and 30). This, together with the generally positive correlations between pileated woodpecker numbers and barred owl responses, gives support to the utility of these 2 models for measuring habitat quality. However, the small number of pileated woodpecker observations may mean that the significant correlation was spurious and not reflective of a biological relationship. Negri (1995) reported that the pileated model accurately described pileated woodpecker requirements in the Upper Peninsula, but validation was limited by the large scale required to obtain multiple pileated woodpecker observations. A pileated woodpecker model specific to Great Lakes region has also recently been developed (Felix et al. 1999), and a logical next step in model validation would be to compare the performance of the 2 models on the same data set.

In attempting to evaluate the fisher HSI model in the Upper Peninsula, Thomasma et al. (1991) found that habitat predicted to be high quality by the model was used more by fishers than predicted low quality habitat, and they recommended using the existing fisher model for habitat evaluations. In this study, a likely reason for the negative relationship between the calculated HSI and the population index for the fisher is that among the 3 ownerships tested (MDNR, Forest Service, and timber industry), there was relatively little variability among suitability index values for the 4 model variables and among the final HSI variables (Table 30). There was much more variability among activity indices across study sites, and the HSI model may not have been sensitive enough to reflect those differences if they were the result of differences in habitat quality. The scale at which fisher surveys were conducted may also have contributed to the poor relationship between HSI scores and activity indices. Fisher home ranges may encompass

16-31 km^2 (Arthur et al. 1989), so even though HSI scores may indicate exceptional habitat quality, the sampling area (12-19 km^2) may encompass only 1 or 2 fisher territories, and population surveys may only indicate presence or absence of fishers.

Paragi et al. (1996) reported that fisher natal dens and resting sites in Maine were located almost exclusively in the cavities of large mature hardwood snags. The existing fisher HSI model evaluates the diameter of overstory trees, but does not consider snags. However, Paragi et al.'s recommendation to maintain a supply of hardwoods >40 cm dbh corresponds well to the model's requirement for an average overstory tree dbh of 38 cm in high quality habitat.

Stand level variables may be important in determining fisher habitat quality if they are averaged over a large enough area. Carroll et al. (1999) found that measurements of 3 stand variables (overstory canopy closure, percent conifer cover, and hardwood tree diameter) aggregated over a regional scale, rather at local scale (0.05 ha) were the best predictors of fisher distribution in California. If the results are applicable to Michigan, the Huron Mountain Club would be expected to have better fisher habitat than the other ownerships, which all had smaller tree diameters and less conifer cover. Carroll et al.'s findings also emphasize the importance of evaluating fisher habitat quality at the scale of the fisher's home range, as was done in this study.

Because the HSI models developed for the red-backed salamander, yellow-rumped warbler, and northern flying squirrel have not yet been used in northern hardwood forests outside of the study area, they should be validated using a framework such as that prescribed by Roloff and Kernohan (1999). Their protocol outlines 7 criteria for testing the reliability of an HSI model, including modeling at the scale of the animal's home range, evaluating a broad range of habitat quality, and using an appropriate measure of species response to habitat quality. The process used to build the salamander model at least partially met 6 of these criteria. However, the model could be strengthened by testing it with a population data set that spans at least 3 years to reduce the impact of stochastic events, and by evaluating stands representing a wider range of habitat conditions, such as heavily thinned northern hardwood stands with slash and stands with very little woody debris.

The models developed for the yellow-rumped warbler, and for the northern flying squirrel in particular, are only initial attempts at modeling wildlife habitat relationships in northern hardwood forests. The sample size of yellow-rumped warbler observations was low, and the published research used to supplement the field data was sparse. Thus, these models will need more extensive testing to be useful to natural resource managers.

Another factor that should be investigated before basing management decisions on HSI results is the relationship between the population data used to develop the model and other demographic characteristics, such as reproductive success and survival. Following Van Horne's (1983) assertions that density is not necessarily an indicator of habitat quality, researchers have become more cautious about testing the assumption that HSI output corresponds to actual species fitness. For example, Breininger et al. (1998) tested an HSI model that was based on relationships between species density and habitat characteristics, and found that under certain habitat conditions, HSI scores were high, Florida scrub-jay (*Aphelocoma coerulescens*) density was high, but mortality exceeded reproductive success due to predation. Although this assumption may be very time consuming and difficult to test, it should at least be borne in mind when conducting a habitat evaluation or using the results.

CHAPTER 2 - Landscape Scale Wildlife Habitat Characteristics and Relationships

INTRODUCTION

Movements and habitats of forest wildlife species often extend beyond the boundaries of a single forest stand. For many wildlife species, stand level habitat evaluations may only partially describe a species' response to its environment, and broader scale landscape evaluations are needed to account for a larger set of habitat variables. Fine filter evaluations that assess stand level habitat attributes may also be time consuming to measure across a large management area such as a national or state forest, and identification of larger scale landscape attributes that contribute to habitat selection may facilitate wildlife habitat quality monitoring, especially when multiple species are being considered. For example, a habitat assessment for a group of ecologically similar species, such as edge sensitive forest songbirds, may include fairly large scale habitat characteristics, such as the size of the forested area, the proportion of different forest types in the management area, and the degree of forest fragmentation in the landscape under management. This type of analysis which assesses the range of habitat conditions for a group of wildlife species can be referred to as a coarse-scale habitat assessment (The Nature Conservancy 1982).

Landscape characteristics arise through natural and human influenced processes. In northern hardwood forests, natural disturbances, primarily in the form of windthrow, can set back succession and create new patches with complex shapes. In forests where human influence is absent, such processes may result in a landscape with a matrix of very large patches and a much smaller proportion of small patches (Mladenoff et al. 1993). Natural resource management activities such as timber harvesting, herbaceous plantings, and road building may also directly affect the arrangement, size, shape, and number of patches on the landscape. Depending on the management goals being pursued, the results may range from a diverse but highly fragmented landscape to one that has a closer resemblance to an undisturbed landscape. Although natural resource managers today may recognize the potential for both direct and cumulative effects of landscape changes on wildlife habitat quality, landscapes are a reflection of past activities that may have sought different objectives and operated under different assumptions than exist today. For example, guidelines for wildlife management in Michigan in the early 1970s specifically stated that managers should promote shade intolerant forest types and prevent conversion to mature forest (Michigan Department of Natural Resources 1973).

Furthermore, the tools for making decisions at a landscape scale and a strong information base on wildlife responses to landscape characteristics are not yet available to many managers. Despite the fact that many researchers have documented relationships between landscape parameters and wildlife habitat quality, many tools for habitat assessment were designed before landscape management principles were firmly in place. Therefore, HSI models that have traditionally evaluated local habitat variables but do not address the importance of landscape characteristics may be inadequate for conducting a thorough evaluation of habitat quality. One of the biggest reasons that these stand-level models are "incomplete" is that there still remains a very large need to identify landscape level requirements of individual species. Although HSI models are valuable for evaluating wildlife habitat at a small spatial scale, habitat suitability analysis can be integrated over a range of spatial scales, depending on the typical home range size of the species of interest, the extent of the area to be managed, and the total number of species for which habitat will be evaluated.

Knowledge of the current condition of a planning landscape, including land managed by other entities, may help natural resource managers evaluate the potential effects of management activities and refine their management objectives to better meet overall goals. In addition, identification of larger scale landscape attributes that contribute to habitat selection may also facilitate wildlife habitat quality monitoring. Using a coarse filter approach, this chapter will compare the characteristics of landscapes within 4 different ownership categories, identify relationships among landscape variables and wildlife population indices, and relate results to differences in wildlife relative abundance in each area.

METHODS

Population survey methods for red-backed salamanders, forest birds, barred owls, and fishers were described in Chapter 1. Relative abundance data for these species for 1996, 1997, and 1998 were used in landscape analyses.

Landscape analyses

Land cover data were obtained from the Michigan Department of Natural Resources (MDNR) for each study county. These data consisted of 1991 Landsat Thematic Mapper satellite imagery of the Upper Peninsula that was classified for a project on deer winter habitat use (MacLean Consultants, Ltd., no date). The imagery was recorded at a 30 m resolution, meaning that the smallest identifiable element is a 30 m x 30 m square cell. The land cover data came in ERDAS format, which is a raster based GIS system, and was converted to Arc/Info format using the IMAGEGRID and GRIDPOLY commands.

The classification system for the land cover data identified a total of 13 nonconiferous cover types and 17 coniferous categories (Table 32). The agricultural/cropland category was combined with the herbaceous openland category for this analysis because both are nonforested cover types that made up a small proportion of the area evaluated. Because the satellite data had been classified for a winter deer habitat study, the coniferous categories were emphasized in the classification system. Most of the coniferous categories were subdivided based on the amount of canopy closure, but the nonconiferous categories were not distinguished in this way. Therefore, the 2 mixed conifer canopy closure categories (<70% canopy closure and >70% canopy closure) were

Table 32. Categories used in the classification of 1991 Upper Peninsula Landsat Thematic Mapper satellite imagery (MacLean Consultants, Ltd. no date).

Non-coniferous cover types	Coniferous cover types	
Urban	Red pine	
Nonvegetative	Jack pine	
Agricultural/cropland	White pine	
Herbaceous openland	Other (mixed) pine	
Shrubland	Tamarack	
Northern hardwoods	Hemlock	<70% crown closure
Oak		>70% crown closure
Aspen/birch	Black spruce	<70% crown closure
Lowland hardwoods		>70% crown closure
Dry hardwood/conifer mix	White spruce	<70% crown closure
Wet hardwood/conifer mix		>70% crown closure
Wetlands	Balsam fir	<70% crown closure
Water		>70% crown closure
	White cedar	<70% crown closure
		>70% crown closure
	Mixed conifer	<70% crown closure
		>70% crown closure

also merged to make the level of discrimination within each category more uniform.

Road coverages were created from data on trails, public streets, county roads, and highways in 1978 MIRIS base map files provided by the MDNR. The MIRIS base map data for each county was obtained in Intergraph Design Format, and the roads data layer was then extracted and converted to Arc/Info format with the IGDSARC command.

Each study site was defined as a landscape; however the boundaries of the study area landscapes were defined separately for each species evaluated, depending on the amount of area beyond survey points species were likely to use. For the Huron Mountain Club study site, all 3 sampling areas were treated as a single study site landscape, unlike the stand level habitat and species abundance analyses presented in Chapter 1, where the 3 sampling areas were analyzed as individual sites within the Huron Mountain Club ownership category. Arc/Info was used to prepare digital representations of each site. For each of the 10 study sites, landscape boundaries were first created in ArcInfo by generating a polygon with the UTM coordinate points associated with red-backed salamander, forest bird, and barred owl, and vegetation sampling points located on the outer boundary of the study site as the vertices (Fig. 8). Survey points had been established across study sites in a superficial grid pattern, approximately 1.6 km apart. Generated coverages were projected from UTM coordinates to state plane coordinates, which was the coordinate system of the satellite imagery and roads data.

A buffer was then added to the exterior of the polygon to capture area outside survey points that was potentially used by the wildlife detected. The size of the buffer depended on the species for which the landscape was being defined. For barred owls, the

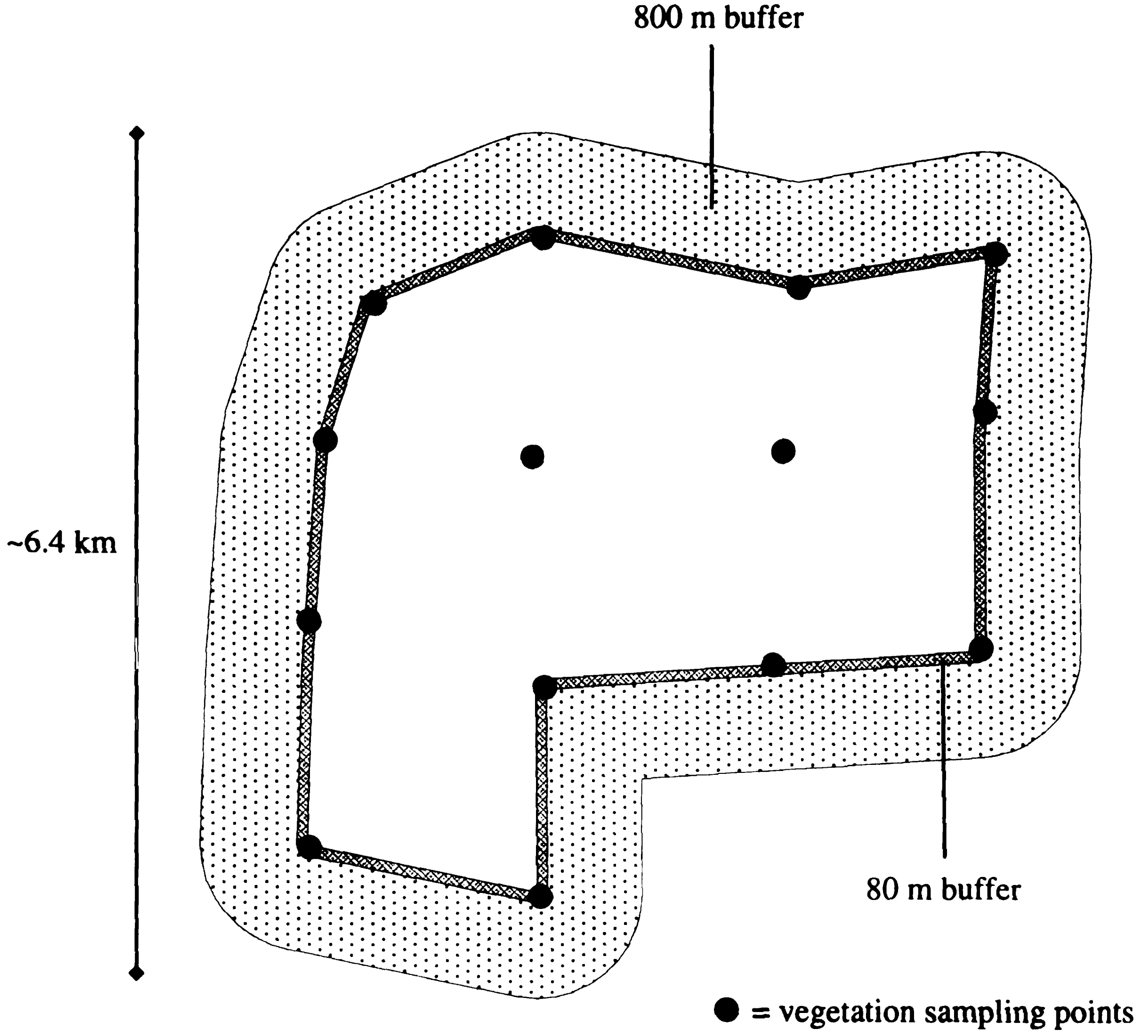


Figure 8. Illustration of sampling points and buffers used to define landscape boundaries for study sites in Michigan's Upper Peninsula.

buffer was 800 m, corresponding to the radius of a 200 ha home range sized circle centered on the survey point (Fig. 8). The average barred owl home range is between 118 and 282 ha (Elody and Sloan 1985), so an intermediate value of 200 ha was chosen as the basis for determining buffer size. The same landscape definition was used for the pileated woodpecker, based on Bull and Meslow's (1977) home range size estimates of 130-243 ha and Kilham's (1959) estimate of 70 ha. Home ranges estimates for songbirds chosen as focal species for this project range from 0.04 ha to 2.5 ha (Table 2). For songbirds, an 80 m buffer was used, corresponding to the distance from a survey point to the edge of a 2 ha home range circle placed over the survey point (Fig. 8). The landscape boundaries for forest birds were also used for red-backed salamanders, and the barred owl landscape definition was used for fisher landscape analysis. Buffered study site polygons were clipped with the satellite imagery and the roads data for each county to obtain a land cover and roads coverage for each study site.

For the barred owl, landscape analyses were performed at 2 spatial scales because the barred owl home range is large enough (approximately 200 ha) to show variations in the land cover data, yet the home range is smaller than the area across which population data were collected (12-19 km^2). The purpose of the home range scale of analysis was to document landscape characteristics that may impact barred owl populations at a spatial scale intermediate between the stand and landscape levels. A similar analysis of songbird home range sized areas was discontinued because there was little variation evident in land cover within 2 ha circular areas. Fisher home ranges are at least as large as each study site, so the area defined in the study site scale of analysis was considered equivalent to a home-range level analysis for fishers. For the red-backed salamander, landscape characteristics were not analyzed at the home range level because of their relatively small home range size (3-5 m^2).

Separate coverages were created for each barred owl survey point and analyses were performed on areas equivalent to a home range sized area centered on barred owl sampling points. The GENERATE command in Arc/Info was used to create circular coverages, representing hypothetical home ranges centered on each survey point. Generated coverages were clipped with corresponding satellite imagery coverages to isolate land cover polygons within the hypothetical home ranges.

The Patch Analyst software extension to ArcView 3.0a was used to calculate landscape metrics for each study site and for hypothetical barred owl home ranges. Of the 38 patch, class, and landscape metrics that Patch Analyst can calculate, a subset of variables was chosen for analysis. A patch was defined as a polygon that had a cover type classification different from adjacent polygons, and each land cover type designation was considered a class. Selected metrics calculated for the study site level of analysis included class area, patch richness, mean patch size, median patch size, edge density, total patch edge, mean shape index, area-weighted shape index, fractal dimension, area-weighted fractal dimension, interspersion and juxtaposition index, Shannon's diversity index, and Simpson's diversity index. These metrics were chosen based on information in published literature, to minimize redundancy among variables, and to quantify relationships that might exist between spatial patterns and ecological functions (O'Neill et al. 1997). Analyses of barred owl home ranges were focused on cover type composition (class area) and total edge because of the relative homogeneity within circles <200 ha.

Explanation of landscape metrics

Shape index is expressed as a unitless value $\geq$ 1.0, where 1.0 is the shape index of a circle, and values >1 represent more complex shapes. Area weighted shape index has the same properties, but patches are given weights proportional to their area in the calculation. Thus, the shape properties of large patches will have a greater influence on the final value than the shape properties of relatively smaller patches (McGarigal and Marks 1995).

Patch density and mean patch size are redundant variables, but are both useful for visualizing a landscape. Mean patch edge and edge density are not entirely redundant variables because edge density is calculated by considering the edge between 2 patches just once, while the calculation for mean patch edge uses the same shared edge for each patch in the landscape (McGarigal and Marks 1995).

Patch fractal dimension can range in value from 1-2, with values near 1 representing relatively simple shapes, such as circles and squares, and values that approach 2 indicating more convoluted perimeters. Area weighted patch fractal dimension has the same properties, but patches are weighted according to their area in the calculation (McGarigal and Marks 1995).

The interspersion and juxtaposition index, expressed as a percentage, is at a maximum (100%) when all patches are equally adjacent to all other patches. As the amount of edge shared between patches becomes more disparate, the index approaches

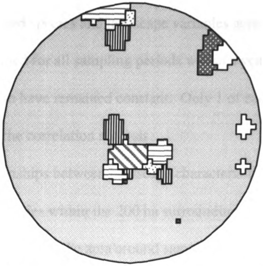
0% (McGarigal and Marks 1995) (Fig. 9).

Both Shannon's diversity index and Simpson's evenness index can be used to quantify landscape compositional diversity. Of the 2 indices, Shannon's diversity index is more sensitive to patch richness and is more influenced by rare patch types. Shannon's diversity index is 0 in a landscape with only 1 patch type, and therefore no patch diversity, and increases without limit in proportion to the number of patch types and the equitability of the proportion of the landscape in each patch type (McGarigal and Marks 1995).

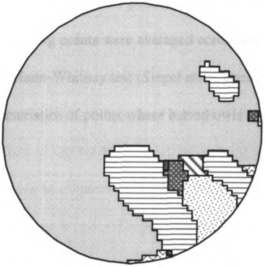
Simpson's evenness index is based on the proportion of each patch type represented in a landscape, and is more strongly influenced by common elements. The index is expressed as a probability that 2 randomly selected patches will be different types. The index is 0.0 when there is only one patch type and approaches 1.0 as the number of patch types increases and the proportion of each patch type in the landscape becomes more equal (McGarigal and Marks 1995).

Data Analysis

Landscape characteristics and cover type composition were compared among ownerships with a Kruskal-Wallis one way analysis of variance, followed by the Kruskal-Wallis multiple comparison statistic (Siegel and Castellan 1988) if significant differences ($p \leq 0.10$) were detected. A nonparametric test was used because of the small study site sample sizes, due to the difficulty in obtaining additional replicate landscapes within each ownership. For all statistical tests, the significance level was set at $\alpha = 0.10$. Comparisons of road densities by cover type were made with a Chi square test.



IJI for northern hardwoods (solid gray matrix) = 88%
IJI for all cover types combined = 69%



IJI for northern hardwoods (solid gray matrix) = 47%
IJI for all cover types combined = 63%

Figure 9. Examples of the interspersion and juxtaposition index. Calculations were performed with the Patch Analyst extension to ArcView.

Spearman rank correlations were used to identify associations between relative abundance for each selected species and landscape variables across the 10 study sites. Species data were combined for all sampling periods within a year because landscape attributes were assumed to have remained constant. Only 1 of each group of redundant variables is presented in the correlation analysis

To identify relationships between landscape characteristics and barred owl abundance, landscape variables within the 200 ha surrounding points where barred owls were present were compared with the area around sampling points where owls were not present. Presence/absence data were used because only a small proportion of barred owl survey points each year had a positive owl response recorded, and during the study, very few survey points accumulated more than 1 positive response. Landscape variables for each of the 2 groups of sampling points were averaged across each study site, and the nonparametric Wilcoxon Mann-Whitney test (Siegel and Castellan 1988) was used to compare landscape characteristics of points where barred owls were either present or absent.

RESULTS

Vegetation cover type distributions

The average proportion of land area covered by northern hardwoods ranged from 70% on Huron Mountain Club land to 89% on Forest Service land for study sites created with 80 m and 800 m buffers (Tables 33 and 34). Each remaining cover type comprised <8% of the landscape for all ownerships except the Huron Mountain Club, where the wet hardwood/conifer mix cover type made up 21% for the 80 m buffered study site and 18% for the 800 m buffered definition. Based on analyses of the smaller landscape definition (80 m buffer), the second most common land cover type on MDNR sites was wetlands, dry hardwood/conifer mix on Forest Service sites, and wet hardwood/conifer mix on timber industry sites. For the landscapes defined by the larger buffer size, a dry hardwood/conifer mix was the second most common cover type on MDNR and Forest Service land, and the mixed conifer cover type was the second most common in the composition of timber industry sites. A combined total of 16 land cover types (i.e patch richness = 16) were represented among the ownerships, ranging from 9 (timber industry) to 14 (Forest Service) types in an ownership (Tables 33 and 34).

Jack pine made up a greater ($p=0.083$) proportion of the land cover on Forest Service and Huron Mountain Club study sites than on the other 2 ownerships (Table 34). The jack pine stands at the Huron Mountain Club are approximately 80 years old and have only been thinned in the last 5 years because of the fire hazard they pose.

No statistical differences occurred among ownerships for all other vegetation cover types. However, at the most expansive scale analyzed, lowland hardwoods were

Table 33. Percent of total land area (means and standard errors) in each cover type identified by satellite imagery for study sites defined with 80 m buffers on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, calculated from 1991 satellite imagery. No significant differences (p>0.10) were detected.

	Ownership category							Probability
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)[a]	of difference among
Land cover types	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	ownerships[b]
Urban	**0.01**	0.01	**0.01**	0.01	**0.00**	0.00	**0.80**	0.214
Herbaceous/agricultural	**1.72**	0.59	**2.21**	0.56	**0.91**	0.91	**0.73**	0.392
Shrubland	**0.30**	0.18	**0.27**	0.22	**0.00**	0.00	**0.10**	0.338
Northern hardwoods	**74.83**	13.76	**89.25**	1.53	**81.17**	7.75	**70.25**	0.539
Aspen/birch	**0.69**	0.24	**1.25**	0.60	**3.36**	3.31	**1.02**	0.921
Dry hardwood/conifer mix	**7.73**	6.46	**3.27**	1.42	**3.18**	3.07	**3.45**	0.784
Wet hardwood/conifer mix	**1.26**	0.81	**1.90**	0.85	**5.50**	4.09	**21.01**	0.263
Wetlands	**8.01**	7.13	**0.52**	0.17	**0.82**	0.44	**1.11**	0.749
Red pine	**0.00**	0.00	**0.03**	0.03	**0.00**	0.00	**0.31**	0.112
Jack pine	**0.00**	0.00	**0.13**	0.13	**0.00**	0.00	**0.36**	0.211
Mixed pines	**3.06**	1.30	**0.35**	0.16	**0.58**	0.58	**0.88**	0.192
Tamarack	**0.23**	0.16	**0.05**	0.03	**0.08**	0.08	**0.00**	0.633
White cedar	**0.00**	0.00	**0.41**	0.41	**0.00**	0.00	**0.00**	0.678
Mixed conifer	**2.16**	0.96	**0.34**	0.16	**4.40**	3.23	**0.00**	0.111

[a] All 3 replicates were analyzed as 1 landscape, therefore, no standard error could be calculated.
[b] Probability levels for tests of differences among ownerships were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

Table 34. Percent of total land area (means and standard errors) in each cover type identified by satellite imagery for study sites defined with 800 m buffers on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, calculated from 1991 satellite imagery.

	Ownership category							Probability of difference among ownerships[b]
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)[a]	
Land cover types	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	
Urban	**0.00**	0.00	**0.03**	0.03	**0.01**	0.01	**0.73**	0.361
Herbaceous/agricultural	**1.87**	0.13	**3.02**	1.31	**1.09**	0.83	**0.43**	0.334
Shrubland	**0.24**	0.11	**0.24**	0.20	**0.02**	0.02	**0.19**	0.372
Northern hardwoods	**74.77**	9.23	**85.33**	2.79	**78.02**	6.34	**70.78**	0.470
Aspen/birch	**2.16**	0.97	**1.75**	0.81	**2.74**	2.54	**1.07**	0.978
Lowland hardwoods	**0.06**	0.06	**0.00**	0.00	**0.00**	0.00	**0.00**	0.506
Dry hardwood/conifer mix	**7.76**	5.14	**5.20**	2.02	**4.59**	4.51	**5.91**	0.784
Wet hardwood/conifer mix	**2.32**	1.00	**1.92**	0.75	**5.03**	3.22	**17.59**	0.397
Wetlands	**5.74**	4.78	**0.78**	0.40	**1.69**	0.34	**1.14**	0.375
Red pine	**0.00**	0.00	**0.05**	0.05	**0.00**	0.00	**0.56**	0.112
Jack pine*	**0.00**[a]	0.00	**0.20**[b]	0.14	**0.00**[a]	0.00	**0.55**[b]	0.083
Mixed pines	**2.43**	0.73	**0.64**	0.43	**0.99**	0.60	**1.06**	0.280
Tamarack	**0.11**	0.07	**0.16**	0.09	**0.04**	0.04	**0.00**	0.602
White spruce	**0.00**	0.00	**<0.01**	0.003	**0.00**	0.00	**0.00**	0.506
White cedar	**0.03**	0.03	**0.25**	0.25	**0.00**	0.00	**0.00**	0.678

Table 34 (Cont). Percent of total land area (means and standard errors) in each cover type identified by satellite imagery for study sites defined with 800 m buffers on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, calculated from 1991 satellite imagery.

	Ownership category							Probability of difference among ownerships[b]
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)[a]	
Land cover types	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	
Mixed conifer	**2.52**	1.21	**0.45**	0.21	**5.78**	2.65	**0.00**	0.111

[a] All 3 replicates were analyzed as 1 landscape, therefore, no standard error could be calculated.

[b] Probability levels for tests of differences among ownerships were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

*Values on the same line with the same letter are not different ($p>0.10$) (Kruskal-Wallis multiple comparison statistic [Siegel and Castellan 1988]).

present on only 1 MDNR site, and white spruce was only identified on 1 Forest Service site (Table 34), both represented by a single polygon. The relatively greater proportion of the urban cover type at the Huron Mountain Club represents the Club "compound", where members and employees are housed and where many of the services of a small "town" are located. The herbaceous/openland cover type was also slightly more common on MDNR and Forest Service sites, and probably represented openings maintained for wildlife.

The fact that the hemlock cover type was not represented in the satellite imagery of the Huron Mountain Club (Tables 33 and 34) is misleading because mature hemlock stands were regularly observed during field work. It is likely that the wet hardwood conifer mix that makes up approximately 20% of the satellite imagery includes the hemlock stands that are prevalent at the Huron Mountain Club, yet were observed much less frequently on all other study sites.

Landscape characteristics of ownerships

Many landscape characteristics of study sites did not differ significantly among ownerships. For both the 80 m and 800 m buffered landscape, timber industry sites tended to have larger and fewer patches, as well as lower patch richness (i.e., number of cover types) (Tables 35 and 36). For the 80 m buffer, the average perimeter associated with each patch was also longer ($p=0.089$) in correspondence with the generally larger patch sizes. The Huron Mountain Club, however, was made up of a relatively larger number of smaller sized patches, and MDNR and Forest Service sites had intermediate mean patch sizes. In the 800 m buffered landscape, both median patch size and average patch edge were greater ($p=0.075$, $p=0.045$) on MDNR and timber industry sites than

Table 35. Values for landscape metrics (means and standard errors) for study sites on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, calculated from 1991 satellite imagery. Values are for study sites created with an 80 m buffer.

Landscape metric	Ownership category							Probability of difference among ownerships[b]
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)[a]	
	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	
Total area (km^2)	**12.88**	1.65	**17.04**	5.23	**12.45**	2.36	**19.09**	0.525
Number of patch types	**10.33**	1.45	**11.00**	0.58	**7.33**	0.88	**12.00**	0.157
Patch size (ha)	**19.38**	5.81	**20.98**	4.76	**34.62**	17.78	**14.57**	0.749
Patch density (#/km^2)	**6.11**	1.65	**5.44**	1.51	**4.47**	1.57	**6.86**	0.749
Median patch size (ha)	**1.33**	0.40	**1.06**	0.11	**2.18**	0.31	**0.92**	0.140
Edge density (m/ha)	**85.40**	29.80	**61.90**	11.00	**76.90**	23.80	**103.60**	0.776
Patch edge (km)*	**1.35**[ab]	0.18	**1.20**[ab]	0.11	**1.82**[c]	0.15	**1.51**[ab]	0.089
Shape index	**1.52**	0.07	**1.44**	0.03	**1.52**	0.02	**1.52**	0.248
Area weighted shape index	**2.62**	0.16	**3.12**	0.10	**3.10**	0.71	**3.29**	0.280
Patch fractal dimension	**1.38**	0.02	**1.36**	0.00	**1.34**	0.00	**1.36**	0.111
Area weighted fractal dimension	**1.30**	0.02	**1.30**	0.00	**1.30**	0.03	**1.33**	0.584
Interspersion and juxtaposition index (%)	**67.50**	1.80	**60.80**	3.10	**58.60**	1.60	**58.10**	0.161
Shannon's diversity index*	**1.73**[a]	0.10	**1.65**[a]	0.01	**1.37**[b]	0.12	**1.74**[a]	0.089

Table 35 (Cont). Values for landscape metrics (means and standard errors) for study sites on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, calculated from 1991 satellite imagery. Values are for study sites created with an 80 m buffer.

Landscape metric	Ownership category							Probability of difference among ownerships[b]
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)[a]	
	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	
Simpson's evenness index	**0.75**	0.01	**0.69**	0.01	**0.69**	0.03	**0.70**	0.188

[a] All 3 replicates were analyzed as 1 landscape, therefore, no standard error could be calculated.

[b] Probability levels reported were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

*Values on the same line with the same letter are not different (p>0.10) (Kruskal-Wallis multiple comparison statistic [Siegel and Castellan 1988]).

Table 36. Values for landscape metrics (means and standard errors) for study sites on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, calculated from 1991 satellite imagery. Values are for study sites created with an 800 m buffer.

	Ownership category							
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)[a]	Probability of difference among ownerships[b]
Landscape metric	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	
Total area (km^2)	**26.23**	2.11	**31.58**	7.36	**26.17**	4.42	**35.43**	0.525
Number of patch types	**11.33**	0.88	**12.33**	1.20	**10.00**	0.58	**12.00**	0.383
Patch size (ha)	**17.42**	3.01	**18.54**	2.42	**25.97**	8.39	**11.69**	0.433
Patch density (#/km^2)	**6.10**	1.07	**5.61**	0.84	**4.58**	1.14	**8.55**	0.433
Median patch size (ha)*	**1.60**[a]	0.10	**1.15**[b]	0.03	**1.73**[a]	0.34	**0.56**[b]	0.075
Edge density (m/ha)	**81.80**	19.40	**65.30**	9.90	**73.00**	18.00	**106.90**	0.539
Patch edge (km)*	**1.32**[a]	0.86	**1.16**[b]	0.15	**1.60**[a]	0.68	**1.25**[b]	0.045
Shape index	**1.47**	0.03	**1.44**	0.03	**1.49**	0.02	**1.47**	0.731
Area weighted shape index	**3.18**	0.14	**3.78**	0.09	**3.50**	0.87	**4.43**	0.334
Patch fractal dimension	**1.37**	0.01	**1.36**	0.01	**1.37**	0.03	**1.39**	0.714
Area weighted fractal dimension	**1.31**	0.01	**1.32**	0.01	**1.31**	0.03	**1.35**	0.647
Interspersion and juxtaposition index (%)	**67.70**	3.20	**61.10**	0.60	**58.90**	2.60	**59.80**	0.220
Shannon's diversity index*	**1.85**[a]	0.08	**1.78**[a]	0.05	**1.63**[b]	0.01	**1.82**[a]	0.098

Table 36 (Cont). Values for landscape metrics (means and standard errors) for study sites on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, calculated from 1991 satellite imagery. Values are for study sites created with an 800 m buffer.

Landscape metric	Ownership category							Probability of difference among ownerships[b]
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)[a]	
	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	
Simpson's evenness index	**0.76**	0.02	**0.71**	0.01	**0.71**	0.01	**0.73**	0.138

[a] All 3 replicates were analyzed as 1 landscape, therefore, no standard error could be calculated.

[b] Probability levels reported were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

*Values on the same line with the same letter are not different (p>0.10) (Kruskal-Wallis multiple comparison statistic [Siegel and Castellan 1988]).

Forest Service (p=0.075) and Huron Mountain Club sites (p=0.045), indicating that landscape patches on MDNR and timber industry sites were skewed towards larger sized patches, while the other ownerships tended to have a higher frequency of relatively small sized patches.

Interestingly, both mean shape index and mean fractal dimension varied little among ownerships (Tables 35 and 36), but the area weighted version of each parameter tended to be greater for the Huron Mountain Club than for the other ownerships. Although the difference was not statistically significant, the data suggest that the largest patches at the Huron Mountain Club are also some of the most elaborately shaped patches.

The interspersion and juxtaposition index is another landscape variable in which a trend among ownerships was evident, although not statistically documented. Michigan Department of Natural Resources sites exhibited the greatest degree of interspersion and juxtaposition among patches for both landscape buffer sizes analyzed, indicating each patch is in contact with a relatively greater number of other patches. As a partial consequence of the lower patch richness on timber industry sites, cover type diversity, expressed by Shannon's diversity index, was lower (80 m buffer, p=0.089; 800 m buffer, p=0.098) on timber industry sites than elsewhere. Simpson's evenness index followed a similar trend as Shannon's diversity index for each ownership, but the trend was not statistically significant (Tables 35 and 36).

Road density

Density of trails, county roads, public streets, and highways ranged from 5.3 m/ha on MDNR sites to 11.7 m/ha on timber industry sites (Table 37). The relatively low road densities calculated (on the order of several m/ha) are due to the fact that the digital data set for roads is based mainly on highways and county roads which occurred infrequently on study sites. Logging roads were under represented in the MIRIS database, compared to what was observed on study sites.

Although timber industry sites tended to have higher road densities than other ownerships, Kruskal-Wallis comparisons of mean road density among ownerships were not significant. In proportion to the land available in each cover type, roads occurred slightly more often in northern hardwoods, upland pine, tamarack, white cedar, and mixed conifers (Fig. 10), but not significantly so ($p=0.28$). Roads were slightly less prevalent in the dry hardwood/conifer, wet hardwood/conifer, and wetlands cover classes, compared to the proportion of these cover types in the landscape.

Landscape characteristics of northern hardwood forest patches

Although there were no significant differences among ownerships for any attributes of northern hardwood forest patches, Forest Service sites were distinguishable from others by the relatively large average size (531 ha) of their northern hardwood patches (Table 38). The very high value (67.25) for median patch size on timber industry sites is due to one timber industry site that had a few very large blocks of unbroken northern hardwoods, while other sites generally exhibited a range of hardwood patch sizes.

Patch edge represents the average perimeter length associated with each patch, and

Table 37. Road densities by cover type (m/ha, means and standard errors) for study sites on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula. No significant differences (p>0.10) were detected.

Landscape buffer size	Ownership category							Probability of difference among ownerships[b]
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)[a]	
	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	
80 m	**5.27**	3.39	**6.13**	1.37	**11.73**	3.76	**6.90**	0.433
800 m	**7.21**	3.06	**7.80**	0.86	**9.45**	2.72	**6.84**	0.921

[a] All 3 replicates were analyzed as 1 landscape, therefore, no standard error could be calculated.

[b] Probability levels reported were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

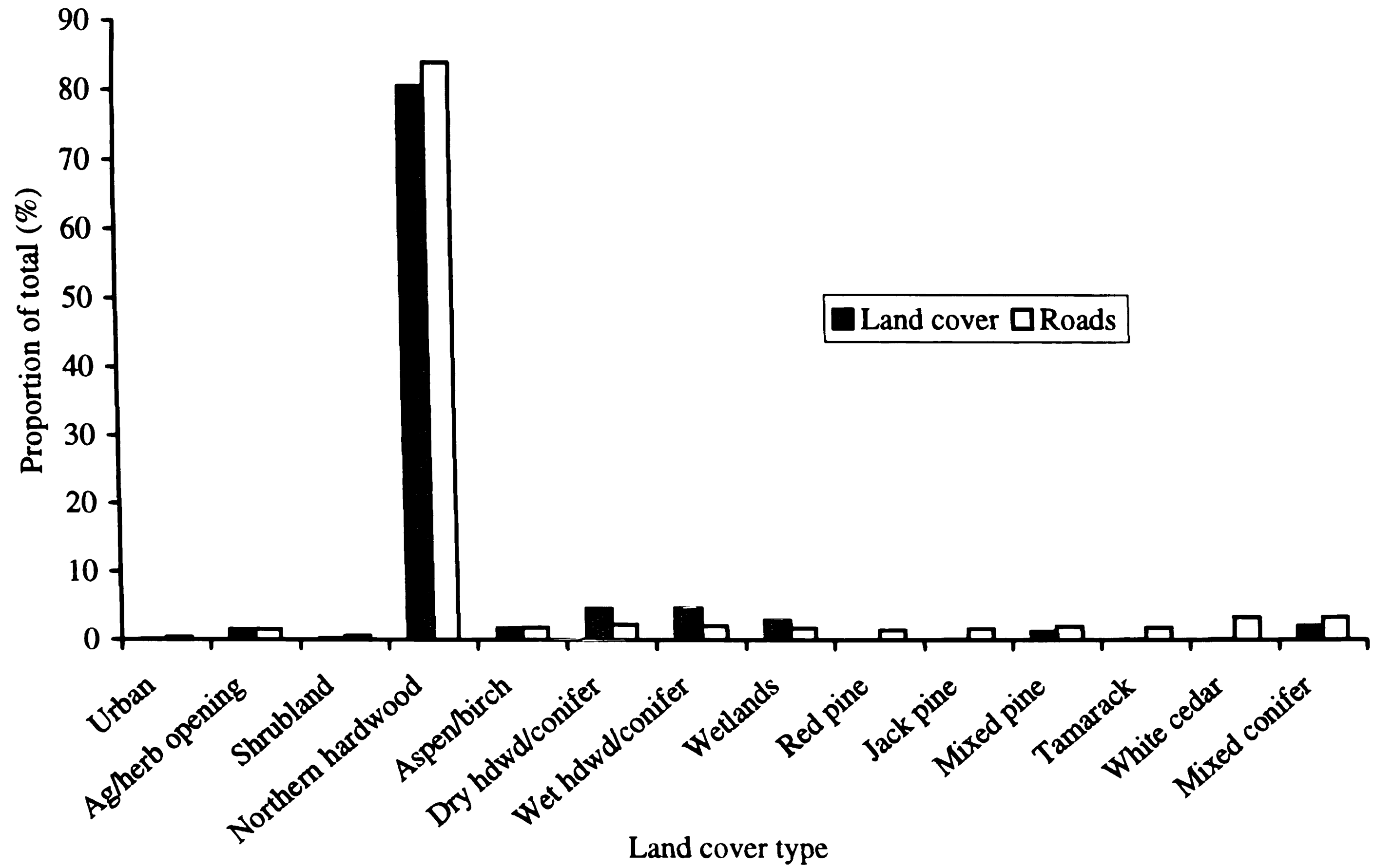


Figure 10. Average proportion of total land cover represented by each cover type and average proportion of total roads in each cover type for study sites created with an 80 m buffer in the Upper Peninsula of Michigan. Probability that the proportion of roads in each cover type differs from the availability of each cover type is 0.28 (Chi square test).

Table 38. Values for landscape metrics (means and standard errors) of northern hardwood forest patches for study sites on Michigan Department of Natural Resources (MDNR), U. S. Forest Service (USFS), timber industry (TI), and Huron Mountain Club (HMC) land in Michigan's Upper Peninsula, calculated from 1991 satellite imagery. Values are for study sites created with an 800 m buffer. No significant differences ($p>0.10$) were detected.

	Ownership category							Probability of difference among ownerships[b]
	MDNR (n=3)		USFS (n=3)		TI (n=3)		HMC (n=3)[a]	
Landscape metric	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	
Total area (ha)	**19.85**	3.74	**27.03**	6.46	**19.88**	3.48	**21.00**	0.647
Patch size (ha)	**289**	170	**531**	253	**289**	81	**88**	0.539
Patch density (#/km^2)	**0.79**	0.54	**0.24**	0.09	**0.31**	0.09	**0.68**	0.539
Median patch size (ha)	**1.28**	0.46	**3.96**	3.87	**67.25**	66.45	**0.46**	0.854
Edge density (m/ha)	**30.9**	7.0	**26.8**	3.9	**28.1**	6.5	**39.0**	0.647
Patch edge (km)	**8.34**	3.64	**15.25**	6.22	**10.80**	4.39	**5.76**	0.344
Shape index	**1.77**	0.09	**2.03**	0.14	**1.96**	0.30	**1.89**	0.525
Area weighted shape index	**3.50**	0.17	**4.16**	0.14	**4.13**	1.23	**5.77**	0.297
Patch fractal dimension	**1.45**	0.03	**1.44**	0.08	**1.54**	0.22	**1.44**	0.921
Area weighted fractal dimension	**1.31**	0.01	**1.32**	0.01	**1.31**	0.03	**1.37**	0.470
Interspersion and juxtaposition index (%)	**80.99**	4.64	**72.61**	3.24	**66.37**	5.21	**67.19**	0.183

[a] All 3 replicates were analyzed as 1 landscape, therefore, no standard error could be calculated.

[b] Probability levels reported were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

is larger for northern hardwood patches than other classes in correspondence with their larger area. The noticeably high value for patch edge for the Forest Service ownership was greatly influenced by a study site which had 1 extremely large patch that was essentially functioning as a matrix in which many other patches, including additional northern hardwood patches, were embedded. Shape index, fractal dimension, and the interspersion and juxtaposition index were also generally higher for northern hardwood patches than for the collection of all patches in the landscape (Tables 36, 37, and 38).

Relationships between wildlife species relative abundance and landscape characteristics

Red-backed salamander

Correlations between red-backed salamander relative abundance and the proportion of vegetation types on each study site revealed very few strong relationships (Tables 39 and 40). Three of the 4 significant ($p \leq 0.10$) correlations that were calculated indicated a negative relationship between the proportion of various pine dominated cover types in the landscape and the number of red-backed salamanders observed. The fourth significant correlation occurred only in 1998 and showed a positive association between the proportion of the mixed pine cover type and salamander relative abundance (Table 39).

Landscape characteristics revealed few consistently significant relationships with red-backed salamander relative abundance (Table 39). Patch size was the only landscape metric for which a relationship occurred in the same direction for each year of the study, with a significant negative correlation in 1997 and in both years combined (Table 40). Significant correlations also occurred for median patch size, patch fractal dimension,

Table 39. Spearman rank correlations between proportion of vegetation cover types in the landscape and red-backed salamander relative abundance (1997 and 1998) on study sites in Michigan's Upper Peninsula.

	Sampling period		
Land cover type	1997 (n=8)	1998 (n=10)	Both years (n=10)
Urban	-0.082	-0.172	0.529
Herbaceous/agricultural	0.048	-0.164	0.273
Shrubland	0.270	-0.175	0.381
Northern hardwoods	-0.575	0.164	-0.418
Aspen/birch	-0.060	-0.394	0.224
Dry hardwood/conifer mix	0.455	-0.261	0.503
Wet hardwood/conifer mix	-0.156	0.152	-0.018
Wetlands	0.491	-0.152	0.261
Red pine	0.157	-0.701*	0.311
Jack pine	0.094	-0.683*	0.208
Mixed pines	0.719*	0.000	0.511
Tamarack	-0.070	0.356	-0.097
White cedar	-0.368	0.294	0.164
Mixed conifer	-0.491	0.188	-0.648*

* Probability level ≤0.10.

Table 40. Spearman rank correlations between landscape metrics calculated from 1991 satellite imagery and red-backed salamander relative abundance (1997 and 1998) on study sites in Michigan's Upper Peninsula.

	Sampling period		
Landscape metric	1997 (n=8)	1998 (n=10)	Both years (n=10)
Total area	-0.515	-0.685*	0.018
Number of patch types	-0.018	-0.207	0.512
Patch size	-0.802*	-0.200	-0.624*
Median patch size	-0.434	0.176	-0.650*
Edge density (m/ha)	0.563	0.067	0.345
Patch edge	-0.108	-0.188	-0.539
Shape index	0.359	-0.152	-0.006
Area weighted shape index	-0.347	-0.309	0.055
Patch fractal dimension	0.431	-0.115	0.636*
Area weighted fractal dimension	0.252	-0.115	0.033
Interspersion and juxtaposition index	0.359	-0.188	0.297
Shannon's diversity index	0.060	-0.467	0.588*
Simpson's evenness index	0.395	-0.273	0.491

* Probability level ≤0.10.

and Shannon's diversity index when both years (1997 and 1998) of data were combined, but results for each individual year did not suggest such a trend.

American redstart

The significant negative correlation between American redstart relative abundance and the proportion of mixed pines in the landscape was the strongest cover type relationship observed (Table 41). In addition, there was a consistently positive correlation between redstart numbers and the proportion of northern hardwoods in the landscape that was significant in 1996, and a negative correlation with the urban cover classification that was statistically significant in 1998.

Several landscape metrics were significantly negatively correlated with American redstart relative abundance combined over 3 years, including patch richness, patch fractal dimension, and Shannon's diversity index (Table 42). A positive correlation with patch size was significant in 1997, and apparent to a lesser degree in other years. Redstart numbers were also positively related to mean patch edge for observations in 1998 and when all 3 years were combined.

Ovenbird

Several conifer cover types were positively correlated with ovenbird relative abundance for at least 1 year of data (Table 43). Results for mixed pine were consistently positive, but the red pine, jack pine, and mixed conifer cover types showed contradictory correlations among years, particularly between 1996 and 1998.

Patch fractal dimension, interspersion and juxtaposition index, and the 2 diversity indices all had significant positive correlations, and patch edge had a negative correlation

Table 41. Spearman rank correlations between proportion of vegetation cover types in the landscape and American redstart relative abundance (1996, 1997, and 1998) on study sites in Michigan's Upper Peninsula.

	Sampling period			
Land cover type	1996 (n=7)	1997 (n=8)	1998 (n=10)	All 3 years (n=10)
Urban	-0.201	-0.191	-0.561*	-0.529
Herbaceous/agricultural	0.346	0.071	-0.049	-0.115
Shrubland	0.165	0.073	-0.233	-0.213
Northern hardwoods	0.764*	0.333	0.274	0.333
Aspen/birch	0.182	0.452	0.255	0.224
Dry hardwood/conifer mix	-0.309	-0.143	-0.140	-0.212
Wet hardwood/conifer mix	0.055	-0.095	0.006	0.006
Wetlands	-0.600	-0.310	-0.419	-0.422
Red pine	-0.113	0.094	-0.026	-0.026
Jack pine	0.113	0.156	0.026	0.026
Mixed pines	-0.927*	-0.548	-0.738*	-0.729*
Tamarack	0.113	0.038	-0.272	-0.213
White cedar	0.318	-0.156	-0.551	-0.510
Mixed conifer	0.091	0.476	0.146	0.248

* Probability level ≤0.10.

Table 42. Spearman rank correlations between landscape metrics calculated from 1991 satellite imagery and American redstart relative abundance (1996, 1997, and 1998) on study sites in Michigan's Upper Peninsula.

	Sampling period			
Landscape metric	1996 (n=7)	1997 (n=8)	1998 (n=10)	All 3 years (n=10)
Total area	0.291	0.452	0.061	0.127
Number of patch types	0.111	-0.120	0.648*	-0.604*
Patch size	0.564	0.738*	0.419	0.527
Median patch size	0.092	0.216	0.393	0.395
Edge density (m/ha)	-0.691	-0.476	-0.219	-0.297
Patch edge	-0.491	0.286	0.596*	0.600*
Shape index	-0.691	-0.167	-0.103	-0.115
Area weighted shape index	0.218	0.310	0.219	0.188
Patch fractal dimension	-0.182	-0.476	-0.863*	-0.867*
Area weighted fractal dimension	-0.691	-0.143	-0.036	-0.103
Interspersion and juxtaposition index	-0.255	0.071	-0.304	-0.188
Shannon's diversity index	-0.182	0.143	-0.675*	-0.600*
Simpson's evenness index	-0.709	-0.024	-0.438	-0.430

* Probability level ≤0.10.

Table 43. Spearman rank correlations between proportion of vegetation cover types in the landscape and ovenbird relative abundance (1996, 1997, and 1998) on study sites in Michigan's Upper Peninsula.

	Sampling period			
Land cover type	1996 (n=7)	1997 (n=8)	1998 (n=10)	All 3 years (n=10)
Urban	-0.451	0.357	0.322	0.201
Herbaceous/agricultural	0.000	-0.551	0.401	0.370
Shrubland	0.330	0.430	0.253	0.537
Northern hardwoods	-0.055	-0.180	-0.432	-0.248
Aspen/birch	-0.164	-0.419	0.377	0.224
Dry hardwood/conifer mix	0.000	-0.299	0.571	0.422
Wet hardwood/conifer mix	-0.546	0.120	-0.261	-0.406
Wetlands	0.164	0.395	0.419	0.394
Red pine	-0.748*	0.243	0.664*	0.164
Jack pine	-0.680	0.133	0.638*	0.182
Mixed pines	0.546	0.814*	0.366	0.626*
Tamarack	0.679	0.415	-0.318	0.213
White cedar	0.136	0.031	-0.104	0.208
Mixed conifer	0.764*	0.108	-0.486	-0.127

* Probability level ≤0.10.

with ovenbird numbers combined for 1996-1998 (Table 44). These trends were consistent for each individual year of the study, reducing the likelihood that the relationships are spurious. Area-weighted mean shape index was significantly correlated in 1996, but the relationship fluctuated among years and was the variable was probably not biologically important by itself.

Veery

The number of veery observations in 1996 was significantly and negatively related to the proportion of shrubland and tamarack in the 80 m buffered landscape (Table 45). There was also a positive relationship with the mixed conifer cover type that was not significant in any 1 year of the study, but was significant for the 3 years of pooled bird survey data.

Landscape metrics that may have influenced veery populations on the study sites sampled were patch fractal dimension, which was negatively correlated with veery relative abundance in 1998 and for all data years combined, and the interspersion and juxtaposition index which was positively correlated and statistically significant in 1996 and 1997 (Table 46). Also, there was a significant negative correlation with mean patch edge in 1996, and a positive correlation with Simpson's evenness index in 1997, but correlations for the pooled data were opposite in sign.

Yellow-rumped warbler

The only compelling correlation between cover type proportions and yellow-rumped warbler relative abundance (Table 47) was the significant positive relationship for the urban cover type. The most likely reason for this is that the urban cover type occurred

Table 44. Spearman rank correlations between landscape metrics calculated from 1991 satellite imagery and ovenbird relative abundance (1996, 1997, and 1998) on study sites in Michigan's Upper Peninsula. Values in bold are significant at p≤0.10.

	Sampling period			
Landscape metric	1996 (n=7)	1997 (n=8)	1998 (n=10)	All 3 years (n=10)
Total area	-0.655	-0.156	0.523	0.042
Number of patch types	-0.167	0.539	0.434	0.549
Patch size	-0.055	-0.180	-0.255	-0.285
Median patch size	0.138	-0.544	-0.335	-0.456
Edge density (m/ha)	-0.055	0.036	0.243	0.103
Patch edge	-0.273	-0.240	-0.176	-0.564*
Shape index	0.000	0.371	-0.140	-0.042
Area weighted shape index	-0.873*	-0.479	0.304	-0.164
Patch fractal dimension	0.327	0.467	0.559	0.806*
Area weighted fractal dimension	-0.218	-0.156	0.292	0.018
Interspersion and juxtaposition index	0.873*	0.551	0.267	0.721*
Shannon's diversity index	0.055	0.814*	0.644*	0.758*
Simpson's evenness index	0.818*	0.335	0.517	0.733*

* Probability level ≤0.10.

Table 45. Spearman rank correlations between proportion of vegetation cover types in the landscape and veery relative abundance (1996, 1997, and 1998) on study sites in Michigan's Upper Peninsula.

	Sampling period			
Land cover type	1996 (n=7)	1997 (n=8)	1998 (n=10)	All 3 years (n=10)
Urban	-0.374	-0.384	-0.396	-0.500
Herbaceous/agricultural	0.214	-0.288	0.036	-0.285
Shrubland	0.775*	0.565	-0.097	-0.149
Northern hardwoods	0.357	0.072	0.134	0.261
Aspen/birch	0.214	0.275	0.061	-0.176
Dry hardwood/conifer mix	-0.214	0.060	-0.231	-0.455
Wet hardwood/conifer mix	-0.143	-0.323	0.231	0.127
Wetlands	-0.321	-0.216	-0.176	-0.200
Red pine	-0.535	-0.486	-0.373	-0.545
Jack pine	-0.401	-0.517	-0.321	-0.493
Mixed pines	-0.107	0.275	-0.424	-0.280
Tamarack	0.852*	0.619	0.266	0.381
White cedar	0.223	-0.220	-0.104	-0.121
Mixed conifer	0.536	0.575	0.407	0.721*

* Probability level ≤0.10.

Table 46. Spearman rank correlations between landscape metrics calculated from 1991 satellite imagery and veery relative abundance (1996, 1997, and 1998) on study sites in Michigan's Upper Peninsula.

Landscape metric	Sampling period 1996 (n=7)	1997 (n=8)	1998 (n=10)	All 3 years (n=10)
Total area	-0.429	-0.599	-0.353	-0.467
Number of patch types	0.164	-0.224	-0.355	-0.476
Patch size	0.250	0.036	0.128	0.309
Median patch size	-0.360	-0.241	0.335	0.444
Edge density (m/ha)	-0.429	-0.132	-0.030	-0.176
Patch edge	-0.821*	-0.180	0.207	0.345
Shape index	-0.571	-0.168	-0.152	0.018
Area weighted shape index	-0.429	-0.503	0.188	-0.212
Patch fractal dimension	0.036	-0.263	-0.602*	-0.600*
Area weighted fractal dimension	-0.464	-0.060	0.085	-0.164
Interspersion and juxtaposition index	0.786*	0.826*	-0.122	0.006
Shannon's diversity index	0.250	0.168	-0.523	-0.539
Simpson's evenness index	0.250	0.671*	-0.243	-0.224

* Probability level ≤0.10.

Table 47. Spearman rank correlations (r_s) between proportion of vegetation cover types in the landscape and yellow-rumped warbler relative abundance (1996, 1997, and 1998, combined) on study sites in Michigan's Upper Peninsula.

Land cover type	r_s (n=10)
Urban	0.615*
Herbaceous/agricultural	-0.350
Shrubland	0.167
Northern hardwoods	0.097
Aspen/birch	-0.052
Dry hardwood/conifer mix	-0.142
Wet hardwood/conifer mix	0.291
Wetlands	-0.216
Red pine	0.383
Jack pine	0.255
Mixed pines	0.082
Tamarack	-0.008
White cedar	0.149
Mixed conifer	-0.246

* Probability level ≤0.10.

primarily at the Huron Mountain Club where most of the yellow-rumped warblers were observed. Thus, it is more likely that the correlation occurred because of a biological association between yellow-rumped warbler abundance and another of the unique characteristics of the Huron Mountain Club. No other significant correlations between yellow-rumped warbler counts and cover type composition or landscape metrics were found (Tables 47 and 48), perhaps because of the low variability in yellow-rumped warbler observations among study sites.

Pileated woodpecker

During the 3 years of the study, pileated woodpeckers were recorded in only 7 of the stands included in this analysis, with no more than 2 observations for any of the stands. Therefore, only correlations with variables calculated for the 800 m buffered landscape are reported.

There was a significant positive correlation between pileated woodpecker numbers and the proportion of the urban cover type in the landscape, and a negative correlation with the mixed conifer cover type (Table 49). The significance of the urban cover type relationship may again be that land classified as urban occurred predominately at the Huron Mountain Club, as did the majority of pileated woodpecker observations. Therefore, as with the yellow-rumped warbler, there are probably other biological relationships underlying the correlation result. Area-weighted mean shape index and area-weighted fractal dimension corresponded strongly to the number of pileated woodpecker observations (Table 50). Values for these landscape metrics also tended to be greater at the Huron Mountain Club (Tables 36 and 37).

Table 48. Spearman rank correlations (r_s) between landscape metrics calculated from 1991 satellite imagery and yellow-rumped warbler relative abundance (1996, 1997, and 1998) on study sites in Michigan's Upper Peninsula. No significant differences (p>0.10) were detected.

Landscape metric	r_s (n=10)
Total area	0.500
Number of patch types	0.450
Patch size	0.127
Median patch size	-0.434
Edge density (m/ha)	-0.127
Patch edge	-0.216
Shape index	-0.186
Area weighted shape index	0.142
Patch fractal dimension	0.022
Area weighted fractal dimension	-0.037
Interspersion and juxtaposition index	-0.231
Shannon's diversity index	0.529
Simpson's evenness index	-0.142

Table 49. Spearman rank correlations (r_s) between proportion of vegetation cover types in the landscape and pileated woodpecker relative abundance (1996, 1997, and 1998) on study sites in Michigan's Upper Peninsula.

Land cover type	r_s (n=10)
Urban	0.642*
Herbaceous/agricultural	0.198
Shrubland	0.384
Northern hardwoods	-0.287
Aspen/birch	0.300
Lowland hardwoods	-0.261
Dry hardwood/conifer mix	0.328
Wet hardwood/conifer mix	0.205
Wetlands	-0.485
Red pine	0.307
Jack pine	0.386
Mixed pines	-0.239
Tamarack	0.007
White spruce	-0.261
White cedar	-0.015
Mixed conifer	-0.655*

* Probability level ≤0.10.

Table 50. Spearman rank correlations (r_s) between landscape metrics calculated from 1991 satellite imagery and pileated woodpecker relative abundance (1996, 1997, and 1998, combined) on study sites in Michigan's Upper Peninsula.

Landscape metric	r_s (n=10)
Total area	0.184
Number of patch types	0.366
Patch size	-0.437
Median patch size	-0.403
Edge density (m/ha)	0.423
Patch edge	-0.437
Shape index	-0.068
Area weighted shape index	0.847*
Patch fractal dimension	-0.137
Area weighted fractal dimension	0.703*
Interspersion and juxtaposition index	-0.280
Shannon's diversity index	0.116
Simpson's evenness index	-0.437

* Probability level ≤0.10.

The number of pileated woodpeckers observed was too small to perform either a correlation analysis with compositional characteristics of home-range sized circles or a comparison of potential home ranges where woodpeckers were present or absent.

Barred owl

Positive correlations with barred owl response frequency were found for the proportion of herbaceous/agricultural and shrubland cover types when all 3 years of data were combined (Table 51). Additionally, there was a negative correlation with the wet hardwood/conifer mix type in 1996, and with the wetlands cover type in 1997, and there was a significant positive association with tamarack in 1997. However, trends for these relationships were not constant among years, making it difficult to assign meaning to them. Shannon's diversity index was also positively correlated with barred owl response frequency for the 3 years of pooled data, but fluctuated among individual years (Table 52).

In a comparison of home range sized (200 ha) circular areas surrounding points where barred owls were detected with points where they were not detected in any of the 3 sampling years, dry hardwood/conifer mix and northern white cedar were the only cover types which differed significantly in the proportion of the area that they composed (Table 53). The dry hardwood/conifer mix made up a larger proportion of the home-range sized areas where owls were detected, but cedar was not present in any of the 200 ha areas where owls were heard. There was also a nonsignificant trend of the wet hardwood/conifer mix being more prevalent in areas where owl responses were not recorded.

Table 51. Spearman rank correlations between proportion of vegetation cover types in the landscape and barred owl relative abundance (1996, 1997, and 1998) on study sites in Michigan's Upper Peninsula.

Land cover type	Sampling period			
	1996 (n=7)	1997 (n=8)	1998 (n=10)	All 3 years (n=10)
Urban	-0.493	-0.211	0.315	0.068
Herbaceous/agricultural	0.214	0.216	0.195	0.564*
Shrubland	-0.607	0.838*	0.262	0.766*
Northern hardwoods	0.286	0.263	0.116	0.297
Aspen/birch	0.214	-0.419	0.231	0.103
Lowland hardwoods	0.408	-0.498	0.000	-0.290
Dry hardwood/conifer mix	0.107	-0.371	0.158	0.164
Wet hardwood/conifer mix	-0.714*	-0.503	-0.158	-0.067
Wetlands	0.536	-0.683*	0.109	-0.467
Red pine	-0.134	0.016	-0.143	-0.147
Jack pine	-0.020	-0.110	-0.045	0.172
Mixed pines	0.107	-0.048	0.219	0.018
Tamarack	-0.408	0.740*	-0.169	0.319
White spruce	0.612	-0.083	0.000	0.290
White cedar	0.045	0.063	0.338	0.320
Mixed conifer	0.357	0.012	0.182	-0.200

* Probability level ≤0.10.

Table 52. Spearman rank correlations between landscape metrics calculated from 1991 satellite imagery and barred owl relative abundance (1996, 1997, and 1998) on study sites in Michigan's Upper Peninsula.

	Sampling period			
Landscape metric	1996 (n=7)	1997 (n=8)	1998 (n=10)	All 3 years (n=10)
Total area	0.250	-0.323	0.474	0.333
Number of patch types	-0.147	-0.025	0.475	0.539
Patch size	0.429	-0.036	0.316	0.127
Median patch size	0.321	-0.323	0.419	-0.164
Edge density (m/ha)	-0.464	-0.180	-0.073	-0.212
Patch edge	0.357	-0.371	0.097	-0.515
Shape index	0.250	-0.539	-0.152	-0.515
Area weighted shape index	-0.607	-0.036	0.188	0.321
Patch fractal dimension	0.071	0.000	-0.310	-0.176
Area weighted fractal dimension	-0.643	-0.204	-0.067	-0.176
Interspersion and juxtaposition index	-0.429	0.695*	0.061	0.418
Shannon's diversity index	-0.357	0.431	0.511	0.758*
Simpson's evenness index	-0.250	0.491	0.085	0.321

* Probability level ≤0.10.

Table 53. Proportion of home ranges (%) in each cover type at sampling points where barred owls were detected and points where they were not detected for 1996, 1997, and 1998 combined on study sites in the Upper Peninsula of Michigan.

	Owls detected (n=33)		Owls not detected (n=41)		Probability level
Land cover type	$\bar{x}$	S.E.	$\bar{x}$	S.E.	
Urban	0.15	0.0	0.88	0.4	0.550
Herbaceous/agricultural	2.23	0.9	2.63	1.3	0.148
Shrubland	0.38	0.1	1.33	0.7	0.763
Northern hardwoods	67.46	5.8	66.70	6.1	0.336
Aspen/birch	2.63	1.3	2.74	1.6	0.221
Lowland hardwoods	1.28	0.0	0.00	0.0	0.265
Dry hardwood/conifer mix	6.52	3.0	2.54	1.1	0.067
Wet hardwood/conifer mix	1.46	0.8	7.42	3.6	0.111
Wetlands	5.05	3.5	1.02	0.7	0.160
Water	6.44	3.4	7.39	3.7	0.323
Red pine	0.11	0.0	0.58	0.1	0.319
Jack pine	2.69	0.6	1.17	0.4	0.613
Mixed pines	1.88	1.2	1.55	0.8	0.506
Tamarack	0.52	0.2	0.19	0.1	0.446
White cedar*	0.00	0.0	1.62	0.4	0.067
Mixed conifer	1.19	0.6	2.25	1.2	0.975

[a] Probability levels for were calculated with the Kruskal-Wallis one-way analysis of variance (Siegel and Castellan 1988).

* Probability level ≤ 0.10.

Fisher

Indices of fisher activity calculated over 3 years for MDNR, Forest Service, and timber industry sites (Table 54) exhibited significant positive correlations with the proportion of urban and herbaceous/agricultural cover in the landscape. The next largest correlation was also positive, though not significant, and occurred for the proportion of shrubland. Area-weighted shape index was the only landscape attribute to have statistically significant relationship with the fisher population index (Table 55).

Table 54. Spearman rank correlations (r_s) between proportion of vegetation cover types in the landscape and fisher relative abundance (1996, 1997, and 1998 combined) on study sites in Michigan's Upper Peninsula.

Land cover type	r_s (n=9)
Urban	0.685*
Herbaceous/agricultural	0.661*
Shrubland	0.562
Northern hardwoods	-0.068
Aspen/birch	0.220
Lowland hardwoods	-0.279
Dry hardwood/conifer mix	0.475
Wet hardwood/conifer mix	-0.153
Wetlands	-0.288
Red pine	0.000
Jack pine	0.093
Mixed pines	-0.170
Tamarack	0.190
White spruce	0.000
White cedar	0.395
Mixed conifer	-0.441

* Probability level ≤0.10.

Table 55. Spearman rank correlations between landscape metrics calculated from 1991 satellite imagery and fisher relative abundance (1996, 1997, and 1998, combined) on study sites in Michigan's Upper Peninsula.

Landscape metric	r_s (n=9)
Total area	0.322
Number of patch types	0.496
Patch size	-0.085
Median patch size	-0.068
Edge density (m/ha)	0.119
Patch edge	-0.220
Shape index	-0.102
Area weighted shape index	0.814*
Patch fractal dimension	-0.068
Area weighted fractal dimension	0.458
Interspersion and juxtaposition index	-0.102
Shannon's diversity index	0.305
Simpson's evenness index	-0.271

* Probability level ≤0.10.

DISCUSSION

Landscape composition and structure

The structure and composition of the Upper Peninsula landscape is a result of a combination of historical and contemporary factors, both of which have natural and anthropological components. Thus, one would not necessarily expect landscape patterns to follow management boundaries exactly, and it is not surprising that few significant differences in landscape structure were found among ownerships in this study at the scale and resolution analyzed. The lack of statistical differences in landscape composition was also not surprising, because study sites were deliberately chosen to be dominated by northern hardwoods, leaving little room for large variations in other cover types.

Patch density tends to increase with increasing fragmentation (Reunanen et al. 2000), but is not necessarily indicative of fragmentation. The high patch density and large amount of edge at the Huron Mountain Club are a result of the diversity of cover types that occur along topographic gradients throughout the site. In contrast, timber industry sites had a more homogeneous landscape structure, as well as a lower representation of land cover types.

Despite the fact that road density calculations did not yield statistically significant results, roads may still have a measurable influence on forested landscapes. Roads may impact wildlife by fragmenting the habitat, providing an avenue for the spread of exotics, and altering hydrology (Trombulak and Frissell 2000). Roads may also affect microhabitat conditions such as soil and litter attributes. Haskell (2000) found a relationship between the presence of a road and a reduction in leaf litter depth up to 100 m into the adjacent forest. Roads also impacted prey availability for forest birds and salamanders by reducing the abundance and diversity of macroinvertebrates in soil up to 15 m from the road. The effects were theorized to be caused by increased exposure to wind, resulting in drying and accelerated decomposition of the litter, as well as physical displacement of leaf litter.

Relationships between wildlife species relative abundance and landscape characteristics

In evaluating species responses to landscape characteristics, it is necessary to make some arbitrary definitions of what constitutes a patch or an edge, when in fact, most landscape features can be described along a continuum. Therefore, the landscape variables calculated represent only 1 point on this continuum, and can only be interpreted for the scale and resolution at which they were measured. The scale and resolution of the available data may or may not be meaningful to a wildlife species, depending on the grain size at which a species perceives heterogeneity. For example, satellite imagery may be able to distinguish patches based on the dominant tree species in the overstory, but within a patch of land with similar overstory composition, distinctions among forest stands of different ages or with different understory composition may not be discernible. Additionally, remote sensing may indicate where edges exist between vegetation types, but it does not provide information on how much of a contrast the edge represents to a species. Wildlife responses are not likely to be uniform for different points along the continuum of possible landscape definitions, and it is important to interpret results of landscape analyses based on the natural history of the species under investigation.

The red-backed salamander is one species which may not perceive landscape attributes as coarse as those measured from satellite imagery in this study, and very few land cover composition characteristics or metrics described the abundance of red-backed salamanders (Tables 39 and 40). Rather, red-backed salamanders were most strongly influenced by characteristics of their immediate environment, as discussed in Chapter 1.

Evaluations of the effects of landscape level characteristics on red-backed salamanders are scarce and inconclusive. Rodewald and Yahner (1999) found that red-backed salamander populations in a relatively unfragmented forest were not influenced by the proportion of forest cover in the landscape. It may be that salamanders do not perceive landscape level effects because of the salamander's limited home range size, or that effects occur at scales other than those examined (Rodewald and Yahner 1999). One type of landscape change that may impact salamanders is the creation of forest edges through silvicultural treatments or road construction. DeMaynadier and Hunter (1998) determined that red-backed salamanders were highly sensitive to the effects of clearcuts on microclimate conditions up to 35 m into an adjacent mature forest.

Many landscape attributes are ecologically relevant because they indicate the degree of habitat fragmentation, which is a concern for its potential impacts to wildlife, particularly song birds. A related concept is that of connectivity, which describes the degree to which animals can access suitable habitat through dispersal. Connectivity is impacted by habitat degradation and fragmentation, and is relative to both an animal's life history and to landscape structural characteristics (Reunanen et al. 2000). Connectivity does not have a mathematical definition, but can be partially described by the degree of dispersion and interspersion of landscape patches.

In this study, ovenbird relative abundance was negatively correlated with patch edge and positively related to patch fractal dimension, interspersion and juxtaposition index, and the 2 diversity indices (Table 44). Ovenbird numbers were also positively related to the proportion of the landscape in a conifer cover type (Table 43). It may be that the conifer component on these sites was responsible for the higher landscape diversity indices that were also associated with ovenbirds, and it is difficult to determine which variable ovenbirds may be responding to.

There are conflicting conclusions regarding the sensitivity of ovenbirds to habitat fragmentation (King et al. 1996, Merrill et al. 1998, Porneluzi and Faaborg 1999). One consistent finding has been that ovenbirds compensate for lower nest success along edges by laying larger clutches and renesting (Flaspohler et al. 2001). In northern and mixed hardwood forests in Wisconsin, clutch size was higher in edge habitats, yet nest success was higher in interior habitats, resulting in comparable productivity in the 2 habitats (Flaspohler et al. 2001). These differences were apparent at about 300 m from a clearcut. However, because the sources of decreased nest success (i.e., cowbird parasitism, ground predators) depend on local responses of nest predators and brown-headed cow birds to increasing amounts of edge, the effect of landscape fragmentation on ovenbird fitness may be specific to a particular landscape. The positive association with the interspersion and juxtaposition index for the ovenbird and the veery was perhaps an indication of the importance of connectivity to these species. The veery in particular often uses lowland hardwood forests (Howe et al. 1995) that may be associated with riparian areas.

Hunt (1998) showed that American redstart numbers were positively associated with the proportion of early successional habitat in the landscape. In this study, the significantly negative correlation between the proportion of the urban cover type in the landscape and the relative abundance of American redstarts (Table 38) may reflect the finding that the Huron Mountain Club had the largest representation of the urban cover class, but at the same time there is little early successional habitat that would favor redstarts. American redstarts are also believed to prefer less conifer cover than is found at the Huron Mountain Club (Minnis and Haufler 1994) (Table 5). Therefore, the negative correlation reflects the lower quality habitat at the Huron Mountain Club based on variables other than the prevalence of the urban cover type.

Time constraints of this project only permitted examination of 2 possibilities of what might be an appropriate scale to analyze barred owl habitat use (i.e., 200 ha and 12-19 km^2). However, in a similar study of sandhill crane habitat use reported by Baker et al. (1995), sandhill cranes were found to select habitat based on features in a core area within the total home range that they used, and few differences in habitat characteristics were found by comparing areas the size of an entire home range. Likewise, an analysis of barred owl habitat use at a scale slightly smaller than 200 ha, or a comparison of several different scales of finer resolution data, might reveal more significant landscape characteristics important to barred owl habitat selection than were evident in this analysis. Additionally, as in Chapter 1, the quality of the barred owl population data may have limited the analysis.

One landscape characteristic that has been linked to fisher habitat quality is the proportion of conifer cover in the landscape. Conifer cover is thought to be important in the winter for reducing ground snow depth and allowing fishers to forage more efficiently (Krohn et al. 1995). If so, then the Huron Mountain Club may provide the best fisher habitat because of the dominance of hemlock in some northern hardwood stands, the stands of pure hemlock that have been mapped there, and the larger area covered by the wet hardwood/conifer mix cover type. The relative importance of conifer cover may also vary geographically with average yearly snowfall and with local marten densities (Krohn et al. 1995).

This analysis examined the relationship of land ownership and wildlife populations with landscape variables that were discernible at a minimum patch size of 900 m^2. Intensive activities, such as timber harvests, that remove the entire canopy may have been interpreted as distinct patches on satellite imagery, but less intensive or finer scale land management activities such as forest stand thinning and logging road construction were not visible at this scale. Analysis of an additional spatial data layer, representing the scale at which management prescriptions are applied (i.e., forest stands), would help fill the gap between the very fine resolution of the vegetation field data collected and the coarser satellite imagery.

Finally, the absence of strong relationships between landscape characteristics and wildlife relative abundance, and the apparent similarity in landscape characteristics among ownerships should not be taken as evidence that management approaches do not affect the landscape. The effects of management activities that may initially only be evident at a small scale may have the potential to accumulate over a much broader spatial and temporal extent (Everett and Lehmkuhl 1999). For example, some forest birds may not respond directly to a propagation of small forest openings across a landscape, but those openings could alter local deer abundance, which in turn could impact forest understory characteristics, and alter habitat quality for some species.

CHAPTER 3 - Old Growth Characteristics and Wildlife Habitat in the Reserve and Nonreserve Areas of the Huron Mountain Club

INTRODUCTION

The Huron Mountain Club is ecologically and historically one of the most unique places in Michigan. The club was established in 1889 with 2,800 ha by a group of prominent families, who agreed at that time to leave the forest and lakes in their natural state. Even in 1938 when people could still remember similar forests before they were logged in other parts of the Upper Peninsula, the property was recognized by Aldo Leopold as a site of tremendous ecological value. When Leopold was invited to the Huron Mountain Club as a consultant to research the area and prepare a management plan (Monthey 2000), he determined that the biggest threat to forest health there was deer overpopulation. The forested property in the 1930s was not capable of supporting the deer densities in the surrounding area, yet artificial feeding and logging encroachment were attracting deer to the area (Monthey 2000).

Leopold's written plan for the Huron Mountain Club recommended that the Club reserve the central area, nearly 2,500 ha, from timber harvesting and use only light selective cutting in a surrounding buffer area (Simpson et al. 1990). At the time the plan was written (1938), selective cutting was a novel alternative to clearcutting (Monthey 2000). As a result of Leopold's recommendations, the only cutting that has occurred in the reserve area was the removal of eastern white pine from about 20% of the 2,500 ha between 1885 and 1900. The surrounding nonreserve area of the Huron Mountain Club was last cut in the 1920s and 1940s (Westover 1971, Simpson et al. 1990). Today, much of the Huron Mountain Club retains the character of a presettlement forest. The general public is not allowed access to the land, and several of Michigan's largest living trees are located there (Wells and Thompson 1972).

Old growth forest, such as that at the Huron Mountain Club, is important not only because of its rarity, but because of the many unique features associated with it. As forest succession proceeds, stand structure becomes more heterogeneous and complex, providing a suite of conditions that are not completely represented in younger forests (Welsh and Droege 2001). An important issue in old growth management has been identifying which individual elements of old-growth forests wildlife respond to, and how those qualities can be preserved or replicated through forest management.

As a relatively unmanipulated ecosystem, the hardwood forests of the Huron Mountain Club can serve as an ecological baseline or "control" against which the effects of management activities can be measured (Arcese and Sinclair 1997). The Huron Mountain Club can also be used as a reference point for evaluating the long-term effects of succession and natural disturbances. Identification of specific properties that are associated with old growth forests may then provide managers with the knowledge to emulate old growth characteristics in a more disturbed setting. This knowledge would allow natural resource managers to maintain a wider range of ecological processes and biodiversity in a landscape. For these reasons, the objective of this chapter is to compare forest and landscape structure and composition, and relative abundance of selected wildlife species, in portions of the Huron Mountain Club that have not been cut since the 1890s and in areas that were last harvested in the early part of the 20th century.

METHODS

Reserve and nonreserve area boundaries were determined from Simpson et al.'s (1989) map of cover types of the Huron Mountain Club and from (Westover 1971). In 1996, vegetation and wildlife surveys were conducted in 2 reserve areas of the Huron Mountain Club, and in 1997 and 1998 data were collected from the 2 reserve areas and from a portion of the nonreserve area. Data collection was focused on the 3 areas of the Huron Mountain Club where the largest blocks of northern hardwood forest were located.

Wildlife population data collection was described in Chapter 1. Methods for generating cover type maps and calculating landscape metrics were generally the same as those outlined in Chapter 2. Sampling sites at the Huron Mountain Club were in relatively close proximity to each other (>1.3 km) and usually separated by more water area than land. Therefore, boundaries of study sites were created using only 80 m buffers to avoid the overlap that would occur if 800 m buffers were used.

Data analysis

Values for stand structure and composition variables were calculated by averaging data for stands within each sampling site, and then averaging the results of the 2 reserve sites. Comparisons of wildlife relative abundance, stand structure and composition, and landscape variables between reserve and nonreserve areas were not tested statistically because of the small number of replicate sites. Instead, data are presented as means for each group and described qualitatively in terms of the history of each site.

RESULTS

Forest stand characteristics

Of the 14 reserve stands sampled, 12 had been cut for eastern white pine in the 1890s, and the remaining 2 have never been logged (A. Turner, Huron Mountain Club, personal commun.). All of the nonreserve area stands were cut for white pine in the same time period as the reserve stands and then clearcut from 1919-1923 (Westover 1971).

As expected in forests that have been harvested, the nonreserve area tended to have more tree stumps than the reserve area. However, stump diameter and height were slightly larger in the reserve area (Table 56). Generally, there were higher shrub densities and slightly more midstory canopy cover in the understories of reserve area stands than in the nonreserve area.

Basal area was similar for reserve and nonreserve stands, but trees in the reserve area tended to be larger in diameter and there were fewer of them (Fig 13). In contrast, the nonreserve area had a larger number of smaller diameter trees. Snag occurrence followed a similar pattern, with reserve area stands having about 13% fewer snags, but snag diameters that were approximately 41% larger.

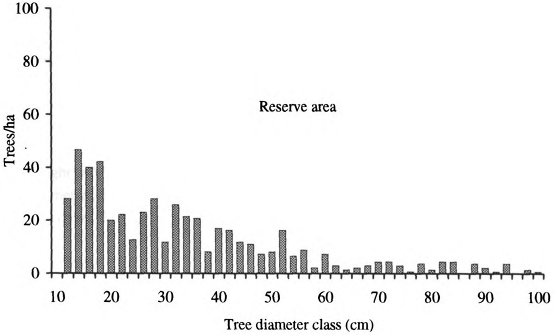
Reserve stands had 22% more conifer cover in the overstory than nonreserve stands (Table 57), yet stem densities of hemlock were actually greater in the nonreserve area (Table 58). Tree species recorded in the reserve area that did not appear in the nonreserve area were American basswood, white spruce, and white ash (Table 58). Quaking aspen, black cherry, and white birch were recorded in the nonreserve area, but not in the old growth portion of the Huron Mountain Club. The nonreserve area also had

Table 56. Mean values for understory vegetation variables measured for stands in the reserve and nonreserve areas of the Huron Mountain Club in Michigan's Upper Peninsula, July and August, 1996, 1997, and 1998.

Variable	Reserve (n=2)[a]	Nonreserve (n=1)[b]
Saplings/ha	288.2	616.7
Shrubs/ha	1523.9	413.3
Shrub height (cm)	82.0	119.5
Stumps/ha	68.9	170.0
Stump height (cm)	67.9	53.8
Stump diameter (cm)	41.4	33.1
Logs/ha	190.0	176.7
Log length (m)	5.9	5.3
Log width (cm)	29.9	24.8
Herbaceous height (cm)	7.9	6.6
Litter depth (cm)	3.4	2.8
Vertical cover (%)		
0-0.5 m	15.0	9.6
0.5-5 m	17.7	13.6
Herbaceous	8.0	6.1
All shrub species	0.08	0.01
Deciduous shrub species	0.08	0.01
Woody debris	9.4	5.2

[a] Mean values were obtained by averaging the stand values for each reserve site to obtain a mean for each site, and then averaging the means of the 2 sites.

[b] Mean values were obtained by averaging values for the 8 stands sampled on the 1 nonreserve site.



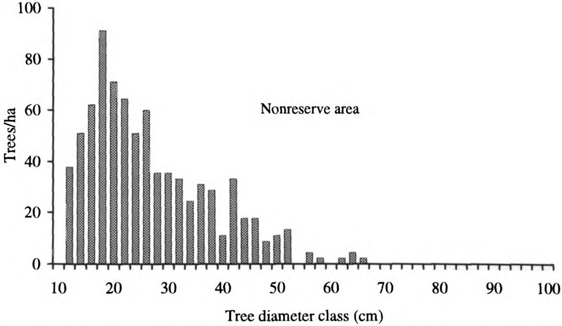


Figure 11. Tree diameter distributions for the reserve and nonreserve areas of the Huron Mountain Club in Michigan's Upper Peninsula, 1996 - 1998.

Table 57. Mean values for overstory vegetation variables measured for stands in the reserve and nonreserve areas of the Huron Mountain Club in Michigan's Upper Peninsula, July and August, 1996, 1997, and 1998.

Variable	Reserve (n=2)[a]	Nonreserve (n=1)[b]
Basal area (m^2/ha)	49.6	46.0
Overstory trees/ha	518	807
Overstory tree DBH (cm)	36.1	27.2
Overstory tree height (m)	21.6	20.1
Snags/ha	45.2	52.2
Snag height (m)	11.3	9.9
Snag diameter (cm)	37.5	22.0
Vertical cover (%)		
>5 m	81.2	85.4
Conifer trees	52.6	39.9
Deciduous trees	54.6	62.9
Hard mast trees >10 in (25.4 cm) DBH	0.79	0.00

[a] Mean values were obtained by averaging the stand values for each reserve site to obtain a mean for each site, and then averaging the means of the 2 sites.

[b] Mean values were obtained by averaging values for the 8 stands sampled on the 1 nonreserve site.

Table 58. Overstory tree species composition (stems/ha) for stands in the reserve and nonreserve areas of the Huron Mountain Club in Michigan's Upper Peninsula, July and August, 1996, 1997, and 1998.

Tree species (*Scientific name*)	Reserve (n=2)[a]	Nonreserve (n=1)[b]
American basswood (*Tilia americana*)	20	0
American elm (*Ulmus americana*)	19	23
Bigtooth aspen (*Populus grandidentata*)	1	33
Black cherry (*Prunus serotina*)	0	1
Eastern white pine (*Pinus strobus*)	1	3
Hemlock (*Tsuga canadensis*)	299	343
Northern red oak *Quercus rubra*	4	3
Northern white cedar (*Thuja occidentalis*)	3	49
Quaking aspen (*Populus tremuloides*)	0	3
Red maple (*Acer rubrum*)	1	221
Striped maple (*Acer pensylvanicum*)	7	4
Sugar maple (*Acer saccharum*)	127	93
White birch (*Betula papyrifera*)	0	1
White spruce (*Picea glauca*)	1	0
White ash (*Fraxinus americana*)	3	0
Yellow birch (*Betula alleghaniensis*)	29	45
All species combined	518	823

[a] Mean values were obtained by averaging the stand values for each reserve site to obtain a mean for each site, and then averaging the means of the 2 sites.

[b] Mean values were obtained by averaging values for the 8 stands sampled on the 1 nonreserve site.

a substantially higher density of red maple than the reserve area, as well as more bigtooth aspen and northern white cedar.

Landscape characteristics

The 2 reserve sites were both smaller than the nonreserve site because they bordered on and were surrounded by lakes (Table 59). Although they spanned several township sections, much of the area was occupied by water rather than land. Despite their smaller size, the reserve area sites contained more cover type classes than the nonreserve area. The urban, agricultural/herbaceous opening, wetlands, and jack pine cover classes were present in the old growth study sites but absent from the nonreserve site (Fig. 12). Northern hardwood forest made up a slightly larger proportion of the nonreserve study site than the old growth sites, and nearly 25% of the area of the nonreserve site was in dry hardwood/conifer mix category. Conversely, there was very little of the dry hardwood/conifer mix cover class on the old growth sites, but close to 30% of the area was covered by the wet hardwood/conifer mix cover type (Fig. 12).

Edge density, patch density, the interspersion and juxtaposition index, and Shannon's diversity index tended to be higher on the reserve sites than on the nonreserve site (Table 59). Conversely, patch size was larger for the nonreserve site.

Wildlife species

In both years of salamander data collection, relatively few salamanders were found in stands on 1 reserve site, an intermediate number were found at the second reserve site, and the most were found in the nonreserve area. During summer surveys in 1997 and 1998, a total of 111 salamanders/ha were located in old growth stands through

Table 59. Mean values for landscape metrics for stands in the reserve and nonreserve areas of the Huron Mountain Club in Michigan's Upper Peninsula, calculated from 1991 satellite imagery.

Landscape metric	Reserve (n=2)	Nonreserve (n=1)
Total area (km^2)	5.88	7.23
Number of patch types	9	5
Patch size (ha)	11.29	15.73
Patch density (#/km^2)	3.42	2.93
Median patch size (ha)	0.79	1.95
Edge density (m/ha)	120.04	110.33
Patch edge (km)	1.24	1.70
Shape index	1.59	1.55
Area weighted shape index	2.20	2.44
Patch fractal dimension	1.46	1.35
Area weighted fractal dimension	1.30	1.34
Interspersion and juxtaposition index (%)	62.53	49.54
Shannon's diversity index	1.54	1.27
Simpson's evenness index	0.75	0.71

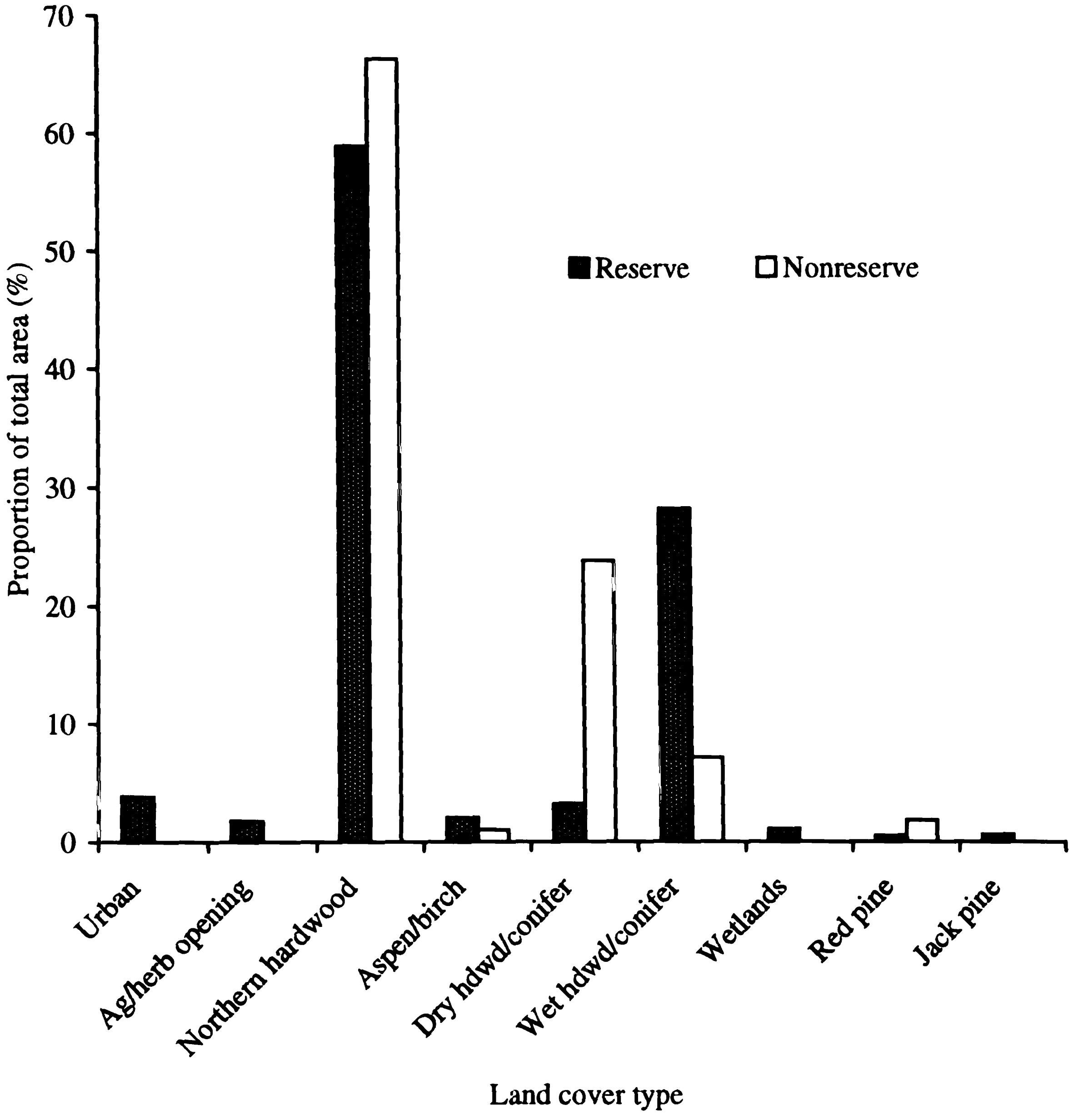


Figure 12. Average proportion of total land area in each land cover class for study sites in reserve and nonreserve areas of the Huron Mountain Club in Michigan's Upper Peninsula, calculated from 1991 satellite imagery.

ground searches, and more than double that number (272 salamanders/ha) were located in nonreserve area stands during the same time period. Numbers of salamanders found under cover boards followed a similar trend, with 25 individuals/ha found under boards on the reserve sites and 44 salamanders/ha under boards on nonreserve sites. Also, a larger proportion of salamanders located through ground transect searches on the nonreserve site were found under the smallest cover objects, while salamanders in old growth stands tended to be distributed more equitably under all available cover object sizes (Fig. 13). All but the smallest (0-5 cm) size classes of woody debris recorded during salamander searches were more abundant in old growth stands than in nonreserve area stands (Fig. 14).

Several bird species, including the black-throated blue warbler, blackburnian warbler, least flycatcher, and northern parula (*Parula americana*), were observed during surveys in the reserve area, but were not recorded in stands in the nonreserve area (Table 60). Some species, such as the downy woodpecker (*Picoides pubescens*), veery, and yellow warbler, were only recorded in the nonreserve area, and although the hermit thrush was detected on all 3 sites, it was much more abundant in stands surveyed in the nonreserve area. The American robin, American redstart, hairy woodpecker (*Picoides villosus*), and pileated woodpecker were observed at least twice as frequently on the nonreserve site as on reserve sites. The red-eyed vireo, ovenbird, and red-breasted nuthatch also tended to be more common in the nonreserve area (Table 60).

Barred owl response rates to taped calls varied greatly during the 3 summers surveys were conducted (Fig. 15), and there was not a discernible pattern to the results.

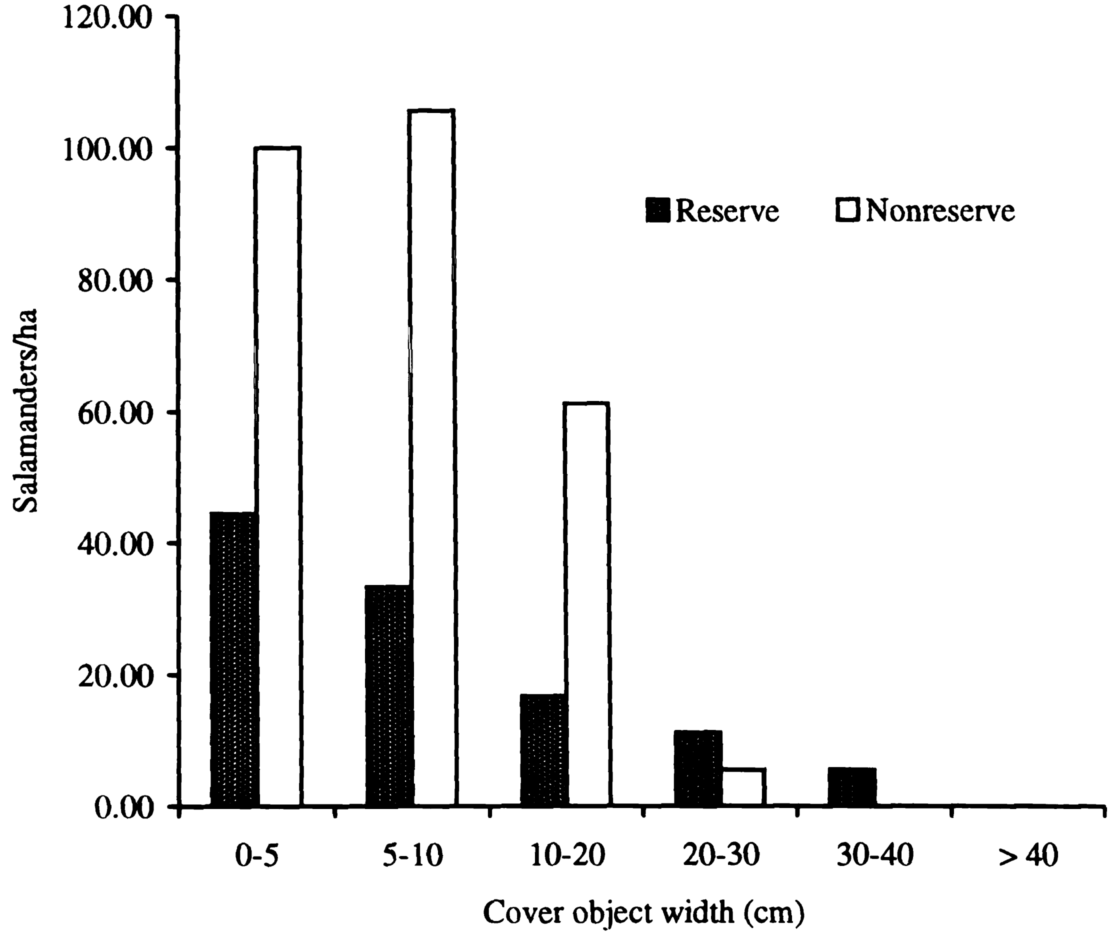


Figure 13. Abundance and size of woody debris used by salamanders for stands in the reserve and nonreserve areas of the Huron Mountain Club in Michigan's Upper Peninsula June, July, and August, 1997 and 1998.

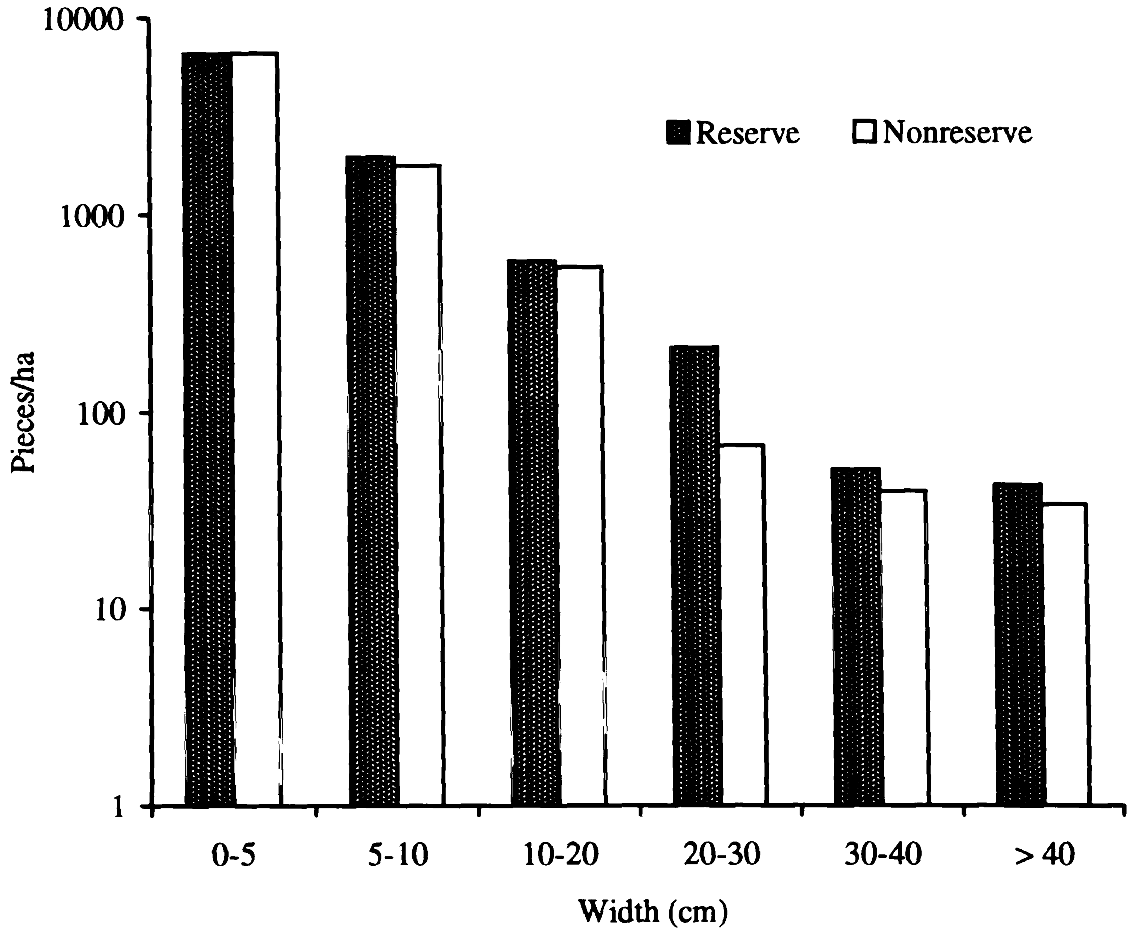


Figure 14. Abundance and size of woody debris for stands in the reserve and non reserve areas of the Huron Mountain Club in Michigan's Upper Peninsula June, July, and August, 1997 and 1998. Note that the scale of the y axis is logarithmic.

Table 60. Mean absolute frequencies (percent of points at which species occurred), pooled over 3 years of data collection, for bird species surveyed in reserve and nonreserve areas of the Huron Mountain Club in Michigan's Upper Peninsula, May-July, 1996, 1997, and 1998. Indicator species are in bold.

Common name	Reserve (n=2)[a]	Nonreserve (n=1)[b]
American crow	2.94	0.00
American redstart	6.86	16.67
American robin	4.90	20.83
Black and white warbler	20.59	8.33
Blackburnian warbler	9.80	0.00
Black-capped chickadee	17.65	29.17
Black-throated blue warbler	5.88	0.00
Black-throated green warbler	77.45	100.00
Blue Jay	3.92	8.33
Brown creeper	5.88	4.17
Chestnut-sided warbler	0.98	0.00
Common raven	0.00	4.17
Downy woodpecker	2.94	8.33
Eastern wood-pewee	1.96	0.00
Great crested flycatcher	2.94	4.17
Hairy woodpecker	2.94	12.50
Hermit thrush	17.65	4.17
Least flycatcher	18.63	0.00
Magnolia warbler	0.98	4.17
Northern parula	4.90	0.00
Ovenbird	52.94	75.00
Pileated woodpecker	4.90	16.67
Pine siskin	1.96	0.00
Pine warbler	1.96	0.00
Red-breasted nuthatch	9.80	25.00
Red-eyed vireo	69.61	91.67
Rose-breasted grosbeak	1.96	0.00
Scarlet tanager	0.98	0.00
Solitary vireo	1.96	4.17

Table 60 (Cont). Mean absolute frequencies (percent of points at which species occurred), pooled over 3 years of data collection, for bird species surveyed in reserve and nonreserve areas of the Huron Mountain Club in Michigan's Upper Peninsula, May-July, 1996, 1997, and 1998. Indicator species are in bold.

Common name	Reserve (n=2)[a]	Nonreserve (n=1)[b]
Swainson's thrush	15.69	8.33
Tennessee warbler	0.98	0.00
Veery	0.00	12.50
White-breasted nuthatch	16.67	0.00
White-throated sparrow	0.98	0.00
Winter wren	36.27	16.67
Wood thrush	4.90	0.00
Yellow-bellied flycatcher	0.98	0.00
Yellow-rumped warbler	5.88	8.33
Yellow warbler	0.00	4.17

[a] Mean values were obtained by averaging the stand values for each reserve site to obtain a mean for each site, and then averaging the means of the 2 sites.

[b] Mean values were obtained by averaging values for the 8 stands sampled on the 1 nonreserve site.

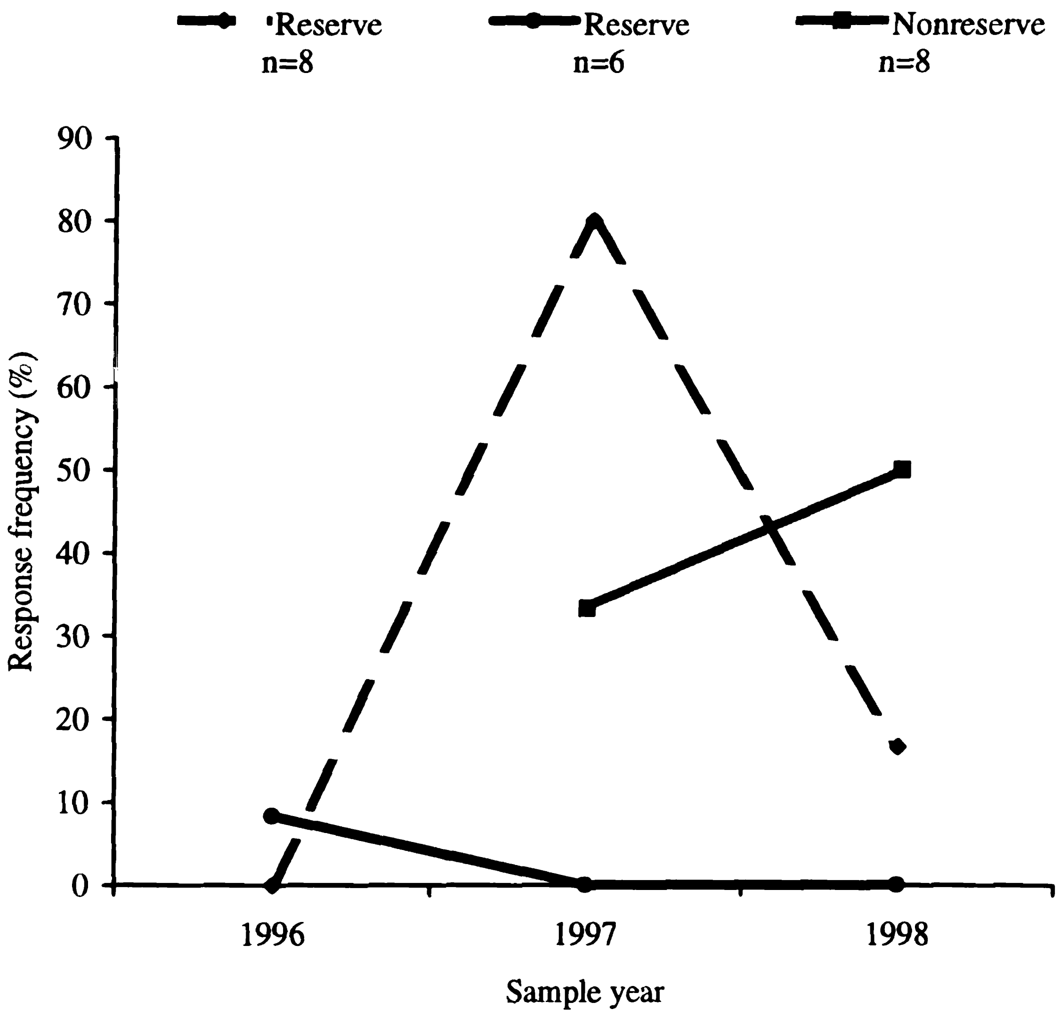


Figure 15. Average response rate of barred owls for stands in 2 reserve areas and 1 nonreserve area of the Huron Mountain Club in Michigan's Upper Peninsula, July-August, 1996, 1997, and 1998.

DISCUSSION

Simpson (1990) found a correlation between the amount of hemlock in the overstory and the structure of the tree seedling layer. In stands where the overstory is dominated by hemlock, there may be <1% canopy coverage in the seedling and sapling layers. As the proportion of hardwoods in the overstory increases, understory canopy coverage may increase to 30-80% (Simpson 1990). This is consistent with data collected from the old growth and logged portions of the Huron Mountain Club. Average deciduous canopy cover was slightly greater in the reserve area, as was the average density of shrub stems. It was also apparent from observations in the field that individual stands followed the same pattern, with nearly pure hemlock stands generally having a completely open forest floor and understory.

Although eastern white pine is known to have been a component of early northern hardwood forests, it was actually slightly more prevalent in the nonreserve portion of the Huron Mountain Club (Table 57). However, the stem densities observed (1-3 trees/ha) are even lower than Price's (1994) estimate of 18 white pine trees/ha in presettlement Michigan northern hardwoods, reflecting the stands' history of pine removal.

A result of logging in the nonreserve area may be an increased density of red maple in the overstory. As a species that establishes opportunistically after disturbance, red maple has increased in prevalence since European settlement. It can also respond as both an early and late successional species (Abrams 1998), although it was nearly absent from the reserve area.

One explanation for the lower stem densities of hemlock, and the higher shrub densities in the reserve area is the presence of treefall gaps in the reserve areas. Tyrell and Crow (1994) determined that old growth hemlock-hardwood forests are composed of at least 10% canopy gaps, with an average gap area of 50 m^2. Treefall gaps are in an earlier successional state than the surrounding stand, and typical tree species include sugar maple, basswood, yellow birch, and striped maple (Wells and Thompson 1972). These young trees occur at relatively high stem densities, but do not provide much canopy cover, so measurements of the deciduous overstory canopy were still low.

The size and abundance of dead and down woody material was one of the most consistent differences between the old growth and previously harvested study sites. The larger stump diameters on the old growth sites probably resulted from the natural falling of mature trees. Hale et al. (1999) similarly found that an abundance of large coarse woody debris distinguished old growth stands from mature managed forest stands in Minnesota. Although the forests in their study were structurally different, plant species diversity was similar, providing managers with the possibility of mimicking old growth characteristics by selectively leaving a few large trees during a timber harvest, and felling cull trees.

Nearly half of the old growth area of the Huron Mountain Club is described by Simpson (1990) as belonging to the hemlock-northern hardwood forest type. Hemlock dominated hardwood stands were occasionally established through fire, and the structure and composition of an old growth hemlock-hardwood stand provides subtle clues about the stand's history. For example, Simpson (1990) determined that stands with >75% hemlock in the overstory were established by crown fires that destroyed the previous forest, whereas hemlock growing in the understory of these stands is an indicator of past ground fires which removed the ground vegetation and litter layer. In contrast, sugar maple-hardwood stands indicate that there has been no fire establishment for several tree generations, and this type of stand is thought to be one of the most constant and unchanging types of forest stands at the Huron Mountain Club (Simpson 1990).

Landscape features tended to be more complex in the old growth portions of the Huron Mountain Club than in the clearcut areas. One possibility for this is that the landscape complexity is a result of natural disturbances that have acted on the landscape and propelled ecosystem processes. For example, large areas of the reserve area forest were established through fires in the last 200-300 years (Simpson 1990), and Frelich and Lorimer (1991) estimated that up to 15% of the reserve area of the Huron Mountain Club has been disturbed in any one decade since 1850.

A second explanation, not mutually exclusive to the first, is that some of the landscape complexity of the old growth area inhibited logging before the Club was established. The steep topography of the interior areas of the Huron Mountain Club where no logging has occurred has resulted in a patchier distribution of vegetation types, and it may also have discouraged serious attempts at logging. The nonreserve area that was sampled is located near the shore of Lake Superior, and the topography is much smoother, making it a much easier prospect for timber harvesting.

Unexpectedly, pileated woodpeckers were surveyed more often in the nonreserve area than on the old growth sites. Snags, which are a component of the pileated woodpecker HSI model, were more numerous on the nonreserve site, but had smaller diameters than those in reserve sites. The HSI values calculated for the Huron Mountain Club did not correspond to the number of pileated observations; instead, the lowest pileated score (0.16) was associated with the nonreserve site. It may be that all 3 Huron Mountain Club sites met the pileated woodpecker's minimum requirements for snag diameter, but the greater density of snags on the nonreserve site was more important in determining habitat quality, despite the model predictions.

Northern parulas were heard singing near streams in the reserve area, but there were no streams near sampling points in the nonreserve area, which may explain the difference in abundance between the 2 areas. Blackburnian warblers are associated with stands of hemlock, and measurements of coniferous canopy cover suggested that both reserve areas sampled had a greater proportion of hemlock in the overstory than in the nonreserve area of the Club. One explanation for the greater abundance of American robins in the nonreserve area may be that robins are more tolerant of human disturbance than other species, and the nonreserve area was close to a more heavily used road than the 2 reserve area sites.

The birds found in the nonreserve area represented a wide range of successional associations. Some early successional species, such as the veery and American redstart, were more common in the logged than the old growth area, yet the hairy and pileated woodpeckers, which tend to be found in mature forests, were also more common in the nonreserve area. Nonreserve area stands also tended to be dominated by a few species, as shown by the high relative abundance values for the black-throated green warbler, ovenbird, and red-eyed vireo (Table 60). Bird communities in the reserve area were represented by a larger number of species, but relative abundances of individual species tended to be lower than in nonreserve stands. This diversity may be a reflection of the structural complexity that existed in some uncut stands, where treefall gaps were often interspersed with enormous old trees. Therefore, implementing management activities that mimic the large degree of stand complexity in old growth stands and landscapes may be another approach enhancing regional biodiversity.

CONCLUSIONS

The diversity of forest management approaches among state, federal, timber industry, and the privately owned forest land in the eastern Upper Peninsula has resulted in a heterogeneous landscape, and a broad range of wildlife habitat conditions. Some the most conspicuous differences in forest stand characteristics occurred between Huron Mountain Club and timber industry sites, with MDNR and Forest Service sites falling in the middle.

Landscape composition did not differ among ownerships, and compared to wildlife and forest stand variables, there were few structural landscape differences among ownerships. Available data on landscape structure and composition were relatively coarse compared to the home ranges of most of the species evaluated, and compared to the level at which forest manipulations take place. As a result, landscape structure and composition were only minimally influenced by land ownership patterns at the scale and resolution examined.

Species selected for population and habitat evaluation in this project were chosen as a sample of species that occur under different conditions in northern hardwood forests. Thus, their relative abundance and distribution were expected to vary across a landscape with varying forest conditions. The relative abundance of red-backed salamanders varied considerably at a relatively small spatial scale, with few significant differences in relative abundance observed among the 4 ownerships. Additionally, 2 salamander survey methods were compared, and it was determined that artificial cover board searches are preferable to ground transect searches when surveys will be repeated at the same location. Although cover board searches yielded fewer salamander observations than ground searches, the cover board method offers the benefits of being a standardized method that is less disruptive to the habitat.

Distinctive bird communities were also associated with each ownership category. For example, timber industry sites had a greater relative abundance of early successional species, such as the American redstart and the veery, and fewer ovenbirds than all other ownerships. Cavity nesting birds, including the pileated woodpecker, were generally most common at the Huron Mountain Club. In general, MDNR and Forest Service sites had relatively similar bird communities, while timber industry and Huron Mountain Club sites had more divergent forest bird associations. Relative abundances of pileated woodpeckers and the 4 songbird species selected for their associations with northern hardwood forests also differed among ownerships. No differences in barred owl or fisher use of study sites were identified.

Data collected at the Huron Mountain Club provided an important reference point for the range of wildlife habitat conditions that may occur in northern hardwood forests. One of the most consistently documented attributes of old growth forests is the abundance of coarse woody debris and standing dead wood (Tyrell and Crow 1994, Carey and Johnson 1995). This was true for the old growth stands at the Huron Mountain Club, and nearly all categories of dead wood were larger in size in the reserve area than in the nonreserve area.

Habitat quality, as calculated from HSI models, varied substantially among species and across ownerships. The lowest calculated habitat quality (0.01) occurred for the pileated woodpecker on MDNR and timber industry sites, and the highest was for the yellow-rumped warbler at the Huron Mountain Club. The performance of HSI models also varied among the 7 models tested in this study, and at least 1 model, the veery, could benefit from revision.

The lack of statistical differences between MDNR and Forest Service sites for many forest stand and wildlife characteristics may be the result of parallels in public agency management approaches. Management goals for state forest land include using commercial timber harvests to enhance timber and wildlife production on a sustained yield basis (Michigan Department of Natural Resources 1991). Management of Forest Service lands has sought to meet multiple use objectives, including wilderness resources, wildlife habitat, recreational opportunities, and economic development, as mandated by the 1960 Multiple Use Sustained Yield Act. These general descriptions of management approaches on state and federal forest land are then translated at a local scale based on social, economic, historical, and ecological factors. State and federal management agencies are also subject to public scrutiny, and therefore are unlikely to reach extremes in their management practices. As a result, forest conditions on MDNR and Forest Service sites represent the likely outcome of management practices that attempt to represent a broad range of interests.

Landscapes are+ dynamic, responding to changes in land use, environmental conditions, and social policies over time, and the results of this study may no longer hold true 5 or 10 years from now. Furthermore, some long term effects of past management approaches may only now be becoming evident in the landscape, and the cumulative effects of current management programs may not be observed for several more years. For example, the Forest Service's management paradigm of focusing on ecosystem management to meet multiple use objectives was only adopted in 1993 (U.S. Department of Agriculture 1995). Therefore, it is likely that the results of this study are a reflection of management over the past several decades as well as current management approaches.

MANAGEMENT AND RESEARCH IMPLICATIONS

While the management goals of the land owners in this study are known in a general sense, the results of this study help describe the effects of those approaches and the effects on forest and wildlife resources across the study landscape. This information may be useful in building partnerships and coordinating regional management goals that support the individual management objectives of each stakeholder. Ecosystem management should include a goal of enhancing biodiversity at a large scale, and managing for complementary regional habitat conditions is one way to achieve that goal, without necessarily sacrificing specific objectives such as commodity production and recreation.

As a partial result of current and past management activities, a broad array of ecological conditions are represented in northern hardwood forests in the Upper Peninsula. The Huron Mountain Club is a particularly unique component the eastern Upper Peninsula because of its old growth characteristics. Unfortunately, the Huron Mountain Club occupies a much smaller proportion of the landscape than state, federal, or industrial forest land, and it has ecological properties that are not easily replicated through management. Shifts in management approaches of other ownerships that require more intensive management, such as increased timber production on public land, will likely result in a more homogeneous landscape. This may be offset if concurrent efforts are made to emulate more unique ecological features, such as connectivity of sensitive habitat types. Such efforts could be part of a larger goal of maintaining stand conditions within historical parameters, and might be accomplished by using silvicultural practices to emulate some elements of historical stand structure and composition.

Collecting adequate population data on many wildlife species, such as amphibians and songbirds is often difficult, expensive, and time consuming, and assessing habitat quality may be more practical for managers than direct population monitoring. Habitat suitability index models are therefore valuable as one component of a comprehensive habitat evaluation, to intensively manage for a single species, or to ensure that habitat requirements are met when a relatively small area is being managed. Additionally, several variables that are included in HSI models, such as overstory canopy cover, species composition, and basal area, are attributes that are already measured in the MDNR's routine forest inventories, and are likely to be in the databases of other organizations, and therefore, can be assessed relatively easily. However, some existing models may not fully describe the habitat requirements for the species surveyed in the Upper Peninsula, and until they receive more extensive validation, they should only be viewed as working hypotheses. Habitat suitability index models developed for this dissertation should also be considered working hypotheses for defining species habitat relationships in Great Lakes northern hardwood forests. It is vital that they be tested and validated in northern hardwood forests in other parts of their applicable range, ideally before the models are used to make habitat management decisions.

Habitat assessment with HSI models may also become labor intensive and inefficient when a large number of species are being evaluated across a landscape. An alternative approach may be to employ limited HSI modeling in combination with a coarse filter, as described by Haufler et al. (1999). Wall (1999) has also outlined an approach to large scale biodiversity conservation on industrial forest land that integrates fine filter habitat assessments with adaptive management to continually evaluate whether species and habitats are responding as predicted.

Another recommendation for managers is to continue or initiate monitoring of red-backed salamander populations in northern hardwood forests. Populations in the Upper Peninsula are abundant and variable enough that trends can be detected with standard techniques, and because salamanders are influenced by microhabitat and stand structure characteristics, management applied to individual forest stands will likely have the most dramatic impacts on salamander populations. Red-backed salamanders are also integral to several fundamental ecosystem processes. They mediate forest litter decomposition through their consumption of invertebrates, and serve as a major food source for forest snakes, birds, and mammals (Wyman 1998). Because they are relatively sessile and physiologically sensitive to environmental changes such as soil acidification (Wyman and Hawksley-Lescault 1987), forest disturbance, and succession (Pough et al. 1987, DeGraaf and Yamasaki 1992, deMaynadier and Hunter 1998), red- backed salamanders may be ideal indicators of ecosystem integrity (Welsh and Droege 2001).

The results of this project suggest some areas on which to focus additional research. Several wildlife species surveyed in this project (e.g. veery and pileated woodpecker) showed distinct associations with land ownerships, raising the question of their usefulness as indicator species for determining the effects of management on northern hardwood forest ecosystems. For example, if the response of pileated woodpeckers to forest stand thinning is representative of the response of other cavity dependent species, managers might be able to make stronger predictions about the effects of management activities on a forest wildlife community. One way to approach the feasibility of using indicator species to predict the effect of management on other species would be to see how well an HSI model for an indicator species predicts the abundance of additional species in the same habitat. This approach would simplify monitoring efforts, but would require careful selection of potential management indicator species and thorough research to build a strong empirical foundation (Niemi et al.1997).

The question of forest and landscape influences on northern flying squirrel populations is one that has been weakly addressed and needs more intensive study. Northern flying squirrels are associated with late successional forest characteristics, yet little is known about their responses to forest management activities. Survey methods for determining population status, habitat requirements, habitat associations with pileated woodpeckers, and the current population status in Michigan would all be worthy research endeavors.

Finally, important information could be gained by analyzing an additional data layer at the resolution of forest management prescriptions and planning. For example, forest compartment maps may provide the level of detail needed for performing home range scale analyses for songbirds and for examining finer scale landscape features. Combined with satellite imagery, such information would be useful for determining the spatial scale at which forest management effects may accumulate and begin to impact a landscape.

APPENDICES

APPENDIX A. Vegetation and wildlife sampling point coordinates.

Table A1. Global positioning system coordinates (taken from the approximate center of the stand) for stands sampled on northern hardwood forest study sites in Michigan's Upper Peninsula, June-August, 1996, 1997, and 1998. Salamander surveys were conducted at the shaded coordinates.

Ownership	Replicate	Easting (m)	Northing (m)	Elevation (m)
MDNR	1	539,364	5,146,788	296
		539,191	5,145,687	219
		539,916	5,144,403	323
		541,795	5,144,868	265
		542,060	5,143,684	152
		540,976	5,142,527	302
		542,724	5,142,177	296
		542,621	5,141,000	460
		543,796	5,141,428	296
	2	625,316	5,155,955	311
		626,924	5,155,981	390
		627,086	5,154,607	390
		627,110	5,154,653	375
		627,737	5,154,739	222
		625,602	5,152,634	390
		627,313	5,152,794	390
		627,327	5,151,187	302
	3	605,002	5,124,425	152
		606,879	5,124,854	152
		605,764	5,123,577	180
		606,960	5,123,946	317
		605,070	5,122,181	283
		606,830	5,122,173	222
		605,528	5,120,588	149
USFS	1	515,375	5,135,122	460
		516,640	5,135,627	390
		518,622	5,135,235	390

Table A1 (cont). Global positioning system coordinates (taken from the approximate center of the stand) for stands sampled on northern hardwood forest study sites in Michigan's Upper Peninsula, June-August, 1996, 1997, and 1998. Salamander surveys were conducted at the shaded coordinates.

Ownership	Replicate	Easting (m)	Northing (m)	Elevation (m)
		520,065	5,135,478	390
		515,047	5,134,073	460
		516,990	5,134,120	207
		518,146	5,133,774	329
		519,967	5,134,097	390
		514,932	5,132,416	168
		516,622	5,132,282	219
		517,239	5,133,085	253
		514,889	5,131,033	207
	2	659,305	5,144,154	168
		662,477	5,144,051	168
		657,933	5,142,266	168
		659,038	5,142,648	168
		660,821	5,142,163	219
		662,703	5,142,516	219
		655,986	5,140,594	168
		657,221	5,140,997	152
		658,827	5,141,100	168
		660,776	5,139,193	219
		659,207	5,139,344	152
		661,001	5,140,877	219
	3	502,352	5,144,109	152
		503,801	5,143,578	186
		505,460	5,143,441	152
		502,442	5,142,951	152
		503,454	5,141,289	152
		503,814	5,142,349	256
		505,479	5,142,292	235
		503,742	5,140,497	332
		505,388	5,140,955	302
TI	1	645,588	5,146,037	448

Table A1 (cont). Global positioning system coordinates (taken from the approximate center of the stand) for stands sampled on northern hardwood forest study sites in Michigan's Upper Peninsula, June-August, 1996, 1997, and 1998. Salamander surveys were conducted at the shaded coordinates.

Ownership	Replicate	Easting (m)	Northing (m)	Elevation (m)
		647,256	5,147,561	360
		647,190	5,146,413	366
		648,874	5,146,156	509
		650,601	5,146,158	302
		651,945	5,144,748	308
		647,277	5,149,632	183
	2	579,831	5,151,447	238
		576,688	5,152,707	363
		575,023	5,152,832	256
		578,292	5,152,586	256
		578,508	5,151,423	393
		575,119	5,150,976	268
		576,755	5,151,027	241
	3	596,056	5,150,173	-6
		595,927	5,148,501	82
		595,941	5,146,730	320
		597,559	5,146,863	180
		597,270	5,149,958	326
		597,557	5,148,423	320
		599,007	5,148,397	171
		600,624	5,148,583	146
		600,570	5,148,345	238
HMC	1	432,989	5,191,152	219
		428,880	5,190,550	244
		429,609	5,190,054	189
		429,637	5,189,459	189
		428,956	5,188,813	430
		429,815	5,189,165	219
		429,575	5,190,509	219
		428,669	5,188,114	308
	2	429,546	5,192,084	552

Table A1 (cont). Global positioning system coordinates (taken from the approximate center of the stand) for stands sampled on northern hardwood forest study sites in Michigan's Upper Peninsula, June-August, 1996, 1997, and 1998. Salamander surveys were conducted at the shaded coordinates.

Ownership	Replicate	Easting (m)	Northing (m)	Elevation (m)
		430,347	5,192,066	393
		431,530	5,190,326	265
		431,039	5,192,270	296
		432,046	5,191,975	207
		432,330	5,191,786	232
		432,388	5,191,323	232
		432,656	5,190,698	265
	3	428,790	5,194,195	375
		430,057	5,194,304	189
		427,016	5,193,731	238
		428,599	5,193,721	378
		430,112	5,193,699	189
		432,083	5,193,760	165

APPENDIX B. A habitat suitability index model for the red-backed salamander (*Plethodon cinereus*) in northern Michigan.

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HABITAT USE INFORMATION

General

Red-backed salamanders are distributed throughout forests in the northeastern United States and southeastern Canada, ranging from eastern Minnesota in the west, across to Wisconsin, Ohio and Indiana, and down to northern North Carolina in the southern part of their range. Vegetation types in which red-backed salamanders live include oak, aspen, hemlock, pine, northern hardwoods, and conifer swamps (Test and Bingham 1948, Test and Heatwole 1962, DeGraaf and Rudis 1990). In northern New England, DeGraaf and Rudis (1990) found that red-backed salamanders were more abundant in northern hardwoods and red maple (*Acer rubrum*) stands than in balsam fir (*Abies balsamea*) forests, and Test and Heatwole (1962) found that in Michigan, red-backed salamanders prefer northern hardwood forests over oak-hickory stands.

Within these vegetation types, red-backed salamanders may be found under stones, in and under logs, and throughout the leaf litter and other organic material on the forest floor (Heatwole 1962, Burton and Likens 1975a). Although the species is most easily observed in the litter and beneath cover objects, a substantial proportion of individuals may occur below ground, at depths up to 30 cm (Taub 1961). In eastern deciduous forests, the surface density of red-backed salamanders can exceed 4 individuals/m^2 (Jaeger 1980), and Kleeberger and Werner (1982) identified home range values of 3.0-4.8 m^2 for red-backed salamanders in Michigan forests. There is evidence that red-backed salamanders are territorial and actively defend the portion of the forest floor included in their home range (Gergits and Jaeger 1988a). Research has also shown that they have homing abilities and will return to within several meters of their original location after being manually displaced by as much as 30 m (Kleeberger and Werner 1982), and that they often return to the most recently used cover object after a foraging trip (Gergits and Jaeger 1988b).

Red-backed salamanders are a major component of the ecosystems in which they occur, aiding in the decomposition processes and serving as a food source for larger snakes, birds, and small mammals. They may be the dominant vertebrate in terms of biomass in a typical northern hardwood New England forest (Burton and Likens 1975b), and are perhaps the most abundant terrestrial vertebrate in general in the northeastern U.S. (Wyman and Hawksley-Lescault 1987).

There is little data available in the literature on the impact of structural characteristics of forest stands on red-backed salamander habitat quality. In evaluating salamander use of artificial cover boards in even-aged northern hardwood forests in New England, DeGraaf and Yamasaki (1992) found no salamanders under boards in seedling stands, intermediate numbers in sapling and poletimber stands, and the most red-backed salamanders in sawtimber or at the edges of sawtimber stands.

Foraging habitat

As much as 75% of the red-backed salamander's diet (by volume) is made up of insects such as beetles and flies. Important non-insect foods include earthworms, snails, and slugs (Jameson 1944). Foraging occurs most often at night on the surfaces of the leaf litter and plants when the ground is wet from rain or dew, or when the relative humidity of the air is high (Heatwole 1962, Burton and Likens 1975b, Pough et al. 1987). Salamanders have been observed climbing on leaves and plant stems up to 2.8 m high (Burton and Likens 1975b).

Breeding habitat

Unlike most other salamanders, the red-backed salamander spends its entire life cycle on land. Mating occurs during the summer, eggs are laid in early fall beneath a rock or log, and the young hatch in late summer or fall (Taub 1961). Red-backed salamander embryos emerge resembling small adults with no intervening larval stage.

Test and Heatwole (1962) found that in habitats where decaying conifer logs (black spruce [*Picea mariana*], northern white cedar [*Thuja occidentalis*], white pine [*Pinus strobus*], or hemlock [*Tsuga canadensis*]) were available, the majority of red-backed salamander egg clutches were found within the conifer logs. On sites where relatively few decaying logs were present, female red-backed salamanders deposited their eggs below ground, using small tunnels and burrows that had been made by other organisms such as earthworms. These researchers hypothesized that in habitats where suitable logs for nesting are present, red-backed salamanders still utilize burrows and underground nest sites, and in situations where a suitable, but undetermined, number of decayed logs are not available, salamanders are dependent on existing burrows in the soil for egg laying.

Microhabitat requirements

Microhabitat variables that have been examined as potential determinants of red-backed salamander habitat quality include soil moisture (Heatwole 1962, Jaeger 1980), soil pH (Wyman and Hawksley-Lescault 1987), soil temperature (Taub 1961), and litter characteristics (Test and Heatwole 1962, Jaeger 1980, Pough et al. 1987).

In some environments, soil acidity has been found to influence the distribution and density of red-backed salamanders in an area. In northern hardwood forests in New York where soil pH ranged from 2.7-5.8, red-backed salamander relative abundance showed a steep decline as soil pH dropped below 3.9 (Wyman and Hawksley-Lescault 1987). Soil pH values in another study where salamanders were observed ranged from 3.6-5.0 (Burton and Likens 1975b), and Vernberg (1955) reported the preferred soil pH range of red-backed salamanders as 6.2-7.2. Test and Heatwole (1962) considered litter characteristics other than depth, and observed that leaves in the litter of Michigan oak-hickory forests are tough and tend to curl, resulting in a looser litter that dries faster and is therefore less favorable to salamanders than litter in northern hardwood forests.

Jaeger (1980) found that the proportion of the surface population of red-backed salamanders in the litter of the forest floor generally increases and the proportion under cover objects decreases with increasing amounts of rainfall. However, the total surface population, compared to the population of red-backed salamanders in the soil, remained relatively steady during seasonal fluctuations in rainfall and soil moisture. Taub (1961) found that salamanders respond to changes in available moisture by moving deeper into the soil under dry conditions and returning to the surface when surface moisture increases. Similarly, Heatwole (1962) found soil moisture to be a factor that influences the movement of salamanders within their home range, but he concluded that soil moisture did not affect the observed frequency of salamander activity above ground. Therefore, soil moisture and rainfall events may be factors that determine the local distribution of a salamanders within an established home range, but there does not seem to be corresponding evidence to suggest that soil moisture has a strong effect on overall habitat quality for red-backed salamanders.

Studies of the importance of litter depth to red-backed salamanders have had mixed results. Pough et al. (1987), working in New York northern hardwood forests with different silvicultural treatments, identified leaf litter depth as the strongest indicator of the surface density of red-backed salamanders. However, Jaeger (1980), working in mixed deciduous forests in Virginia, and DeGraaf and Yamasaki (1992) in New Hampshire northern hardwood forests concluded that surface densities of salamanders were not dependent on litter depths across a wide range of stand ages.

The range of temperatures tolerated by red-backed salamanders with no apparent negative effects is between 4 and 25 C. At temperatures below 4 C, red-backed salamanders retreat underground (Taub 1961). Burton and Likens (1975b) identified 10-15 C as the optimum temperature range for salamanders. Although in Virginia salamanders are thought to have fully emerged from hibernation and establish territories by mid-June (Jaeger 1979), Caldwell (1975) observed congregations of active red-backed salamanders in breeding condition occupying ant mounds during January in Indiana.

HABITAT SUITABILITY INDEX (HSI) MODEL

Model development

This HSI model was developed through an analysis of data collected from the Upper Peninsula of Michigan, during June, July, and August of 1996, 1997, and 1998. Data on red-backed salamander relative abundance, forest stand characteristics, and soil attributes were collected in 54 northern hardwood forest stands within 4 different land ownerships. The number of salamanders observed during ground transect searches and artificial cover board surveys ranged from 0 to 450 salamanders/ha. Based on the distribution of salamander relative abundances recorded and the fact that 40% of stands sampled had <67 salamanders/ha observed, stands in which <67 salamanders/ha were found were considered to provide relatively poor quality red-backed salamander habitat. Stands in which ≥67 salamanders/ha were recorded were identified as sites where red-backed salamander habitat quality was relatively high. Using the assumption that there is a positive linear relationship between red-backed salamander relative abundance and habitat quality, multiple regression analysis and the Kruskal-Wallis one-way analysis of variance were used to identify the habitat variables that are most important in determining red-backed salamander habitat suitability.

Model applicability

The data used to develop this model were collected in the central and eastern Upper Peninsula of Michigan, in the Luce, Mackinac, and Michigamme districts of Michigan classified by Albert et al. (1986). Therefore, the model will have the strongest application to Michigan's Upper Peninsula, but it is also expected to retain applicability in forested portions of nearby Great Lakes states, including Wisconsin, Minnesota, and Indiana. The ecological units where data were collected are described as having a cool lacustrine climate influenced by the Lake Superior, a mixture of well drained sandy soils and poorly drained sand and clay soils, with elevations of 178-604 m (Albert 1986). The model is based on vegetation measurements and relative abundance data collected during June-August and is therefore appropriate during that time period. The model was developed for use in individual forest stands, within which vegetation conditions are assumed to have minimal variation, and where the salamander population can be expected to respond uniformly to conditions in the surrounding environment, given their small home range size. Additionally, this model is only applicable in areas where soil conditions are not strongly acidic (pH must be $\geq$3.7).

Model variables

Based on the analyses described above, the density of overstory trees $\geq$10.2 cm in diameter (Variable 1), the percent canopy cover of shrubs and regenerating trees (50 cm - 5 m tall and <10.2 cm dbh) (Variable 2), and the density (#/ha) of cover objects were chosen as components of the final HSI model. It was found that red-backed salamander relative abundance was positively related to tree stem densities and negatively related to several measures of the amount of vegetation between 0.5 and 5.0 m tall.

Variable 1 (Tree stem density)

Stands identified as representing relatively high quality red-backed salamander habitat had densities of tree stems $\geq$10.2 cm dbh ranging from 280-1,093 stems/ha, and a mean of 599 stems/ha. In stands with relatively low quality habitat, stem densities ranged from 267-720 stems/ha, with a mean of 481. For this model, it was determined that stands with 0 trees would receive a suitability index (SI) value of 0 for Variable 1, and as the number of trees increased to 1,100 stems/ha, habitat suitability would increase proportionally, reaching a value of 1.0 in stands with ≥1,100 stems/ha. The equation for calculating a suitability index value for Variable 1 is SI1 = (stems/ha)/1,100 (Fig B1).

One explanation for the biological importance of tree density to salamanders may be that a higher density of tree stems might hold moisture in the soil around the tree roots, and there may be a greater concentration of invertebrates surrounding tree trunks for salamanders to feed on. The greater abundance of red-backed salamanders in stands with more mature trees (≥10.2 cm dbh) may also be related to the amount or quality of litter that is produced. Although litter depth was not identified as a determining variable of salamander habitat quality, other characteristics of the litter, such as the volume, degree of compaction, and moisture holding capacity, may be important for salamander foraging activities or as hiding cover (Test and Heatwole 1962), and these variables may be influenced by tree stem densities or a related factor.

Variable 2 (Shrub canopy cover)

In the final habitat model, salamander habitat quality is considered to be highest when there is no vegetation in the 0.5-5.0 m stratum. Habitat quality then decreases linearly with increasing vegetation cover in the midstory, reaching a value of 0 for stands with 100% cover (Fig. B2). The negative relationship between salamander relative abundance and the amount of shrub canopy cover may be because shrubs and regenerating trees influence microhabitat characteristics that were not measured in this study, such as nutrient ratios in the soil or daily soil moisture fluctuations. The equation for calculating a suitability index value for Variable 2 is SI2 = 1 - (% midstory canopy cover/100).

Variable 3 (Abundance of cover objects)

The final variable included in the model is the abundance of cover objects that are likely to be used by salamanders. All salamanders observed in this study were found beneath cover objects, such as sticks >1 cm wide and logs. Although log area and cover object abundance did not differ significantly (independent t-test, $p>0.10$) between sites with relatively high and low habitat quality, woody debris has been noted as an important element of red-backed salamander habitat (Jaeger 1980, DeGraaf and Yamasaki 1992). Of all the cover objects that we examined for salamanders, a greater percentage (5.5%) of objects in size classes between 10 and 40 cm had salamanders beneath them than size classes smaller than 10 cm diameter (1.1%), suggesting that salamanders prefer certain cover object sizes. Based on our analyses, the abundance of cover objects was assumed to be adequate in all stands where salamanders were surveyed, but woody debris 10-40 cm wide were considered optimal. The minimum density of cover objects, in the form of woody debris 10-40 cm wide was 117 pieces/ha, and this value was chosen as the minimum amount of woody debris that will provide high quality salamander habitat (Fig. B3). Therefore, stands with ≥117 pieces of woody debris/ha, receive an SI of 1.0, and stands with 0 cover objects receive an SI of 0.0. In stands with <117 pieces/ha, the SI value is calculated with the equation SI3 = woody debris pieces/ha *0.00855.

HSI determination

In the equation for the final HSI value, Variable 3 is used as modifying variable for Variables 1 and 2 because salamanders are not expected to inhabit stands with no cover objects, because cover objects allow salamanders to respond to precipitation and changes in soil moisture Jaeger 1979). The equation for calculating the HSI value is the geometric mean of the suitability index values for Variable 1 and Variable 2, multiplied by SI3: **HSI = SI3((SI1 + SI2)^0.5)**

Figure B1. Relationship between Variable 1, the density of trees ≥ 10.2 cm dbh, and red-backed salamander habitat quality.

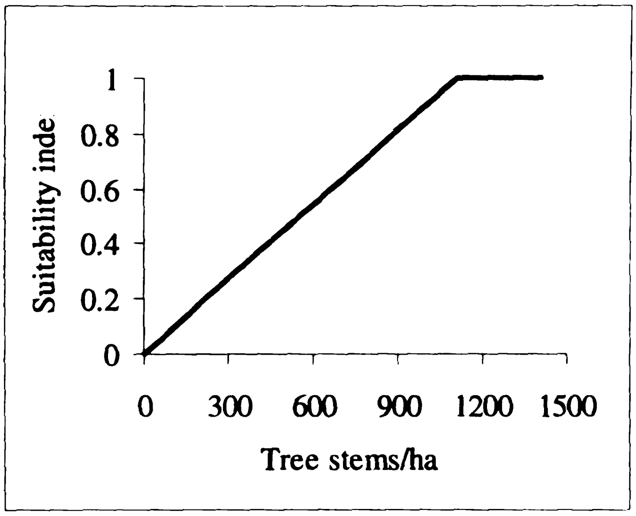


Figure B2. Relationship between Variable 2, the percent canopy cover of shrubs and regenerating trees 0.5-5 m high, and red-backed salamander habitat quality.

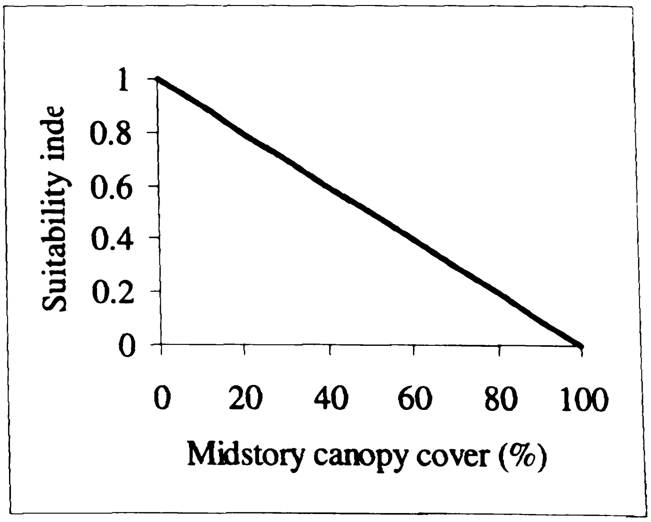
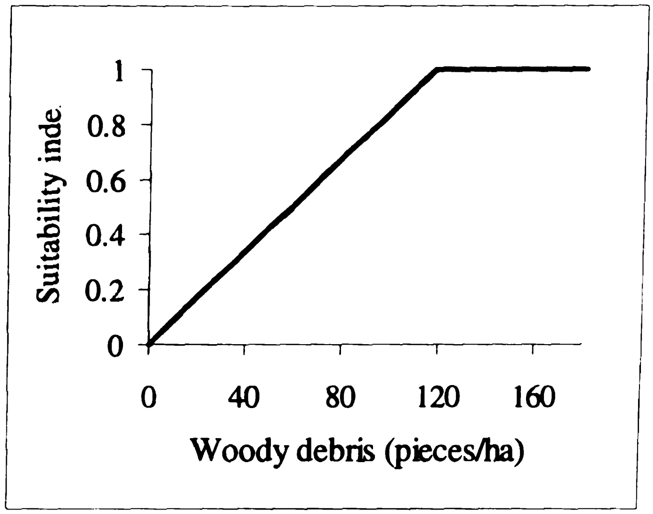


Figure B3. Relationship between Variable 3, the density of woody debris 10-40 cm wide, and red-backed salamander habitat quality.



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APPENDIX C. A model of habitat suitability for the yellow-rumped warbler (*Dendroica coronata*) in the Upper Great Lakes region of the United States.

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HABITAT USE INFORMATION

General

The geographic range of the yellow-rumped warbler during the breeding season includes most of the northern United States (including Alaska), the Canadian provinces, and the western United States (Eastman 1991, Grondahl 1999). Yellow-rumped warblers are migratory, leaving the Midwest in October and returning during April and May (Eastman 1991). They also winter farther north than any other warbler species, and may remain in the southern parts of their summer range year round (Grondahl 1999).

Yellow-rumped warblers are typically associated with mature coniferous forests (DeGraaf et al. 1991, Eastman 1991, Schulte and Niemi 1998), although they are also frequently observed near the edges of forest openings, pine plantations, boreal bogs, and mixed forests (DeGraaf et al. 1991, Eastman 1991). Howe et al. (1995) identified lowland conifers, red pine (*Pinus resinosa*), and jack pine (*Pinus banksiana*) as forest types preferred by yellow-rumped warblers, and very late successional and very early successional hardwood forests as avoided forest types. Schulte and Niemi (1998) also reported a very low abundance of yellow-rumped warblers in regenerating clearcuts and burned forests, compared to other forest bird species observed.

In a study of industrial forests in Maine (Hagan et al. 1997), yellow-rumped warblers were most abundant in medium aged (20-60 years) and mature (>60 years) softwood forests dominated by balsam fir (*Abies balsamea*), white pine (*Pinus strobus*), and spruces (*Picea spp.*) with "full or medium crown closure", and they were less abundant in clearcut or regenerating stands and in predominantly hardwood forests. Thus, yellow-rumped warblers appear able to tolerate a fairly broad range of forest conditions.

Foraging habitat

Yellow-rumped warblers are insectivorous during the breeding season, but they can also survive on berries (their winter food) for short periods during the summer (Grondahl 1999). Insects are obtained primarily by hawking, as well as by gleaning and hovering (Franzreb 1983, DeGraaf et al. 1991). Franzreb (1983) documented that 80% of male yellow-rumped warblers and 65% of females foraged from trees that were >18 m tall. This study took place in a high-elevation mixed conifer forest in Arizona, and the tree heights may not be directly comparable to those in Great Lakes forest types. However, the data suggest that yellow-rumped warblers use relatively tall trees for foraging, and therefore may choose habitats where taller trees are present.

Nesting habitat

The yellow-rumped warbler nests almost exclusively in conifers (DeGraaf et al. 1991, Grondahl 1999), and therefore requires an adequate number of conifer trees from which to select a nest location. Materials used to build the bulky, open nest include twigs, bark, feathers, and grass, and the nest is typically placed far out on a horizontal branch (Eastman 1991, Grondahl 1999). Nests are generally located 3-6 m above the ground, but nest heights may range from 1-15 m (Grondahl 1999).

An analysis of Hanaburgh's (this volume, Chapter 1) data sets for yellow-rumped warbler relative abundance and forest stand characteristics suggested that understory stem density may be an important variable in yellow-rumped warbler habitat. In these data sets, stands where yellow-rumped warblers were observed had a significantly lower density ($p=0.04$) of shrubs and tree seedlings <5 m tall than stands where the warblers were not encountered. In the one outside study consulted for this model where understory stem density was evaluated (Schulte and Niemi 1998), the authors found that yellow-rumped warblers in recently burned stands or in clearcut stands with residual trees were associated more strongly with sites that had lower shrub densities. One way in which stem densities may influence habitat quality is if a lack of understory allows more open space for the birds to catch insects in flight, resulting in more favorable foraging conditions.

HABITAT SUITABILITY INDEX (HSI) MODEL

Model development

In developing this model, a set of potential model variables was first identified based on quantitative and qualitative reports of important habitat components and characteristics in the published literature. This information was combined with empirical data sets of bird species relative abundance and forest stand measurements collected in northern hardwood forests in the Upper Peninsula of Michigan during 1996-1998. In these empirical data sets, independent paired t-tests were used to compare stands where yellow-rumped warblers were observed during data collection with stands where yellow-rumped warblers were not observed. These results were used to associate quantitative values with an index of habitat quality for each variable identified from the literature. The empirical data were also used to identify shrub and seedling density as an additional model variable which had significantly different ($p \leq 0.10$) values between stands where yellow-rumped warblers were observed and stands where they were not observed, although no published references to the importance of this variable were found.

Model applicability

This model is applicable for the Upper Great Lakes region, which includes the northern parts of Wisconsin and Minnesota, the Upper Peninsula and northern Lower Peninsula of Michigan, and southern Ontario. Although yellow-rumped warblers are most commonly associated with coniferous forests (i.e., lowland conifers, red pine, and jack pine), other forest types, such as northern hardwoods may also provide habitat for yellow-rumped warblers if they contain a minor conifer component. Therefore, within the specified geographic area, the model may be used in northern hardwoods forest, mixed hardwoods/conifer forest, and boreal forest types. The model is applicable during the breeding season only, from April through early October.

Model variables

The most important aspect of yellow-rumped warbler habitat quality is the availability of mature coniferous trees to nest in, so the amount of overstory conifer cover was chosen as a model variable. The average height of mature trees was identified as a significant attribute of foraging habitat. Additional variables that determine yellow-rumped warbler habitat suitability are the amount of overstory canopy cover in a stand

and the density of shrubs and seedlings in the understory.

Variable 1 (Overstory conifer cover)

In the data set used to create this model, overstory (>5 m) conifer cover values averaged 31% (S.E. = 7.8%) in stands where yellow-rumped warblers were recorded and 16% (S.E. = 2.1%.) in stands where they were not observed. Based on this comparison, 30% was chosen to represent the minimum amount of conifer cover that will contribute to relatively high quality habitat for yellow-rumped warblers (Fig. C1). Stands that meet or exceed this minimum requirement are assigned an SI value of 1.0, and SI values decrease proportionally as the average amount of conifer cover decreases towards 0. For stands with <30% conifer cover in the overstory, the SI value is calculated with the equation SI1 = [0.033*(% conifer cover)], where 0.033 is the slope of the portion of the graph (Fig. C1) with conifer cover values between 0 and 30.

Variable 2 (Height of overstory trees)

In the empirical data set used to build this model, yellow-rumped warblers were not found in stands where the average height of mature trees (defined as trees ≥5 m tall and ≥10.2 cm dbh) was <20 m, although average tree heights ranged from 14-29 m among all the stands sampled. Average tree height in stands used by yellow-rumped warblers and stands not used by yellow-rumped warblers was not significantly different ($p=0.705$), yet this variable has been indicated in the literature as an important habitat characteristic for yellow-rumped warblers. Assuming that yellow-rumped warblers prefer to forage in the taller trees in a stand, 20 m was used as the minimum average tree height associated with high quality yellow-rumped warbler habitat. Stands with an average tree height $\geq$20 m receive an SI value of 1, and SI values in stands with an average tree height <20 m are calculated with the equation SI2 = [0.05*(average tree height)], derived from the linear equation for the slope of the portion of the graph with tree height values between 0 and 20 m (Fig. C2).

Variable 3 (Overstory canopy cover)

Although published information indicates that yellow-rumped warblers tolerate a broad range of overstory canopy cover conditions, they prefer forest stands with at least moderate, if not complete canopy cover (Hagan et al. 1997). Overstory canopy cover was not statistically different between stands where yellow-rumped warblers were observed and stands where they were not observed, perhaps due to the small sample size. Yellow-rumped warblers in Hanaburgh's (this volume) Upper Peninsula study were found in stands with at least 73% overstory cover. Rounding this value to 70%, stands with overstory canopy cover values between 70% and 100% are considered necessary for optimal yellow-rumped habitat quality. An SI value of 1.0 is assigned to stands with 70-100% cover, and for stands with <70% overstory canopy cover, the SI value is calculated with the equation SI3 = [0.014*(% canopy cover)] (Fig. C3).

Variable 4 (Density of shrubs and seedlings)

In the data set used to build this model, the mean understory stem density in stands with yellow-rumped warblers was only 2,111 stems/ha (S.E. = 566 stems/ha), compared with 11,067 stems/ha (S.E. = 1,236 stems/ha) in stands where yellow-rumped warblers were not recorded. Therefore, stands with $\leq$ 2,000 shrub or seedling stems/ha are assigned an SI value of 1.0. and stands with $\geq$ 11,000 understory stems/ha are assigned an SI value of 0.0 (Fig. C4). Suitability index values for stands with 2,000-11,000 understory stems/ha can be calculated with the equation SI4 = [-0.000112*(understory stem density)+(1.236)]. In this equation, 1.236 is the y-intercept and -0.000112 is the slope of the portion of the graph with stem density values between 2,000 and 11,000 (Fig. C4).

HSI determination

The most important element of the yellow-rumped warbler's habitat is the availability of mature conifer trees to nest in. This attribute, represented by Variable 1 in the model, is likely to have the strongest and most direct impact on a yellow-rumped warbler's choice of habitat. The other variables identified in this model (overstory canopy cover, tree height, and shrub and seedling density) also contribute to habitat quality; however, because the yellow-rumped warbler tolerates a somewhat broader range of other forest conditions, these variables are less important in determining overall habitat quality for an area. The final HSI equation represents this relationship by using the conifer cover SI value to modify the average of the other 3 SI values:

HSI = SI1*[(SI2+SI3+SI4)/3]

Figure C1. Relationship between Variable 1, the percent conifer cover in the overstory, and yellow-rumped warbler habitat quality.

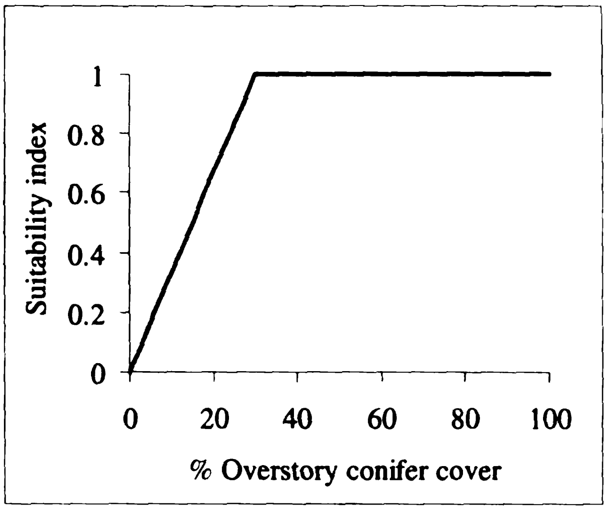


Figure C2. Relationship between Variable 2, the average height of overstory trees (≥5 m tall, ≥10.2 cm dbh) and yellow-rumped warbler habitat quality.

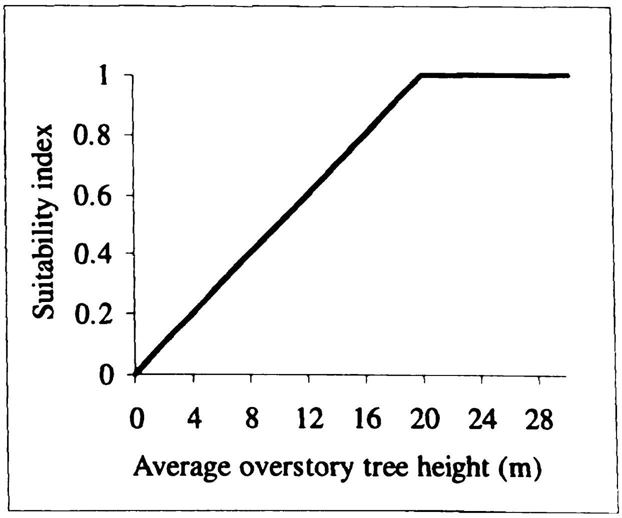


Figure C3. Relationship between Variable 3, the total percent overstory canopy cover, and yellow-rumped warbler habitat quality.

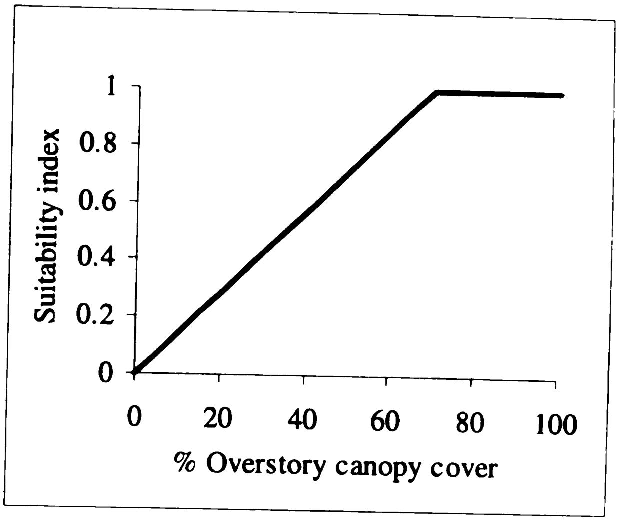
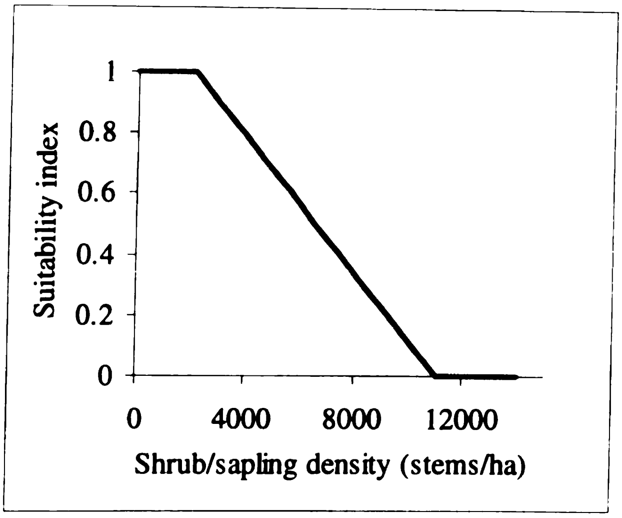


Figure C4. Relationship between Variable 4, the density of shrubs and saplings <5 m tall, and yellow-rumped warbler habitat quality.



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APPENDIX D. A habitat suitability index model for the northern flying squirrel (*Glaucomys sabrinus*) in the Upper Great Lakes region of the United States.

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HABITAT USE INFORMATION

General

Northern flying squirrels are found in coniferous and hardwood forests across most of the northern half of North America, from the Atlantic coast to the Pacific coast. Their range extends south into the Appalachians of North Carolina, Virginia, and West Virginia where the federally endangered subspecies *Glaucomys sabrinus fuscus* exists in scattered populations at high elevations (Payne et al. 1989). In the Upper Great Lakes region, northern flying squirrels are most commonly associated with boreal, mixed hardwood/conifer, and northern hardwood forests (Weigl 1978, Wells-Gosling 1982), and they are found in both relatively fragmented and unfragmented landscapes (Bayne and Hobson 1998). In Michigan, the species has been reported in conifer swamps (Green 1925), mixed hardwoods and upland conifers (Laundre 1975), and jack pine (*Pinus banksiana*) stands (Manville 1948), and a mature forest of mixed conifers and hardwoods forest was identified as favorable habitat in southern Quebec (Wrigley 1969).

Home ranges of the northern flying squirrel have been estimated at 3.1-12.5 ha in Pennsylvania and North Carolina (Weigl and Osgood 1974) and 3.4-4.9 ha in western Oregon (Witt 1992). In New Brunswick, Canada, Gerrow et al. (1998) found that the median home range of female northern flying squirrels was 2.8 ha. The median home range for males was 12.5 ha, and male home ranges often overlapped with several female home ranges.

Foraging habitat

Because northern flying squirrels do not hibernate, they must have access to a food supply throughout the winter. In the moist forests of the Pacific Northwest, lichens and fungi are the staples of the northern flying squirrel diet (Maser et al. 1985). However, unlike northern flying squirrels in western North America which are dependent on lichens and fungi as a food source, northern flying squirrels in the Upper Great Lakes seem to have a more flexible diet. Northern flying squirrels in the Great Lakes area cache conifer seeds, beechnuts, hazelnuts, and acorns for the winter, and in the spring and summer they also consume insects, soft mast, and bird eggs and nestlings (Baker 1983, Vander Haegen and DeGraaf 1996, Bayne and Hobson 1997). Baker (1983) suggested that in Michigan, a stored supply of the autumn seed crop is one of the most important factors in a northern flying squirrel's survival. Northern flying squirrels generally meet their water requirements through the food they eat and they are not thought to have any habitat requirements related to water (Wells-Gosling and Heaney 1984).

Much of the southern part of the northern flying squirrel's geographic range coincides with the northern limits of the southern flying squirrel's (*Glaucomys volans*) geographic distribution, and it has been hypothesized that in regions where the 2 species are sympatric, the northern flying squirrel's habitat use is influenced by competitive interactions with the southern flying squirrel (Weigl 1978). In a laboratory setting consisting of a divided outdoor cage planted with sweetgum (*Liquidambar styraciflua*) on one side and red spruce (*Picea rubens*) on the other, Weigl (1978) observed that northern flying squirrels paired with other northern flying squirrels did not show a distinct preference for either hardwood or conifer habitats. However, when paired with southern flying squirrels, the northern flying squirrels spent nearly 100% of their time in the conifer habitat, while the southern flying squirrels spent nearly 100% of their time in the hardwood habitat. Thus, although pure hardwood forests may meet the northern flying squirrel's habitat requirements, they are better able to compete for their habitat requirements in habitats that have a conifer component. One factor that may give northern flying squirrels a competitive advantage in conifer habitats is their unique ability to subsist on lichens and fungi in winter, which are more abundant in forests with a coniferous component than in purely deciduous forests (Weigl 1978).

An additional aspect of northern flying squirrel foraging requirements may be the density of overstory trees. Gerrow et al. (1998) reported an overstory tree density of 933 trees/ha $\geq$4 m tall in areas used by northern flying squirrels and a significantly greater tree density of 1,167 trees/ha in areas outside of the squirrels' home ranges. One reason for the difference may be that the wider spacing of fewer trees may allow the squirrels to glide farther and more efficiently in search of food than they could in a more densely treed forest.

Nesting habitat

Adequate nesting sites are considered a critical component of the northern flying squirrel's habitat (Weigl 1978). Northern flying squirrels nest either in tree cavities or in exterior nests built in tree branches, tree crotches, or on the ground (Cowan 1936, Weigl 1978, Gerrow et al. 1998). An individual flying squirrel may use 1-4 nests in its home range, and several flying squirrels may share a nest temporarily (Weigl and Osgood 1974). Carey et al. (1997) observed that cavities were used year round, and cavity use by females increased in late spring and summer, corresponding to the period when young are born and raised. The authors suggested that cavities provide better shelter from predators and weather than outside nests, and may be particularly important in harsh climates. Cowan (1936) emphasized the importance of cavities as winter nest sites, but observed more outside nests used by flying squirrels (males and females) than cavities in the summer. In New Brunswick, outside nests in trees were used during all seasons except winter, cavity nests were used year round, and ground nests were used only in winter, especially during periods of heavy snow cover (Gerrow et al. 1998). These accounts indicate that tree cavities may be preferred as nest sites under more critical conditions, such as while giving birth by females and during inclement weather, while outside nests may be sufficient in less stressful situations.

In New Brunswick, the majority of outside nests were located in live conifers, usually red spruce or balsam fir (*Abies balsamea*). The average diameter of trees in which outside nests were built was 29 cm and nest trees were an average of 14.5 m tall. Cavity nests in the New Brunswick study were found in trees with an average diameter of 34.4 cm in live trees and 29.7 cm in snags. Average tree heights were 7.4-9.8 m, and most of the cavities used were in dead trees. Gerrow et al. (1998) also reported that the average diameter of trees within flying squirrel home ranges was larger than that of random trees measured outside the home ranges. The average diameter of trees with cavity nests reported by Witt (1992) in Oregon was 63.5 cm, and the average height of cavity nest trees was 19.6 m. Cavity nests reported by Weigl and Osgood (1974) in Pennsylvania were located in hardwood trees with an average diameter of 57 cm. The large variation in the size of nest trees in these studies is most likely due to the wide geographic separation and the ecological attributes of the forest types and dominant tree species at each study site. Despite these differences, common factors in these studies are the northern flying squirrel's slight preference for conifer trees and the requirement of a tree structure that can support a relatively large cavity.

In the Upper Great Lakes region, pileated woodpeckers (*Dryocopus pileatus*) create more large sized tree cavities than any other forest animal, and the cavities they create are used by many forest animals, including northern flying squirrels, long after the woodpeckers are done with them (Bonar 2000). Therefore, a logical assumption is that habitats where pileated woodpeckers have chosen to excavate tree cavities should have characteristics that overlap with the nesting habitat requirements of northern flying squirrels. A pileated woodpecker habitat suitability index model developed for the Upper Great Lakes region (Felix et al. 1999) evaluates pileated woodpecker nesting habitat based on the density of large overstory trees and snags and the average diameter of mature trees and snags. This model determined that optimal pileated woodpecker nesting conditions are present in forest stands with at least 95 trees/ha $\geq$30 cm in diameter, an average diameter of at least 55 cm for all trees and snags at least 30 dbh, and a minimum of 0.6 snags/ha $\geq$55 cm dbh (Felix et al. 1999).

HABITAT SUITABILITY INDEX (HSI) MODEL

Model development

The majority of published literature on northern flying squirrels is based on research conducted in the northwestern region of the United States, and a habitat suitability index model has been developed for northern flying squirrels in the Pacific Northwest and Intermountain West (Felix and Campa 1999). Some information from populations in the Appalachian Mountains has also been published, but much less data exists for northern flying squirrels in the eastern and midwestern portions of their range. In the absence of relevant information on northern flying squirrel habitat requirements in the Upper Great Lakes region, information from other geographic areas was consulted to develop this model.

Model applicability

The geographic region in which this model is applicable is the Upper Great Lakes region, which includes northern parts of Wisconsin and Minnesota, the Upper Peninsula and northern Lower Peninsula of Michigan, and southern Ontario. This region is roughly equivalent to the area of the Laurentian mixed forest described by Bailey and Cushwa (1981). Within this geographic area, the model may be used in northern hardwood forest, mixed hardwood/conifer forest, and boreal forest types. Northern flying squirrels are not migratory and do not hibernate, so the model has been developed to determine the minimum habitat quality provided in an area throughout the year.

Model variables

The key variable identified as a determinant of northern flying squirrel foraging habitat quality is the density of overstory trees. An additional variable that influences foraging habitat quality is the proportion of coniferous canopy cover in the forest overstory. Variables that describe nesting habitat requirements are the densities of large ($\geq$30 cm dbh) trees and snags.

Variable 1 (density of overstory trees)

Northern flying squirrel habitat is thought to be best when the density of overstory trees ($\geq$10.2 cm dbh) is 933 stems/ha, and it is likely that a range of stem densities values surrounding 933 stems/ha also provide high quality habitat. In the absence of empirical data that define the true range of suitable habitat conditions, stem densities within 10% higher or lower than 933 stems/ha (840-1,026 stems/ha) are assigned a SI value of 1.0. Habitat suitability decreases as the tree density increases to 1,167 stems/ha, beyond which habitat is considered unsuitable and is assigned an SI value of 0 (Fig. D1). Habitat suitability also decreases linearly from the lower end of the range of optimal stem density values (840 stems/ha) towards 0 stems/ha. The suitability index value in stands with less than 840 stems/ha can be calculated with the equation SI1 = [(#trees/ha)/840]. Suitability index values in stands with 1,026-1,137 stems/ha can be described by the equation SI1 =[-0.009*(trees/ha) + 10.51], and stands with >1,137 trees/ha receive a SI value of 0.

Variable 2 (Density of trees $\geq$30 cm dbh)

Published measurements on the average size of trees in which northern flying squirrels use cavity nests range from 27 cm to 64 cm in various habitats. Based on the Northern Great Lakes pileated woodpecker HSI model (Felix et al. 1999), tree densities of $\geq$95 stems/ha (for trees $\geq$30 cm dbh) are assumed to maximize the possibility that an area will be inhabited by pileated woodpeckers that will create cavities for flying squirrels to eventually nest in. Stands that meet this minimum requirement will be assigned an SI value of 1.0 (Fig. D2). For stands that have <95 trees (≥30 cm dbh) per ha, the habitat quality relationship is expressed by the equation, SI2 = [0.010526*(# trees/ha ≥30 cm dbh)].

Variable 3 (Snag density)

In the absence of pileated woodpecker activity, flying squirrels will have to rely on natural cavities, primarily in snags, to meet their cavity nesting requirements. The average diameter of snags containing natural cavities used by northern flying squirrels in New Brunswick was 30 cm. Using a minimum home range estimate of 2.8 ha per female and a requirement of up to 4 nests per individual (Gerrow et al. 1998), a minimum of 1.4 cavities/ha would be required. To be considered suitable for northern flying squirrels, a habitat with 1.4 snags/ha ≥30 cm dbh would necessitate that each snag have an unoccupied suitable cavity and that northern flying squirrels be able to locate every suitable cavity. At the same time, a northern flying squirrel probably does not require that all 4 of the nests be a cavity nest. It is therefore assumed in this model that forests with at least 1.4 snags/ha ≥30 cm dbh will generally provide suitable flying squirrel habitat, and habitat quality will decline as the snag density decreases towards 0 (Fig. D3). For stands in which there are <1.4 snags/ha ≥30 cm dbh, the relationship is expressed by the equation, SI3 = [0.7*(#snags/ha ≥30 cm dbh)].

Variable 4 (Percent coniferous canopy cover)

Some degree of conifer cover has been identified as an element of preferred habitat for northern flying squirrels, although the amount of conifer cover that defines optimal habitat has not been quantified. Northern flying squirrel nests have been located more often, but not exclusively, in conifer trees, and some research has indicated that the structural diversity present in a mixed conifer hardwood stand is important to northern flying squirrels (Gerrow et al. 1998). A conservative interpretation of these data is that a nominal percentage of at least 10% conifer cover and a maximum of 90% coniferous cover will provide suitable northern flying squirrel habitat. Therefore, Variable 4 is assigned a suitability index value of 1 if at least 10% and <90% conifer cover is present in the overstory of a forest stand (Fig. D4). Suitability index values in forest stands with conifer cover values outside of this range decrease linearly towards 0. The suitability index value equation for stands with <10% conifer cover is SI4 =[0.10*(% conifer cover)], and the equation in stands with >90% conifer cover is SI4 = [-0.1*(% conifer cover)+10].

HSI determination

Each of the variables described in this HSI model contributes to the overall determination of habitat quality for northern flying squirrels in the area being evaluated. An individual SI value of 0 does not mean that the habitat is entirely unsuitable for northern flying squirrels, because moderate quality habitat may be present if some of the flying squirrel's other habitat requirements are met. Similarly, a value of 1.0 for a single variable is not enough to assign the whole habitat optimal status if conditions described by the other variables are less than optimal. Instead, the final HSI value is calculated by combining the suitability index values for all 4 variables for a given area, giving each value equal weight in determining overall habitat suitability of an area. The equation for calculating the HSI value is the mean of the suitability index values for each of the 4 variables: **HSI = (SI1+SI2+SI3+SI4)/4**

Figure D1. Relationship between Variable 1, the number of overstory trees/ha ≥ 10.2 cm dbh, and northern flying squirrel habitat quality.

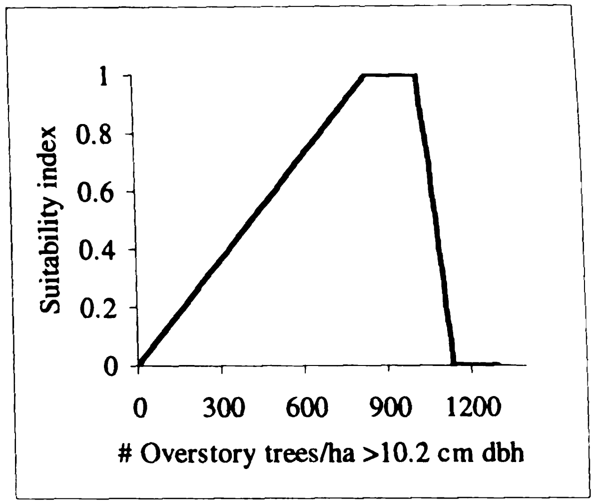


Figure D2. Relationship between Variable 2, the number of overstory trees/ha ≥30 cm dbh, and northern flying squirrel habitat quality.

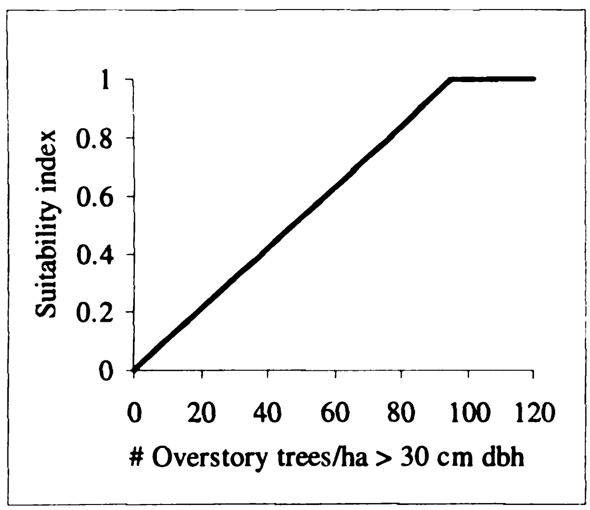


Figure D3. Relationship between Variable 3, the number of snags/ha ≥30 cm dbh, and northern flying squirrel habitat quality.

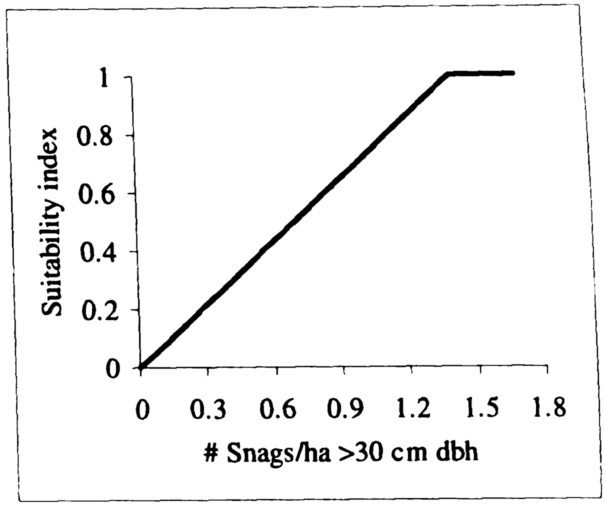
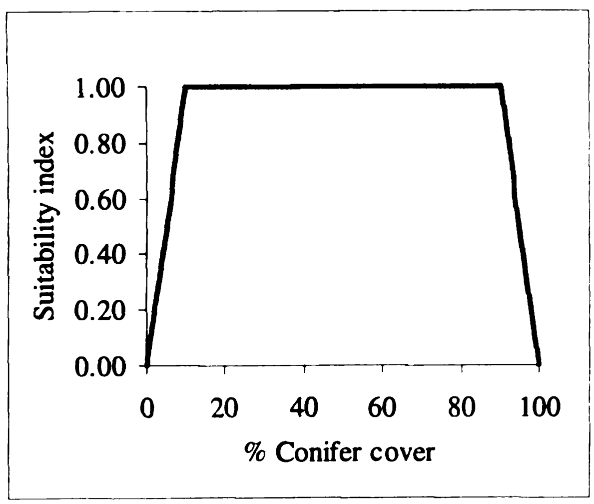


Figure D4. Relationship between Variable 4, the percent conifer cover in the overstory, and northern flying squirrel habitat quality.



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APPENDIX E. Scientific names of songbirds surveyed.

Table E1. Common and scientific names of bird species recorded on northern hardwood forest study sites in Michigan's Upper Peninsula, June-August, 1996, 1997, and 1998.

Common name	Scientific name
American crow	*Corvus brachyrhynchos*
American redstart	*Setophaga ruticilla*
American robin	*Turdus migratorius*
Black and white warbler	*Mniotilta varia*
Black-billed cuckoo	*Coccyzus erythropthalmus*
Blackburnian warbler	*Dendroica fusca*
Black-capped chickadee	*Parus atricapillus*
Black-throated blue warbler	*Dendroica caerulescens*
Black-throated green warbler	*Dendroica virens*
Blue jay	*Cyanocitta cristata*
Brown creeper	*Certhia familiaris*
Brown-headed cowbird	*Molothrus ater*
Cerulean warbler	*Dendroica cerulea*
Chestnut-sided warbler	*Dendroica pensylvanica*
Common flicker	*Colaptes auratus*
Common raven	*Corvus corax*
Downy woodpecker	*Picoides pubescens*
Eastern wood pewee	*Contopus virens*
Golden-crowned kinglet	*Regulus satrapa*
Great crested flycatcher	*Myiarchus crinitis*
Hairy woodpecker	*Picoides villosus*
Hawk spp.	*Buteo spp.*
Hermit thrush	*Catharus guttatus*
Least flycatcher	*Empidonax minimus*
Magnolia warbler	*Melanerpes erythrocephalus*
Mourning warbler	*Oporornis philadelphia*
Nashville warbler	*Vermivora ruficapilla*
Northern parula	*Parula americana*
Ovenbird	*Seiurus aurocapillus*
Pileated woodpecker	*Drycopus pileatus*
Pine siskin	*Carduelis pinus*

Table E1 (cont).

Pine warbler	*Dendroica pinus*
Red-breasted nuthatch	*Sitta canadensis*
Red-eyed vireo	*Vireo olivaceus*
Red-headed woodpecker	*Melanerpes erythrocephalus*
Rose-breasted grosbeak	*Pheucticus ludovicianus*
Ruby-throated hummingbird	*Archilochus colubris*
Sandhill crane	*Grus canadensis*
Scarlet tanager	*Piranga olivacea*
Solitary vireo	*Vireo solitarius*
Swainson's thrush	*Catharus ustulatus*
Tennessee warbler	*Vermivora peregrina*
Veery	*Catharus fuscescens*
White-breasted nuthatch	*Sitta carolinensis*
White-throated sparrow	*Zonotrichia leucophrys*
Winter wren	*Troglodytes troglodytes*
Wood thrush	*Hylocichla mustelina*
Yellow-bellied flycatcher	*Empidonax flaviventris*
Yellow-bellied sapsucker	*Sphyrapicus varius*
Yellow-rumped warbler	*Dendroica coronata*
Yellow warbler	*Dendroica petechia*

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