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LANDSCAPE LEVEL RAPTOR HABITAT ASSOCIATIONS IN NORTHWEST CONNECTICUT

by

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(ABSTRACT)

I measured habitat characteristics at 21 barred owl, 30 northern goshawk, and 17 red-shouldered hawk nest areas, and at 49 random areas within a 780 km^2 area in northwest Connecticut. Measurements were taken at a macro ground level and from 1:12,000 and 1:40,000 black and white and 1:58,000 and 1:126,000 color infrared aerial photography. Among-species nest area analyses at the ground level indicated that higher beech and red maple densities were associated with red-shouldered hawk nest areas than with nest areas of barred owls or northern goshawks. Analyses between species and random areas indicated that barred owl nest areas had higher sugar maple density and basal area than random areas. Denser canopy, greater tree density and basal area, a greater percentage of forested land, and greater hemlock density were associated with nest areas of both northern goshawks and red-shouldered hawks. Northern goshawk nest areas had higher red maple and conifer densities and were found farther from human activity and forest openings than random (available) habitat. Red-shouldered hawk nest areas had higher beech and deciduous tree densities and basal areas than expected based on available habitat. Six of 21 habitat characteristics measured from 4 scales of aerial photography were significantly different either among species nest areas or between species and random areas. Northern goshawks nested in areas with little open water. Red-shouldered hawks had higher percentages of open water near nest sites and were significantly closer to water than available habitat. Four variables related to contiguity of the forest were significant in the analyses. The greatest number of cover type patches generally was associated with random areas followed by barred owl then red-shouldered hawk nest areas. Red-shouldered hawks and northern goshawk nest areas were

in relatively contiguous tracts of forested land and farthest from forest openings. The highest percentages of agricultural and non-forested land were found at random areas and barred owl nest areas, with lowest percentages at red-shouldered hawk and northern goshawk nest areas. The percentage of open water and swamp were most easily identified and measured from 1:58,000 color infrared aerial photography. Distance to water was most consistently measured from 1:58,000 CIR or 1:40,000 B&W aerial photography. The distance to opening was measured most consistently from the 1:12,000 scale. The 1:40,000 and 1:12,000 scales of aerial photography provided the most consistent measurements of the percentages of agricultural and non-forested land.

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Introduction

Natural resource management agencies require accurate and current information regarding the status of wildlife habitat to make wise decisions. Land managers will increasingly depend on larger scale information provided by analysis of landscape scale patterns via remote sensing, geographic information systems, etc. Many agencies are increasing their use of remotely sensed data for natural resource planning activities. However, quantitative methods for large-scale habitat assessment (particularly from aerial photography) have not been developed or evaluated. Information provided by habitat assessments at a small scale may not be appropriate for many large, wide ranging, and/or migratory species. Aerial photography enables a broad, landscape perspective that may provide additional insight into a variety of wildlife-habitat associations. Assessment of habitat at a large scale also provides the opportunity to evaluate elements of entire landscapes and to assess the degree of habitat fragmentation or disturbance.

The red-shouldered hawk and the northern goshawk have been classified rare species by the state of Connecticut (Dowhan and Craig 1976). This designation indicates that although they are few in numbers or populations, breeding populations are stable. Because of their scarcity, however, their populations could be threatened with local extirpation if important habitat was diminished or destroyed (Dowhan and Craig 1976). Information on habitat associations of these two species in northeastern forests is limited. The barred owl is not a species of special status in Connecticut. Although thought to be relatively abundant (Dowhan and Craig 1976), information on its numbers and distribution in the state is not available. It recently has been selected as a management indicator species for several eastern national forests (McGarigal and Fraser 1984).

Forest and land management activities may affect different species in different ways. Data collected at the nest sites of several species may provide information for simultaneous management for multiple species. Gathering habitat data at raptor nest sites allows identification of habitat characteristics associated with specific species. Several researchers have compared characteristics of raptor nest areas with 'average' habitat characteristics in the same area (Titus and Mosher 1981, Devereaux and Mosher 1984). These types of studies allow evaluation of habitat used versus habitat available within a designated study area. Studies have shown that sympatric species often select different nest site characteristics, but few studies have attempted to elucidate patterns of raptor nesting habitat use in relation to availability. Identifying specific habitat types associated with raptor species is useful to land and wildlife managers in defining and protecting important habitat characteristics for a species.

Raptor nest sites in New England have been described in a qualitative manner by Sage et al. (1913), and Bent (1938). Many studies have examined and defined raptor habitat associations quantitatively at micro-level scales (Allen 1978, Titus and Mosher 1981, Bednarz and Dinsmore 1981, 1982, Reynolds et al. 1982, Moore and Henny 1983, Morris and Lemon 1983, and Hall 1984). Micro-level data provides insight regarding a species selection of particular nesting habitat. However, data collected at a micro level does not necessarily provide the same information as data collected at larger scales.

Due to the time required and expense associated with gathering micro-scale data, because micro-habitat is often more difficult to manage, and because researchers are beginning to question the relevance of micro-level habitat evaluation for wide-ranging species or those with large home ranges, interest in identifying larger-scale habitat characteristics associated with wildlife/raptor species has increased in recent years. Identifying similar significant habitat characteristics at a variety of scales also should strengthen a manager's or researcher's confidence in that variable (habitat characteristic) as an indicator of potential nesting habitat for a species.

Landscape ecology and the issue of wildlife habitat fragmentation are gaining wider consideration by those responsible for managing mobile, wide-ranging species such as raptors. The literature suggests that large, undisturbed forested tracts may be important for some raptor species. As forest size increases above 40 ha there is increasing diversity because of the addition of carnivorous species with large minimum habitat size requirements (Forman et al. 1976, Galli et al. 1976). Species that seem most sensitive to fragmentation are those with large territories (Rosenburg and Raphael 1986). Red-shouldered hawks and northern goshawks generally nest in and may require continuous forested areas (Robbins 1979, Galli et al. 1982, Kostrzewa 1987, Speiser and Bosakowski 1987). Even small-scale clearing for cottage development fragments forested habitat and could influence red-shouldered hawk breeding success (Armstrong and Euler 1982). Large, remote forested areas of mature and old-growth timber were important to barred owl nesting success in New Jersey (Bosakowski et al. 1987). As fragmentation and/or human disturbance of forested habitat continues, large-scale landscape characteristics influencing raptor populations need to be identified and managed appropriately.

Several investigators have determined large-scale characteristics of landscape associated with raptor species from topographic maps and/or aerial photographs. They have evaluated distance to human disturbance, percentage of forest versus non-forest, percentage of foraging habitat, proportion of woodland versus farmland, and other similar variables in a qualitative manner. Some raptor studies have assessed large scale landscape patterns at various scales either directly or indirectly. Distance from raptor nest sites to human disturbance was quantified by Lokemoen and Duebbert (1976), Bildstein (1978), Bednarz and Dinsmore (1981), Titus and Mosher (1981), Morris and Lemon (1983), McGarigal and Fraser

(1984), Schmutz (1984), Colvin (1985), Bosakowski et al. (1987), Kostrzewa (1987), and Speiser and Bosakowski (1987). Others have classified land-use or land cover categories in a variety of ways and measured area and/or perimeters (edge) of the resulting patches. Howe (1984) calculated the percent forest within 0.5 km of the nest sites of various bird species. Bednarz and Dinsmore (1981, 1982) identified two cover-based red-shouldered hawk hunting areas that they measured from aerial photographs. They also measured the linear distance of woodland edge within 314 ha circles centered on nest sites. Hill (1985) measured the areas and perimeters of forested versus non-forested areas in a county-wide area from aerial photographs. The areas of 19 cover types were measured from maps at northern goshawk nest sites in California by Hall (1984). Newton et al. (1977, 1981, 1982) measured the proportion of three cover types within circles with radii of 1 km, 3 km, and 5 km at raptor nest sites in Wales. Other researchers have identified land-use and/or land cover types on study areas, but have not quantified areas or perimeters (Gilmer and Stewart 1983, Howard and Wolfe 1976, Lokemoen and Duebbert 1976, Schmutz 1984, Schnell 1968, and Speiser and Bosakowski 1987). Circular plots around nest sites were employed in most of the studies cited. Mosher et al. (1987) provide a detailed evaluation of sampling unit characteristics for raptor studies. No study has attempted to evaluate many large-scale landscape characteristics simultaneously for the purpose of assessing patterns associated with raptor species.

Selection of appropriate types and scales of aerial photography for assessment of wildlife habitat has not been well defined or evaluated. Land and wildlife managers are often at a loss when faced with the array of aerial photography available and procedures for its acquisition. Mayer (1984) reviewed the use of selected scales of aerial photography for habitat inventories. He identified appropriate scales and film types for assessment of specific habitat diversity elements for areas of varying size. Medium-level (at a scale of approximately 1:10,000) and high flight (at a scale between 1:30,000 and 1:120,000) were rated most appropriate for measuring elements of habitat diversity (horizontal patchiness, patch shape, patch size, cultural features, and juxtaposition).

Black and white panchromatic film has been used for most projects in Connecticut. It is the least expensive and most available film type. Color infrared film is more expensive and generally less available, although superior to black and white for some types of cover/land use interpretation. The human eye is capable of distinguishing many more shades of color than shades of gray (Lillesand and Kiefer 1987). Thus, color infrared film enables trained photo interpreters to distinguish many more vegetation types than possible on black and white photography. In forested situations, particularly when differences between coniferous and deciduous species or tree species are required for interpretation purposes, color infrared generally is preferred.

It is often prohibitively expensive for biologists or land managers to fly their own photography and obtain the exact scale and film type they consider appropriate for their uses. Most often, the project or research needs must fit within the capabilities of existing aerial photographs. The state of Connecticut maintains current information on the availability of existing aerial photography for the state (Civco et al. 1978). The Agricultural Stabilization and Conservation Service (ASCS) in Utah and the National Cartographic Information Center (NCIC) in South Dakota have additional information regarding existing photography.

Sparse information exists regarding macro scale raptor-habitat associations in eastern forests. Because of the increasing need for development and evaluation of macro-scale habitat assessment methods, five objectives were developed for this study: 1) to characterize habitat used by red-shouldered hawks, northern goshawks, and barred owls in northwest Connecticut at the scale of the nest area (80 ha circular plot) and at a community or landscape level from 4 scales of aerial photography 2) to describe nesting habitat used by the 3 species of interest in relation to available habitat 3) to develop and assess methods for measuring macro habitat (elements of landscape, degree of habitat fragmentation) at raptor nest areas 4) to compare habitat measurements at several scales of aerial photography, and 5) to develop nesting habitat-use models for barred owls, northern goshawks, and red-shouldered hawks in northwest Connecticut.

Study area and methods

Study area

The 777 km^2 study area was located primarily within Litchfield County, northwest Connecticut (41° 40′ to 42° 10′ N, 73° 10′ to 73° 30′ W), and extended several kilometers into Berkshire County, Massachusetts, and Dutchess County, New York. Sixty-eight percent of the area was forested, and approximately 86% of the forest land was privately owned (Dickson and McAfee 1988). Forested areas occurred in large tracts (>2000 ha) interspersed with small farms and villages. Several large tracts were operated as corporations or associations of landowners and were managed with input from forest and wildlife consultants. There has been a regional trend toward division of large parcels into smaller parcels resulting in a pattern of fragmented ownerships, increased human presence and activity, and decreased options for management (Brooks 1989). Agricultural activity in the form of pastureland for dairy cattle, fields planted in alfalfa, some row crops and scattered orchards occurred primarily along the larger rivers and in areas of rich calcareous soil (Dowhan and Craig 1976). The terrain was rolling with abundant small streams, lakes and wooded swamps. Recent population increases of beaver (*Castor canadensis*) in the area have resulted in an increase in the number of wooded swamps (Paul Rego, pers. commun.)

The study area was within 2 major ecoregions of Connecticut (Dowhan and Craig 1976), the northwest highlands ecoregion and the northwest upland ecoregion. These were underlaid by metamorphic gneisses and schists of Precambrian and Paleozoic age, complexly folded in north-trending belts. Soils were developed on glacial till in the uplands and on local deposits of stratified sand, gravel, and silt in the valleys.

The area was within the New England section of the hemlock (*Tsuga canadensis*)-white pine (*Pinus strobus*)-northern hardwoods region (Braun 1950). Dominant vegetation on well-drained soils of the northwest highlands ecoregion included sugar maple (*Acer saccharum*), American beech (*Fagus grandifolia*), yellow birch (*Betula lutea*) eastern hemlock and white pine. The dominant vegetation on mesic sites of the northwest uplands ecoregion was transition hardwoods of red oak (*Quercus rubra*), basswood (*Tilia americana*), and black birch (*Betula lenta*).

Four "critical habitats" identified by Dowhan and Craig (1976) were represented within the study area: high windswept summits of the northwest highland ecoregion, old growth forests, black spruce (*Picea marinara*) bogs, and along the upper reaches of the Housatonic River, lush calcareous habitats.

Ground methods

The raptor nest sites considered in this study were located by National Audubon Society employees and several local raptor enthusiasts between 1976 and 1984. Wildlife biologists from the U.S. Fish and Wildlife Service (Patuxent Wildlife Research Center) provided technical assistance. Nest sites generally were located in the winter and spring months during leaf-off periods. Search methods included using topographic maps to delineate potential nesting habitat, observing courtship flights and vocalizations, playing tape recordings of vocalizations, and checking rebuilt and 'decorated' (with fresh green sprigs) nests. Barred owl nests were located by scratching or striking any live or dead tree that appeared suitable for nesting. Over a 9-year period more than 1000 hours were spent in the field by cooperators to locate nests. Field searchers located >100 nests of 6 sympatric raptors (Coopers hawk, northern goshawk, red-shouldered hawk, broad-winged hawk, barred owl, and red-tailed hawk) between 1976 and 1984.

Barred owls, northern goshawks, and red-shouldered hawks were considered in this study because of the relatively large number of known nest sites for these species: 21, 30, and 17 respectively. I measured habitat characteristics at a community or landscape scale by conducting ground habitat sampling April through August, 1987, in 80 ha plots. The 80 ha plots represented a compromise between the realities of field data collection time and costs, and an attempt to measure a biologically meaningful area for the 3 species of interest. Craighead and Craighead (1956) estimated that northern goshawks occupy an area of approximately 212 ha and red-shouldered hawks an area of approximately 150 ha. Eng and Gullion (1962) estimated an area of 1979 ha for northern goshawks, and Reynolds (1979) estimated an area of 2463 ha for northern goshawks based on the distance between nests. Based on over 249,623 telemetry locations of 13 barred owls in Minnesota, Nicholls and Fuller (1987) estimated the home range of barred owls to be approximately 274 ha. Average barred owl territory size was approximately 282 ha in winter and 118 ha in summer in Michigan (Elody 1983). The 80 ha plot was considered an 'activity area' or area of intensive use as described by Mosher et al. (1987).

Habitat characteristics (Table 1) were measured at the 67 raptor nest sites and at 49 random areas. Nest sites and random points were plotted on USGS topographic maps. Nest trees were located in the field with the assistance of P. DeSimone of the National Audubon Society, who was one of the primary nest locators and conductors of the 1982-1983 research project. Random sampling of forested areas was conducted to estimate characteristics of available nesting habitat. A computerized random number generator was used to select pairs of 2-digit numbers that corresponded to UTM coordinates for the area. Once the approximate random point was located in the field, a random compass direction was taken, and the closest tree in that direction was used as the plot center. The random point had to be within a forested area with a canopy height $\geq$10m. This criteria excluded some habitat in which woodland raptors do not nest, but included some forested areas where nesting is unlikely (pole-stage thickets, timber-stand improvement areas and pine plantations). Titus and Mosher (1981) believed that this was a reasonable approach for sampling total forest area.

From each plot center, 500 m transects were oriented in each of the 4 cardinal directions. Twenty-one sampling points were established within each 80 ha plot. Sampling points were established at 100 m intervals along each 500 m transect line, as well as at the nest site/random point. Each point was divided into 4 quadrants and the nearest tree greater than 10 cm dbh in each quadrant was recorded (Cottam and Curtis 1956) and the species, its distance from the sampling point, and the dbh were noted. For each sample quarter I established an arbitrary cutoff point of 25 m and recorded a blank if a tree > 10 cm dbh was not within this distance from the nest site or random point. The correction factor described by Warde and Petranka (1981) was used in calculations for plots with missing data (empty quarters). Canopy cover was estimated at the sample point by averaging four readings from a forest densiometer. Average canopy height was estimated with a clinometer.

Mean point-to-tree distance, mean tree dbh, mean canopy cover and mean canopy height were estimated for species nest area and random area plots at the ground scale (Table 2). The overall basal area in m^2/ha and the overall tree density in #trees/ha were calculated for the plot and for each tree species group (Table 2) (Appendix 1) within the plot. A variable called % forest was created by dividing the number of forested quarters by the total number of quarters/plot (84). Elevation and slope at the plot center and distance from the plot center to the nearest water (stream, swamp, lake/reservoir) and nearest disturbance/opening (agri-

Table 1. Variables measured in 80 ha plots at barred owl, northern goshawk, and red-shouldered hawk nest areas and random areas in Litchfield County, Connecticut, 1987.

Physiographic characteristics	
	elevation at sample point center (m)
	aspect at sample point center (N,E,S,W)
	slope at sample point center (%)
	distance to nearest water (m)
	distance to nearest opening or disturbance (m)
Categorical variables	
	type of nearest water (stream, lake/reservoir, wooded/non-wooded swamp)
	type of nearest forest opening (agricultural, residential, water)
Forest stand variables	
	canopy cover (%)
	canopy height (m)
	overall tree density at sample plot (#trees/ha)
	density of species groups (#trees/ha)
	dominance (all species) for sample plot (basal area in m^2/ha)
	dominance of species groups (basal area in m^2/ha)
	% forest (100 (# forested quarters ÷ total # quarters))

cultural, road, powerline, residential, lake, reservoir) were measured from 1:24,000 USGS topographic maps (these areas appeared white on topographic maps.

Aerial photography methods

Twenty-one large scale (landscape or community) habitat characteristics (Table 3) were measured from four scales and two types of aerial photography; black and white photography at 1:12,000 and 1:40,000 and color infrared photography at 1:58,000 and 1:126,000. The 1:12,000 black and white, and the 1:58,000 color infrared photography were exposed during leaf-off periods (March 1985 for both scales). The 1:40,000 black and white and the 1:126,000 scales were exposed September 1980 and May 1973, respectively - both during leaf-on periods. These scales and types of aerial photography represent recent photography (since 1973) that was available for the study area as well as a sample of the scales and types of photography most commonly available to and used by resource managers and researchers.

Four people interpreted the aerial photography. All had the same level of training, which consisted of a basic course in photogrammetry. The author had extensive knowledge of the study area after conducting the ground level data collection for this project. Sample sizes varied from scale to scale due to the availability of aerial photography for specific nest or random areas (Table 4). Nest and random areas were plotted on 1:24,000 USGS topographic maps then transferred to the 4 sets of aerial photography. Each interpreter was randomly assigned nest and random areas at each scale. These sample areas varied for each interpreter from scale to scale. Stereo pairs of photographs and stereoscopes were used to interpret all nest and random areas.

Classification of vegetation groups or cover types is sometimes arbitrary (Pielou 1977) and care must be taken to designate the types in accordance with the biological requirements

Table 2. Description of variables analyzed at the ground scale for barred owl, northern goshawk, red-shouldered hawk nest areas, and random areas in Litchfield County, Connecticut.

Mean tree dbh (cm)
Mean canopy cover (% - forest densiometer)
Mean canopy height (m - Sunto clinometer)
Percentage of forest (100 (forested quarters ÷ total quarters)
Ash density (#trees/ha)
Beech density (#trees/ha)
Birch density (#trees/ha)
Oak density (#trees/ha)
Pine density (#trees/ha)
Hickory density (#trees/ha)
Hemlock density (#trees/ha)
Sugar maple density (#trees/ha)
Red maple density (#trees/ha)
Conifer density (#trees/ha)
Deciduous density (#trees/ha)
Ash basal area (m^2/ha)
Beech basal area (m^2/ha)
Birch basal area (m^2/ha)
Oak basal area (m^2/ha)
Pine basal area (m^2/ha)
Hickory basal area (m^2/ha)
Hemlock basal area (m^2/ha)
Sugar maple basal area (m^2/ha)
Red maple basal area (m^2/ha)
Conifer basal area (m^2/ha)
Deciduous basal area (m^2/ha)
Elevation - estimated from topographic maps (m)
Slope - estimated from topographic maps with land & slope indicator template
Aspect - estimated at nest tree or random point (N,E,S,W)
Distance to water - measured on topographic map (m)
Distance to disturbance - measured on topographic map (m)

Table 3. Description of variables measured at 4 scales of aerial photography for barred owls, northern goshawks, red-shouldered hawks, and random points in Litchfield County, Connecticut.

Distance to water (m)
Distance to nearest opening (m)
Distance to nearest edge (m)
Total edge (m)
Total length of corridors (m)
Total length of road corridors (m)
Total length of wooded corridors (m)
Total length of stream corridors (m)
Total length of powerline corridors (m)
% Evergreen cover (>70% evergreen)
% Deciduous cover (>70% deciduous)
% Mixed cover (<70% evergreen or dediduous)
% Agricultural cover (pastureland, cropland, orchards)
% Residential cover (development other than agricultural)
% Water (open water -lakes and reservoirs)
% Swamp (wooded or non-wooded)
% Clearcut
% Plantation
% Other = % Other + % Clearcut + % Plantation
% Forest = % Evergreen + % Deciduous + % Mixed
% Non-forest = % Agricultural + % Residential + % Other
Number of patches
Time for interpretation and digitizing

Table 4. Sample sizes for species/random points at each scale of aerial photography.

	1:12,000	1:40,000	1:58,000	1:126,000
Barred owl	20	20	20	5
Northern goshawk	25	27	28	7
Red-shouldered hawk	17	17	18	1
Random point	41	44	46	12

of the organisms involved and management applications. Patches were defined as plant species assemblages surrounded by a matrix with dissimilar community structure or composition (Forman and Godron 1986). The cover variables or patch types measured (evergreen, deciduous, mixed, agricultural, residential, open water, swamp, other) were selected based on species biology, the characteristics of the landscape in northwest Connecticut, and ability to measure the variable from the scales and types of aerial photography available. These cover types were also inclusive of those found within the study area.

Several distance measures were taken for comparison with other raptor studies. Distance from the nest site or random point to the nearest water, the nearest forest opening, and nearest edge were measured directly from the aerial photographs with a millimeter or micromillimeter ruler to the nearest 0.5mm. The type of nearest water was categorized in one of the following groups: lake or reservoir, wooded or nonwooded swamp, or stream. The type of opening >5 ha was defined as agricultural, residential-urban, or water.

Corridors were defined as vegetated or nonvegetated strips resulting from man-caused actions or natural occurrences that bisect a landscape (Forman and Godron 1986). Road corridors included paved, dirt, and woods roads; wooded corridors included both tree and shrub corridors; stream and powerline corridors also were identified.

Cover types were outlined and corridors drawn on acetate overlays (Figure 1). Cover type areas and perimeters, corridor lengths and total edge per sample were measured with a digitizer.

Additional variables were generated from information gathered from the aerial photographs. The time for interpretation and digitizing of each sample plot was recorded to provide information for assessment of time and cost efficiency/amount of information provided at each scale. The percent of the 80 ha sample in each cover type, the percent of forested cover versus non-forested cover, and a calculation of the number of patches per sample provided information that enabled assessment of habitat patchiness.

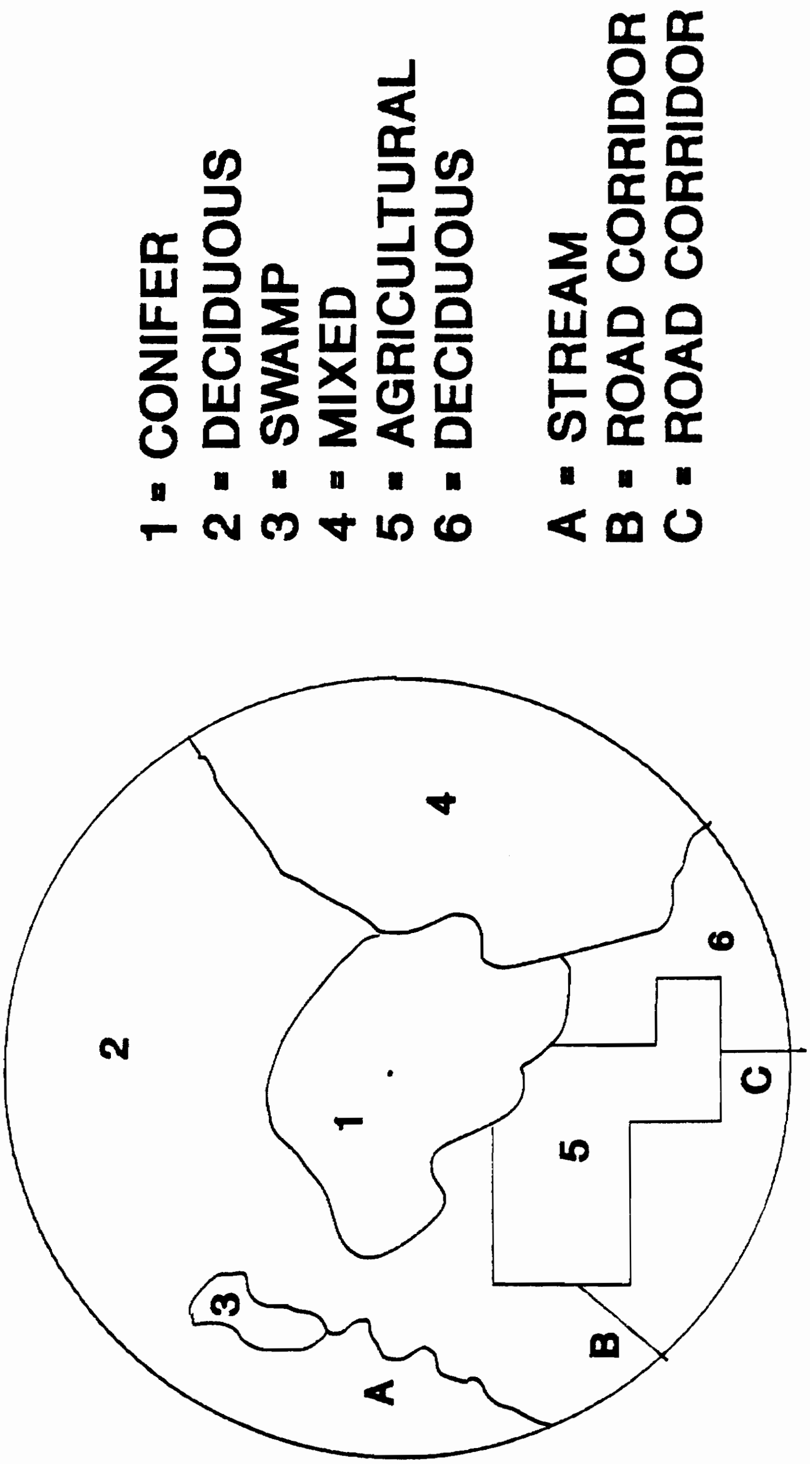

Figure 1. Example of an acetate drawing of the interpretation of an 80 ha plot from an aerial photograph.

Statistical methods

Canopy cover and canopy height, dbh, all densities and basal areas, and distance to water and human disturbance were log transformed for parametric analyses. Percentage of forest and slope were arcsine-square root transformed. Distance and length measurements from aerial photographs were log transformed and proportions were arcsine-square root transformed for t-tests, ANOVA's, and discriminant analysis procedures (Zar 1984). A Wilcoxon rank-sum test was used for two group tests, and the Kruskal- Wallis test was used for analyses among ≥ 2 groups when variables were not normal or when variances were unequal.

The first objective of this study was to characterize habitat used by red-shouldered hawks, northern goshawks, and barred owls in northwest Connecticut at several scales. One-way analysis of variance (ANOVA) or Kruskal-Wallis tested habitat differences among the nest areas of the three raptor species. ANOVA's were conducted with 3 species groups for 31 habitat characteristics gathered at a ground level, and 21 habitat characteristics gathered at each of 4 scales of aerial photography. Scheffe's multiple comparison test was used to identify which species differed for each habitat characteristic when ANOVA's indicated a significant difference.

The second objective of the study was to describe nesting habitat used by each of the 3 raptor species compared to available habitat as described by 49 random areas. T-tests (Wilcoxon) were used to analyze data collected at nest areas of each raptor species and random areas (31 ground level habitat characteristics and 21 habitat characteristics at each of 4 scales of aerial photography) to enable description of nesting habitat used by each species in relation to available habitat.

Multivariate techniques have received greater emphasis from the ecological community (Johnson 1981) in the past 15 years. Shugart (1981) discussed 3 advantages of using a multivariate approach in analyzing habitat data: 1) multivariate procedures intrinsically fit ecological problems and data 2) many multivariate methods seem to be robust in the face of mild deviations from underlying assumptions, and

3) there already exists a hypergeometric interpretation of the relationship among animals that is essentially based on a multivariate sample space. Capen et al. (1986) described the usefulness of multivariate statistics in developing models to distinguish between 'used' and 'unused' areas of potential habitat. Many researchers have used these methods to describe habitat selected and species separation by analysis of vegetative structure at nest sites (James 1971, Anderson and Shugart 1974, Cody 1987, Holmes et al. 1979, Reynolds et al. 1982, Titus and Mosher 1981).

In this study multivariate techniques were used for analysis of habitat characteristics associated with each species. Variables were selected for discriminant analysis procedures by examining significance levels from univariate analyses. Variables that were significant in any univariate analysis were used for all discriminant analyses (ie. for all among species nest area analyses and for between individual raptor species nest area/random area analyses).

Canonical discriminant analysis was used to assess the relative contribution of each variable to species/random point differences and among species differences and to assess the capability of the habitat variables to identify suitable nest sites. Discriminant function analysis allowed classification of species nest areas and random areas into groups based on habitat characteristics. Habitat-use models were developed for barred owls, red-shouldered hawks, and northern goshawks using discriminant function analysis. Model classification abilities were evaluated by calculating producer's and user's accuracy as described by Story and Congalton (1986). Because of the disparity of sample sizes among species and between species and random areas, the large number of variables in relation to the number of groups, and the similarity or overlap among groups (Williams and Titus 1988), Cohen's kappa statistic also was calculated (Titus and Williams 1984) as a test of the classification ability of the discriminant function analysis. I used caution in interpreting the results of the multivariate analyses because of the problems inherent in my data sets (Rexstad et al. 1988).

ANOVA's (Kruskal-Wallis) also were used to test for differences in habitat characteristics among the four scales of aerial photography. Friedman's test for concordance (Lehman 1975) provided a quantitative assessment of the consistency of measurement of a particular variable among 4 scales of aerial photography. Coefficients of variation of the habitat variables also were examined to provide an indication of the variability of the data among scales of aerial photography. Means of the coefficients of variation for all distance measures, all corridor length measures, and all patch (cover) types were calculated. I used these mean values as an indication of the variability of these groups of variables among scales for each species. I considered the variables total edge, total corridor length, number of patches and time individually.

The time required for interpretation of aerial photographs was recorded by each interpreter. We also recorded the time required to digitize area, perimeter, and edge information. These two estimates were combined to provide an estimate of the overall time spent gathering the required information from the aerial photographs. I calculated a total cost for each scale of aerial photography by multiplying the mean time (hours) for interpretation at each scale by the hourly wage of the interpreters and adding the cost of purchase at each scale (acquisition cost). Cost per nest area or random area at each scale was also calculated.

Literature Review

Scale in wildlife-habitat assessment

When choosing the appropriate scale for measuring habitat characteristics it is important to consider the species of interest, the biological and/or management questions relevant to a particular research project, and the cost and time effectiveness of gathering data at different scales. The issue of scale in wildlife habitat assessment has been discussed in the literature (Mosher et al. 1987, Best and Stauffer 1986, Hamel et al. 1986). The underlying biological questions are a function of the scale at which the species of interest is selecting habitat for nesting, feeding, perching, and other activities. Moore and Henny (1983) postulated that perceptual responses to complex habitats by birds are not well known, and habitat selection probably is not based on any single environmental cue. Janes (1985) identified prey distribution, factors that influence foraging behavior, detecting and capturing prey, locating nest sites, the presence or absence of predators and competitors, and factors relating to physiology via the thermal environment and morphology of the species as some of the many factors that might influence raptor habitat selection. Selection may be released by a gestalt perception of the environment rather than by a few proximate factors (Lack 1933). James (1971) felt that each species has a characteristic perception of vegetative requirements of its habitat (the niche gestalt). This idea has been supported by several studies that have provided evidence that birds respond to vegetational and structural features in selecting their habitats (Pitelka 1941, Sturman 1968, Wiens 1969, Reynolds et al. 1982). Consistent occurrence of a species when specific structural features of vegetation are present has been observed in raptor studies conducted in different regions. Hennessey (1978) in Utah and Reynolds et al. (1982) in Oregon found that differences in habitat use among *Accipiter* species were related to the vegetative structure immediately surrounding the nest site, which reflected the successional stage of the forest stand. Newton et al. (1977) found that the European sparrowhawk (*Accipiter nisus*) nested only in woodlands of a vegetative structure equated with old growth. It is clear that habitat selection by raptors is complex and many questions remain, including which specific features of the environment are being chosen, how these factors relate to the biology of the species, and how inter- and intra-specific interactions influence habitat occupancy and selection (Janes 1985). It may be true that the structural components of habitat in songbird habitat analysis (at a microhabitat scale) are strongly associated with a species of interest because they are closely related to feeding substrate and available food resources. Whether these associations exist at the scale at which raptors select habitat is not clear.

Management considerations regarding scale are related to obtaining information on raptor habitat associations that are not only biologically relevant, but also time and cost effective to gather, whether by field collection or from topographic maps, aerial photographs, and/or satellite imagery. Consistency of data at a variety of scales, and for a particular species in different regions would lend credibility and assurance to the use of available raptor-habitat information in management of habitat and/or species.

Studies of raptor habitat associations have been conducted at a variety of scales and with different objectives. Most quantitative studies have been conducted in plots centered on nest sites. Plot sizes have varied, and philosophies regarding appropriate plot size (scale of measurement) have been modified over the last several decades. Many of the initial quantitative raptor habitat studies were conducted within 0.04 ha circular plots like those used in studies of passerines by James and Shuggart (1970). These 0.04 ha plots were modified for use in raptor studies (Mosher et al. 1987, Devereaux and Mosher 1984, Morris and Lemon 1983, Titus and Mosher 1981), but were criticized as being too small to accurately assess habitat associations for species with larger home ranges and greater mobility (Speiser and Bosakowski 1987). More recently, plot sizes have increased but still are centered primarily on the nest site. Moore and Henny (1983) measured habitat characteristics at nest sites of 3 *Accipiters* in northwest Oregon in 0.08 ha plots with a radius of 16.03 m. Speiser and Bosakowski (1987) used 0.145 ha plots with a 43 m diameter for a northern goshawk study conducted in New Jersey and New York. Wood et al. (1989) measured habitat characteristics at bald eagle nest sites in Florida within 0.4 ha plots centered on eagle nest trees. A study of 3 raptors in Germany used 113 ha plots with a 600 m radius (Kostrzewa 1987). Another study of 3 *Accipiters* in Germany collected habitat data at the nest tree (level I microhabitat), within a radius of 15 m around the nest site (level II microhabitat), and within a 250 m radius of the nest site (macrohabitat) (Gamauf 1988). Several researchers have assessed habitat associations at even larger scales. Bednarz and Dinsmore (1981, 1982) measured habitat characteristics at red-shouldered hawk nest sites in Iowa in 314 ha plots, and Hall (1984) sampled random areas with in the entire stand within which northern goshawk nests were located in Calif. ~~Oregon~~. A few researchers have measured raptor habitat characteristics at an even larger scales from topographic maps and aerial photographs (Newton et al. 1977, 1981, 1982, Bednarz and Dinsmore 1981 and 1982, Hall 1984, Hill 1985, Bryant 1986, and Wood et al. 1989). These micro- and macro-level studies generally used different scales of measurement to accomplish different objectives.

Some research conducted on non-raptorial species has concentrated on bird-centered or activity-centered vegetation sampling (James 1971, Whitmore 1975, Roth 1979, Karr and Freemark 1983, Larson and Bock 1986). Some researchers also have either modified or moved away from the nest-centered approach to raptor habitat evaluation. Reynolds et al. (1982) used a plotless method to sample habitat characteristics at points both randomly located within the area of a nest and at known prey-plucking and roosting sites.

A thorough discussion of the variables used in raptor habitat studies is available in Mosher et al. (1987). The same or similar variables have been used in many studies, however, specific variables used are dependent upon the scale at which a study is conducted. When similar variables are not used, comparison of habitat characteristics associated with a species among different regions is difficult.

Barred owl habitat associations

Large, continuous forests with mature timber stands or old growth are important to barred owls (Craighead and Craighead 1969, Nicholls and Warner 1972, Fuller 1979, Elody 1983, McGarigal and Fraser 1984, Devereaux and Mosher 1984, Sutton and Sutton 1985). Several reasons for this association have been proposed. McGarigal and Fraser (1984) hypothesized that owls may require large trees found in mature stands for nest cavities and old stands appear to have lower stem densities with more subcanopy flying space which allows owls to fly unimpeded. Fuller (1979) and Nicholls and Warner (1972) also commented on the importance of unimpeded travelways in habitat selection by raptorial birds.

The literature also describes an association of barred owls with mixed woodlands (Wilson 1938, Smith 1978, Elody 1983, Bosakowski et al. 1987). Elody (1983) noted that coniferous growth, particularly hemlock, was found at barred owl nest areas in Michigan. He, Carter (1925) and Stirling (1970) have postulated that the coniferous growth provided dense forest cover to prevent mobbing and offer an escape medium. Bosakowski et al. (1987), in qualitative assessments of forest types in northern New Jersey, noted a higher occurrence of hemlocks and northern hardwoods (including sugar maple and beech) at barred owl nest areas than at random areas. species. Fuller (1979) and Nicholls and Warner (1972) found that barred owls used oak-upland habitat more frequently and consistently than any other habitat type and postulated that this was due to the greater availability of nest sites, abundance of hunting perches, open understory for hunting and greater opportunity to hear prey in dry oak-upland habitat. Oak was found in relatively low densities around northwest Connecticut barred owl nests.

Qualitative descriptions of barred owl habitat (Carter 1925, Errington and McDonald 1937, Bent 1938, Stearns 1947, Soucy 1976, and Sutton and Sutton 1985) identified a positive association of barred owls with wet areas. Bosakowski et al. (1987) also noted a positive association of a categorical topographic variable called swamp/marsh habitat with barred owl nest sites. Fuller (1979), in a radiotelemetry study of barred owls in Minnesota, noted that dense lowland habitats (marshes and swamps) were used most frequently during reduced activity periods. Elody (1983) also found a positive correlation with marsh use and 7 radioed barred owls in Michigan. It is possible that the dense vegetation associated with marshes and swamps offered protection from mobbing and/or predation as suggested by Elody (1983), Carter (1925), and Stirling (1970).

Bosakowski et al. (1987) suggested that swamps and marshes "almost always" were associated with greater abundance and diversity of prey than other topographic types on their study area. Small mammals composed approximately 80% of the barred owls' diet in Michigan (44% Rodentia, 35% Insectivora, 9.8% songbirds, 7.2% Arthropoda, and 2.4% Amphibia and Reptilia, Elody 1983). Cricetidae and Soricidae composed 81.5% of the mammals and 53.7% of the total prey in a Maryland barred owl study (Devereaux and Mosher 1984). Root and DeSimone (unpubl. rep.) collected food habits information by direct observation of prey brought to nests, prey remains found in nests, and pellet analysis. Birds composed 70% of the diet, mammals 24% (12% meadow voles, *Microtus pennsylvanicus*), and amphibians 6%. *Microtus* may be associated with wet areas, the other birds and mammals most often found as prey were not necessarily marsh/swamp related species (common flicker, *Colaptes auratus*, blackbirds and northern orioles, Family Icteridae, starlings, *Sturnus vulgaris*, white-breasted nuthatches, *Sitta carolinensis*, etc.). Root and DeSimone (unpubl. rep.) also observed that barred owl nests generally were close (average of 39 m) to swamps or streams. Closer examination of the habitat associations of these prey species might correlate with observation of certain raptor-habitat associations.

Smith (1978) found that barred owls in Connecticut avoided lakes and marshes as the nearest water. Devereaux and Mosher (1984) found no difference in the proximity to water between barred owl nest sites and random sites in Maryland. They suggested that because wet areas are often inaccessible to logging and development activities, trees have been undisturbed for longer periods, providing old growth and abundant nesting cavities. The association of barred owls with water appears to be complex and possibly related to a number of factors including food, protection afforded by denser forests associated with wet areas, and the greater numbers of large, old, decadent trees due to inaccessibility of wet areas.

Elody (1983) reported the highest known breeding densities of barred owls and found nest sites in forests that primarily were contiguous with very few openings. Smith (1978) found a negative correlation of barred owl occurrence with human dwellings in Connecticut and New Hampshire. Bosakowski et al. (1987) qualitatively noted a lack of human dwellings and roads, and fewer forest openings around barred owl nest sites than at nest sites of 2 other strigiformes. Barred owls were less often found within 100 m of human habitation and seemed to favor sites >500 m from human activity. McGarigal and Fraser (1984) noted whether barred owls located while responding to tape recorded vocalization were >1 km or ≤ 1 km from farmland habitat. They found no association of barred owls with this habitat type, although great horned owls (*Bubo virginianus*) were found closer to farmland. In radiotelemetry studies Nicholls and Warner (1972) found that barred owls avoided fields and open marsh. However, Fuller (1979) showed greater use of fields by barred owls in a radiotelemetry study in the same area that sampled more frequent locations of barred owl habitat use. Devereaux and Mosher (1984) reported that barred owl nests in the central Appalachians were closer to forest openings, which included any break in forest continuity such as created by trails, roads, fields, etc., than random points.

Goshawk habitat associations

Research conducted in the United States, and in Europe have shown that northern goshawk nests were found most often in dense, mixed stands of mature or old growth forest. Seventeen of 22 northern goshawk nests in New Jersey and New York were in forests with mature or old growth mixed stands having greater basal areas and greater densities of trees over 20 cm dbh (overall density of 662 trees/ha) than stands where random points were located (Speiser and Bosakowski 1987). They noted selection of mixed stands dominated by conifers (hemlock, pine, and cedar) and northern hardwoods, with hemlocks being the most dominant species at nest sites and oak the least dominant. Allen (1978) reported that northern goshawks nested in mature beech-maple or sugar maple-yellow birch habitat in the Adirondacks of New York. Moore and Henny (1983) and Reynolds et al. (1982) found northern goshawks in old growth conifer stands. Reynolds et al. (1982) reported densities of 482 trees/ha at northern goshawk nest areas. In a study conducted in Germany, Dietzen (1978) found northern goshawks selected nest trees in mixed stands of fir, pine, and beech. Other investigations of northern goshawk nesting habitat from western North America (Schnell 1968, Shuster 1980, Hall 1984) and Europe (Hoglund 1964, Marquiss and Newton 1982) also indicated an association with mature and old-growth forest.

Explanations for the association with dense, mature, mixed forests have been postulated and are similar to those presented for the barred owls association with these habitat types.

Northern goshawks often select the largest tree in a stand for nesting (Dietzen 1978, Reynolds et al. 1982). Mature forests provide more suitable nest trees and the open understory affords flyway space which may enhance prey vulnerability and hunting success (Moore and Henny 1983, Devereaux and Mosher 1984). Moore and Henny (1983) noted higher insolation (particularly prior to deciduous leaf-out when northern goshawks return to nest) at northern goshawk nests provided by denser canopy and greater percentage of conifer species. Because they are early nesters, thermoregulation may be a selective factor. Vegetation also might protect adults and fledged young from predators and provide shade and relatively mild environments during the summer months (Reynolds 1983). Research in a variety of regions also shows that northern goshawks avoid southern slopes (Speiser and Bosakowski 1987), and generally are found on gentle to moderate slopes with northerly aspects (Dietzen 1978, Reynolds et al. 1982). Reynolds (1983) suggested that there is less solar radiation and evaporation on northerly aspects, resulting in higher soil moisture and a greater tree density favoring tree species with greater leaf area which result in more shading. The northern goshawk, having evolved primarily in shaded forests (Wattel 1973), may have a low tolerance of high temperatures and direct sunlight. The recent southern range expansion of the northern goshawk has been attributed to the maturation of eastern U.S. forests (Bull 1974, Postupalsky 1975, Speiser and Bosakowski 1987). Destruction of old growth forest stands in the northwest has been cited as a cause of the near extirpation of northern goshawks in northeastern Oregon (Mannan and Meslow 1984). However, radiotelemetry studies conducted by Kenward (1982) in Europe provide somewhat conflicting information. Northern goshawks in his study area showed a preference for woodland edge and an avoidance of both open country and deep woodland. Birds were selecting home ranges with small woods rather than extensive forest, but woodlands were important to the birds; they spent 50% of the daylight hours in wooded areas even though only 12% of their ranges were wooded.

Proximity to forest openings and/or human disturbance factors also have been measured by researchers in North America and in Europe. Gamauf (1988) noted that northern goshawk nests in Germany were farther from openings, roads, and human habitation than nests of two other raptors. Kostrzewa (1987), also in Germany, observed that nests were a greater distance to wood edges and found only in uninfluenced plots with no human interference. Northern goshawks were statistically separated from the 2 other raptors due to human interference variables and variables concerning landscape (distance to forest edge, number of lanes (roads, trails, etc.) (Kostrzewa 1987). In studies conducted by Hennessy (1978) and Speiser and Bosakowski (1987) nest sites were farther from human habitation than random sites, however Speiser and Bosakowski (1987) found that nests were significantly closer to woods roads than random sites. In their study area, woods roads represented the only break in otherwise contiguous forest and the authors suggested that the roads may be landmarks providing orientation to nest sites. This association also was noted by Root and DeSimone (unpubl. rep.) in the same Connecticut study area, and for some of the same nest sites I measured during this study. They measured distance to nearest woods roads on the ground and found that nests were an average distance of 153 m from the nearest woods road. Other researchers have noted the association with woods roads and attributed it to search bias along roads (Titus pers. commun.) or explained it as an association due to northern goshawk's use of woods roads as flight paths for hunting and/or ease of travel. Speiser and Bosakowski (1987) also determined that northern goshawk nests were found at higher elevations than random sites. Remote expanses of forest were more common at higher altitudes on their study area (northern New Jersey and southeastern New York). These high elevation wilderness areas could be important reserves for raptor species (Fraser 1986).

An association of northern goshawk nests with water has been noted in several studies (Hennessy 1978, Reynolds et al. 1982, and Speiser and Bosakowski 1987). Nests were found most often in forest stands with springs or quiet streams in Oregon (Reynolds et al. 1982). Nests were significantly closer to swamps in New Jersey and New York and Speiser and Bosakowski (1987) suggested that moisture and soil conditions in these areas may favor growth of conifers and northern hardwoods in otherwise oak dominated areas. Swamps generally are less accessible and experience less human disturbance. Greater density and diversity of prey also might be associated with swamp areas, as was discussed previously for barred owls.

Red-shouldered hawk habitat associations

The prominence of mature forest at red-shouldered hawk nests has been reported by Wright (1916), Beardslee and Mitchell (1965), and Moore and Henny (1973) in the southeast, Portnoy and Dodge (1979) in Massachusetts, Titus and Mosher (1981) in Maryland, Bednarz and Dinsmore (1981) in Iowa, Morris and Lemon (1983) in Quebec, and Bryant (1986) in Ontario. Galli et al. (1976) and Robbins (1979) believed that red-shouldered hawks required a contiguous forested area of 10-100 ha. High basal areas (relative to those found at nests of several other raptors), more large overstory trees and a well developed mature understory stratum were forest characteristics reflecting the old growth timber associated with red-shouldered hawk nest sites in Maryland (Titus and Mosher 1981). Red-shouldered hawks nested in mature forest stands dominated by sugar maple or American beech in southwestern Quebec (Morris and Lemon 1983). Those stands had a relatively high density of mature trees (227/ha) and reduced understory. Extent of forest does not appear to be as important to red-shouldered hawks as northern goshawks, however. Red-shouldered hawks have been found nesting in areas ranging from small woodlots to extensive wooded areas in Quebec (Morris and Lemon 1983), suggesting that they might be relatively flexible in this aspect of their nest site selection. They observed that although red-shouldered hawks might prefer seclusion, they sometimes nested surprisingly close to human habitation.

Morris and Lemon (1983) calculated frequency of occurrence and importance values for tree species measured at red-shouldered hawk nest sites in Quebec. Sugar maple, American beech, red maple, basswood, and hemlock had highest importance values, the importance of American beech was significantly greater at nests than at random points.

Stewart (1949) and Bent (1938) first described an association of red-shouldered hawks with moist areas; Bednarz and Dinsmore (1981), Titus and Mosher (1981) and Morris and Lemon (1983) also observed the association of wet areas, marshes, and/or swamps and red-shouldered hawks. In Iowa, the dominant topographic features associated with red-shouldered hawk nests were floodplain forest, upland forest or marsh (Bednarz and Dinsmore 1981). Bottomland forest was particularly important habitat, and red-shouldered hawks generally were found where this habitat type was concentrated or clumped. Upland forest was used only in areas immediately adjacent to bottomland habitat. Morris and Lemon (1983) and Bednarz and Dinsmore (1981) used water-related variables (distance to seasonal water, distance to permanent water, area of floodplain forest, area of marsh, etc) to evaluate food availability and hunting habitat. An analysis of prey remains in Iowa (Bednarz 1979) showed that red-shouldered hawks obtained most of their prey from marshes and wetlands. Information regarding hunting habitat of red-shouldered hawks in Connecticut is based on direct observation of types of prey brought to the nests, prey remains found in nests, pellet analysis, and an attempt to associate these prey items with appropriate habitat and topographic types (Root and DeSimone unpubl. rep.). The primary food source during the breeding season in Connecticut was the eastern chipmunk (*Tamias striatus*). Mammals composed 53% of the diet, amphibians 28%, birds 12%, and reptiles 7%. It could be assumed that the amphibians were obtained in swamp or wetland habitat. Morris and Lemon (1983) cautioned researchers interpreting the role of food supplies in nest site selection by red-shouldered hawks. They noted the situation in Quebec where migrant red-shouldered hawks return to nest and begin egg laying in late March or early April when the abundance or location of prey species may not be immediately evident due to late winter conditions and seasonality of many of the prey (dates and situations similar in Connecticut). Food supplies may be of questionable use as a proximate cue in nest site selection (Sturman 1968, Hilden 1965).

Results

Ground level habitat associations

Among-species differences

Differences primarily occurred between red-shouldered hawk nest areas and nest areas of the other two species (Table 5). The density of red maple was greater (Table 6) at red-shouldered hawk nest areas than at northern goshawk or barred owl nest areas and beech density was greater at red-shouldered hawk nest areas than at northern goshawk nest areas. Tree density, density of hemlock, beech, and red maple, and red maple and deciduous species basal areas were greatest at red-shouldered hawk nest areas. The percentage of forest, pine density and conifer basal area were greatest at northern goshawk nest areas (Table 6, Appendix 2 reports exact significance levels of all tests for differences among ground habitat variables).

Fourteen habitat characteristics showed significant differences among species in univariate parametric and nonparametric analyses. Tree density, basal area, percentage of forested land, beech, hemlock, sugar maple, red maple, conifer species, and deciduous species densities, and basal areas of beech, oak, hemlock, sugar maple, red maple, conifer species, and deciduous species were used for the discriminant analysis procedures. User's accuracy was highest for northern goshawk nest areas, producer's accuracy was highest for red-shouldered hawk nest areas, and Cohen's kappa was .69 (Table 7).

The first canonical function was significant and accounted for 63.1% of the variation. It was interpreted to represent greatest red maple and beech density, and greatest beech basal area at red-shouldered hawk nest areas (Table 8). These 3 habitat characteristics were most responsible for separating red-shouldered hawk nest areas (high values on the variables) from northern goshawk nest areas (low values), with intermediate values on the variables for barred owl nest areas. Appendix 4 presents discriminant function models derived from this analysis.

Species-random area differences

The second objective of the study was to describe differences in habitat characteristics at nest areas used by red-shouldered hawks, northern goshawks, and barred owls when compared to random areas. The 49 random areas represented an estimate of habitat available to the 3 raptor species within the study area.

Sugar maple density and basal area were greater at barred owl nest areas than at random areas. These were the only variables differing between barred owl nest areas and random points (Table 6).

Table 5. Habitat characteristics measured at the ground scale in Litchfield County, Connecticut, 1987, that differed among barred owl, northern goshawk, and red-shouldered hawk nest areas.

Variable	P	Difference[a]
Tree density[b]	0.044	BO-RS
% Forest	0.026[c]	
Beech density	0.004	GO-RS
Red maple density	0.001	BO-RS GO-RS
Pine density	0.050[c]	
Hemlock density	0.025[c]	
Beech basal area[d]	0.043	GO-RS
Red maple basal area	0.050[c]	
Conifer basal area	0.039	BO-GO
Deciduous basal area	0.036	GO-RS

[a] BO = barred owl
GO = goshawk
RS = red-shouldered hawk
[b] Densities in # trees/ha
[c] Significance determined by Wilcoxon rank-sum test
[d] Basal areas in m^2/ha

Table 6. Means (SE) of 34 habitat characteristics measured at a ground scale at barred owl, goshawk, and red-shouldered hawk nest areas, and random areas in Litchfield County, Connecticut, in 1987.

Variable	Barred owl n=21	Northern goshawk n=30	Red-shouldered hawk n=17	Random points n=49
Dbh (cm)	26 (0.6)	27 (0.6)	26 (0.7)	26 (0.3)
Tree density[a]	516 (43.9)	583 (36.4)**[b]	687 (54.7)**	436 (17.6)
Basal area[c]	35 (3.2)	39 (2.3)**	46 (4.9)**	29 (1.1)
Canopy cover (%)	42 (0.6)	42 (0.4)**	43 (0.5)**	40 (0.4)
Canopy height (m)	22 (0.7)*	21 (0.8)**	20 (0.5)**	25 (0.5)
% Forest	94.0 (2.0)	98.2 (0.9)**	96.6 (1.6)*	87.7 (1.9)
Ash density	44 (8.4)	38 (8.6)	27 (7.9)	34 (4.9)
Beech density	43 (12.3)	26 (7.6)	90 (21.4)*	24 (6.6)
Birch density	67 (11.2)	60 (8.6)	65 (10.0)	59 (5.3)
Oak density	39 (9.4)	91 (18.5)	57 (12.1)	51 (7.4)
Pine density	58 (17.1)	85 (22.0)	23 (9.9)	39 (9.1)
Hickory density	8 (2.5)	10 (2.9)	5 (2.1)	7 (1.9)
Hemlock density	85 (16.0)	135 (23.1)*	200 (35.6)**	66 (9.3)
Sugar maple density	56 (12.7)**	36 (6.2)	44 (14.7)	18 (2.7)
Red maple density	84 (15.2)	71 (9.8)*	144 (17.1)*	103 (6.4)
Misc. spp. density	28 (3.7)	26 (5.3)	28 (5.0)	31 (3.9)
Conifer density	143 (19.6)	221 (25.4)**	223 (33.1)**	105 (12.0)
Deciduous density	372 (38.8)	361 (24.3)	463 (35.1)*	330 (14.3)
Ash basal area	2 (0.5)	2.3 (0.6)	2.5 (0.5)	2.9 (0.4)
Beech basal area	3.3 (0.9)	2.6 (0.6)	6.4 (1.6)*	2.3 (0.4)

Table 6 continued.

Variable	Barred owl n=21	Northern goshawk n=30	Red-shouldered hawk n=17	Random points n=49
Birch basal area	3.1 (0.6)	3.0 (0.5)	3.5 (0.6)	3.0 (0.3)
Oak basal area	4.2 (0.8)	8.3 (1.3)	7.0 (1.4)	4.9 (0.6)
Pine basal area	9.7 (2.3)	9.7 (2.2)	6.0 (2.1)	5.8 (1.3)
Hickory basal area	1.1 (0.3)	1.2 (0.3)	1.1 (0.4)	1.2 (0.4)
Hemlock basal area	6.5 (1.2)	11.2 (1.7)*	13.1 (2.4)*	5.4 (0.7)
Sugar maple basal area	5.8 (2.5)*	1.8 (0.4)	2.4 (0.7)	1.8 (0.4)
Red maple basal area	5.0 (0.9)	4.7 (0.6)	10.0 (2.0)	5.6 (0.4)
Misc. spp. basal area	1.6 (0.3)	1.4 (0.3)	1.9 (0.3)	1.8 (0.3)
Conifer basal area	11.8 (1.8)	19.1 (2.0)**	16.0 (2.5)	9.2 (1.0)
Deciduous basal area	23.8 (3.2)	21.2 (1.6)	30.6 (3.0)*	20.4 (0.9)
Elevation (m)	342.2 (23.8)	347.8 (18.0)	400.5 (23.1)	358.6 (15.6)
Slope (%)	45.9 (5.0)	55.3 (4.7)	42.1 (6.0)	52.0 (4.5)
Distance to water (m)	177.7 (39.3)	187.2 (29.7)	104.3 (35.3)	186.2 (26.7)
Distance to disturbance (m)	234.1 (43.3)	376.7 (46.9)*	282.6 (47.7)	212.1 (30.8)

[a] Densities in # trees/ha
[b] ** Variable significant ($P < 0.001$) for individual species/random analysis (t-test or Wilcoxon rank-sum test)
 * Variable significant ($P < 0.01$) for individual species/random analysis (t-test or Wilcoxon rank-sum test)
[c] Basal areas in m^2/ha

Table 7. Accuracy assessment of discriminant analysis conducted to predict species association of habitat plots based on 14 habitat characteristics measured at barred owl, northern goshawk, and red-shouldered hawk nest areas in Litchfield County, Connecticut, 1987.

	Predicted Group Associations						
Actual Group Associations	Barred owl n=21	Northern goshawk n=30	Red-shouldered hawk n=17	Row Total	Producer's Accuracy	User's Accuracy	Kappa
Barred owl	13	6	2	21	68%	62%	.69
Northern goshawk	2	27	0	29	79%	93%	
Red-shouldered hawk	4	1	12	17	86%	71%	
Column total	19	34	14	67			

Table 8. Correlations of variables with canonical functions derived from 4 discriminant function analyses to describe differences among nest areas of 3 species of raptors and between all possible pairs. Data were measured for 80 ha circular plots centered on the nest sites.

	Canonical function				
	BO/GO/RS[a]		BO/RA	GO/RA	RS/RA
Variable	I	II	I	I	I
Tree density[b]	0.19	0.51	0.41	0.59	0.84
Basal area[c]	0.17	0.44	0.47	0.64	0.77
% Forested	-0.25	0.37	0.40	0.59	0.46
Beech density	0.57	0.28	0.30	0.02	0.64
Hemlock density	0.19	0.61	0.22	0.48	0.78
Sugar maple density	0.16	-0.25	0.75	0.45	0.45
Red maple density	0.59	0.39	-0.28	-0.42	0.48
Conifer density	-0.11	0.51	0.34	0.65	0.67
Deciduous density	0.36	0.28	0.26	0.19	0.67
Beech basal area	0.52	0.35	0.21	0.01	0.62
Hemlock basal area	0.07	0.63	0.10	0.52	0.72
Sugar maple basal area	0.15	-0.46	0.51	0.11	0.19
Conifer basal area	-0.26	0.42	0.31	0.66	0.52
Deciduous basal area	0.45	0.22	0.28	0.07	0.69
Distance to disturbance	-0.34	0.30	0.08	0.46	0.21
Cumulative variance accounted for	63.1	36.9	100.0	100.0	100.0
Significance of canonical function[d]	0.005	0.092	0.019	0.001	0.001

[a] BO = barred owl
GO = northern goshawk
RS = red-shouldered hawk
[b] Densities in # trees/ha.
[c] Basal areas in m^2/ha.
[d] As determined by Wilk's lambda.

Hemlock and conifer species density and basal area were greater at northern goshawk nest areas than random areas. Red maple density was lower at northern goshawk nest areas than random areas. Northern goshawk nest areas also were farther from areas of human influence than random areas.

Red-shouldered hawk nest areas had greater densities of beech, hemlock, red maple, conifer species, and deciduous species than random areas (Table 6). Beech, hemlock and deciduous species basal areas were greater at red-shouldered hawk nest areas than random areas.

Percent canopy cover, tree density, basal area, and the percentage of forest area were greater at northern goshawk and red-shouldered hawk nest areas than random areas. Canopy height was consistently higher at random areas than barred owl, northern goshawk, or red-shouldered hawk nest areas (Table 6, Appendix 5 contains significance levels of all ground habitat characteristics).

Producer's accuracy was highest for red-shouldered hawk nest areas (100%) and lowest for barred owl nest areas. Cohen's kappa was highest for the red-shouldered hawk/random area analysis and lowest for the barred owl/random area analysis (Table 9, Appendix 6 contains the discriminant functions for these analyses).

The canonical function for the barred owl nest area/random area discriminant analysis represented greater sugar maple density and basal area at barred owl nest areas than random areas (Table 8). The canonical function for the northern goshawk nest area/random area discriminant analysis was highly significant. It represented greater basal area and conifer density and basal area, with a higher percentage of forested land, and greater hemlock density and basal area at northern goshawk nest areas than random areas. The canonical function for the red-shouldered hawk nest area/random area analysis showed greater tree density and basal area and greater hemlock density and basal area at red-shouldered hawk nest areas than random areas. Appendix 6 contains the discriminant functions for these analyses.

Table 9. Accuracy assessment of 3 discriminant function analyses conducted for habitat characteristics measured at a ground scale between barred owl, northern goshawk and red-shouldered hawk nest areas, and random areas in Litchfield County, Connecticut, 1987.

Actual Group Association	Predicted Group Association: Barred owl n=21	Random area n=49	Row Total	Producer's Accuracy	User's Accuracy	Kappa
Barred owl	13	8	21	72%	62%	.50
Random	5	44	49	85%	90%	
Column total	18	52	70			

	Northern goshawk n=30	Random area n=49	Row Total	Producer's Accuracy	User's Accuracy	Kappa
Northern goshawk	23	6	29	82%	79%	.70
Random area	5	44	49	88%	90%	
Column total	28	50	78			

	Red-shouldered hawk n=17	Random area n=49	Row Total	Producer's Accuracy	User's Accuracy	Kappa
Red-shouldered hawk	12	5	17	100%	71%	.78
Random area	0	49	49	91%	100%	
Column total	12	54	66			

Raptor habitat associations based on 4 scales of aerial photography

Among-species differences

Differences in habitat characteristics among the 3 raptor species were detected only at the 1:12,000 scale of aerial photography (Tables 10, 11, 12, and 13). Barred owl nest areas had more patches than northern goshawk or red-shouldered hawk nest areas. Barred owl nest areas also had a greater percentage of open water than northern goshawk nest areas where no open water was identified (Appendix 7 contains significance levels of all variables for these analyses).

Seven habitat characteristics were statistically significant in univariate parametric analyses conducted among species. Distance to water and distance to opening, number of patches, and the percentage of open water, non-forested, swamp, and agricultural land were used for the discriminant analysis procedures. Producer's and user's accuracies were highest for northern goshawks and lowest for red-shouldered hawks (Table 14).

The first canonical function in the among-species analysis at the 1:12,000 scale of aerial photography was significant and represented a higher percentage of open water and a greater number of patches per 80 ha sample at barred owl nest areas than northern goshawk or red-shouldered hawk nest areas (Table 15).

Results of discriminant analyses at the 1:40,000 and 1:58,000 scales were not significant (Table 15). Small sample sizes at the 1:126,000 scale did not allow meaningful interpretation of the results of the discriminant analyses.

Table 10. Means (SE) of 21 habitat characteristics at barred owl, northern goshawk, and red-shouldered hawk nest areas, and random areas, as determined from 1:12,000 B&W aerial photography.

Variable	Barred owl n=20	Northern goshawk n=25	Red-shouldered hawk n=17	Random areas n=41
Distance to water (m)	6898 (1264.9)	10647 (1537.5)	4573 (1280.6)	6935 (920.9)
Distance to opening (m)	7165 (939.1)	10043 (1234.7)*[a]	8340 (2225.7)	6537 (949.1)
Distance to edge (m)	1509 (300.4)	2689 (626.8)	1605 (290.1)	1819 (354.4)
Total edge (m)	5291 (341.8)	4556 (344.4)	5036 (317.9)	5366 (240.7
Road corridors (m)	701 (137.2)	518 (128.3)	513 (129.9)	771 (135.32)
Wooded corridors (m)	0 (0.0)	10 (7.9)	0 (0.0)	0 (0.0)
Stream corridors (m)	201 (80.8)	154 (49.3)	614 (200.4)	305 (83.3)
Powerline corridors (m)	25 (25.3)	38 (38.0)	0 (0.0)	95 (41.9)
Total corridor length (m)	1042 (161.3)	742 (140.7)	1128 (250.3)	1238 (171.6)
Number of patches [b]	9.1 (.52)	6.9 (.45)**	7.0 (.49)**	9.6 (.45)
% Evergreen	29.8 (5.0)	39.2 (4.7)	32.5 (4.6)	32.2 (3.5)
% Deciduous	31.2 (4.0)	30.7 (5.5)	31.8 (6.6)	36.3 (4.0)
% Mixed	21.2 (4.0)	16.7 (3.5)	23.8 (5.2)	16.9 (3.0)
% Agricultural	4.3 (1.0)	4.7 (1.5)	1.4 (0.9)	6.9 (2.0)
% Residential	1.8 (1.0)	3.2 (1.4)	0.5 (0.4)	2.0 (1.0)
% Open water [b]	4.2 (2.0)	0.0 (0.0)**	1.5 (1.1)	1.0 (1.0)
% Swamp	5.4 (2.0)	3.8 (1.6)	7.7 (4.1)	2.8 (1.0)
% Other	2.1 (1.5)	1.8 (0.4)	0.0 (0.0)	0.0 (0.0)
% Forest	82.1 (2.9)	86.6 (2.7)	88.0 (4.2)	85.3 (2.0)
% Non-forested	10.4 (3.4)	11.3 (2.8)	3.6 (1.6)	10.0 (2.1)
Time (minutes)[b]	27.7 (1.76)	22.4 (1.34)	23.0 (1.4)	25.7 (1.1)

[a]** Significance ($P < 0.001$) as determined by analysis (t-test or Wilcoxon rank-sum test) between species nest areas/random areas

* Significance ($P < 0.01$) as determined by analysis (t-test or Wilcoxon rank-sum test) between species nest areas/ random areas.

[b] Significance ($P < 0.01$) as determined by ANOVA among 3 raptor species.

Table 11. Means (SE) of 21 habitat characteristics measured at barred owl, northern goshawk, and red-shouldered hawk nest areas, and random areas as determined from 1:40,000 B&W aerial photography.

Variable	Barred owl n=20	Northern goshawk n=27	Red-shouldered hawk n=17	Random areas n=44
Distance to water (m)	13103 (4107.7)	14784 (3271.9)	10118 (2617.1)	13637 (2651.5)
Distance to opening (m)	7406 (1175.8)	9907 (1314.4)**[a]	9054 (1997.7)	5267 (755.6)
Distance to edge (m)	3012 (513.8)	5027 (967.8)	2653 (445.3)	3662 (638.9)
Total edge (m)	3784 (297.4)	3063 (201.3)	3653 (419.9)	3429 (228.6)
Road corridors (m)	626 (169.1)	393 (116.4)	412 (121.9)	763 (130.0)
Wooded corridors (m)	87 (61.1)	0 (0.0)	30 (30.9)	23 (12.2)
Stream corridors (m)	171 (87.8)	148 (55.6)	520 (219.3)	281 (87.3)
Powerline corridors (m)	48 (48.4)	93 (68.2)	0 (0.0)	55 (29.3)
Total corridor length (m)	994 (195.3)	752 (159.4)	964 (234.9)	1306 (173.0)
Number of patches	6.5 (.65)	4.9 (.40)	5.4 (.61)	5.6 (.43)
% Evergreen	13.0 (4.0)	11.8 (3.5)	17.6 (7.0)	17.2 (3.0)
% Deciduous	26.4 (7.0)	30.2 (6.2)	26.3 (7.8)	25.5 (4.0)
% Mixed	39.4 (7.7)	41.9 (6.0)	37.8 (8.2)	37.3 (5.0)
% Agricultural	6.3 (1.6)	5.3 (2.0)	1.4 (0.7)*	9.5 (2.0)
% Residential	0.4 (0.2)	3.1 (1.4)	0.6 (0.5)	2.2 (1.0)
% Open water	4.4 (1.8)	0.7 (0.4)	2.8 (1.4)	1.7 (0.1)
% Swamp	6.9 (2.3)	5.7 (2.0)	10.7 (2.9)*	4.1 (0.1)
% Other	3.3 (2.0)	1.2 (0.8)	2.7 (2.4)	2.4 (2.2)
% Forest	78.8 (3.0)	83.9 (3.1)	81.7 (2.4)	80.0 (2.5)
% Non-forested	13.3 (3.5)	11.0 (3.1)	6.2 (2.4)	15.5 (2.8)
Time (minutes)	37.3 (5.1)	26.3 (3.4)	30.9 (3.9)	32.8 (2.6)

[a] **Significance ($P < 0.001$) as determined by analysis (t-test or Wilcoxon rank-sum test) between species nest areas/random areas.

* Significance ($P < 0.01$) as determined by analysis (t-test or Wilcoxon rank-sum test) between species nest areas/random areas.

Table 12. Means (SE) of 21 habitat characteristics at barred owl, northern goshawk, and red-shouldered hawk nest areas, and random areas, as determined from 1:58,000 CIR aerial photography.

Variable	Barred owl n=20	Northern goshawk n=28	Red-shouldered hawk n=17	Random areas n=46
Distance to water (m)[a]	7825 (1736.3)	11658 (1948.3)	3141 (801.3)**[b]	10114 (1516.7)
Distance to opening (m)	7734 (999.7)	10695 (1414.8)	8864 (1495.3)	7398 (875.8)
Distance to edge (m)	2027 (396.8)	3249 (595.6)	1964 (294.1)	3339 (439.2)
Total edge (m)	3728 (382.9)	3473 (274.9)	3650 (196.5)	3138 (191.1)
Road corridors (m)	612 (118.1)	394 (111.9)	566 (153.1)	653 (10.7)
Wooded corridors (m)	0 (0.0)	15 (15.0)	0 (0.0)	6 (6.1)
Stream corridors (m)	170.4 (80.6)	141.0 (60.4)	261.6 (119.9)	195.9 (53.7)
Powerline corridors (m)	0 (0.0)	61 (42.8)	0 (0.0)	30 (22.5)
Total corridor length (m)	789 (125.1)	612 (144.9)	828 (177.4)	911 (133.7)
Number of patches	5.4 (.44)	5.1 (.40)	5.9 (.40)	4.9 (.26)
% Evergreen	32.8 (5.6)	36.4 (4.1)	34.6 (5.6)	23.9 (3.0)
% Deciduous	30.8 (6.2)	25.3 (5.4)	26.6 (4.7)	40.1 (4.0)
% Mixed	13.9 (3.9)	20.8 (3.9)	19.3 (5.1)	18.2 (3.0)
% Agricultural	6.9 (2.5)	6.0 (1.9)	1.3 (1.1)*	8.7 (2.0)
% Residential	1.1 (1.0)	2.1 (1.0)	0.9 (0.9)	2.9 (2.0)
% Open water	7.2 (2.7)	1.1 (0.5)	3.3 (1.2)	2.5 (1.0)
% Swamp	6.2 (2.2)	7.8 (1.9)*	13.7 (3.4)**	3.5 (2.0)
% Other	5.2 (3.3)	6.0 (2.5)	4.1 (1.3)	3.8 (2.1)
% Forested	77.5 (3.9)	82.5 (2.6)	80.5 (3.3)	82.2 (2.8)
% Non-forested	10.1 (2.8)	9.0 (2.2)	2.9 (1.5)*	12.0 (2.6)
Time (minutes)	17.5 (1.7)	16.2 (1.8)	17.2 (1.8)	15.2 (1.2)

[a] Significance ($P < 0.01$) as determined by ANOVA or Kruskal-Wallis.
[b]**Significance ($P < 0.001$) as determined by analysis (t-test or Wilcoxon rank-sum test) between species nest areas/random areas.
*Significance ($P < 0.01$) as determined by analysis (t-test or Wilcoxon rank-sum test) between species nest areas/random areas.

Table 13. Means (SE) of 21 habitat characteristics measured at barred owl, northern goshawk, and red-shouldered hawk nest areas, and random areas, as determined from 1:126,000 CIR aerial photography.

Variable	Barred owl n=5	Northern goshawk n=7	Red-shouldered hawk n=1[a]	Random area n=12
Distance to water (m)	10982 (3139.6)	8700 (3638.0)	1664	8347 (1586.8)
Distance to opening (m)	8652 (1996.8)	14500 (3751.1)	9984	8626 (1852.7)
Distance to edge (m)	6057 (2162.9)	5419 (2926.4)	1664	4381 (1043.5)
Total edge (m)	1934 (620.1)	1552 (516.1)	2710	1909 (257.4)
Road corridors (m)	687 (184.2)	105 (105.3)	0	0 (0)
Wooded corridors (m)	0 (0)	0 (0)	0	239 (103.4)
Stream corridors (m)	345 (345.0)	108 (108.4)	0	378 (212.9)
Powerline corridors (m)	0 (0)	0 (0)	0	63 (63.5)
Total corridor length (m)	1032 (418.8)	213 (213.7)	0	681 (278.7)
Number of patches	3.2 (.58)	2.6 (0.6)	6.0	3.4 (.40)
% Evergreen	0 (0)	0 (0)	0	7.0 (3.0)
% Deciduous	28.5 (17.8)	50.6 (16.0)	75.3	43.4 (11.6)
% Mixed	42.8 (18.5)	30.3 (14.0)	0.0	31.5 (10.0)
% Agricultural	10.2 (5.7)	5.7 (4.5)	4.7	14.6 (4.0)
% Residential	5.0 (5.0)	0 (0)	0	0 (0)
% Open water	2.0 (2.0)	2.1 (2.1)	0.0	1.3 (1.0)
% Swamp	11.4 (10.0)	11.3 (5.5)	20.0	2.3 (2.3)
% Other	0 (0)	0 (0)	0	0 (0)
% Forested	71.3 (10.3)	80.8 (6.7)	75.3	81.9 (3.6)
% Non-forested	15.2 (8.1)	5.7 (4.5)	4.7	14.6 (4.0)
Time (minutes)	9.6 (1.4)	8.3 (1.5)	10.0	9.4 (1.0)

[a] Standard error not calculated for this data

Table 14. Accuracy assessment of discriminant function analysis among barred owl, northern goshawk, and red-shouldered hawk nest areas conducted on 7 habitat characteristics as determined from 4 scales of aerial photography.

	Predicted Group Association						
Actual Group Association (Scale/film type)	Barred owl n=21	Northern goshawk n=30	Red-shouldered hawk n=17	Row Total	Producer's Accuracy	User's Accuracy	Kappa
1:12,000 B&W							
Barred owl	12	4	4	20	63%	60%	.47
Northern goshawk	2	20	3	25	69%	80%	
Red-shouldered hawk	5	5	7	17	50%	41%	
Column total	19	29	14	62			
1:40,000 B&W							
Barred owl	11	7	2	20	65%	55%	.36
Northern goshawk	4	19	4	27	57%	74%	
Red-shoulered hawk	4	8	5	17	58%	41%	
Column total	17	35	12	64			
1:58,000 CIR							
Barred owl	6	12	2	20	60%	30%	.38
Northern goshawk	1	23	4	28	59%	82%	
Red-shouldered hawk	3	4	10	17	65%	61%	
Column total	10	39	17	66			

Table 14. Continued.

Actual Group Association (Scale/film type)	Predicted Group Association: Barred owl n=21	Northern goshawk n=30	Red-shouldered hawk n=17	Row Total	Producer's Accuracy	User's Accuracy	Kappa
1:126,000 CIR							
Barred owl	3	2		5	75%	60%	.40
Northern goshawk	1	6		7	67%	86%	
Red-shouldered hawk	0	1		1			
Column total	4	9		13			

Table 15. Correlations of variables with canonical functions derived from 4 discriminant function analyses to describe differences among nest areas of 3 species of raptors and between all possible pairs. Data were measured from 4 scales of aerial photography.

	Canonical function				
	BO/GO/RS[a]		BO/RA	GO/RA	RS/RA
Variable	I	II	I	I	I
1:12,000					
Number of patches	0.67	0.42	-0.26	0.70	0.79
% Open water	0.76	-0.05	0.56	0.53	0.11
% Non-forested	-0.05	0.75	-0.15	0.02	0.55
% Swamp	0.17	-0.36	0.55	-0.07	-0.44
% Agricultural	0.04	0.72	-0.25	0.15	0.58
Distance to water	-0.27	0.61	-0.22	-0.29	0.41
Distance to opening	-0.25	0.38	-0.17	-0.50	-0.01
Cumulative variance accounted for	77.3	22.7	100.0	100.0	100.0
Significance of canonical function[b]	0.004	0.235	0.520	0.001	0.001
1:40,000					
Number of patches	0.58	0.23	0.28	0.32	-0.09
% Open water	0.80	-0.04	0.50	0.40	0.25
% Non-forested	0.08	0.58	-0.13	0.31	-0.62
% Swamp	0.24	-0.55	0.33	-0.21	0.71
% Agricultural	0.20	0.73	-0.16	0.47	-0.72
Distance to water	-0.25	0.05	-0.18	-0.04	-0.14
Distance to opening	-0.20	0.13	0.53	-0.80	0.49
Cumulative variance accounted for	60.6	39.4	100.0	100.0	
Significance of canonical function[b]	0.130	0.230	0.023	0.101	0.062

Table 15 continued

Variable	Canonical function: BO/GO/RS I	BO/GO/RS II	BO/RA I	GO/RA I	RS/RA I
1:58,000					
Number of patches	-0.29	0.07	0.35	0.19	0.44
% Open water	-0.18	0.65	-0.32	0.20	
% Non-forested	0.58	0.16	-0.11	-0.14	-0.51
% Swamp	-0.51	-0.30	0.48	0.65	0.78
% Agricultural	0.53	0.26	-0.13	-0.26	-0.54
Distance to water	0.67	-0.09	-0.34	-0.04	-0.74
Distance to opening	0.21	-0.40	0.34	0.66	0.20
Cumulative variance accounted for	72.7	27.3	100.0	100.0	100.0
Significance of canonical function[b]	0.013	0.213	0.284	0.094	0.001
1:126,000					
Number of patches	-0.53	0.51	-0.11	-0.52	0.55
% Open water	0.14	0.00	0.06	0.02	-0.17
% Non-forested	0.10	0.58	0.02	-0.78	-0.18
% Swamp	-0.25	0.03	0.48	0.73	0.71
% Agricultural	0.01	0.42	-0.28	-0.78	-0.18
Distance to water	0.28	0.51	0.29	-0.47	-0.37
Distance to opening	-0.09	-0.36	0.18	0.52	0.16
Cumulative variance accounted for	88.7	11.3	100.0	100.0	100.0
Significance of canonical function[b]	0.422	0.781	0.394	0.543	0.113

[a] BO = barred owl
GO = northern goshawk
RS = red-shouldered hawk
[b] As determined by Wilk's lambda.

Species-random area differences

There were no differences between barred owl nest areas and random areas based on the 21 habitat characteristics measured from four scales of aerial photography (Tables 10, 11, 12, and 13).

Northern goshawk nest areas were farther from forest openings than random areas at the 1:12,000 and 1:40,000 scales of aerial photography (Table 10). Northern goshawk nest areas had fewer patches and a lower percentage of open water than was found at random areas at the 1:12,000 scale; these differences were not noted at any other scale. There also was a greater percentage of swamp at northern goshawk nest areas than random areas at the 1:58,000 scale.

Red-shouldered hawk nest areas differed from random areas more consistently among scales than barred owl or northern goshawk nest areas. Red-shouldered hawk nests were farther from water than random points at the 1:58,000 scale of aerial photography (Table 12). This trend was apparent at the other scales of aerial photography, but not significant. Random areas had more habitat patches than red-shouldered hawk nest areas at the 1:12,000 scale. This trend was not significant at other scales. There was less agricultural land associated with red-shouldered hawk nest areas than random areas at the 1:40,000 and 1:58,000 scales of aerial photography. The percentage of non-forested land also was lower at red-shouldered hawk nest areas than at random areas at the 1:58,000 scale (Tables 11 and 12). Red-shouldered hawk nest areas had a higher percentage of swamp than random areas at the 1:40,000 and 1:58,000 scales (Appendices 9, 10, and 11 present significance levels for species nest area/random area analyses).

Habitat characteristics used in discriminant analyses between raptor species nest areas and random areas were distance to water, distance to opening, number of patches; and percent water, non-forested area, swamp, and agricultural land. Results of these analyses are presented in Tables 16, 17, and 18.

Table 16. Accuracy assessments based on 4 discriminant function analyses between barred owl nest areas/random areas conducted on habitat characteristics as determined from 4 scales of aerial photography.

	Predicted Group Association					
Actual Group Association (Scale/film type)	Barred owl	Random area	Row Total	Producer's Accuracy	User's Accuracy	Kappa
1:12,000 B&W (n=20/41)						
Barred owl	6	14	20	55%	30%	.20
Random	5	36	41	72%	88%	
Column total	11	50	61			
1:40,000 B&W (n=20/44)						
Barred owl	10	10	20	71%	50%	.45
Random area	4	40	44	80%	91%	
Column total	14	50	64			
1:58,000 CIR (n=20/46)						
Barred owl	4	16	20	67%	20%	.20
Random area	2	44	46	73%	96%	
Column total	6	60	66			
126,000 CIR (n=5/12)						
Barred owl	4	1	5	100%	80%	.85
Random area	0	12	12	92%	100%	
Column total	4	13	17			

Table 17. Accuracy assessment based on 4 discriminant function analyeis between northern goshawk nest areas/random areas conducted on habitat characteristics as determined from 4 scales of aerial photography.

	Predicted Group Association					
	Northern goshawk	Random area	Row Total	Producer's Accuracy	User's Accuracy	Kappa
Actual Group Association (Scale/film type)						
1:12,000 B&W (n=25/41)						
Northern goshawk	19	6	25	70%	76%	.56
Random area	8	33	41	85%	80%	
Column total	27	39	66			
1:40,000 B&W (n=27/44)						
Northern goshawk	13	14	27	65%	48%	.34
Random area	7	37	44	73%	84%	
Column total	20	51	71			
1:58,000 CIR (n=28/46)						
Northern goshawk	14	14	28	82%	50%	.47
Random area	3	43	46	75%	93%	
Column total	17	57	74			
126,000 CIR (n=7/12)						
Northern goshawk	3	4	7	60%	43%	.28
Random area	2	10	12	71%	83%	
Column total	5	14	19			

Table 18. Accuracy assessments based on 3 discriminant function analyses between red-shouldered hawk nest areas/random areas conducted on habitat characteristics as determined from 4 scales of aerial photography.

Actual Group Association (Scale/film type)	Predicted Group Association: Red-shouldered hawk	Random area	Row Total	Producer's Accuracy	User's Accuracy	Kappa
1:12,000 B&W (n = 17/41)						
Red-shouldered hawk	8	9	17	67%	47%	.41
Random area	4	37	41	80%	90%	
Column total	12	46	58			
1:40,000 B&W (n = 17/44)						
Red-shouldered hawk	7	10	17	64%	41%	.36
Random area	4	40	44	80%	91%	
Column total	11	50	61			
1:58,000 CIR (n = 17/46)						
Red-shouldered hawk	12	6	18	75%	67%	.60
Random area	4	42	46	88%	91%	
Column total	16	48	64			
1:126,000 CIR (No data)						

Correct classification (in terms of kappa) of northern goshawk nest areas was ordered from best to worst scales as follows 1:12,000, 1:58,000, 1:40,000, and 1:126,000 (Table 17). This is an opposite pattern of best scales for correct classification when compared to the barred owl nest area/random area discriminant analysis. Producer's accuracy was highest at the 1:58,000 scale and user's accuracy was highest at the 1:12,000 scale. The 1:58,000 scale had the highest kappa for red-shouldered hawk nest area classification. The 1:12,000 and 1:40,000 scales followed (Table 18). There were no red-shouldered hawk nest area samples at the 1:126,000 scale. Producer's and user's accuracies were highest for red-shouldered hawks at the 1:58,000 scale. Correct classification rates varied for specific scales among species (Tables 16, 17, 18, Appendix 12). Northern goshawk and red-shouldered hawk nest areas were correctly classified a greater percentage of the time at the 1:12,000 (B&W) and 1:58,000 (CIR) scales, and barred owl nest areas were correctly classified a greater percentage of the time at 1:40,000 (B&W) and 1:126,000 (CIR).

Canonical functions were not significant at any scale of aerial photography in analyses between barred owl nest areas and random areas (Table 15).

Northern goshawk nest areas had fewer habitat patches and were farther from areas of human influence than random areas at the 1:12,000 scale (Table 15). Canonical functions at the 1:40,000, 1:58,000, and 1:126,000 scales were not significant.

Red-shouldered hawk nest areas were associated with fewer habitat patches and a lower percentage of non-forested and agricultural land than random areas at the 1:12,000 scale (Table 15). Canonical functions at the 1:40,000 scale were not significant. Red-shouldered hawk nest areas had a greater percentage of swamp, were closer to water, and had lower percentages of non-forested and agricultural land than random areas at the 1:58,000 scale.

Summary of differences among raptor species and between species and random points

Barred owl

Of 31 habitat characteristics analyzed at the ground scale in northwest Connecticut, only density and basal area of sugar maple were significantly associated with barred owl nest areas. Overall basal area and tree density were not significantly higher at barred owl nest areas in our study, which was surprising considering the consistent identification of mature timber and old growth as an important variable in most other barred owl studies (Craighead and Craighead 1969, Nicholls and Warner 1972, Fuller 1979, Elody 1983, McGarigal and Fraser 1984, Devereaux and Mosher 1984, Sutton and Sutton 1985). None of the 21 habitat characteristics measured from 4 scales of aerial photography were comparable to variables describing mature or old growth forests. This exemplifies the importance of selecting appropriate variables and the appropriate scale of measurement in habitat assessment. I was not able to identify many barred owl habitat associations based on the variables chosen, or scales at which they were measured. Although density and basal area of hemlocks, pines, and coniferous species combined were measured at the ground scale, and the percentage of mixed and evergreen forest/80 ha area were measured from aerial photographs for the Connecticut study area, no significant association was noted for barred owls with these habitat characteristics in any analysis. This is particularly interesting considering the abundance of these three species on the study area, and their strong association with the other two raptors. Barred owl nest areas generally were in forests composed of deciduous species.

The only ground variable that directly measured association with water was linear distance to water, which was measured from 1:24,000 topographic maps. This variable showed no relationship with barred owls. Several measures of association with water were made from 4 scales of aerial photography (linear distance to water, percentage of wooded or non-wooded swamp/80 ha sample, and percentage of open water/80 ha sample). There was significantly more water (lakes and reservoirs) associated with barred owl nest areas than northern goshawk or red-shouldered hawk nest areas at the 1:12,000 scale. Differences among species were not significant at the other scales of aerial photography.

Results from the ground level in the Connecticut study indicated that barred owl nests were not significantly farther from or closer to openings than northern goshawk or red-shouldered hawk nest areas or random areas. At the 1:12,000 scale of aerial photography more habitat patches were found around barred owl nest than at northern goshawk or red-shouldered hawk nests. This pattern was not necessarily consistent from scale to scale, habitat patches were most evident at the 1:12,000 scale. Barred owls were closer to openings and edges than northern goshawks or red-shouldered hawks. but farther from openings and edges than random areas at all scales of aerial photography except 1:126,000. Care must be exercised in interpreting these results, however, because the definition of a habitat patch included various forested cover types as well as open cover types. These were not distinguished when counting the number of habitat patches. Greater numbers of patches could represent more complex habitat and a greater amount of edge, although total edge/80 ha sample was also measured and analyzed, and was not significant.

Northern goshawk

Nine of 31 habitat characteristics measured at the ground level in Connecticut enabled me to characterize the forest associated with northern goshawks on the study area as mature (high basal area, and high hemlock and conifer basal area), relatively dense (high tree density, percent canopy cover, percentage of forest, and hemlock and conifer density), and primarily coniferous (high hemlock and conifer density and basal area). An association with primarily mixed forests was not seen on the Connecticut study area, where northern goshawks were strongly associated with conifers.

Northern goshawks seemed sensitive to several human disturbance factors on the Connecticut study area. Distance to disturbance was measured from topographic maps for the ground study and was significantly farther fro northern goshawks than for barred owls, red-shouldered hawks, or random points. The distance to nearest opening (including agricultural, residential, open water) was measured from 4 scales of aerial photography. An avoidance of openings was noted at the 1:12,000 and 1:40,000 scales, but not at the 1:58,000 or 1:126,000 scales. The number of habitat patches also were measured from 4 scales of aerial photography. At the 1:12,000 scale there were significantly fewer patches in the area of northern goshawk nests than around barred owl or red-shouldered hawk nest areas, or random areas (significant associations were not observed at any other scale of aerial photography). This indicated selection of unbroken forest tracts on the Connecticut study area and avoidance of human disturbance factors.

I measured water variables at a much larger scale than other studies. I did not measure ground distances to the nearest small stream while at the nest site, and in many cases these did exist in the area. Small streams were often intermittent and not always evident on topographic maps or aerial photographs. There was no association of northern goshawks with water based on measurements of the distance to nearest water from topographic maps. Water variables measured from aerial photographs included the percentage of open water and swamps/80 ha sample and the linear distance to the nearest water. The percentage of open water was significantly negatively associated with northern goshawks at the 1:12,000 scale or aerial photography. No open water was measured within a 500 m radius of any northern goshawk nest at this scale. There was an association of northern goshawks with swamps at the 1:58,000 scale of aerial photography, one of the 2 scales of aerial photography from which swamp habitat was most easily identified. This association probably is due to similar factors described for barred owl nest area associations with swamp or wet areas.

Red-shouldered hawk

Higher tree density, basal area, and canopy cover were found at red- shouldered hawk nest areas than nest areas of barred owls and northern goshawks or at random areas. These results support other researchers observations indicating an association of red-shouldered hawk nest areas with mature forests (Wright 1916, Beardslee and Mitchell 1965, Moore and Henny 1973, Portnoy and Dodge 1979, Titus and Mosher 1981, Bednarz and Dinsmore 1981, Morris and Lemon 1983, and Bryant 1986). Red-shouldered hawk nest areas were located in areas with fewer habitat patches at the 1:12,000 scale of aerial photography, in areas with less agricultural land at the 1:40,000 and 1:58,000 scales of aerial photography, and in areas with a higher percentage of forested land than random areas at the 1:58,000 scale. These patterns were more consistent across scales than for any other species or variable, and therefore might be considered the strongest patterns of association observed in this study.

Analysis at 4 scales of aerial photography showed a significantly higher percentage of swamps in the area of red-shouldered hawk nest areas compared to random areas at the 1:40,000 and 1:58,000 scales of aerial photography. There generally was more swamp habitat associated with red-shouldered hawk nest areas than with nest areas of barred owls or northern goshawks, or random areas at all scales. The distance to water was significantly less to red-shouldered hawk nests than to random points at the 1:58,000 scale. This observed association with water probably is the result of complex and interacting factors, as was the case for northern goshawks. Increased density of forest, increased frequency of hemlock and red maple, greater density and diversity of food resources, and increased isolation of wet areas due to their inaccessibility all may be important characteristics of wet areas influencing selection of these areas as nest sites by red-shouldered hawks and northern goshawks.

Differences among scales of aerial photography

Total edge and time for interpretation were different among scales for barred owl, northern goshawk, and red-shouldered hawk nest areas, random areas, and all groups combined (Tables 19, 20, 21, 22, and 23). The greatest amount of edge always was measured at the 1:12,000 scale, the least at 1:126,000. Time for interpretation was greatest at the 1:40,000 scale and least at 1:126,000.

The number of patches and percentage of evergreen and mixed cover differed among scales for all groups except red-shouldered hawk nest areas. The percentage of forest/80 ha sample was different among scales for all groups except northern goshawk nest areas, and the percentage of deciduous cover/sample differed among scales only for random areas. In addition to those variables previously noted, distance to edge, length of road corridors, total corridor length and percentage of the catchall 'other' cover type were different among scales when all groups were combined for analysis (Table 24).

Distance to edge measurements differed among the 1:12,000 and the 1:40,000 scales, and the 1:12,000 and 1:58,000 scales (Table 24). Mean distance to edge measurements were ordered from least to greatest as follows: 1:12,000, 1:40,000, 1:58,000, 1:126,000 (Tables 19, 20, 21, 22, and 23).

Less road corridor length was measured at 1:126,000 than at 1:12,000; there was overlap between 1:40,000 and 1:58,000 scales in the amount of road corridor. The means of road corridor length were ordered from least to greatest as follows: 1:126,000, 1:58,000, 1:40,000,

Table 19. Means (SE) of 21 habitat characteristics measured at barred owl nest areas from 4 scales of aerial photography.

Variable	Scale 1:12,000 n=20	1:40,000 n=20	1:58,000 n=20	1:126,000 n=5	p[a]	Scale difference[b]
Distance to water (m)	6898 (1264.9)	13101 (4107.7)	7825 (1736.3)	10982 (3139.6)	0.589	
Distance to opening (m)	7165 (939.1)	7406 (1175.8)	7734 (999.7)	8652 (1996.8)	0.729	
Distance to edge (m)	1509 (300.4)	3012 (513.8)	2026 (39.8)	6057 (2162.9)	0.012	12-126 58-126
Total edge (m)	5291 (341.8)	3784 (297.4)	3728 (382.9)	1934 (620.1)	0.001	12-40 12-58 12-126
Road corridors (m)	701 (137.2)	626 (169.0)	612 (118.1)	687 (184.2)	0.860	
Wooded corridors (m)	0 (0.0)	87 (6.1)	6 (6.5)	0 (0)	0.262	
Stream corridors (m)	201 (80.8)	171 (87.8)	170 (80.6)	345 (345.0)	0.808	
Powerline corridors (m)	25 (25.3)	48 (48.4)	0 (0)	0 (0)	0.744	
Total corridor length (m)	1042 (161.3)	994 (195.3)	789 (125.1)	1032 (418.8)	0.285	
Number of patches	9.1 (0.5)	6.5 (0.7)	5.4 (0.4)	9.6 (1.4)	0.001	12-40 12-58 12-126
% Evergreen	29.8 (5.0)	13.0 (4.1)	32.8 (5.6)	0.0 (0.0)	0.001	12-126 40-58 58-126
% Deciduous	31.2 (4.0)	26.4 (7.0)	30.8 (6.2)	28.5 (17.8)	0.529	
% Mixed	21.2 (4.0)	39.4 (7.7)	13.9 (3.9)	42.8 (18.5)	0.034	
% Agricultural	4.3 (1.0)	6.3 (1.6)	6.9 (2.5)	10.2 (5.7)	0.724	
% Residential	1.8 (1.0)	0.4 (0.2)	1.1 (0.9)	5.0 (5.0)	0.455	
% Water	4.2 (2.0)	4.4 (1.8)	7.2 (2.7)	2.0 (2.0)	0.694	
% Swamp	5.4 (2.0)	6.8 (2.3)	6.2 (2.2)	11.4 (10.0)	0.946	
% Other	2.1 (1.5)	3.2 (1.0)	1.0 (0.8)	0.0 (0.0)	0.479	
% Forested	82.1 (29.3)	78.8 (3.0)	77.5 (3.9)	71.3 (10.3)	0.001	12-40 12-126
% Non-forested	8.2 (2.2)	10.6 (2.2)	9.1 (2.6)	15.2 (8.1)	0.781	
Time (minutes)	27.7 (1.8)	37.3 (5.1)	17.5 (1.7)	9.6 (1.4)	0.001	40-58 40-126

[a] Arcsin square root transformations were performed on % cover data and log transformations were performed on corridor and distance data prior to conducting ANOVA and multiple comparison tests.
[b] Significantly different means ($P < 0.05$) indicated by Scheffe's Multiple Range Test.
12 = 1:12,000 black and white aerial photography
40 = 1:40,000 black and white aerial photography
58 = 1:58,000 color infrared aerial photography
126 = 1:126,000 color infrared aerial photography

Table 20. Means (SE) of 21 habitat characteristics measured at northern goshawk nest areas from 4 scales of aerial photography.

Variable	Scale 1:12,000 n=25	Scale 1:40,000 n=27	Scale 1:58,000 n=28	Scale 1:126,000 n=7	p[a]	Scale difference[b]
Distance to water (m)	10647 (1537.5)	14784 (3271.9)	11658 (1948.3)	8700 (3637.9)	0.459	
Distance to opening (m)	10043 (1234.7)	9907 (1301.5)	10695 (1414.8)	14500 (3751.1)	0.589	
Distance to edge (m)	2689 (626.8)	5027 (967.8)	3249 (595.6)	5419 (2926.4)	0.242	
Total edge (m)	4556 (344.4)	3063 (201.3)	3473 (274.9)	1552 (516.1)	0.001	12-40 12-126 58-126
Road corridors (m)	518 (128.3)	393 (116.4)	394 (111.9)	105 (105.3)	0.222	
Wooded corridors (m)	10 (7.9)	0 (0)	15(15.0)	0 (0)	0.647	
Stream corridors (m)	154 (49.3)	148 (55.6)	141 (60.4)	108 (108.4)	0.731	
Powerline corridors (m)	38 (38.0)	92 (68.2)	61 (42.8)	0 (0)	0.774	
Total corridor length (m)	742 (140.7)	752 (159.4)	612 (144.9)	213 (213.7)	0.151	
Number of patches	6.9 (0.5)	4.9 (.40)	5.1 (.39)	2.6 (.57)	0.001	12-40 12-58 12-126 58-126
% Evergreen	39.2 (4.8)	11.8 (3.5)	36.4 (4.1)	0.0 (0.0)	0.001	12-40 12-126 40-58 58-126
% Deciduous	30.7 (5.5)	30.2 (6.2)	25.3 (5.4)	50.6 (16.3)	0.258	
% Mixed	16.7 (3.5)	41.9 (6.0)	20.8 (3.9)	30.3 (14.4)	0.020	12-40
% Agricultural	4.7 (1.5)	5.3 (1.9)	6.0 (1.9)	5.7 (4.5)	0.989	
% Residential	3.2 (1.4)	3.1 (1.4)	2.1 (1.0)	0.0 (0.0)	0.580	
% Water	0.0 (0.0)	0.7 (0.4)	1.1 (0.5)	2.1 (2.1)	0.126	
% Swamp	3.8 (1.6)	5.7 (1.9)	7.8 (1.9)	11.3 (5.5)	0.423	
% Other	1.8 (1.4)	1.2 (0.8)	0.4 (0.3)	0.0 (0.0)	0.376	
% Forested	86.6 (2.7)	83.9 (3.1)	82.5 (2.6)	80.8 (6.7)	0.023	
% Non-forested	9.6 (2.3)	9.7 (2.8)	8.5 (2.2)	5.7 (4.5)	0.634	
Time (minutes)	22.4 (1.3)	26.3 (3.4)	16.2 (1.5)	8.3 (1.5)	0.001	12-126 40-58 40-126

[a] Arcsine square root transformations were performed on % cover data and log transformations were performed on corridor and distance data prior conducting ANOVA and multiple comparison tests.

[b] Significantly different means ($P < 0.05$) indicated by Scheffe's Multiple Range Test.
12 = 1:12,000 black and white aerial photographs
40 = 1:40,000 black and white aerial photographs
58 = 1:58,000 color infrared aerial photographs
126 = 1:126,000 color infrared aerial photographs

Table 21. Means (SE) of 21 habitat characteristics measured at red-shouldered hawk nest areas at 4 scales of aerial photography.

Variable	Scale					
	1:12,000 n=17	1:40,000 n=17	1:58,000 n=18	1:126,000 n=1	p[a]	Scale difference[b]
Distance to water (m)	4573 (1280.6)	10118 (2617.1)	3141 (801.3)	1664 (1664)	0.120	
Distance to opening (m)	8339 (2225.7)	9054 (1997.7)	8864 (1495.3)	9984 (9984)	0.696	
Distance to edge (m)	1605 (290.1)	2653 (445.3)	1964 (294.1)	1664 (1664)	0.204	
Total edge (m)	5036 (317.9)	3653 (419.9)	3650 (196.5)	2710 (2710)	0.015	12-40 12-58
Road corridors (m)	513 (130.0)	412 (121.9)	566 (153.1)	0 (0.0)	0.681	
Wooded corridors (m)	0 (0.0)	30 (30.9)	0 (0.0)	0 (0.0)	0.561	
Stream corridors (m)	614 (200.4)	520 (219.3)	261 (119.9)	0 (0.0)	0.421	
Powerline corridors (m)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0) (0)		
Total corridor length (m)	1128 (250.3)	964 (234.9)	828 (177.4)	0 (0.0)	0.467	
Number of patches	7.0 (.49)	5.4 (.61)	5.9 (.40)	6.0 (.59)	0.153	
% Evergreen	32.5 (4.5)	17.6 (7.0)	34.6 (5.6)	0 (0.0)	0.020	
% Deciduous	31.8 (6.6)	26.3 (8.0)	26.6 (4.7)	75.3 (75.3)	0.415	
% Mixed	23.8 (5.2)	37.8 (8.0)	19.3 (5.1)	0 (0.0)	0.191	
% Agricultural	1.4 (0.9)	1.4 (0.7)	1.3 (1.1)	4.7 (4.7)	0.452	
% Residential	0.5 (0.4)	0.6 (0.5)	0.9 (0.9)	0 (0.0)	0.989	
% Water	1.5 (1.1)	2.8 (1.4)	3.3 (1.2)	0 (0.0)	0.519	
% Swamp	7.7 (4.1)	10.7 (2.9)	13.7 (3.4)	2.0 (2.0)	0.053	
% Other	0.8 (0.5)	2.7 (2.4)	0.3 (0.3)	0 (0.0)	0.378	
% Forested	88.0 (4.2)	81.7 (2.4)	80.5 (3.3)	75.3 (75.3)	0.008	12-40
% Non-forested	2.8 (1.3)	4.8 (1.5)	2.5 (1.4)	4.7 (4.7)	0.412	
Time (minutes)	23.0 (1.4)	30.9 (3.9)	17.5 (1.7)	10.0	0.003	40-58

[a]Arcsine square root transformations were performed on % cover data and log transformations were performed on corridor and distance data prior to conducting ANOVA multiple comparison tests.
[b]Significantly different means ($P < 0.05$) indicated by Scheffe's Multiple Range Test.
12 = 1:12,000 black and white aerial photography
40 = 1:40,000 black and white aerial photography
58 = 1:58,000 color infrared aerial photography
126 = 1:126,000 color infrared aerial photography

Table 22. Means (SE) of 21 habitat characteristics measured at random areas from 4 scales of aerial photography.

Variable	Scale 1:12,000 n=41	1:40,000 n=44	1:58,000 n=46	1:126,000 n=12	p[a]	Scale difference[b]
Distance to water (m)	6935 (920.9)	13637 (2651.5)	10114 (1516.7)	8347 (1586.8)	0.317	
Distance to opening (m)	6537 (949.1)	5267 (755.6)	7389 (875.8)	8625 (1852.7)	0.124	
Distance to edge (m)	1819 (354.4)	3662 (639.0)	3339 (439.2)	4381 (1043.5)	0.003	
Total edge (m)	5366 (240.7)	3429 (228.6)	3138 (191.1)	1909 (257.4)	0.001	12-40 12-58 12-126 40-126
Road corridors (m)	771 (135.3)	763 (130.0)	653 (108.7)	239 (103.4)	0.106	
Wooded corridors (m)	0 (0)	23 (12.2)	6 (6.1)	0 (0.0)	0.108	
Stream corridors (m)	305 (83.3)	281 (87.3)	196 (53.7)	378 (212.9)	0.551	
Powerline corridors (m)	95 (41.9)	54 (29.3)	30 (22.5)	63 (63.5)	0.609	
Total corridor length (m)	1238 (171.6)	911 (133.7)	0	681 (278.7)	0.014	
Number of patches	9.6 (.45)	5.6 (.43)	4.9 (.26)	3.4 (.40)	0.001	12-40 12-58 12-126 58-126
% Evergreen	32.2 (3.5)	17.2 (3.1)	23.9 (3.0)	7.0 (3.4)	0.001	12-40 12-126 58-126
% Deciduous	36.3 (3.7)	25.5 (3.9)	40.1 (4.2)	43.4 (11.6)	0.024	40-58
% Mixed	16.9 (2.5)	37.3 (4.7)	18.2 (3.0)	31.5 (9.8)	0.008	40-58
% Agricultural	6.9 (1.7)	9.5 (2.1)	8.7 (2.0)	14.6 (4.0)	0.187	
% Residential	2.0 (0.7)	2.2 (0.9)	2.9 (1.7)	0.0 (0.0)	0.466	
% Water	2.1 (0.8)	1.7 (0.7)	2.5 (0.8)	1.3 (0.8)	0.836	
% Swamp	2.8 (0.9)	4.1 (1.5)	3.5 (1.8)	2.3 (2.3)	0.639	
% Other	0.8 (0.5)	2.4 (2.0)	0.2 (0.1)	0.0 (0.0)	0.047	
% Forested	85.3 (2.1)	80.0 (2.5)	82.2 (2.8)	81.9 (3.6)	0.001	12-40 12-126
% Non-forested	9.7 (2.0)	14.2 (2.6)	11.8 (2.6)	14.6 (4.0)	0.587	
Time (minutes)	25.7 (1.1)	32.8 (2.6)	15.2 (1.2)	9.4 (1.0)	0.001	12-40 12-58 12-126 40-58 40-126

[a] Arcsine square root transformations were performed on % cover data and log transformations were performed on corridor and distance data prior to conducting ANOVA and multiple comparison tests.

[b] Significantly different means ($P < 0.05$) indicated by Scheffe's Multiple Range Test.
12 = 1:12,000 black and white aerial photography
40 = 1:40,000 black and white aerial photography
58 = 1:58,000 color infrared aerial photography
126 = 1:126,000 color infrared aerial photography

Table 23. Means (SE) of 21 habitat characteristics measured at barred owl, northern goshawk, and red-shouldered hawk nest areas, and random areas combined, from 4 scales of aerial photography.

Variable	Scale 1:12,000 n=103	1:40,000 n=108	1:58,000 n=112	1:126,000 n=25	p[a]	Scale difference[b]
Distance to water (m)	7439 (638.0)	13271 (1593.1)	8971 (891.2)	8706 (1391.9)	0.106	
Distance to opening (m)	7807 (638.2)	7419 (611.4)	8518 (592.9)	10330 (1468.9)	0.073	
Distance to edge (m)	1935 (222.3)	3724 (379.0)	2861 (253.2)	4898 (1015.9)	0.001	12-40 12-126 58-126
Total edge (m)	5100 (154.0)	3439 (136.7)	3409 (129.0)	1846 (220.1)	0.001	12-40 12-58 12-126 40-126 58-126
Road corridors (m)	653 (71.1)	590 (71.6)	567 (61.9)	282 (78.5)	0.019	12-126
Wooded corridors (m)	2 (1.9)	30 (13.3)	6 (4.5)	0 (0)	0.118	
Stream corridors (m)	300 (52.2)	265 (54.4)	188 (35.6)	281 (124.4)	0.119	
Powerline corridors (m)	52 (19.8)	54 (22.5)	27 (14.2)	30 (30.5)	0.654	
Total corridor length (m)	1062 (93.1)	1056 (97.3)	801 (75.1)	593 (173.7)	0.001	12-58 12-126 40-58 40-126
Number of patches	8.4 (.27)	5.6 (.26)	5.2 (.18)	3.2 (.30)	0.001	12-40 12-58 12-126 40-126 58-126
% Evergreen	33.5 (2.2)	15.1 (2.0)	30.4 (2.2)	3.4 (1.8)	0.001	12-40 12-126 40-58 40-126 58-126
% Deciduous	33.2 (2.4)	27.0 (3.0)	32.6 (2.6)	43.7 (7.9)	0.015	
% Mixed	18.8 (1.7)	38.9 (3.0)	18.3 (1.9)	32.1 (7.0)	0.001	12-40 40-58
% Agricultural	5.0 (0.8)	6.6 (1.0)	6.5 (1.1)	10.8 (2.6)	0.088	
% Residential	2.0 (0.5)	1.9 (0.5)	2.1 (0.8)	1.0 (1.0)	0.453	
% Water	1.9 (0.5)	2.1 (0.5)	3.1 (0.6)	1.6 (0.8)	0.256	
% Swamp	4.4 (0.9)	6.0 (1.0)	6.7 (1.1)	7.3 (2.8)	0.757	

Table 23 continued.

Variable	Scale					
	1:12,000 n=103	1:40,000 n=108	1:58,000 n=112	1:126,000 n=25	p[a]	Scale difference[b]
% Other	1.3 (0.6)	2.4 (1.0)	0.4 (0.3)	0.0 (0.0)	0.002	40-58 40-126
% Forested	85.4 (1.4)	81.0 (1.4)	81.2 (1.6)	79.2 (3.2)	0.001	12-40 12-58 12-126 40-58 58-126
% Non-forested	8.2 (1.1)	10.8 (1.4)	9.0 (1.3)	11.8 (2.8)	0.329	
Time (minutes)	24.8 (7.1)	31.7 (1.8)	16.2 (0.7)	9.2 (0.7)	0.001	12-40 12-58 12-126 40-58 40-126

[a]Arcsine square root transformations were performed on % cover data and log transformations were performed on corridor and distance data prior to conducting ANOVA and multiple comparison tests.
[b]Significantly different means ($P < 0.05$) indicated by Scheffe's Multiple Range Test.
12 = 1:12,000 black and white aerial photography
40 = 1:40,000 black and white aerial photography
58 = 1:58,000 color infrared aerial photography
126 = 1:126,000 color infrared aerial photography

Table 24. Habitat characteristics that differed ($P < 0.05$, ANOVA among scales) for all data groups combined, among 4 scales of aerial photography.

Variable	1:12,000/ 1:40,000	1:12,000/ 1:58,000	1:12,000/ 1:126,000	1:40,000/ 1:58,000	1:40,000/ 1:126,000	1:58,000/ 1:126,000
Distance to edge (m)	X		X			X
Total edge (m)	X	X	X		X	X
Road corridors (m)			X			
Total corridor length (m)		X	X	X	X	
Number of patches	X	X	X		X	X
% Evergreen	X		X	X	X	X
% Deciduous				X		
% Mixed				X		
% Other				X		
% Forested	X	X	X	X		X
Time (minutes)	X	X	X	X	X	

1:12,000 (Tables 19, 20, 21, 22, 23), with significant differences between 1:12,000 and 1:58,000, 1:12,000 and 1:126,000, 1:40,000 and 1:58,000, and 1:40,000 and 1:126,000 (Table 24).

The greatest number of habitat patches generally were counted at the 1:12,000 scale of aerial photography (Tables 19, 20, 21, 22, and 23). The 1:40,000 and 1:58,000 scales were similar in the number of patches identified; the 1:126,000 scale consistently had fewest patches. Significant differences in the number of patches were found among all scale combinations except the 1:40,000 and 1:58,000 comparison (Table 24).

The lowest percentage of evergreen cover was measured from the 1:126,000 scale; the greatest percentage from the 1:12,000 and 1:58,000 scales (Tables 19, 20, 21, 22, and 23). Differences among scales for combined data were significant for all combinations of scales except 1:12,000 and 1:58,000 (Table 24). Measurements at these 2 scales were similar and generally twice as great as measurements at the 1:40,000 scale.

Variability was high among species and random groups in the ordering of means among scales for percentage of deciduous cover. Ordering of the means from least to greatest generally was 1:40,000, 1:12,000, 1:58,000, 1:126,000 (Tables 19, 20, 21, 22, and 23) with significant differences only between 1:40,000 (B&W) and 1:58,000 (CIR) scales (Table 24).

Differences in percentage of mixed cover occurred only between 1:40,000 and 1:58,000 scales (Table 24). Means of percentage of mixed forest were ordered (least to greatest) 1:58,000, 1:12,000, 1:126,000, 1:40,000 (Tables 19, 20, 21, 22, and 23).

Measurements of percentage of forest per sample were consistent across species and random groups. The ordering of the means followed the pattern 1:126,000, 1:58,000, 1:40,000, and 1:12,000 with the least percentage of forest at the 1:126,000 scale (Tables 19, 20, 21, 22) and differences among all scales except 1:40,000 and 1:126,000 (Table 24).

The 1:126,000 scale of aerial photography took the least time for interpretation and digitizing. Means were ordered (from least to greatest) across species and random groups for each scale: 1:126,000, 1:58,000, 1:12,000, 1:40,000 (Table 23). There were differences in time required for interpretation and digitizing among all scales except 1:58,000 and 1:126,000 (Table 24).

Friedman's test for concordance (Lehman 1975) was conducted on means of habitat characteristics ordered from least to greatest across scales. These tests provided information which allowed an assessment of the consistency of measurement of a particular variable among scales. The tests indicated a significant degree of consistency among scales for all distance variables (Table 25). There was consistency among scales for the road corridor length per sample but for none of the other corridor variables. The percentage of swamp was the only cover type variable that showed consistency among scales.

Coefficients of variation provided an indication of the variability of habitat characteristics among scales. I assigned most of the habitat characteristics into 3 groups including distance measurements, corridor length measurements, and patch variables. Total edge, total corridor length, number of patches, and time were considered individually. I calculated means of the coefficients of variation for each group and compared these means among scales and species (Table 26). Distance variables generally had the lowest coefficients of variation of the grouped variables (ranging from 65-113). Corridor length variables had the highest coefficients of variation (ranging from 119-369); cover type variables had intermediate values for the coefficient of variation (ranging from 155-238). Time, total edge, and number of patches generally had the lowest overall coefficients of variation, with the total length of corridors being higher than these three, but generally lower than any of the groups of variables.

Coefficients of variation for the distance variables were highest at the 1:40,000 scale of aerial photography for barred owl nest areas and random areas, highest at the 1:12,000 scale for red-shouldered hawk nest areas, and highest for northern goshawks at the 1:126,000 scale. Coefficients of variation for the corridor variables generally were highest for barred owl nest areas at the 1:40,000 scale and lowest at the 1:126,000 scale; highest for northern goshawk nest areas at 1:58,000 and lowest at 1:40,000; highest for red-shouldered hawk nest areas at 1:40,000 and lowest at 1:12,000; and highest for random areas at 1:58,000 and lowest at 1:12,000.

Patch variable coefficients of variation were highest for barred owl nest areas at 1:58,000 and lowest at 1:40,000; highest for northern goshawks at 1:40,000 and lowest at 1:12,000;

Table 25. Ordered means (least to greatest) and significance (determined by Friedman's test of concordance) of habitat characteristics measured at 4 scales of aerial photography.

	Distance to water $P = 0.012$	Distance to opening $P < 0.001$	Distance to edge $P < 0.001$	Total edge $P < 0.001$
1:12000	RS BO RA GO	RA BO RS GO	BO RS RA GO	GO RS BO RA
1:40000	RS BO RA GO	RA BO RS GO	RS BO RA GO	GO RA RS BO
1:58000	RS BO RA GO	RA BO RS GO	RS BO GO RA	RA GO RS BO
1:126000	RS RA GO BO	RA BO RS GO	RS RA GO BO	GO RA BO RS
	Road corridors $P < 0.003$	**Wooded corridors $P = 0.141$**	**Stream corridors $P = 0.077$**	**Powerlines $P = 0.052$**
1:12000	RS GO BO RA	RS GO BO RA	GO BO RA RS	RS BO GO RA
1:40000	RS GO BO RA	RS BO GO RA	GO BO RA RS	RS BO RA GO
1:58000	GO RS BO RA	RS GO BO RA	GO BO RA RS	BO RS RA GO
1:126000	RS GO RA BO			BO GO RS RA
	Total corridor[a] $P = 0.141$	**# Patches $P = 0.141$**	**% Evergreen $P = 0.141$**	**% Deciduous $P = 0.141$**
1:12000	GO BO RS RA	GO RS BO RA	BO RA RS GO	GO BO RS RA
1:40000	GO RS BO RA	GO RS BO RA	GO BO RA RS	RA RS BO GO
1:58000		RA GO BO RS	RA BO RS GO	GO RS BO RA
1:126000	RS GO RA BO	GO BO RA RS	RA BO GO RS	BO RA GO RS

Table 25 continued.

	% Mixed P = 0.141	% Agricultural P = 0.141	% Residential[a] P = 0.141	% Water P = 0.141
1:12000	GO RA BO RS	RS BO GO RA	RS BO RA GO	GO RS RA BO
1:40000	RA RS BO GO	RS GO BO RA	BO RS GO RA	GO RA RS BO
1:58000	BO RA RS GO	RS GO BO RA		GO RA RS BO
1:126000	RS GO RS BO	RS GO BO RA	GO RS RA BO	RS RA BO GO
	% Swamp P < 0.001	**% Other[b] P = 0.141**	**% Forest P = 0.033**	**% Non-forest P = 0.033**
1:12000	RA GO BO RS	BO GO RS RA	BO RA GO RS	RS RA BO GO
1:40000	RA GO BO RS	BO GO RA RS	RS GO BO RA	RS GO BO RA
1:58000	RA BO GO RS	RA RS BO GO	BO RS RA GO	RS GO BO RA
1:126000	RA GO BO RS		BO RS GO RA	RS GO RA BO
	% Time P = 0.033			
1:12000	GO RS RA BO			
1:40000	GO RS RA BO			
1:58000	RA GO RS BO			
1:126000	GO RA BO RS			

[a] missing data for 1:58,000 scale of aerial photography.
[b] missing data for 1:126,000 scale of aerial photography.
BO = barred owl
GO = northern goshawk
RS = red-shouldered hawk
RA = random area

Table 26. Coefficients of variation for 21 habitat characteristics at barred owl, northern goshawk and red-shouldered hawk nest areas, and random areas, at 4 scales of aerial photography. Blank spaces indicate that there were no samples for a variable at a given scale.

Variable	1:12,000	1:40,000	1:58,000	1:126,000
Barred owl				
Distance to water (m)	82.0	140.2	99.2	63.9
Distance to opening (m)	58.6	71.0	57.8	51.6
Distance to edge (m)	89.0	76.3	87.6	79.9
Total edge (m)	28.9	35.1	45.9	71.7
Road corridors (m)	87.5	120.7	86.3	59.9
Wooded corridors (m)		312.9		
Stream corridors (m)	179.1	228.6	211.4	223.6
Powerline corridors (m)	447.2	447.2		
Total corridor length (m)	69.2	87.8	70.9	90.7
Number of patches	25.5	44.8	36.5	46.5
% Evergreen	74.5	139.8	76.7	
% Deciduous	56.4	119.5	90.6	139.8
% Mixed	80.1	87.1	124.5	96.4
% Agricultural	135.2	115.1	162.7	125.2
% Residential	242.3	225.6	391.5	223.6
% Water	185.6	181.7	165.5	223.6
% Swamp	175.8	149.4	161.3	195.3
% Other	313.4	227.9	319.9	
% Forest	16.0	17.2	22.4	32.3
% Non-forested	119.9	98.2	128.8	118.7
Time (minutes)	28.4	60.7	43.1	33.4
Northern Goshawk				
Distance to water (m)	72.2	115.0	88.4	110.6
Distance to opening (m)	61.5	68.9	70.0	68.4
Distance to edge (m)	116.5	100.0	97.0	142.9
Total edge (m)	37.8	34.1	41.9	88.0
Road corridors (m)	123.8	153.6	150.1	262.6
Wooded corridors (m)	362.7		529.2	
Stream corridors (m)	159.3	194.1	226.6	264.6
Powerline corridors (m)	500.0	380.8	367.5	
Total corridor length (m)	94.7	110.1	125.2	264.6
Number of patches	32.8	42.1	40.6	58.8
% Evergreen	60.6	154.1	60.3	
% Deciduous	89.4	106.0	113.1	85.2
% Mixed	105.8	73.9	99.3	125.6
% Agricultural	156.5	188.0	168.5	205.2
% Residential	216.2	239.7	257.5	
% Water		304.1	239.8	264.6
% Swamp	208.8	171.0	131.5	129.1
% Other	294.0	258.2	288.4	
% Forest	15.6	19.0	16.4	21.8
% Non-forested	120.1	152.8	137.1	205.2
Time (minutes)	29.9	67.8	48.1	47.1

Table 26 continued.

Variable	1:12,000	1:40,000	1:58,000	1:126,000 [a]
Red-shouldered hawk				
Distance to water (m)	115.4	106.6	108.2	
Distance to opening (m)	110.0	91.0	71.6	
Distance to edge (m)	74.5	69.2	63.5	
Total edge (m)	26.0	47.4	22.8	
Road corridors (m)	104.3	121.8	114.6	
Wooded corridors (m)		412.3		
Stream corridors (m)	134.4	173.7	194.4	
Powerline corridors (m)				
Total corridor length (m)	91.4	100.5	90.9	
Number of patches	28.6	46.7	29.1	
% Evergreen	58.0	163.5	68.2	
% Deciduous	86.1	122.7	75.1	
% Mixed	90.5	89.8	112.1	
% Agricultural	254.2	202.8	365.1	
% Residential	293.9	301.2	424.3	
% Water	290.2	212.5	159.2	
% Swamp	218.3	113.0	105.0	
% Other	240.3	234.9	424.3	
% Forest	19.9	12.2	17.2	
% Non-forested	187.1	132.7	234.3	
Time (minutes)	25.8	52.0	43.4	
Random point				
Distance to water (m)	85.0	129.0	101.7	65.8
Distance to opening (m)	93.0	95.2	80.3	74.4
Distance to edge (m)	124.7	115.7	89.2	82.5
Total edge (m)	28.7	44.2	41.3	46.7
Road corridors (m)	112.4	112.9	112.9	149.5
Wooded corridors (m)		343.3	678.2	
Stream corridors (m)	174.8	205.4	185.7	194.8
Powerline corridors (m)	281.9	353.4	503.0	346.4
Total corridor length (m)	88.7	87.8	99.5	141.6
Number of patches	30.1	51.3	35.9	40.4
% Evergreen	69.5	121.2	93.6	168.7
% Deciduous	65.0	102.4	71.0	92.6
% Mixed	96.6	84.1	112.4	107.4
% Agricultural	156.3	145.4	161.0	94.4
% Residential	239.6	255.4	402.5	
% Water	239.1	254.0	206.3	225.3
% Swamp	199.8	242.1	347.0	346.4
% Other	223.9	329.1	507.3	
% Forest	15.4	21.0	23.2	15.3
% Non-forested	133.9	119.5	150.8	94.4
Time (minutes)	27.8	53.1	52.1	35.8

[a] No data for red-shouldered hawk at this scale.

highest for red-shouldered hawk nest areas at 1:58,000 and lowest at 1:40,000; and highest for random areas at 1:58,000 and lowest at 1:12,000. The total edge coefficient of variation was highest for barred owl nest areas at 1:126,000 and lowest at 1:12,000; highest for northern goshawk nest areas at 1:126,000 and lowest at 1:40,000; highest for red-shouldered hawk nest areas at 1:40,000 and lowest at 1:58,000; and highest for random areas at 1:126,000 and lowest at 1:12,000. The coefficient of variation for the total corridor length variable was highest for barred owl and northern goshawk nest areas at 1:126,000 and lowest at 1:12,000; highest for red-shouldered hawk nest areas at 1:40,000 and lowest at 1:58,000; and highest for random areas at 1:126,000 and lowest at 1:40,000. The number of patches had the highest coefficient of variation for barred owls and northern goshawks at the 1:126,000 or 1:40,000 scales. Red-shouldered hawk nest areas and random areas had the highest coefficient of variation at 1:40,000. The coefficient of variation was lowest for all species and random points at the 1:12,000 scale. The time for interpretation variable had the highest coefficient of variation at the 1:40,000 scale and lowest at the 1:12,000 scale for all groups.

Coefficients of variation generally were similar among species and random points. All species except red-shouldered hawks had the lowest mean coefficient of variation at the 1:12,000 scale and highest at the 1:58,000 scale. Red-shouldered hawk nest areas had the lowest coefficient of variation at 1:58,000 and the highest at 1:40,000.

I analyzed the amount of time required for interpretation of the 80 ha sample plot at 4 scales of aerial photography. The 1:40,000 scale required the greatest amount of time for interpretation and digitizing. There were differences among time required for interpretation and digitizing between the 1:12,000 scale and the other 3 scales, and between the 1:40,000 scale and the other scales (Table 24). The 1:12,000 scale of aerial photography required the most photos and was therefore the most expensive scale (Table 27). The 1:40,000 and 1:58,000 scales required approximately one third the number of photos. The number of photos available at the 1:126,000 scale was so low because only a very small portion of the study area had been photographed at this scale. Interpretation costs were highest at the 1:40,000 scale and lowest at the 1:126,000 scale. When acquisition and interpretation costs were combined, there was a pattern of decreasing total cost with increasing scale (Table 27).

The relative ease or difficulty of acquisition of photography was not quantitatively addressed. In the future, it would be useful to record the number of hours required to obtain aerial photography at each scale. The 1:58,000 color infrared and 1:40,000 black and white photography were ordered from the ASCS office in Salt Lake City, Utah (Table 27). Ordering from this source was the most straightforward. I provided the office with southeast latitude/longitude coordinate for each of the 11 1:24,000 USGS topographic map covering the study area. The 1:126,000 color infrared photography was somewhat more difficult to order, primarily because of the difficulties involved in identifying the specific series or flight line required to cover the area without access to blueprint proofs. The 1:12,000 photographs were the most time consuming to order because each nest location/random point had to be plotted on blueline maps provided by the company they were ordered from.

Table 27 . Summary information concerning the cost of gathering information from various scales and types of aerial photography.

Scale	Type	# Photos	Cost/photo	Aquisition cost	Cost of Interpretation	Total Cost	Cost/ Site	Supplier
1:12,000	B&W	156	$3.17	$495.00	$247.50	$742.50	$7.20	Aerographics
1:40,000	B&W	96	$3.00	$288.00	$328.00	$616.00	$5.70	ASCS
1:58,000	CIR	48	$8.00	$384.00	$163.15	$547.15	$4.89	ASCS
1:126,000	CIR	25	$16.00	$400.00	$21.00	$421.00	$16.84	EROS

Aerographics, P.O. Box 248, Bohemia, NY., 11716
ASCS, Aerial Photography Field Office, 2222W-2300S, Salt Lake City, UT, 84119
EROS Data Center, Sioux Falls, SD, 57198

Discussion

Raptor habitat associations

The primary literature regarding barred owl, northern goshawk and red-shouldered hawk habitat generally describes several characteristics associated with the 3 raptor species. Large, mature timber stands or old growth, mixed forests with interspersed or nearby wet areas somewhat free of human influence may be important to all 3 raptors (Wright 1916, Hoglund 1964, Beardslee and Mitchell 1965, Schnell 1968, Craighead and Craighead 1969, Nicholls and Warner 1972, Moore and Henny 1973, Allen 1978, Fuller 1979, Portnoy and Dodge 1979, Shuster 1980, Bednarz and Dinsmore 1981, Titus and Mosher 1981, Marquiss and Newton 1982, Reynolds et al. 1982, Elody 1983, Moore and Henny 1983, Morris and Lemon 1983, Hall 1984, McGarigal and Fraser 1984, Devereaux and Mosher 1984, Sutton and Sutton 1985, Bryant 1986, and Speiser and Bosakowski 1987). Habitat characteristics measured from a ground scale and 4 scales of aerial photography in northwest Connecticut generally supported earlier research conducted in the United States and Europe. Results indicated barred owls might represent a species with a wider range of suitable habitat i.e., they are more flexible in nest area selection than northern goshawks or red-shouldered hawks. They might be less habitat specific, possibly more generalists except in that they require cavities for nesting. The only significant variables in any analyses at the ground level or at 4 scales of aerial photography were sugar maple density and basal area, which probably indicate selection of a tree species or forest type that has a high probability of containing tree cavities on this study area. I interpreted high basal area as an indication of mature forest stands. Sugar maple often were the oldest, most decadent trees in upland forests on the study area. They may have been retained for their maple sugar producing capabilities during times of forest clearing in the northeast (Falk and Stauffer 1989). Sugar maple also were and still are considered useful as shade trees in yards and developed areas. In New England large old sugar maples often were associated with areas of previous human occupation (old home sites and farms). Some of the most decadent stands of trees offering the best cavities may be located within these old sugar maple stands. These results indicated either that barred owl nesting habitat in Connecticut was not very different from available habitat, or that I was measuring habitat with inappropriate variables at inappropriate scales.

Northern goshawks and red-shouldered hawks seemed similar in their requirements of mature or old growth forests based on the results of this study. Northern goshawks were strongly associated with conifer forests and red-shouldered hawks with mixed hemlock/red maple/beech forests. Their nest areas were more dramatically different from available habitat than was observed for barred owl nest areas; their requirements may be more specific. They also were found to be associated with areas of low human activity and/or influence - northern goshawks possibly less so than was indicated by the available literature (Hennessey 1978, Kostrzewa 1987, Speiser and Bosakowski 1987, and Gamauf 1988), red-shouldered hawks possibly more so (Morris and Lemon 1983). Red-shouldered hawk nest areas generally were the most isolated from even small scale agriculture and the seemingly unobtrusive rural residential development (minimal in the study area). This could, however, be more closely related to the red-shouldered hawks obvious preference for wet areas (noted to be a stronger association than for northern goshawks in this study area). Most wetlands/swamps were more isolated because they were, and had been for a long period of time, inaccessible. Northern goshawks showed less association with wet areas in this study than has been noted in most other work on the species (Hennessey 1978, Reynolds et al. 1982, and Speiser and Bosakowski 1987). The habitat characteristics that were measured at the ground scale and chosen for discriminant analysis procedures were not particularly good at discriminating barred owl nesting habitat from nesting habitat of the other two species, but were relatively good at discriminating northern goshawk and red-shouldered hawk nest areas. There appeared to be separation of the 3 raptors based on these habitat characteristics. Calculation of producer's accuracy showed that barred owl and northern goshawk nest areas, and random areas were not often classified as red-shouldered hawk nest areas. Only 2 barred owl nests were classified as red-shouldered hawk nest areas at the ground scale; no northern goshawk nest areas were classified as red-shouldered hawk nest areas. Of 49 random areas analyzed at the ground scale, some were classified as barred owl or northern goshawk nest areas, but none were classified as red-shouldered hawk nest areas. Few of these other areas seemed to have characteristics similar enough to allow them to be classified into the red-shouldered hawk nest area group. This indicates that red-shouldered hawk nest areas have habitat characteristics that separate them from the other two raptors, and from random areas (available habitat). It might also indicate that much of the northwest Connecticut habitat does not have characteristics making it suitable for red-shouldered hawk nesting.

User's accuracy calculations showed that northern goshawk nest areas were seldom classified as barred owl or red-shouldered nest areas, or as random areas. Very few northern goshawk nest areas were classified into other groups. This suggests that northern goshawk nest areas were distinct from the other groups and had less variability.

Multivariate analyses between raptor nest areas and random areas at the ground scale suggested that red-shouldered hawks might occupy the habitat that is most different from available habitat (as judged by random areas measured). It was also interesting that in the red-shouldered hawk/random area analysis, no random areas were classified as red-shouldered nest areas. This might be interpreted as an indication that little of the available habitat on the study area was suitable for red-shouldered hawks. Again, it is evident that either I did not select appropriate variables at the ground scale for barred owls, or that their nesting habitat is least different of all species from available habitat. Barred owls could be selecting primarily for trees with cavities (measured at a much smaller scale), which may not be correlated with habitat characteristics at the scales I measured.

Barred owl, northern goshawk, and red-shouldered hawk nest areas were distinct from one another based on results of one-way analysis of variance conducted on variables from 4 scales of aerial photography; raptor nest areas also were distinct from random areas based on results of t-tests. The canonical function for the barred owl/random analyses was significant only at the 1:40,000 scale of aerial photography. Water-related variables were those most heavily weighted at all scales, however. It appears that water-related variables (particularly % swamp and % open water) were those most responsible for separating barred owl nest areas from random areas. This consistency across scales was not observed in the univariate analyses. It seems to lend more support to many researchers observation of an association of barred owls with wet areas. However, the results of this canonical analysis could be misleading and affected by some of the variability and problems discussed in the introduction of this section. Classification of barred owl nest areas as barred owl nest areas was extremely poor at all scales of aerial photography. Barred owl nests were more often classified as random areas at all scales except 1:40,000, where classification was 50-50 barred owl-random. This points to an inability of the models to distinguish barred owl habitat from available habitat.

In general, variables that indicated openings in the forest canopy, human disturbance, and water were those most responsible in separating northern goshawk nest areas from random areas. The best classification occurred at the 1:12,000 scale (kappa = 56%), where only half of the northern goshawk nest areas were misclassified as random areas. It is also interesting that it was for the northern goshawk/random analyses at all scales that the most random areas were misclassified as northern goshawk nest areas. This might be interpreted to mean that the available habitat (described by our random areas) more closely resembles northern goshawk habitat than nest areas of barred owls or red-shouldered hawks, and therefore, that there is more northern goshawk habitat available in the Connecticut study area.

Canonical functions were significant for red-shouldered hawk/random analyses at the 1;12,000 and 1:58,000 scales of aerial photography. Water-related, and variables indicating breaks in forest cover type generally were most heavily weighted at all scales. Over 50% of the red-shouldered hawk nest areas were misclassified as random areas at the 1:12,000 and 1:40,000 scales of aerial photography. Classification was best for red-shouldered hawk nest areas at the 1:58,000 scale. This also represents the highest kappa for any of the species/random discriminant analyses. The 1:58,000 scale appears to be the best scale in terms of distinguishing red-shouldered hawk nesting habitat. Random areas were misclassified at about the same rate as for the barred owl/random analyses at all scales.

User's accuracy was consistently higher for northern goshawk nest areas than for barred owl or red-shouldered hawk nest areas at the ground scale and at all scales of aerial photography. At all scales, northern goshawk nest areas were more often correctly classified as northern goshawk nest areas than red-shouldered hawk or barred owl nest areas. The pattern of producer's accuracy being highest for red-shouldered hawk nest areas (indicating specificity of nest site selection) held at the ground scale and the 1:58,000 scale of aerial photography. At these two scales few nest areas of the other 2 species or random areas were classified as red-shouldered hawks. Producer's accuracy was highest for northern goshawk nest areas at the 1:12,000 scale and for barred owl nest areas at the 1:40,000 scale.

Coefficients of variation for all variables were examined to provide an indication of variability that might exist within each species. Generally, habitat characteristics measured at barred owl nest areas had the highest coefficients of variation (compared to those of the nest areas of the other 2 raptors) at the ground level, and the lowest coefficients of variation at all 4 scales of aerial photography. Variables measured at the nest areas of northern goshawks had the lowest coefficients of variation at the ground scale and the highest at the 1:58,000 and

1:126,000 scales. Red-shouldered hawk nest area variables had the highest coefficients of variation at the 1:12,000 and 1:40,000 scales of aerial photography (intermediate at the ground level). The coefficient's of variation are difficult to interpret and don't necessarily support the results of the univariate and multivariate analyses.

This study considered only an 80 ha area around the nest. How the raptors in Connecticut actually use this 80 ha area, or the even larger range they occupy is not known. Morris and Lemon (1983) suggested that we need to know more about patterns of habitat use (territorial and prey requirements, hunting behavior) to more reliably and completely predict the response of any raptor to a particular set of habitat characteristics. Speiser and Bosakowski (1987) also suggested that additional factors such as prey density and accessibility, competition, and the presence of predators need to be addressed. Several authors (Reynolds 1983, Kenward 1982) discuss the need for more radio-telemetric monitoring of raptors.

It is difficult to define the quantity and extent of habitat use considering the mobility of raptors. Johnson (1980) stated that conclusions reached from use-availability studies depend to a degree on what an investigator describes as available. The Connecticut study area was defined as the political unit (Litchfield County) that encompassed known raptor nest sites. We defined available habitat as forested areas with trees > 10 cm dbh. This eliminated non-forested areas and most forested areas with trees too young and small to support raptor nesting activity, but included some habitat that might not be used by raptors.

Johnson (1980) also noted that the fact that an animal has a nest where it does is already an indication that the animal has made a selection. Degrees of nest site tenacity must be considered in relation to this idea. Reynolds (1979) reported that northern goshawks exhibited nest site tenacity, Nicholls and Warner (1972) and Nicholls and Fuller (1987) reported nest site tenacity in the barred owl, and Bryant (1986) reported the same for red-shouldered hawks. Raptors may select a nest site that was preferred habitat at some point in time. Habitat or land use modifications may have caused changes that cause a nest area to be less preferred, but due to a biological characteristic of a species (nest site tenacity), a pair of raptors might remain at the less preferred site. It is also possible that in many cases raptors may no longer have access to preferred habitat, but may select what is closest to preferred based on what remains (Fuller, pers. commun.). This study focused on observed patterns of association at one point in time. No experimentation (cause and effect situations) was conducted to simulate habitat change or allow observation or raptor response to such change.

Van Horne (1983) proposed we consider several question when creating wildlife-habitat models: 1) are the species generalists or specialists? 2) are they affected by intrinsic or extrinsic factors? 3) what is their reproductive capability? 4) what are their social dominance patterns? 5) is their habitat homogeneous or heterogeneous? 6) are they migratory? Answers to some of these questions are known for barred owls, northern goshawks, and red-shouldered hawks in northwest Connecticut, but our knowledge is still too limited to enable full explanation of all the associations.

Assessment of scale

Measuring variables such as distance to nearest water or distance to nearest road from topographic maps or aerial photographs may have limited my ability to detect a strong association of a species with these characteristics. Within-species variation and other sources of variability and error related to measurement of habitat characteristics from 4 scales of aerial photography also must be considered.

Intensive initial training of interpreters was extremely important in insuring uniformity in data collection and repeatability of measurements from the aerial photography. Periodic checks of the data, and open lines of communication among interpreters insured that variables were being identified and measured correctly. Even with good training and follow up, some interpreter variability was unavoidable. Recognizing it, and considering it a source of error when interpreting the results of a study is important. In most research and management situations, it is unlikely that one interpreter will collect all data. In actual management situations, some degree of error associated with different interpreters is expected.

Interpreters could make 2 types of errors, measurement errors and errors in interpreting habitat characteristics. Measurement errors resulted from varying abilities to measure habitat characteristics at different scales. Tracing cover type boundaries and digitizing the perimeter of the cover type would probably produce more error at the 1:12,000 scale than at the 1:58,000 scale. Measuring distances could result in more error at the 1:58,000 scale than at the 1:12,000 scale where there is more detail of habitat. Errors of interpretation could have occurred when interpreters were trying to distinguish between cover type categories like mixed forest and evergreen forest. The two cover types occurred along a continuum and deciding where one type became the other was often more subjective than objective.

I used several analyses to try to determine the reliability or 'goodness' of interpretation at each scale of aerial photography. Analysis of variance (Kruskall-Wallis) was used to detect differences among scales of aerial photography. These analyses should help a researcher or manager select the scale of aerial photography that provides the most information for a variable that is important to assess in measuring habitat characteristics for a species of interest. Only those variables that were significantly associated with barred owl, northern goshawk, or red-shouldered hawk nest areas will be discussed.

There was consistency among scales for most of the distance measurements as indicated by the results of Friedman's test of concordance and examination of coefficients of variation for groups of variables. Distance to water and distance to opening were the distance measures most associated with the raptor species in this study. Choice of scale and type of aerial photography is not as critical for these types of variables as it may be for some of the habitat cover type variables. Of all cover type variables measured, only percentage of swamp exhibited any degree of consistency across scales. Coefficients of variation also were high for cover type variables (although this might be as much a result of the low frequency of occurrence of these variables - % agricultural, residential, etc.). Care must be exercised in selecting the scale and type of photography that allows the best interpretation of the variables of interest.

The greatest number of patches generally was identified at the 1:12,000 scale of aerial photography. This scale offered the greatest amount of detail, therefore cover types could be identified more easily. The 1:40,000 and 1:58,000 scales were similar in the number of patches identified. The 1:40,000 scale had more detail in terms of size, but the larger scale 1:58,000 photography was color infrared photography and some cover types were more obvious (eg. swamps, mixed forest).

The highest percentage of evergreen cover generally was measured at the 1:58,000 or 1:12,000 scale of aerial photography. This is reasonable considering that the 1:58,000 scale was color infrared and coniferous/deciduous distinctions can be made more readily from color infrared film than black and white film. The 1;12,000 scale was exposed during leaf off, so the conifer/evergreen species were much darker than the deciduous species. There also was enough detail at the 1:12,000 scale that conifer and deciduous species could often be distinguished based on shape of the tree crown. This smaller scale allowed interpreters to pick up much more detail.

The highest percentage of deciduous cover generally was measured at the 1:126,000 scale. This scale of color infrared photography was exposed during leaf on. Interpreters had the greatest difficulty distinguishing between deciduous, conifer and mixed cover types at this scale. The different cover types were identifiable as subtly different shades of red which were somewhat difficult to interpret. The second highest percentages of deciduous cover generally were measured from the 1:12,000 scale, with the 1:58,000 scale having the third highest percentages. The same explanation that held for this pattern in the discussion of the percentage of evergreen cover apply here. The 1:40,000 scale was black and white photography exposed during leaf on. It was the most difficult scale from which to distinguish forest cover types. Distinguishing shades of gray was more difficult than distinguishing shades of a color (red) (Lillesand and Kiefer 1987). The 1:40,000 scale also did not have as much detail as the 1:12,000 scale, so tree crown differences evident at the 1:12,000 scale could not be determined as easily at the 1:40,000 scale.

The highest values for percentage of mixed forest were obtained at the 1:40,000 scale of aerial photography. Again, this scale was black and white photography exposed during leaf on. Determinations of forest cover types were at times difficult, and identification of the point where a cover type was no longer coniferous, but mixed, was more unclear at this scale. Interpreters seemed less likely to commit to identification of a cover type as either deciduous or coniferous/evergreen, therefore more mixed cover was identified.

The percentage of agricultural land was more uniform across scales with the highest values generally measured at the 1:126,000 or 1:40,000 scales. The percentage of open water was consistently highest at the 1:58,000 scale. The percentage of swamp showed uniform measurement among scales (determined by Friedman's test of concordance), but the scale at which highest values for the variable were found was not consistent. Water-related variables were most evident and easily identified at the 1:58,000 scales of aerial photography. The highest percentage of forested land was measured at the 1:12,000 scale, correspondingly, values for the percentage of non-forested land generally were lowest at 1:12,000.

Caution must be exercised in selecting the most appropriate scale of aerial photography. It might be erroneous to assume that the scale from which the greatest amount of a habitat characteristic is measured is the best scale for interpretation. The mixed forest cover type had highest measurements at the 1:40,000 scale of aerial photography, but not because there was more of this cover type at the 1:40,000 scale. Interpreters generally identified more mixed forest than coniferous or deciduous because of the difficulty associated with distinguishing among these types from the black and white, leaf-on 1:40,000 aerial photography. If these types of biases can be identified, then the scale from which the greatest amount of a habitat characteristic can be accurately measured would be the best choice. For example, if the number of habitat patches is strongly associated with a species of interest and this characteristic is best distinguished (and therefore has higher values) at a particular scale, then that scale should be used.

Water-related variables including percentages of open water and swamp, distance to water, and distance to human disturbance-related variables including number of habitat patches, and percentages of agricultural and non-forested lands were habitat characteristics most important in separating species nest areas, and species nest areas from available habitat. I was not able to identify the variables or a scale of measurement that provided adequate information on nest habitat associations of barred owls. Forest composition (particularly presence of conifer species) and human influence factors were important in distinguishing northern goshawk nest areas from the other raptor species nest areas and random areas. The 1:12,000 scale of aerial photography provided the most reliable interpretation of habitat characteristics associated with northern goshawk nest areas. The 1:58,000 scale provided the most reliable interpretation of habitat characteristics important in distinguishing red-shouldered hawk nest areas from northern goshawk and barred owl nest areas, and from random areas. This primarily was due to ease of identification of water- and human disturbance-related variables at this scale.

The time required for interpretation and cost per nest area also are important factors to consider when selecting the most appropriate scale for interpretation. For example, I measured forest stand and forest composition characteristics within 80 ha plots that were measured by other researchers (some at the same nest areas I sampled) in 0.04 ha plots. My results were similar in terms of interpretation of habitat characteristics important to species of interest (except for information on the sugar maple-barred owl association). I gathered information over a larger area which may have been more representative of the area actually used by the raptors of interest. But if the results were the same, consideration of time and cost effectiveness may become more important factors to consider. Mosher et al. (1986) reported that it took approximately 1.5 hours to gather habitat data from which forest stand and composition information was estimated. I spent 2.5 to 4.5 hours collecting point-centered quarter data at 21 points within 80 ha plots in northwest Connecticut. This did not include travel time to the nest or random site. If the same information is provided by measuring habitat characteristics in small plots, thereby reducing time and cost, it might be appropriate to do so. Selection of aerial photography should be based on cost and time for interpretation factors in addition to the quality of information provided by a particular scale for a given species.

Conclusions

Results of this study contribute to a broader understanding (from a larger, landscape perspective) of raptor-habitat associations. The information gathered at a large ground scale and 4 scales of aerial photography supports the findings of other researchers at a variety of scales. Many of the large scale characteristics quantified in this study previously have been evaluated only in a qualitative manner. Methods have been developed and assessed in this study that provide a quantitative approach to landscape level raptor-habitat assessment.

Results were the least informative for barred owls at the 4 scales of aerial photography where no significant variables were identified. However, a strong association of barred owl nest areas with sugar maple was identified at the ground level of habitat evaluation. Recognizing this association in the management of public and private lands in northwest Connecticut and attempting to protect large old stands of sugar maple could be important to the species. Insuring that there will be trees old and decadent enough to provide nesting cavities for barred owls also should be a concern of individuals concerned with preserving habitat for this species.

The nesting habitat characteristics presumably most significant to northern goshawks were best identified at the ground scale and at the 1:12,000 and 1:58,000 scales of aerial photography. The characteristics that most clearly distinguished northern goshawk nest areas from the nest areas of the other raptors and from available habitat were high densities of conifers and avoidance of human disturbance factors.

The habitat characteristics most strongly associated with red-shouldered hawk nests were high beech, red maple and hemlock densities and basal areas. These forest composition characteristics were identified most reliably from the ground scale. They also showed an avoidance of areas of human influence and openings in the forest canopy. A very strong association of red-shouldered hawks with swamp habitat, especially at the 1:58,000 scale, supported findings at the ground scale. Red maple and hemlock are strongly associated with swamp or wet habitat in northwest Connecticut. Red maple swamps are the predominant type of forested wetland in the northeast (Newton 1988). Newton (1988) also reported an increasing loss of forested wetlands due to conversion of open ponds, housing development and other factors.

The results of this study provide information that should be considered in habitat management for barred owls, northern goshawks and red-shouldered hawks. The importance of dense, mature forested habitat is evident particularly for northern goshawks and red-shouldered hawks. These habitats are relatively well managed and protected in Connecticut and the southern region of the northeast. In fact, forested habitat has increased in the northeast over the last several decades (Dickson and McAffee 1988). All three species showed some association with wetland habitat. These habitats seem more threatened in the northeast. Wise management and protection of wetlands in general, but particularly of those that are presently remote and relatively pristine, may be important in providing nesting habitat for these 3 raptor species.

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Appendices

Appendix 1. Tree species measured in 80 ha plots via the point-centered quarter technique at barred owl, northern goshawk, and red-shouldered hawk nest areas, and random areas, in Litchfield County, Connecticut, in 1987.

Scientific name	Common name	ID	Species combined
Acer pensylvanicum	Striped maple	STMA	
Acer rubrum	Red maple	REMA	
Acer saccharum	Sugar maple	SUMA	
Amelanchier sp.	Shad-bush	SHAD	
Betula lenta	Black birch	BBIR	
Betula lutea	Yellow birch	YBIR	
Betula papyrifera	White birch	WBIR	
Betula populifolia	Gray birch	GBIR	
Carya glabra	Pignut hickory	PHIC	
Carya ovata	Shagbark hickory	SHIC	
Carya sp.	Hickory sp	HICS	
Carya tomentosa	Mockernut hickory	MHIC	
Castenea dentata	American chestnut	CHES	
Fagus grandifolia	American beech	AMBE	
Fraxinus americana	White ash	WASH	
Fraxinus nigra	Black ash	BASH	
Fraxinus pennsylvancia	Green ash	GASH	
Fraxinus sp.	Ash sp.	ASHS	
Juglans nigra	Butternut	BHIC	
Larix larcina	Tamarack	TAMA	
Liriodendron tulipifera	Tulip poplar	LIRI	
Ostrya virginiana	Hop Hornbeam	HHOR	
Picea marinara	Black spruce	BLSP	
Pinus resinosa	Red pine	REPI	
Pinus strobus	White pine	WHPI	
Populus grandidentata	Bigtooth aspen	BIAS	
Populus tremuloides	Quaking aspen	QUAS	
Prunus serotina	Black cherry	BLCH	

Appendix 1 continued.

Scientific name	Common name	ID	Species combined
Pyrus malus	Apple	APPL	
Quercus alba	White oak	WOAK	
Quercus coccinea	Scarlet oak	SOAK	
Quercus rubra	Red oak	ROAK	
Quercus prinus	Chestnut oak	COAK	
Quercus velutina	Black oak	BOAK	
Robinia pseudoacacia	Black locust	BLLO	
Thuja occidentalis	Eastern red cedar	ERCE	
Tilia americana	Basswood	BAWO	
Tsuga canadensis	Hemlock	HEML	
Ulnus americana	American elm	AMEL	
	Non-forested	NFOR	
		ASH	Black, green, and white ash
		BEECH	American beech
		BIRCH	Black, green, white, and yellow birch
		OAK	Black, chestnut, red, scarlet, and white oak
		PINESPCE	White and red pine, black spruce, eastern red cedar
		HICKORY	Mockernut, pignut, shagbark hickory
		HEMLOCK	Hemlock and tamarack
		SUGMAPLE	Sugar maple
		REDMAPLE	Red maple
		MISC	American elm, quaking and bigtooth aspen, apple, basswood, butternut, black cherry, black locust, chesnut, hop hornbeam, tulip poplar, shadbush, striped maple
		CONIFER	Hemlock, white and red pine, black spruce, eastern red cedar, tamarack
		DECIDUOUS	Ash spp., aspen spp., beech, birch spp. oak spp., hickory spp., butternut, elm, maple spp., hop hornbeam, black locust, black cherry, apple, basswood, chestnut, tulip poplar, shadbush

Appendix 2. Significance of tests of 34 habitat characteristics measured at a ground scale among barred owl, northern goshawk, and red-shouldered hawk nest areas in Litchfield County, Connecticut, in 1987.

Variable	P	Difference[a]
Dbh (cm)	0.600	
Tree density[b]	0.044	BO-RS
Basal area[c]	0.097	
Canopy cover (%)	0.568[d]	
Canopy height (m)	0.010[d]	
% Forest	0.026[d]	
Ash density	0.233[d]	
Beech density	0.004	GO-RS
Birch density	0.842	
Oak density	0.191[d]	
Pine density	0.050[d]	
Hickory density	0.569[d]	
Hemlock density	0.025[d]	BO-RS
Sugar maple density	0.272[d]	
Red maple density	0.001	BO-RS GO-RS
Misc. spp. density	0.935	
Conifer density	0.062	
Deciduous density	0.077	
Ash basal area	0.829[d]	
Beech basal area	0.043	GO-RS
Birch basal area	0.795	
Oak basal area	0.125[d]	BO-GO
Pine basal area	0.775[d]	
Hickory basal area	0.999[d]	
Hemlock basal area	0.180[d]	
Sugar maple basal area	0.062[d]	
Red maple basal area	0.050[d]	BO-RS GO-RS
Misc. spp. basal area	0.039	BO-GO
Conifer basal area	0.039	BO-GO
Deciduous basal area	0.036	GO-RS
Elevation (m)	0.153[d]	
Slope (%)	0.180	
Distance to water (m)	0.074[d]	
Distance to disturbance (m)	0.117[d]	

[a] BO = barred owl
GO = northern goshawk
RS = red-shouldered hawk

[b] Tree densities in # trees/ha.

[c] Basal areas in m^2/ha.

[d] Significance determined by Kruskal-Wallis test (ANOVA used to determine significance all other variables).

Appendix 3. Cohen's kappa for discriminant function analyses at a ground scale and 4 scales of aerial photography.

	P_C[a]	P_O[b]	Kappa	Significance of SE of Kappa[c]	95% CI on Kappa
GROUND					
BO/GO/RS[d] (21/29/17)[e]	0.780	0.363	0.686	***	0.533 to 0.840
BO/RA (21/49)	0.814	0.597	0.504	***	0.369 to 0.638
GO/RA (29/49)	0.859	0.543	0.696	***	0.526 to 0.866
RS/RA (17/49)	0.924	0.654	0.781	***	0.592 to 0.969
AIR					
BO/GO/RS					
1:12,000 (20/25/17)	0.790	0.349	0.678	***	0.519 to 0.837
1:40,000 (20/27/17)	0.594	0.364	0.361	***	0.168 to 0.554
1:58,000 (20/28/17)	0.606	0.367	0.378	***	0.187 to 0.568
1:126,000 (5/7/1)	0.692	0.488	0.399	**	0.274 to 0.524
BO/RA					
1:12,000 (20/41)	0.689	0.610	0.202	*	-0.102 to 0.505
1:40,000 (20/44)	0.781	0.606	0.445	**	0.182 to 0.708
1:58,000 (20/46)	0.727	0.661	0.195	**	-0.128 to 0.518
1:126,000 (5/12)	0.941	0.610	0.849	**	0.557 to 1.141
GO/RA					
1:12,000 (25/41)	0.788	0.522	0.556	***	0.346 to 0.767
1:40,000 (27/44)	0.704	0.552	0.339	**	0.097 to 0.582
1:58,000 (28/46)	0.770	0.565	0.472	***	0.246 to 0.697
1:126,000 (7/12)	0.684	0.560	0.282	**	-0.201 to 0.766

Appendix 3 continued.

	P_c[a]	P_o[b]	Kappa	Significance of SE of Kappa[c]	95% CI on Kappa
RS/RA					
1:12,000					
(17/41)	0.776	0.621	0.409	**	0.119 to 0.698
1:40,000					
(17/44)	0.771	0.642	0.359	**	0.058 to 0.660
1:58,000					
17/46)	0.844	0.609	0.600	***	0.368 to 0.832
1:126,000					
NO DATA					

[a] P_c = sum of the chance expected proportion of agreement.
[b] P_o = sum of the observed proportion of agreement.
[c] *** = $P < 0.001$, ** = $P < 0.01$, * = $P < 0.05$.
[d] BO = barred owl
GO = northern goshawk
RS = red-shouldered hawk
[e] Sample size

Appendix 4. Discriminant functions for significant ground habitat characteristics measured at a ground scale at barred owl, northern goshawk, and red-shouldered hawk nest areas in Litchfield County, Connecticut, in 1987.

Variable	Barred owl	Northern goshawk	Red-shouldered hawk
Constant	-125.52	-136.36	-131.78
Tree density[a]	-1.40	-1.20	-1.62
Basal area[b]	-0.68	-0.72	-0.55
% Forested	2.50	2.57	2.53
Beech density	-0.27	-0.30	-0.31
Hemlock density	0.02	0.02	0.02
Sugar maple density	-0.02	-0.02	-0.02
Red maple density	0.02	0.00	0.04
Conifer density	1.40	1.20	1.63
Deciduous density	1.46	1.27	1.67
Beech basal area	4.78	5.21	5.52
Hemlock basal area	-0.68	-0.60	-0.61
Sugar maple basal area	1.32	1.23	0.97
Conifer basal area	1.27	1.42	1.09
Deciduous basal area	0.00	0.00	0.00
Distance to disturbance	0.00	0.00	0.00

[a] Densities in # trees/ha.
[b] Basal areas in m^2/ha.

Appendix 5. Significance of tests of of 34 habitat characteristics at a ground scale between barred owl, northern goshawk, and red-shouldered hawk nest areas, and random areas, in Litchfield County, Connecticut, in 1987.

Variable	Barred owl/ Random point n=21	Goshawk/ Random point n=30	Red-shouldered hawk/ Random point n=17
Dbh (cm)	0.723	0.449	0.515
Tree density[a]	0.046[b]	0.001	0.000
Basal area[c]	0.034[b]	0.000	0.001[b]
Canopy cover (%)	0.011	0.000	0.000
Canopy height (m)	0.007	0.000[b]	0.000
% Forest	0.099[b]	0.000[b]	0.010[b]
Ash density	0.193[b]	0.938[b]	0.410[b]
Beech density	0.410[b]	0.944[b]	0.004[b]
Birch density	0.459	0.784[b]	0.545
Oak density	0.328	0.163[b]	0.459[b]
Pine density	0.467[b]	0.131[b]	0.155[b]
Hickory density	0.262[b]	0.404[b]	0.801[b]
Hemlock density	0.415[b]	0.007[b]	0.000[b]
Sugar maple density	0.000[b]	0.017[b]	0.196[b]
Red maple density	0.183[b]	0.007	0.007[b]
Misc. spp. density	0.923[b]	0.438[b]	0.666
Conifer density	0.051	0.000[b]	0.000
Deciduous density	0.786	0.940	0.003
Ash basal area	0.416[b]	0.314[b]	0.409
Beech basal area	0.346[b]	0.865[b]	0.005[b]
Birch basal area	0.865[b]	0.883[b]	0.546[b]
Oak basal area	0.503[b]	0.066[b]	0.307[b]
Pine basal area	0.086[b]	0.708[b]	0.839[b]
Hickory basal area	0.366[b]	0.220[b]	0.633[b]
Hemlock basal area	0.428	0.006[b]	0.010[b]
Sugar maple basal area	0.007[b]	0.932[b]	0.727[b]
Red maple basal area	0.451	0.210	0.026[b]
Misc spp. basal area	0.715[b]	0.664[b]	0.244[b]
Conifer basal area	0.100	0.000	0.001
Deciduous basal area	0.545	0.471	0.002[b]
Elevation (m)	0.540	0.611	0.074[b]
Slope (%)	0.312[b]	0.682[b]	0.342[b]
Distance to disturbance (m)	0.449[b]	0.003[b]	0.168[b]
Distance to water (m)	0.908[b]	0.641[b]	0.065[b]

[a] Densities in # trees/ha.
[b] Significance determined by Wilcoxon rank-sum test (t-test used to determine all other significance levels.
[c] Basal areas in m^2/ha.

Appendix 6. Discriminant functions for significant habitat characteristics measured at a ground scale between barred owl, northern goshawk, and red-shouldered hawk nest areas and random areas in Litchfield County, Connecticut, in 1987. Analyses were conducted between each raptor species nest areas and random areas.

Variable	Barred owl	Random area	Goshawk	Random area	Red-shouldered hawk	Random area
Constant	-49.62	-42.52	-63.94	-52.43	-41.68	-53.04
Tree density[a]	-0.01	-0.01	-1.52	-1.71	0.04	0.04
Basal area[b]	0.23	0.22	0.35	0.23	-0.35	-0.30
% Forested	0.85	0.80	0.98	0.93	0.79	0.84
Beech density	-0.13	-0.13	-0.20	-0.17	-0.18	-0.22
Hemlock density	-0.00	-0.01	-0.04	-0.04	0.04	0.05
Sugar maple density	0.14	0.07	0.13	0.07	-0.06	-0.00
Red maple density	0.10	0.11	0.14	0.15	0.07	0.09
Conifer density	-0.01	-0.01	1.53	1.73	-0.03	0.03
Deciduous density	0.00	0.00	1.52	1.71	0.00	0.00
Beech basal area	1.09	1.21	2.65	2.17	2.54	3.25
Hemlock basal area	-0.56	-0.36	-0.02	-0.03	-1.00	-0.97
Sugar maple basal area	-0.37	-0.12	0.19	0.53	1.41	0.96
Conifer basal area	0.65	0.51	0.33	0.22	0.65	0.61
Deciduous basal area	0.00	0.00	0.00	0.00	0.00	0.00
Distance to disturbance	-0.01	-0.01	0.00	0.00	-0.01	-0.01

[a] Densities in # trees/ha.
[b] Basal areas in m^2/ha.

Appendix 7. Significance of 21 habitat characteristics measured at 4 scales of aerial photography among barred owl, northern goshawk, and red-shouldered hawk nest areas.

Variable	1:12,000	1:40,000	1:58,000	1:126,000[a]
Distance to water (m)	0.014*	0.696	0.005* (GO-RS)	0.408
Distance to opening (m)	0.158*	0.737	0.347	0.750
Distance to edge (m)	0.412*	0.407	0.218*	0.646
Total edge (m)	0.264*	0.236	0.810*	0.590*
Road corridors (m)	0.453*	0.412*	0.026*	0.052*
Wooded corridors (m)	0.222*	0.264*	0.507*	
Stream corridors (m)	0.252*	0.255*	0.768*	0.737
Powerline corridors (m)	0.673*	0.531*	0.252*	
Total corridor length (m)	0.562*	0.471*	0.398*	0.109*
Number of patches	0.003 (BO-GO,BO-RS)	0.127*	0.349*	0.129
% Evergreen	0.481*	0.751*	0.839	
% Deciduous	0.825	0.892*	0.783*	0.567
% Mixed	0.363	0.902*	0.500*	0.595
% Agricultural	0.075*	0.062*	0.026*	0.648*
% Residential	0.624*	0.611*	0.285*	0.449*
% Water	0.000* (BO-GO)	0.014* (BO-GO)	0.069* (BO-GO)	0.905*
% Swamp	0.333*	0.208*	0.077*	0.829*
% Other	0.613*	0.889*	0.469*	
% Forest	0.987	0.769	0.807	0.694
% Non-forested	0.114*	0.232*	0.025* (BO-RS)	0.553*
Time (minutes)	0.033* (BO-GO)	0.119*	0.850*	0.793

[a] No data for variables left blank
* Significance determined by Kruskal-Wallis test (all other significance levels determined by ANOVA).
BO = barred owl
GO = goshawk
RS = red-shouldered hawk

Appendix 8. Discriminant functions for significant habitat characteristics measured from 4 scales of aerial photography among barred owl, northern goshawk, and red-shouldered hawk nest areas.

Variable	Barred owl	Goshawk	Red-shouldered hawk[a]
1:12,000			
Constant	-44.58	-37.49	-36.33
Number of patches	4.02	3.33	3.54
% Open water	13.65	5.40	8.10
% Non-forested	-19.57	-14.63	-17.82
% Swamp	23.23	19.63	21.47
% Agricultural	15.21	11.31	10.66
Distance to water	2.97	2.90	2.75
Distance to opening	2.84	2.78	2.61
1:40,000			
Constant	-78.37	-72.86	-74.22
Number of patches	1.04	0.86	0.93
% Open water	50.28	42.73	47.93
% Non-forested	10.57	10.37	10.25
% Swamp	23.16	21.14	24.65
% Agricultural	14.99	12.97	10.10
Distance to water	4.33	4.24	4.62
Distance to opening	10.79	10.56	10.15
1:58,000			
Constant	-209.73	-214.73	-194.50
Number of patches	1.55	1.63	1.80
% Open water	68.46	63.84	62.14
% Non-forested	53.14	53.89	48.66
% Swamp	64.31	66.50	64.32
% Agricultural	22.94	21.54	20.83
Distance to water	11.89	12.27	11.45
Distance to opening	30.83	31.04	29.53
1:126,000			
Constant	-1697.26	-1646.19	
Number of patches	-25.56	-23.99	
% Open water	1646.31	1620.34	
% Non-forested	138.74	126.79	
% Swamp	-13.29	-21.49	
% Agricultural	705.24	701.37	
Distance to water	41.01	39.33	
Distance to opening	310.30	306.58	

[a] No data for 1:126,000 scale

Appendix 9. Significance of 21 habitat characteristics measured from 4 scales of aerial photography between barred owl nest areas and random areas.

Variable	1:12,000	1:40,000	1:58,000	1:126,000
Distance to water (m)	0.957*	0.479	0.446*	0.522*
Distance to opening (m)	0.228*	0.056*	0.493*	0.627
Distance to edge (m)	0.920*	0.538	0.040*	0.556*
Total edge (m)	0.880	0.393*	0.295*	0.667
Road corridors (m)	0.994*	0.481*	0.914*	0.035*
Wooded corridors (m)		0.830*	0.531*	
Stream corridors (m)	0.715*	0.557*	0.690*	0.944*
Powerline corridors (m)	0.349*	0.630*	0.360*	0.606*
Total corridor length (m)	0.763*	0.468*	0.839*	0.436*
Number of patches	0.515	0.167*	0.358*	0.824*
% Evergreen	0.494*	0.730*	0.170	0.179*
% Deciduous	0.608	0.923*	0.287	0.785*
% Mixed	0.298	0.844*	0.449*	0.785*
% Agricultural	0.733*	0.800*	0.924*	0.560*
% Residential	0.761*	0.407*	0.447*	0.156*
% Open water	0.182*	0.066*	0.164*	0.944*
% Swamp	0.173*	0.167*	0.055*	0.154*
% Other	0.603*	0.548*	0.049*	
% Forest	0.843	0.642	0.423	0.199
% Non-forested	0.813*	0.809*	0.902*	0.949
Time (minutes)	0.314	0.622*	0.267*	0.919

*As determined by Wilcoxon rank-sum test (t-test used to determine all other significance levels).

Appendix 10. Significance 21 habitat characteristics measured from 4 scales of aerial photography between northern goshawk nest areas and random areas.

Variable	1:12,000	1:40,000	1:58,000	1:126,000
Distance to water (m)	0.035*	0.722*	0.607*	0.798*
Distance to opening (m)	0.010*	0.002*	0.033*	0.234
Distance to edge (m)	0.151*	0.148*	0.620*	0.601*
Total edge (m)	0.095*	0.365*	0.329*	0.526*
Road corridors (m)	0.287*	0.036*	0.094*	0.414*
Wooded corridors (m)	0.071*	0.113*	0.721*	
Stream corridors (m)	0.786*	0.484*	0.610*	0.515*
Powerline corridors (m)	0.289*	0.854*	0.619*	0.513*
Total corridor length (m)	0.209*	0.030*	0.120*	0.282*
Number of patches	0.000	0.431*	0.631*	0.219*
% Evergreen	0.398*	0.275*	0.027*	0.110*
% Deciduous	0.338	0.719*	0.015*	0.633*
% Mixed	0.705	0.489*	0.518*	0.823*
% Agricultural	0.551*	0.106*	0.395*	0.065
% Residential	0.715*	0.822*	0.690*	
% Open water	0.001*	0.097*	0.363*	0.767*
% Swamp	0.911*	0.579*	0.007*	0.110*
% Other	0.635*	0.954*	0.135*	
% Forest	0.822*	0.804*	0.757	0.810
% Non-forested	0.941*	0.173*	0.671*	0.065
Time (minutes)	0.074	0.061*	0.581*	0.514

* As determined by Wilcoxon rank-sum test (t-test used to determine all other significance levels).

Appendix 11. Significance of 21 habitat characteristics measured from 4 scales of aerial photography between red-shouldered hawk nest areas and random areas.

Variable	1:12,000	1:40,000	1:58,000	1:126,000
Distance to water (m)	0.070*	0.615	0.001*	0.285
Distance to opening (m)	0.579*	0.116*	0.342*	0.660
Distance to edge (m)	0.693*	0.954	0.071*	0.771
Total edge (m)	0.544	0.961*	0.112*	0.404
Road corridors (m)	0.343*	0.111*	0.692*	0.624*
Wooded corridors (m)		0.748*	0.555*	
Stream corridors (m)	0.218*	0.285*	0.751*	0.718*
Powerline corridors (m)	0.141*	0.209*	0.386*	0.790*
Total corridor length (m)	0.616*	0.197*	0.874*	0.542*
Number of patches	0.001	0.948*	0.034	0.099
% Evergreen	0.765*	0.710*	0.098*	0.642*
% Deciduous	0.274	0.914*	0.087*	0.680*
% Mixed	0.263	0.968*	0.994*	0.399*
% Agricultural	0.015*	0.009*	0.004*	0.605
% Residential	0.174*	0.222*	0.241*	
% Open water	0.817*	0.413*	0.246*	0.718*
% Swamp	0.122*	0.008*	0.000*	0.056*
% Other	0.809*	0.770*	0.854*	
% Forest	0.910	0.231*	0.841	0.401
% Non-forested	0.030*	0.042*	0.009*	0.605
Time (minutes)	0.181	0.778*	0.378	0.871

* As determined by Wilcoxon rank-sum test (t-test used to determine all other significance levels).

Appendix 12. Discriminant functions for habitat characteristics measured from 4 scales of aerial photography for raptor nest areas/random areas.

Variable	Barred owl	Random area	Goshawk	Random area	Red-shouldered hawk	Random area
1:12,000						
Constant	-41.94	-40.33	-104.96	-103.09	-48.77	-42.57
Number of patches	2.46	2.58	2.47	3.07	2.21	1.80
% Open water	26.54	22.25	54.51	61.98	20.57	17.70
% Non-forested	-3.34	-4.24	12.15	6.77	-4.16	-3.42
% Swamp	14.67	11.32	57.16	55.71	30.37	32.28
% Agricultural	2.55	2.17	12.94	16.33	10.70	7.59
Distance to water	2.97	3.05	9.27	9.04	5.43	5.25
Distance to opening	3.58	3.40	10.84	10.43	3.08	2.82
1:40,000						
Constant	-57.07	-48.10	-65.82	-61.39	-41.45	-46.59
Number of patches	1.49	1.38	1.70	1.70	1.15	1.11
% Open water	40.78	34.31	27.97	31.74	21.17	24.15
% Non-forested	-2.56	-3.03	-0.07	-1.04	7.55	9.15
% Swamp	29.66	25.88	48.96	47.63	21.22	25.48
% Agricultural	16.85	15.05	11.27	13.38	1.82	-1.78
Distance to water	4.43	4.60	6.60	6.71	4.51	4.52
Distance to opening	5.90	5.02	6.05	5.45	3.68	4.08

Appendix 12 continued.

Variable	Barred owl	Random area	Goshawk	Random area	Red-shouldered hawk	Random area
1:58,000						
Constant	-115.58	-107.67	-124.40	-114.99	-95.36	-93.76
Number of patches	-0.46	-0.46	0.37	0.26	1.00	1.48
% Open water	56.29	51.53	63.24	64.10	43.58	44.01
% Non-forested	42.21	40.27	45.61	43.28	32.16	31.56
% Swamp	36.99	34.46	31.59	28.49	28.03	31.22
% Agricultural	-4.88	-4.42	-1.61	0.35	-0.79	-3.99
Distance to water	9.46	9.35	7.98	7.79	7.75	7.11
Distance to opening	14.48	13.92	17.22	16.52	12.15	12.12
1:126,000						
Constant	-251.69	-227.19	-341.86	-330.23		
Number of patches	0.73	1.43	-0.32	0.03		
% Open water	20.41	19.17	101.86	101.83		
% Non-forested	28.81	15.88	133.67	134.52		
% Swamp	104.52	92.17	282.08	270.95		
% Agricultural	91.15	98.21	0.00	0.00		
Distance to water	22.30	20.48	39.90	38.74		
Distance to opening	26.79	26.14	29.98	29.88		

Vita

Judith A. Falk received a Bachelor's Degree in Biology from Central Michigan University in 1978. She held positions as a naturalist, environmental education specialist, and research and resource management technician for the National Park Service in Yellowstone, Everglades, and Yosemite National Parks. In 1986 she was granted a graduate research assistantship at Virginia Polytechnic Institute and State University where she became a candidate for the Masters of Science degree in Fisheries and Wildlife Sciences. Upon completion of her thesis she accepted a permanent wildlife biologist position with the U.S. Forest Service in Juneau, AK.

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