Habitat Relations

Large-Scale Forest Composition Influences Northern Goshawk Nesting in Wisconsin

DEAHN M. DONNER,[1] *U.S. Forest Service, Northern Research Station, Institute for Applied Ecosystem Studies, 5985 Highway K, Rhinelander, WI 54501, USA*

DEAN ANDERSON, *Landcare Research, Lincoln 7640, New Zealand*

DANIEL EKLUND, *U.S. Forest Service, Chequamegon-Nicolet National Forest, Park Falls, WI 54552, USA*

MATTHEW ST. PIERRE, *U.S. Forest Service, Chequamegon-Nicolet National Forest, Rhinelander, WI 54501, USA*

ABSTRACT The northern goshawk (*Accipiter gentilis atricapillus*) is a woodland raptor that uses a variety of forest types for nesting across its breeding range, but strongly depends on older forests with large trees and open understories. Goshawks may select nesting locations by maximizing the convergence of nesting and foraging habitats. Insights into goshawk responses to heterogeneous landscapes can be gained by examining the location of active nest sites through time and at multiple spatial scales. We examined the landscape-scale forest conditions that influenced the probability of active goshawk nests in the United States Forest Service, Chequamegon-Nicolet National Forest (CNNF) in northern Wisconsin. We used goshawk nest survey and monitoring data from 1997 to 2006 to determine the probability of an active nest site over time in relation to forest composition and road density at 3 scales (200-m, 500-m, and 1,000-m radii). Goshawk nests were located primarily in upland hardwood (64%), conifer (23%), and older aspen–birch ($\geq$26 yrs old; 11%) habitat cover types. We used Bayesian temporal autoregressive models of nest locations across multiple spatial scales to analyze these data. The probability of active goshawk nest occurrence increased with increasing conifer cover (1,000 m) and decreased with increasing cover of older aspen–birch and density of primary roads (500 m). In addition, lesser proportions of older aspen–birch at intermediate scales around goshawk nests had a stronger effect on the probability of a nest being active than conifer and primary roads. Thus, the ratio of conifer cover (within 1,000 m) to older aspen–birch cover (within 500 m) in landscapes surrounding nest sites was the key driver in predicting the probability of an active nest site. This finding can be used by forest managers to help sustain the active status of a goshawk nesting area through time (i.e., annually), and foster goshawk nesting activity in areas where active nesting is not currently occurring.

KEY WORDS *Accipiter gentilis atricapillus*, Bayesian inference, Chequamegon-Nicolet National Forest, nesting habitat, northern goshawk, spatial scales, Wisconsin.

The northern goshawk (*Accipiter gentilis atricapillus*) is a circumboreal woodland raptor with a North American breeding distribution extending into the western Great Lakes region (Johnsgard 1990). This region represents the southern extent of its breeding range, where they are uncommon breeders (Rosenfield et al. 1998). Research shows goshawks use a wide variety of forest types for nesting across its range, but select for older forests with large trees and open understories within the perspective landscape (Kennedy et al. 1994, Daw and DeStefano 2001, Andersen et al. 2005, Boal et al. 2006, Reynolds et al. 2008). Goshawks nest in large conifer or deciduous trees that are able to support the nest (Squires and Reynolds 1997, Andersen et al. 2005, Boal et al. 2005), and find horizontal layers of open space in the subcanopy to facilitate nest accessibility and flight for hunting (Beier and Drennan 1997, Penteriani et al. 2001, Reynolds et al. 2006, Boal et al. 2005).

Received: 2 September 2011; Accepted: 31 August 2012
Published: 4 January 2013

[1]*E-mail: ddonnerwright@fs.fed.us*

Insights into goshawk responses to altered landscapes can be gained by examining the habitat condition of active nest sites relative to sites without nests at multiple spatial scales. Studies suggest that goshawks may be selecting habitat by maximizing the convergence of nesting and foraging habitats. Reviews of goshawk literature (Reynolds et al. 2006, Squires and Kennedy 2006) conclude that although the availability of nest sites (i.e., large trees in dense, closed canopy stands; Reynolds et al. 1992, Andersen et al. 2005, Boal et al. 2005) is important to the persistence of goshawks, forest structural conditions at broad spatial scales also influence occupancy (Reynolds et al. 1992, Daw and DeStefano 2001, Finn et al. 2002, McGrath et al. 2003), because these conditions determine prey availability and accessibility (Beier and Drennan 1997, Penteriani et al. 2001). Goshawks are prey generalists, and forage on a suite of 8–15 mammalian species within the families Sciurids and Leporids, and grouse

(*Bonasa* spp. and *Dendragapus* spp.) depending on the region (Reynolds et al. 1992, Andersen et al. 2005). Preferred hunting areas should reflect a trade-off between prey abundance, foraging sites (e.g., perches), and flying conditions that influence hunting success (Widén 1997, Squires and Kennedy 2006).

Managing goshawk breeding habitat involves considering habitat composition and structure at several nested spatial scales including nest, post-fledging, and foraging areas (Reynolds et al. 1992, Kennedy et al. 1994, Andersen et al. 2005, Carroll et al. 2006, Woodbridge and Hargis 2006). Given the geographical variability in spatial habitat use (Squires and Kennedy 2006), an understanding of the spatial scale at which goshawks interact with the habitat surrounding nest sites is lacking across the species' distribution (Finn et al. 2002, Reich et al. 2004) complicating the management of goshawk habitat. In the western Great Lakes region, less is known about the spatial scale at which goshawks interact with habitat surrounding nests as most studies have been conducted in the western United States. Arguably, goshawk habitat use reported in the West may not apply directly to other regions of North America where the forest systems and environmental conditions are much different (e.g., topographic relief, summer temperatures and precipitation; Boal et al. 2006). However, habitat assessment is difficult because information on goshawk relations with its habitat and prey for the region is incomplete (Boal et al. 2006). Effective conservation and management of goshawks in this region would be aided by an improved understanding of how goshawks respond to spatial and temporal variability in forest composition and structure.

Our study was motivated by the need to understand how forest attributes (composition and age structure) at large scales within the United States Forest Service Chequamegon-Nicolet National Forest (CNNF) in northern Wisconsin influence goshawk nesting activity over time. Such understanding is relevant to better assess the effect timber management (e.g., clearcuts) occurring in landscapes surrounding goshawk nests may have on nesting activity in this region. Conservation measures for the species on the CNNF and throughout northern Wisconsin (U.S. Department of Agriculture Forest Service [USDA] 2004*a*) have focused on avoiding disturbance in the nest stand by placing protective buffers around nest sites (200-m radius; 12 ha) and limiting timber activities within another 100 m around the protection zone (total 28 ha). Although these steps appear to be effective in reducing disturbance to nesting pairs, limited information is available on habitat use at scales beyond the nest protection zone for this region. Our objective was to evaluate the type and spatial scale of forest cover surrounding active goshawk nests to gain a better understanding of habitat composition at local and intermediate scales surrounding a nest site. Given the nested use of habitat for nesting, post-fledging, and foraging purposes, we predicted that active nest sites would tend to be surrounded by habitat characterized by a mixture of older forest (for nesting) and early successional habitat (for hunting) at the post-fledging and foraging scales. We used 10 years of goshawk nest survey and monitoring data to determine the probability of nest site use over time in relation to forest composition and road density at 3 scales (200-m, 500-m, and 1,000-m radii).

STUDY AREA

Our study considered all lands within the CNNF excluding the Washburn District, which is ecologically distinct from the rest of the CNNF. The CNNF is located in northern Wisconsin within the Southern Superior Uplands Section of the Laurentian Mixed Forest Province (McNab et al. 2007; Fig. 1). This region experiences a continental climate of long winters with extremely cold temperatures possible, and short and fairly warm summers resulting in 100–140 frost-free days per year. The landforms within CNNF are diverse, ranging from glacial outwash plains to glacial moraines and drumlins (elongated hills) to areas of pitted outwash. Topography is characterized by linear drumlins interspersed with long, narrow drainage ways and slopes of 5–20%. Greater slopes are found along stretches of the Brule River, which forms the northern edge of the eastern side of the forest, but are otherwise lacking throughout the study area. Lakes of glacial origin, bogs, and perennial streams are abundant throughout the region. Wetland and organic soils comprise about 25% of the CNNF (USDA 2004*a*).

Historically, the region had the largest and most contiguous expanse of hemlock-hardwood forest in the Lake States (Curtis 1959, Tyrrell and Crow 1994). Like many forests of the eastern United States, timber was extracted at a significant rate during the late 19th and early 20th centuries. When the CNNF was established in the 1930s, the lands were largely cut-over, burned, farmed, and subsequently abandoned (Stearns 1949). As a result, the CNNF today is predominately young (70–80-yr-old) northern hardwoods with scattered conifers and aspen stands of various ages. The CNNF lies within one of the largest expanses of maple-dominated hardwood forest within the western Great Lakes region (USDA 2004*b*). Sugar maple (*Acer saccharum*), American beech (*Fagus grandifolia*), red maple (*Acer rubrum*), basswood (*Tilia americana*), white ash (*Fraxinus americana*), red oak (*Quercus rubra*), quaking aspen (*Populus tremuloides*), yellow birch (*Betula alleghaniensis*), and eastern hemlock (*Tsuga canadensis*) typify the maple-dominated hardwoods. Conifer species associated with these forests are white spruce (*Picea glauca*), balsam fir (*Abies balsamea*), black spruce (*Picea mariana*), northern white-cedar (*Thuja occidentalis*), and tamarack (*Larix laricina*). The aspen–birch system consists of quaking and big-tooth aspen (*P. grandidentata*), paper birch (*Betula papyrifera*), red maple, and balsam fir (Curtis 1959).

METHODS

Goshawk Surveys

We used historical CNNF nest location and monitoring data collected from 1997 to 2006. During this monitoring effort, 2 survey methods (i.e., opportunistic and systematic) were used to determine if an area held an active goshawk nest. Opportunistic surveys included goshawk nests and sightings

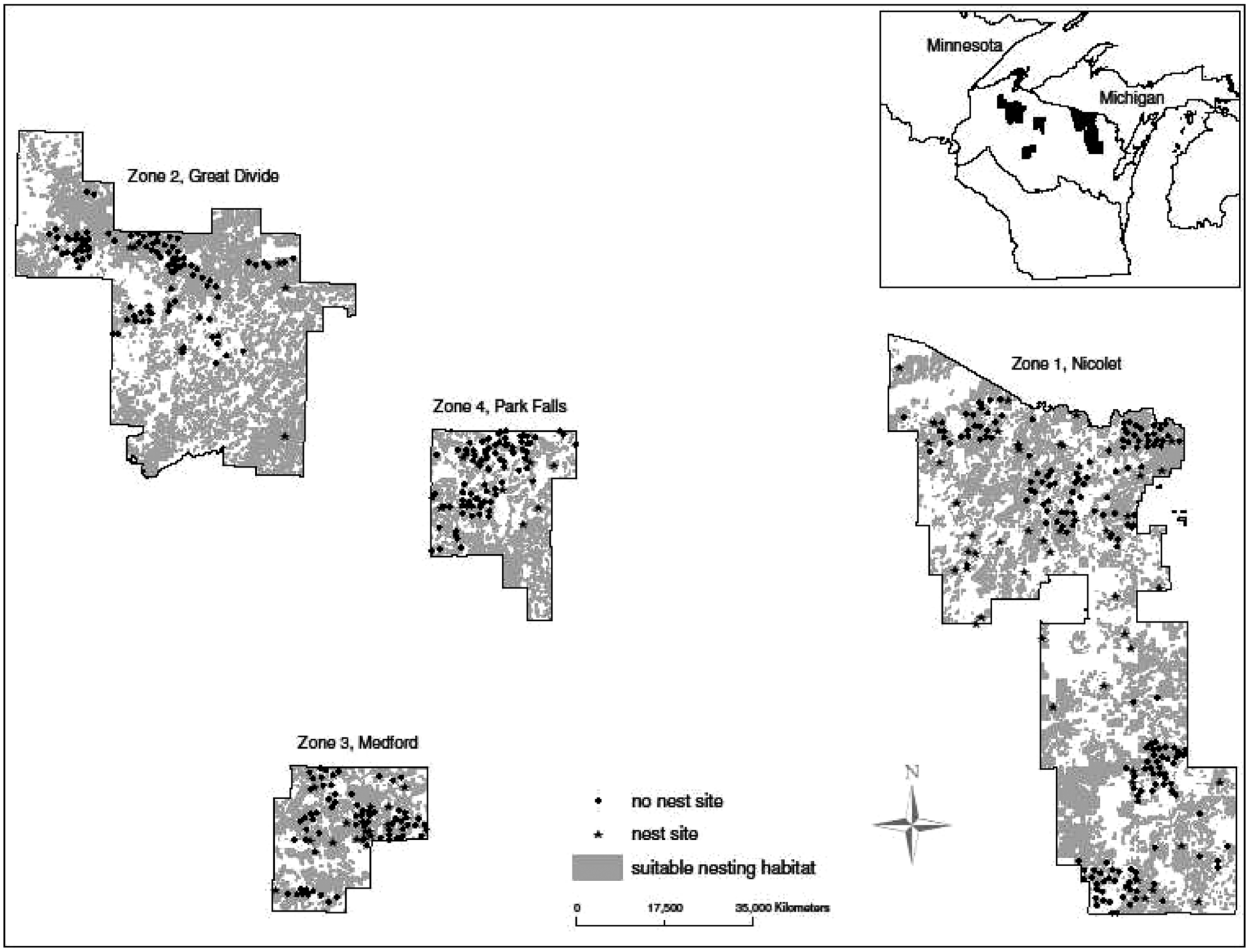

Figure 1. Study area within the Chequamegon-Nicolet National Forest, Wisconsin, USA, 1997–2006. We used goshawk nest sites (stars) and a random subset of surveyed sites (no-nest sites; solid circle) to assess forest composition and road density effects on active goshawk nesting sites at several scales, 1997–2006. Zones represent management districts on the national forest. Suitable habitat was defined as northern hardwood, hemlock, red pine, and aspen stands $\geq$50 years.

(e.g., goshawk perched in tree, fly-throughs) recorded by United States Forest Service (USFS) personnel during pre-harvest stand examination (i.e., found while conducting timber inventory and marking activities) from 1997 to 2000. We also used opportunistic goshawk nest sightings reported by falconers, the public, and other researchers during the entire study period. These opportunistic sightings were checked in spring by USFS wildlife personnel to visually confirm the presence of an active nest and document surrounding forest cover types.

Systematic detection methods were used from 2001 to 2006 to locate goshawk nests in suitable nesting habitat within forest management project areas. Twenty-eight projects averaged 11,444.1 ha ($\pm$8,476.1 SD) and comprised 51.9% of the CNNF land area. Suitable nesting habitat was defined as northern hardwood, hemlock, red pine (*Pinus resinosa*), and aspen stands greater than 50 years old based on goshawks association with older forests that retain the structure required to hold their large nests (Squires and Kennedy 2006; Fig. 1). Timber harvest projects were divided into management stands, and within each management stand of suitable nesting habitat a call-response technique (Kennedy and Stahlecker 1993, Bosakowski and Vaughn 1995, Bosakowski 1999) was used along transects that were spaced 200 m apart and traversed the entire stand. Transects extended 300 m into adjacent stands of suitable habitat not scheduled for harvest. At survey stations spaced 200 m along transects, alarm calls were broadcast 3 times, each for 10 seconds followed by a 30-second listening and waiting period. The surveyor rotated in 120-degree increments between calls to ensure coverage around the survey station. Surveys were conducted 15 March–31 July by USFS or Wisconsin Department of Natural Resources (WDNR) staff trained in the sampling protocol, or by private contractors considered to be woodland raptor experts with working knowledge of protocol application. From 15 June to 31 July, observers used a fledgling begging call rather than the alarm call to enhance detection during the fledgling period.

When observers detected a nest structure or bird sighting, they marked the location on a forest stand management map or collected a Global Positioning System (GPS) point. Observers monitored all locations during annual visits to determine if a nest structure existed, and if so, whether signs of active nesting were present during breeding and post-fledging periods (e.g., molted feathers, feces, remains of prey, young). Because goshawks typically do not lay eggs for periods of 1–5 years or more on breeding areas (Reynolds et al. 1994, 2005; Kennedy 1997; McClaren et al. 2002; Salafsky et al. 2005) and they often move to alternate nest locations within a territory across years (Squires and Reynolds 1997, Reynolds et al. 2005), all known nest structures were surveyed annually regardless of whether the nest was active the previous year. If a nest structure was found inactive, the immediate surrounding area ($\leq$400 m) was searched for an alternate nest structure either visually or by playing call-response recordings during spring or early summer. Alternate nests are often grouped or clustered (Squires and Reynolds 1997). In eastern deciduous forests, most alternative nests were found to be within 0.4 km of one another (Reynolds and Wright 1978, Speiser and Bosakowski 1987, Reynolds et al. 1994, Woodbridge and Detrich 1994, Reynolds and Joy 1998). In northeastern Wisconsin, alternative nests were generally found to be within 1.6 km of each other (T. Dick and D. Plumpton, 1998, U.S. Fish and Wildlife Services, Minnesota, unpublished report). In CNNF, the majority of alternate nests have been found within this distance as observed with banding data (D. Eklund, U.S. Forest Service, personal observation). In western systems, Reynolds et al. (2005) found the median distance between alternate nests was 402 m. We considered inactive nest sites as unoccupied sites, and the alternate nest sites as the active (occupied) site. We used the spatial coordinates of the nest structure in analysis.

We used the spatial coordinates of the centroid of the management stand to represent those management stands surveyed using either opportunistic or systematic detection method for which no nest was found (i.e., no-nest sites or unoccupied). Within each year, we randomly selected no-nest sites that were separated by at least 1,000 m from other no-nest and active nest sites, because territoriality among conspecifics influences spatial distribution of nests (Reich et al. 2004). This threshold distance was selected because it resulted in high coverage of the study area (Fig. 1) and approximated the minimum separation distance between CNNF goshawk nest locations in our data set (1,394 m). The combination of these no-nest locations with annual survey data for nesting activity at known nest locations resulted in a spatiotemporal data set. The data analysis (see below) accounted for the inherent temporal dependence in the probability of a location having an active nest (i.e., an active nest at location i at time t will increase the estimated probability of an active nest at time $t + 1$).

Landscape Variables

We calculated the proportion of forest cover types and road density within 200-m, 500-m, and 1,000-m radii around all locations using stand-level forest inventory data collected by CNNF. These radii are equivalent to 12.6 ha, 78.5 ha, and 314 ha; 200 m corresponds to reported nest areas (8–12 ha) and the protective buffer where no land management activities are allowed around the nest, whereas 500-m and 1,000-m radii are below and above (bracket) reported post-fledging areas found in the West (170 ha; Reynolds et al. 1992, Kennedy et al. 1994). A nest area is defined as the area surrounding a nest that includes the nest, roosts, and prey plucking sites. A post-fledging area encompasses the area used by fledglings until independence and the defended portion of a territory (Reynolds et al. 1992, Kennedy et al. 1994). Foraging areas are often >2,100 ha. We classified lands surrounding nest sites but outside CNNF boundaries using 2005 aerial photography from the National Agriculture Imagery Program (1-m resolution) in reference with 1998 black and white Digital Ortho Quarter Quads (DOQQS); cover type patches had to be $\geq$2 ha to be classified. We classified habitat cover types broadly as conifer, upland hardwood, lowland hardwood, shrub, aspen–birch (>26 yrs old), or regenerating aspen–birch ($\leq$26 yrs old). Habitat cover types were verified during stand exams that were completed for all forested and non-forested lands within the forest management project areas (i.e., study area); cover typing occurred in tandem with goshawk surveys. Forested habitat cover types were verified during 3 years of stocking surveys after harvest. Additionally, the project areas were much larger than the largest buffer size used in this study, ensuring correct habitat classification surrounding our sites. Habitat cover types surrounding nests reported by the public were verified during the spring visits by USFS personnel. Because aspen–birch stands are managed through clearcutting on a 40–50-year rotation, which results in stand conversion in terms of age, this cover type was reclassified to regenerating aspen (<26 yrs old) based on the management stand's year of origin in relation to the year the goshawk survey was completed. Aspen–birch forests are early-successional areas with high stem density (i.e., dense understories) during the first 26 years. Aspen–birch cover types were no longer considered regenerating when >26 years old, which is the approximate age when the understory becomes more open as well. Other cover types remained the same throughout the study duration. Lowland hardwoods were stands dominated by white or black ash (*Fraxinus nigra*), and red maple, whereas upland hardwoods were dominated by sugar maple. Shrubs included upland and lowland shrubs such as beaked hazelnut (*Corylus cornuta*), elderberry (*Sambucus canadensis*), and tag alder (*Alnus serrulata*).

We classified roads into primary and secondary categories. Primary roads were suitable for speeds exceeding 50 km/hr, and were paved or had an aggregate surface. Secondary roads were traveled at slower speeds and may not have had an aggregate surface, and included seasonal roads such as old logging roads and wide trails used for multiple purposes such as snowmobiling, skiing, hunting, and hiking where open understories are maintained.

Data Analysis

We explored models of the probability of presence of an active nest in 2 steps. First, for each landscape variable, we conducted uni-variable analyses to identify the spatial scale that best explained the data (see below). Second, we used the best explanatory scale for each variable in multi-variable models. We took this 2-step process because a priori we did not know the scale at which goshawks were responding to each cover type given their reported use of habitat for different purposes (e.g., nesting, pre-fledging, foraging). Using the spatial scales best-supported in the uni-variable analyses, we assembled 40 2- and 3-variable models using combinations of habitat cover types related to preferred nest habitat and foraging habitat based on prey habitat preferences reported in the literature for this region, and habitat disturbance factors such as roads and trails that may disrupt nesting activity (e.g., primary roads) or create flyways (e.g., trails with open understories; Table 3).

We used the presence–absence of active goshawks nests and logistic regression to explore the probability of active nest presence as a function of landscape conditions. We used Markov chain Monte Carlo methods to make Bayesian inference on parameters in the regression models. This modeling framework facilitates the full accounting of spatial and temporal biases in the data, and temporal autocorrelation in goshawk selection for nest sites in successive years. We modeled the presence–absence data (y_{ij}) across nest sites (i), years (j), and forest zones (k) as a Bernoulli process:

$$y_{ijk} \sim \text{Bernoulli}(\theta_{ijk})$$
$$\text{logit}(\theta_{ijk}) = X_i'\beta + \phi y_{i,j-1} + \kappa_k + \tau_j$$

where θ_{ij} is the probability of presence of an active nest, $X_i\beta$ is the product of the landscape variables and the associated coefficients, ϕ is a temporal autoregressive parameter (AR1) to account for temporal dependence in the probability of presence, κ_k is the forest-zone effect, and τ_j is the year effect. The τ_j accounts for the potential bias in survey techniques over time. We imposed a sum-to-zero constraint on the zone and year effects. We divided the CNNF into 4 zones to account for the spatial variation in site locations (Fig. 1). We used a logit transformation to constrain the Bernoulli-distributed probability to the range 0–1. We used weakly informative Cauchy priors with center zero and scale 2.5 for ϕ and the β parameters for the landscape covariates (Gelman et al. 2008). We used Cauchy priors with center zero and scale 10 for the intercept, and the zone- and year-effect parameters. Estimating nest activity at each nest site for the year prior to the first survey was necessary to properly parameterize the ϕ AR1 term. We used a uniform Beta prior [Beta(1,1)] for the prior probability of an active nest in year $j = 0$.

We sampled all conditional posteriors using a Metropolis algorithm (Clark 2007:175–177). We assessed within-chain serial autocorrelation to determine the appropriate thinning rate. We confirmed convergence on the posterior target distribution with a scale reduction factor ($\hat{R}$) < 1.2 calculated on 4 parallel chains (Gelman and Rubin 1992, Gelman et al. 2004). We achieved convergence for all models with 5,000 iterations, and obtained posterior summaries from 4 chains containing 30,000 samples with a thinning rate of 15 (i.e., 8,000 samples). We used the Deviance Information Criterion (DIC) to compare competing models (Spiegelhalter et al. 2002). If competing uni-variable models had a ΔDIC < 2.5, we selected the larger scale for analysis in the multi-variable models. We checked collinearity and found it to be low in the multi-variable models ($r < 0.30$).

RESULTS

Overall, observers found 655 no-nest sites and 141 active nest sites (representing nests of 74 individual goshawks based on banding information); 45 of the nest sites were found opportunistically. Goshawks placed their nests in trees primarily within upland hardwood management stands (64%), which was more frequent than what was available in the land base surveyed (29.2%). Conversely, 11% of the goshawk nests were in trees located within aspen–birch management stands even though aspen–birch represented 21.7% of the land base surveyed. Conifer stands had 23% of the goshawk nests, which was similar to conifer availability on the surveyed land base (20.3%). Goshawk nests were not located in the remaining cover types. Regenerating aspen, lowland hardwoods, and shrubs composed 6.8% (based on a 10-yr average due to definition of regenerating aspen), 4.9%, and 3.4% of the land base surveyed, respectively. These results represent management stands (i.e., cover type) in which the nest was located rather than the cover types surrounding the nest, management stands may or may not have been larger than the radii used. Within the 200-m radius surrounding nest sites, the proportion of upland hardwood was approximately double that found in the surveyed land base and similar to nest site location results, but the proportion of upland hardwood decreased with increasing radius from the nest location (Table 1). Conversely, proportions of aspen–birch and lowland hardwoods were lowest at the 200-m radius and increased slightly with increasing radius, but still remained much lower than the forest at large, and the proportion of conifer increased with increasing radius from the nest location. Ranges of other forest types were represented at approximately the same proportion inside the circular analysis regions compared to what was available in the surveyed area. These results indicate goshawks are placing nests in trees found primarily in upland hardwoods, but will use trees in other forest cover types.

Among the uni-variable models, upland and lowland hardwoods, conifers, and shrubs were most explanatory of active goshawk nest sites at the 1,000-m scale (Table 2). Aspen–birch, regenerating aspen, and density of primary roads were most explanatory at the 500-m scale. Only density of secondary roads was most explanatory at the 200-m scale. The credible intervals for the best-supported scales for all variables, except density of secondary roads, did not overlap zero. The credible intervals for density of secondary roads overlapped zero at all 3 spatial scales.

Using the spatial scales best supported in the uni-variable analyses, we found that the probability of occurrence of an active nest increased with increasing conifer cover at the largest scale (1,000 m), and decreased with increasing cover of aspen–birch and density of primary roads at intermediate scales (500 m) as indicated by the model with the smallest

Table 1. Percent forest cover types and road density (km/km^2) within 3 circular analysis regions around goshawk nest site locations and centroids of surveyed stands where no goshawk nests were found within the Chequamegon-Nicolet National Forest, Wisconsin, 1997–2006. U represents nest-free sites ($n = 655$); O represents active nest sites ($n = 74$). Max % represents maximum proportion; all variables had minimum proportion of 0.

Landscape variable	Unoccupied/ occupied	200-m radius mean (SD; max %)	500-m radius mean (SD; max %)	1,000-m radius mean (SD; max %)
Aspen–birch	U	16.7 (24.4, 100.0)	17.29 (17.3, 74.7)	17.0 (12.8, 57.8)
	O	8.1 (18.3, 72.1)	8.4 (13.2, 56.6)	10.5 (11.0, 48.0)
Conifer	U	17.2 (24.1, 98.6)	20.8 (19.3, 89.6)	23.0 (14.9, 79.1)
	O	23.2 (25.5, 86.6)	27.3 (19.2, 75.2)	29.8 (15.5, 77.8)
Upland hardwood	U	51.5 (36.6, 100.0)	42.0 (28.4, 100.0)	35.5 (22.2, 95.3)
	O	60.3 (33.6, 100.0)	49.9 (25.8, 100.0)	41.0 (19.3, 82.0)
Lowland hardwood	U	1.3 (5.9, 55.8)	2.3 (5.2, 32.2)	3.1 (5.1, 31.3)
	O	3.0 (9.2, 52.9)	4.1 (6.9, 32.2)	4.2 (4.8, 17.3)
Regenerating aspen	U	4.6 (10.6, 60.4)	6.0 (9.3, 71.2)	6.6 (7.1, 40.8)
	O	2.1 (6.9, 49.6)	3.7 (5.7, 23.0)	5.1 (6.4, 36.5)
Shrub	U	2.2 (7.4, 81.2)	3.0 (6.6, 44.6)	3.9 (6.3, 43.7)
	O	0.6 (3.1, 25.9)	1.9 (4.0, 24.7)	3.1 (4.1, 19.4)
Primary roads	U	10.0 (16.1, 83.4)	8.3 (8.4, 31.8)	7.0 (5.0, 22.7)
	O	7.2 (14.1, 57.9)	5.5 (7.2, 27.1)	5.5 (4.6, 19.9)
Secondary roads	U	21.1 (22.5, 103.2)	19.2 (14.8, 78.9)	16.7 (10.2, 51.6)
	O	23.1 (22.7, 74.8)	19.5 (14.8, 73.4)	15.8 (10.0, 50.6)

DIC (Table 4). These variables had 3 of the 4 smallest DIC values among the uni-variate models (Table 2). Furthermore, conifer and aspen–birch cover types were included in the second and third best models (ΔDIC = 3.7 and 5.8, respectively; Table 3) indicating the influence of these variables at these scales on the probability of an active goshawk nest.

We expected the proportion of upland hardwoods and regenerating aspen to be influential because of nesting habitat preferences and foraging habitat (i.e., availability of prey), respectively. The best uni-variable model in the 500-m buffer was the proportion of upland hardwoods, but it was a poor predictor of nest location in comparison with proportion of conifer cover (1,000 m; ΔDIC = 26.6; Table 2). Although upland hardwood cover was in the fourth and fifth best multi-variable models (ΔDIC = 7.2 and 7.6, respectively; Table 3), this ranking was likely due to the inclusion of conifer cover in these models. Similarly, we predicted regenerating aspen cover to harbor a high density of prey species, but it did not emerge as influencing active goshawk nest locations. It had a low uni-variable model DIC value (Table 2), but did not figure in the top 6 multi-variable models (Table 3).

Table 2. Deviance Information Criterion (DIC) results of the uni-variable model analyses of active goshawk nest sites, Chequamegon-Nicolet National Forest, Wisconsin, 1997–2006. We used these results to determine the best circular analysis region (scale) to include in the final multi-variable model analyses. Values with an asterisk signify the radius distance (scale) used in the multi-variable models for that predictor variable; if ΔDIC (value in parentheses) among scales differed by <2.5, we used the larger scale.

	DIC (ΔDIC)		
Predictor variable	200 m	500 m	1,000 m
Upland hardwood	809.1 (5.3)	803.8 (0)	804.0 (0.2)*
Lowland hardwood	806.0 (0)	806.2 (0.2)	808.0 (2.0)*
Conifer	790.3 (12.9)	786.7 (9.3)	777.4 (0)*
Aspen–birch	788.7 (25.3)	763.5 (0)*	779.7 (16.1)
Regenerating aspen	799.9 (3.6)	796.2 (0)*	803.1 (7.0)
Shrub	799.7 (0.5)	801.3 (2.1)	799.2 (0)*
Secondary road density	808.4 (0)*	811.1 (2.8)	810.9 (2.5)
Primary road density	807.7 (9.9)	797.8 (0)*	805.6 (7.9)

The probability of an active goshawk nest was influenced more by lesser proportions of aspen–birch at intermediate scales around nest sites than conifer and primary roads as indicated by the magnitude of the negative median parameter estimate for aspen–birch (−2.18) compared to conifer and primary roads (1.10 and −0.86, respectively) in the best approximating model. Scaling of the environmental variables allowed for this direct comparison of the strength of their respective influence in the model. In addition, the probability of an active nest being used in the following year will exceed 0.8 when forest cover is 80% conifer, and aspen–birch and primary roads are not present (Fig. 2A). This probability drops to <0.4 with 80% conifer cover when aspen–birch cover is equal to its 90th quantile (40% cover; Fig. 2B). Further, the probability of an active nest being present in a location in a given year is much lower if the location did not have an active nest in the preceding year (Fig. 2C,D), as indicated by the positive estimate for the temporal dependence parameter (ϕ).

We included random year and zone effects to account for suspected biases in the data created by spatial or temporal variations in the sampled goshawk population and survey methods, and it allowed for more accurate estimation of the parameters of interest (i.e., landscape variables). Deviations from the baseline probability of an active nest (95% credible intervals for some zones and years do not overlap zero; Table 4) indicate spatial and temporal variability existed. The probability of active goshawk nests were lesser in the Great Divide District of the CNNF (forest zone 2) and greater in the Medford District (forest zone 3) compared to the baseline probability as indicated by the low and high random intercepts, respectively. Temporally, the probability of an active goshawk nest being present was greater in years 1997 and 2000, but lesser in year 2006. All other years had 95% credible intervals that overlapped zero (i.e., no deviation).

Table 3. Candidate set of models used to examine the probability of active northern goshawk nest sites within the Chequamegon-Nicolet National Forest, Wisconsin, 1997–2006 and the difference in Deviance Information Criterion values (ΔDIC) for each model. Roads were measured as density (km/km^2), and forest cover types were measured as proportion within 200-m, 500-m, and 1,000-m radii around nest structures and centroids of nest-free surveyed management stands. UH, upland hardwood; LH, lowland hardwood; CO, conifer; AB, aspen–birch; RA, regenerating aspen; SH, shrub; PR, primary road density; SR, secondary road density. The subscript in parentheses indicates the radius used in the analysis.

Model emphasis	Parameters (scale)	ΔDIC
2-parameter models		
Nesting habitat	$UH_{(1,000)} + CO_{(1,000)}$	14.7
	$LH_{(1,000)} + CO_{(1,000)}$	25.1
	$CO_{(1,000)} + AB_{(500)}$	5.8
	$UH_{(1,000)} + AB_{(500)}$	20.7
Foraging habitat	$SH_{(1,000)} + RA_{(500)}$	47.0
Disturbance	$PR_{(500)} + SR_{(200)}$	57.7
Nesting/disturbance	$CO_{(1,000)} + PR_{(500)}$	28.8
	$CO_{(1,000)} + SR_{(200)}$	36.2
	$LH_{(1,000)} + PR_{(500)}$	56.8
	$LH_{(1,000)} + SR_{(200)}$	66.3
	$AB_{(500)} + PR_{(500)}$	11.6
	$AB_{(500)} + SR_{(200)}$	22.1
Nesting/foraging habitat	$CO_{(1,000)} + RA_{(500)}$	29.6
	$LH_{(1,000)} + RA_{(500)}$	55.4
	$AB_{(500)} + RA_{(500)}$	14.8
	$UH_{(1,000)} + RA_{(500)}$	54.9
Foraging/disturbance	$RA_{(500)} + PR_{(500)}$	46.6
	$RA_{(500)} + SR_{(200)}$	55.5
	$SH_{(1,000)} + PR_{(500)}$	48.6
	$SH_{(1,000)} + SR_{(200)}$	59.6
3-parameter models		
Nesting habitat	$UH_{(1,000)} + LH_{(1,000)} + CO_{(1,000)}$	7.6
	$UH_{(1,000)} + CO_{(1,000)} + AB_{(500)}$	26.2
	$LH_{(1,000)} + CO_{(1,000)} + AB_{(500)}$	3.7
Foraging habitat	$AB_{(500)} + RA_{(500)} + SH_{(1,000)}$	18.0
Nesting/foraging combo	$UH_{(1,000)} + CO_{(1,000)} + RA_{(500)}$	15.5
	$LH_{(1,000)} + CO_{(1,000)} + SH_{(1,000)}$	24.9
Nesting/disturbance	$UH_{(1,000)} + CO_{(1,000)} + SR_{(200)}$	18.4
	$UH_{(1,000)} + CO_{(1,000)} + PR_{(500)}$	7.2
	$AB_{(500)} + CO_{(1,000)} + SR_{(200)}$	11.0
	$AB_{(500)} + CO_{(1,000)} + PR_{(500)}$	0.0
	$LH_{(1,000)} + CO_{(1,000)} + SR_{(200)}$	31.7
	$LH_{(1,000)} + CO_{(1,000)} + PR_{(500)}$	22.1
Foraging/disturbance	$RA_{(500)} + SH_{(1,000)} + SR_{(200)}$	53.3
	$RA_{(500)} + SH_{(1,000)} + PR_{(500)}$	43.6
Nesting/foraging/disturbance	$CO_{(1,000)} + RA_{(500)} + SR_{(200)}$	34.4
	$CO_{(1,000)} + RA_{(500)} + PR_{(500)}$	26.6
	$LH_{(1,000)} + SH_{(1,000)} + SR_{(200)}$	62.3
	$LH_{(1,000)} + RA_{(500)} + SR_{(200)}$	59.6
	$LH_{(1,000)} + RA_{(500)} + PR_{(500)}$	53.0
	$CO_{(1,000)} + SH_{(1,000)} + SR_{(200)}$	34.2

Table 4. Posterior parameter distributions (median and 95% credible intervals) of the best-supported model relating probability of active goshawk nest site presence to proportion of forest cover types and road density within the Chequamegon-Nicolet National Forest, Wisconsin, 1997–2006. The subscript in parentheses indicates the circular radius (m) used in the analysis. ϕ is a temporal autoregressive parameter (AR1) to account for temporal dependence in the probability of presence.

Predictor variable	Median coefficient	2.5% CI	97.5% CI
Intercept	−3.17	−3.74	−2.7
Aspen–birch cover$_{(500)}$	−2.18	−2.99	−1.5
Conifer cover$_{(1,000)}$	1.10	0.68	1.5
Primary road density$_{(500)}$	−0.86	−1.38	−0.4
ϕ (AR1)	2.02	1.40	2.6
Zone 1: Nicolet	−0.08	−0.45	0.3
Zone 2: Great Divide	−0.95	−1.94	−0.1
Zone 3: Medford	1.19	0.35	2.1
Zone 4: Park Falls	−0.13	−1.05	0.8
Year 1997	0.92	0.15	1.67
Year 1998	0.08	−0.67	0.80
Year 1999	0.60	−0.17	1.35
Year 2000	1.27	0.60	2.00
Year 2001	0.12	−0.65	0.84
Year 2002	0.25	−0.45	0.95
Year 2003	−0.41	−0.95	0.19
Year 2004	0.35	−0.47	1.12
Year 2005	−0.55	−1.40	0.22
Year 2006	−2.58	−4.23	−1.31

DISCUSSION

We examined the landscape-scale forest conditions that influence the probability of an active goshawk nest location on lands within the USFS Chequamegon-Nicolet National Forest in northern Wisconsin. Whereas many goshawk habitat studies have shown that goshawks prefer older forest at fine scales (nesting and surrounding trees; see review by Squires and Kennedy (2006)), survival and reproduction will likely be highly influenced by forest conditions throughout their home range. Goshawks require a diversity of forests types at larger extents (i.e., foraging areas) presumably to find an adequate supply of food, and the diversity of forest types reflects the habitat of prey species (Finn et al. 2002, Reich et al. 2004, Andersen et al. 2005, Boal et al. 2005, Boyce et al. 2006). Indeed, our findings demonstrated that active goshawk nest sites in this region were influenced by forest cover types and road densities at 1,000 m and 500 m, respectively, beyond the nesting site, indicating nesting goshawks are responding to the broader landscape.

Specifically, our finding that goshawks in north-central Wisconsin placed nests in areas with greater conifer cover in the surrounding area than was typically available is consistent with reported goshawk habitat use within the western Great Lakes region. Nesting goshawks selected strongly for high percentage of conifer cover at broad scales despite the tendency to place nests in upland hardwood cover types (64% of nests) and areas with a large amount of upland hardwood within the immediate surroundings (i.e., within the 200-m radius). The focus of this study was not on the nest site locations, and these findings suggest that although upland hardwoods are selected at fine scales, high cover of conifer, and less cover of older aspen–birch at broad-scales is critical. The absence of percent cover of upland hardwood forests in the top models does not indicate that this forest type is not selected by goshawks for nesting, only that its selection by nesting goshawks is occurring at finer spatial scales than were examined here.

Foraging habitat (570–3,500 ha as defined from western studies; Squires and Reynolds 1997) consists of early- and late-successional upland deciduous and conifer stands in northern Minnesota (Boal et al. 2005) to mixed hardwood-conifer and jack pine (*Pinus banksiana*) forest types in Michigan (Lapinski 2000). The strength of the relationship between active goshawk nests and conifer cover

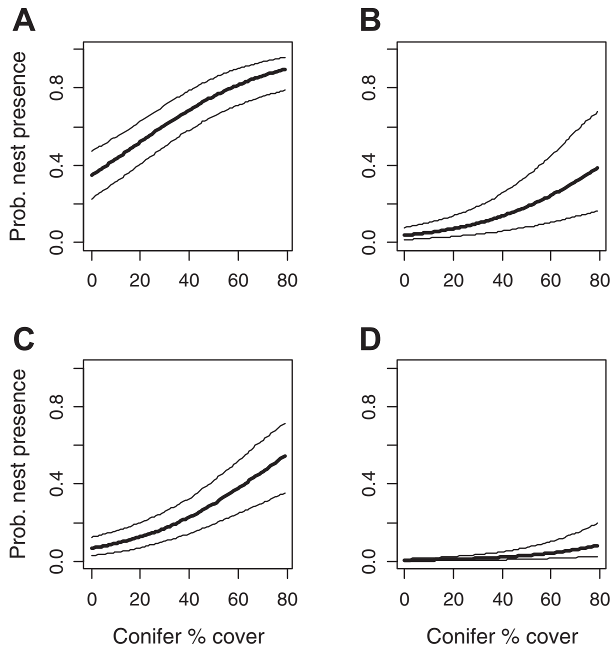

Figure 2. Predicted probability (prob.) of presence of an active goshawk nest across the observed range of conifer cover when the site had a nest (A,B) or no nest found (C,D) in the preceding year within the Chequamegon-Nicolet National Forest, Wisconsin, USA, 1997–2006. The road density for all panels = 0 km/km^2. Panels A and C have low aspen–birch cover (10th quantile = 0%), and panels C and D have high aspen–birch cover (90th quantile = 40.22%).

increased with increasing scale, as has been found elsewhere (Finn et al. 2002, McGrath et al. 2003). Our larger scales, however, correspond to reported post-fledging area rather than larger foraging scales. At the post-fledging area, Beck et al. (2011) found conifer cover to be the best discriminating variable between primary (i.e., active nests in higher quality habitat) and secondary nesting locations using results from the national goshawk monitoring program across 15 national forests in the Rocky Mountain region (Woodbridge and Hargis 2006). The biological process (e.g., flight paths, thermal regulation, or prey accessibility) that is influenced by conifer cover, however, remains unknown and merits further study.

Post-fledging areas may provide prey to develop hunting skills, or to provide cover from predators or for prey (Reynolds et al. 1992, Squires and Kennedy 2006). The selection of conifer habitat by nesting goshawks may be attributed to habitat associated with their primary prey species, which include red squirrel (*Tamiasciurus hudsonicus*), eastern chipmunk (*Tamias striatus*), snowshoe hare (*Lepus americanus*), and ruffed grouse (*Bonasa umbellus*) in this region (Erdman et al. 1998, Roberson et al. 2003, Smithers et al. 2005, Boal et al. 2006, Woodford et al. 2008). Red squirrels and snowshoe hares are associated with lowland conifers in this region (Pietz and Tester 1983, Steele 1998). However, nearly half of the conifer cover type in this study was lowland conifers (e.g., low-lying areas dominated by black spruce, northern white cedar, and tamarack), which were found to be used less than expected by male goshawks at the larger foraging area scale in Minnesota (Boal et al. 2005) and avoided by female goshawks (Lapinski 2000). Despite these findings, Boal et al. (2006) suggests habitat types used less than expected during the breeding season may still influence prey production or may be used during the non-breeding season. Conifers may also be offering greater nest concealment from predators such as fishers (*Martes pennanti*) and great-horned owls (*Bubo virginianus*) as postulated by Erdman et al. (1998).

Our results indicated that goshawk nest locations were not in areas with large amounts of older aspen–birch stands (>26 yrs old) at the mid-extent (78.5 ha; 500-m radius around nest), and the negative relationship was actually stronger than the preference for high conifer cover (Tables 2 and 4). Although a small percent of nests were found in older aspen–birch stands, results support the general nesting habitat requirements of mature deciduous and mixed deciduous forests at large scales, which for this region are maple-dominated hardwood forests. Because post-fledging areas are likely to vary in size (McGrath et al. 2003) and can be smaller than the originally proposed 170 ha (Squires and Kennedy 2006), our findings may be a reflection of the size of post-fledging areas within the CNNF, but radio-telemetry data would be required for confirmation. Alternatively, the younger stage of this cover type (i.e., regenerating aspen) did not strongly influence active nesting as we had hypothesized based on the prediction that convergence of prey habitat (i.e., regenerating aspen and shrubs would have high prey densities) with nesting habitat was expected to be attractive to nesting goshawks. Aspen–birch stands are early-successional areas with high stem density from 0 to 20 year olds, and these high densities coupled with dense shrubs probably made accessibility to preferred prey species difficult (Beier and Drennan 1997, Penteriani et al. 2001).

Because of the difficulty locating nests and the variability in nest use through time and space, non-standardized methods are often used in goshawk nesting habitat use studies making interpretation of habitat use complicated (Reynolds et al. 2005, Woodbridge and Hargis 2006). Of concern is the potential bias in characterizing habitat surrounding nests discovered opportunistically verses systematically (Squires and Reynolds 1997) as in our study. When comparing habitat characteristics around nest sites found by each search method, however, Daw et al. (1998) found similar density of large trees and canopy closure within a 0.4-ha area around nests. We used a Bayesian modeling approach that facilitates the partitioning of model error into spatial and temporal random effects (Clark 2005), which causes the spread in the posterior parameter distributions for the landscape covariates to decrease and become easier to interpret. The random spatial and temporal effects we found across our 10-year study were due to factors not included in our models that influence an active nest site in time and space (Andersen et al. 2005) such as spring weather conditions and prey densities. The temporal patterns may be a result of the different survey methods. The 2 years with high random intercept values (i.e., high year effect) occurred prior to the onset of systematic searches for goshawk nests that began in 2001. Prior to 2001, the survey technique focused on existing nests and opportunistic sightings; therefore, we were not surprised that the probability of an active nest was substantially greater in 2 of those years. Following the onset of systematic surveys, where more diverse and suitable habitats were searched, we found a single year with a low random effect. A relatively high year effect could also result from an increase in the number of goshawks present in that year (e.g., population cycling). Prey abundance has been found to influence nest area occupancy rate (Postupalsky 1998) and productivity (Erdman et al. 1998) within this region. Ruffed grouse drumming surveys in Wisconsin indicate numbers were at relatively higher levels in 1997 and 2000, and at lower levels in 2006 (WDNR 2010), but the influence this prey species had on the number of active nest sites in a year is unknown.

Our results describe higher quality nesting habitat in terms of increased nest use through time because habitat surrounding nest locations was allowed to enter into the model as an active nest only when nesting activity was observed that year (otherwise, habitat entered as a nest-free location). Habitat selection by goshawks is thought to follow the ideal free distribution (Fretwell and Lucas 1970) modified by territoriality (Woodbridge and Hargis 2006) based on equal spacing of active nests often observed in the field (Woodbridge and Detrich 1994, Reynolds and Joy 1998, Reynolds et al. 2005). Territoriality, however, can increase use of secondary habitats before resources become limiting in the primary habitat, which confounds interpretation of habitat quality when the population level is not known. Because we do not know goshawk population levels in northern Wisconsin, our ability to distinguish primary from secondary breeding habitat is limited and our results must be interpreted within this constraint.

MANAGEMENT IMPLICATIONS

Forest management practices should include large-scale habitat needs beyond nesting site conservation (i.e., beyond protection buffers) that will result in higher quality habitat to ensure consistent goshawk breeding in this region. The ratio of conifer cover (within 1,000 m) to older aspen–birch cover (within 500 m) in landscapes surrounding nest sites could be manipulated by forest managers to increase the likelihood of sustaining active goshawk breeding territories through time (i.e., annually), and optimizing these ratios may encourage goshawk nesting activity in areas where active nesting is not currently occurring. For example, retaining conifer components (e.g., hemlocks and spruce) within 1,000 m of nesting sites to the extent possible will increase the probability of that area remaining active, especially in landscapes with low aspen–birch within 500 m (exceeding 0.80 in 80% conifer cover and assuming no primary roads within 500 m; Fig. 2A). The probability of nest re-use declines rapidly to near zero with decreasing conifer cover (Fig. 2B,C). Our findings can also be used to identify areas within the forest that may be suitable for (re)colonization by nesting goshawks, especially within landscapes dominated by northern hardwoods. For example, the probability a stand will be colonized approaches 0.50 in 80% conifer cover (and assuming no primary roads within 500 m; Fig. 2C) and little to no older aspen–birch present within 500 m radius. A stand has a low probability of being colonized if the aspen–birch cover is high, even with high conifer cover (Fig. 2D) because nesting and post-fledging habitat requirements cannot be met. By optimizing these ratios in surrounding forest composition, managers may be able to tailor forest management plans and activities beyond the designated protective buffer area to promote consistent nesting activity in an area through time, and to increase the likelihood of (re)colonization of unused areas.

ACKNOWLEDGMENTS

We thank D. Andersen, D. Rugg, J. Squires, and 2 anonymous reviewers for valuable comments and contributions to this manuscript. B. Frater and S. Lietz were invaluable in combining the goshawk monitoring results and manipulating the forest composition spatial layers.

LITERATURE CITED

Andersen, D. E., S. DeStefano, M. I. Goldstein, K. Titus, C. Crocker-Bedord, J. J. Keane, R. G. Anthony, and R. N. Rosenfield. 2005. Technical review of the status of northern goshawks in the Western United States. Journal of Raptor Research 39:192–209.

Beck, J. L., R. C. Skorkowsky, and G. D. Hayward. 2011. Estimating occupancy to monitor northern goshawk in the Central Rocky Mountains. Journal of Wildlife Management 75:513–524.

Beier, P., and J. E. Drennan. 1997. Forest structure and prey abundance in foraging areas of northern goshawks. Ecological Applications 7:564–571.

Boal, C. W., D. E. Andersen, and P. L. Kennedy. 2005. Foraging and nesting habitat of breeding male northern goshawks in the Laurentian mixed Forest Province, Minnesota. Journal of Wildlife Management 69:1516–1527.

Boal, C. W., D. E. Andersen, P. L. Kennedy, and A. M. Roberson. 2006. Northern goshawk ecology in the Western Great Lakes Region. Studies in Avian Biology 31:128–136.

Bosakowski, T. 1999. Northern goshawk: ecology, behavior, and management in North America. Hancock House Publishing, Blaine, Washington, USA.

Bosakowski, T., and M. E. Vaughn. 1995. Developing a practical method for surveying northern goshawks in managed forests of the western Washing Cascades. Western Journal of Applied Forestry 11:109–113.

Boyce, D. A., R. T. Reynolds, and R. T. Graham. 2006. Goshawk status and management: what do we know, what have we done, where are we going? Studies in Avian Biology 31:312–325.

Carroll, C., R. L. Rodriguez, C. McCarthy, and K. M. Paulin. 2006. Resource selection function models as tools for regional conservation planning for northern goshawk in Utah. Studies in Avian Biology 31:288–298.

Clark, J. S. 2005. Why environmental scientists are becoming Bayesians. Ecology Letters 8:2–14.

Clark, J. S. 2007. Models for ecological data. Princeton University, Princeton, New Jersey, USA.

Curtis, J. T. 1959. The vegetation of Wisconsin: an ordination of plant communities. University of Wisconsin Press, Madison, USA.

Daw, S. K., and S. DeStefano. 2001. Forest characteristics of northern goshawk nest stands and post-fledging areas in Oregon. Journal of Wildlife Management 65:59–65.

Daw, S. K., S. DeStefano, and R. J. Steidl. 1998. Does survey method bias the description of northern goshawk nest-site structure? Journal of Wildlife Management 62:1379–1384.

Dick, T., and D. Plumpton. 1998. Review of information on the status of the northern goshawk (*Accipiter gentilis atricapillus*) in the Western Great Lakes Region. USDA Fish and Wildlife Service, Fort Snelling, Minnesota, USA.

Erdman, T. C., D. R. Brinker, J. P. Jacobs, J. Wilde, and T. O. Meyer. 1998. Productivity, population trends, and status of northern goshawks, *Accipiter* *gentilis atricapillus*, in northeastern Wisconsin. Canadian Field-Naturalist 112:17–27.

Finn, S. P., J. M. Marzluff, and D. E. Varland. 2002. Effects of landscape and local habitat attributes on northern goshawk site occupancy in western Washington. Forest Science 48:427–436.

Fretwell, S. D., and H. L. Lucas. 1970. On territorial behavior and other factors influencing habitat distribution in birds. Acta Biotheorestica 19:16–36.

Gelman, A., J. B. Carlin, H. S. Stern, and D. B. Rubin. 2004. Bayesian data analysis. Chapman & Hall/CRC, Boca Raton, Florida, USA.

Gelman, A., A. Jakulin, M. Grazia Pittau, and Y. Su. 2008. A weakly informative default prior distribution for logistic and other regression models. Annals of Applied Statistics 2:1360–1383.

Gelman, A., and D. B. Rubin. 1992. Inference from iterative simulation using multiple sequences. Statistical Science 7:457–511.

Johnsgard, P. A. 1990. Hawks, eagles, and falcons of North America. Smithsonian Institution Scholarly, Washington, DC, USA.

Kennedy, P. L. 1997. The northern goshawk (*Accipiter gentilis atricapillus*): is there evidence of a population decline? Journal of Raptor Research 31:95–106.

Kennedy, P. L., and D. W. Stahlecker. 1993. Responsiveness of nesting northern goshawks to taped broadcasts of 3 conspecific calls. Journal of Wildlife Management 57:249–257.

Kennedy, P. L., J. M. Ward, G. A. Rinker, and J. A. Gessaman. 1994. Post-fledging areas in northern goshawk home ranges. Studies in Avian Biology 16:75–82.

Lapinski, N. 2000. Habitat use and productivity of the northern goshawk in the Upper peninsula of Michigan. Thesis, Northern Michigan University, Marquette, USA.

McClaren, E. L., P. L. Kennedy, and S. R. Dewey. 2002. Do some northern goshawk nest areas fledge more young than others? Condor 104:343–352.

McGrath, M. T., S. DeStefano, R. A. Riggs, L. L. Irwon, and G. J. Roloff. 2003. Spatially explicit influences on northern goshawk nesting habitat in the interior Pacific Northwest. Wildlife Monographs 67:1–63.

McNab, W. H., D. T. Cleland, J. A. Freeouf, J. E. Keys, Jr., G. J. Nowacki, C. A. Carpenter. compilers. 2007. Description of ecological subregions: sections of the conterminous United States [CD-ROM]. General Technical Report WO-76B. Department of Agriculture, Forest Service, Washington, DC, USA.

Penteriani, V., B. Faivre, and B. Frochot. 2001. An approach to identify factors and levels of nesting habitat selection: a cross-scale analysis of goshawk's preferences. Ornis Fennica 78:159–167.

Pietz, P. J., and J. R. Tester. 1983. Habitat selection by snowshoe hares in north central Minnesota. Journal of Wildlife Management 47:686–696.

Postupalsky, S. 1998. A study of breeding northern goshawks in Michigan. Pages 13–14. *in* J. Noll West, editor. Status of the northern goshawk in the Midwest. U.S. Fish and Wildlife Service, Fort Snelling, Minnesota, USA.

Reich, R. M., S. M. Joy, and R. T. Reynolds. 2004. Predicting the location of northern goshawk nests: modeling the spatial dependency between nest locations and forest structure. Ecological Modeling 176:109–133.

Reynolds, R. T., R. T. Graham, and D. A. Boyce. , Jr. 2008. Northern goshawk habitat: an intersection of science, management, and conservation. Journal of Wildlife Management 72:1047–1055.

Reynolds, R. T., R. T. Graham, M. H. Reiser, R. L. Bassett, P. L. Kennedy, D. A. Boyce, Jr., G. Goodwin, R. Smith, and E. L. Fisher. 1992. Management recommendations for the northern goshawk in the southwestern United States. USDA Forest Service, General Technical Report RM-217. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, USA.

Reynolds, R. T., and S. M. Joy. 1998. Distribution, territory occupancy, dispersal and demography of northern goshawks on the Kaibab Plateau, Arizona. Final Report. Heritage Project No. I94045. Arizona Game and Fish Department, Phoenix, USA.

Reynolds, R. T., S. M. Joy, and D. G. Leslie. 1994. Nest productivity, fidelity, and spacing of northern goshawks in northern Arizona. Studies in Avian Biology 16:106–113.

Reynolds, R. T., D. J. Wiens, S. M. Joy, and S. R. Salafsky. 2005. Sampling considerations for demographic and habitat studies of northern goshawks. Journal of Raptor Research 39:274–285.

Reynolds, R. T., J. D. Wiens, and S. R. Salafsky. 2006. A review and evaluation of factors limiting northern goshawk populations. Studies in Avian Biology 31:260–273.

Reynolds, R. T., and H. M. Wright. 1978. Distribution, density, and productivity of accipiter hawks breeding in Oregon. Wilson Bulletin 90:182–196.

Roberson, A. M., D. E. Anderson, and P. L. Kennedy. 2003. The northern goshawk (*Accipiter gentilis atricapillus*) in the western Great Lakes Region: a technical conservation assessment. U.S. Geological Survey, Minnesota Cooperative Fish and Wildlife Research Unit, University of Minnesota, St. Paul, USA.

Rosenfield, R. N., J. Bielefieldt, D. R. Trexel, and T. C. J. Doolittle. 1998. Breeding distribution and nest-site habitat of northern goshawks in Wisconsin. Journal of Raptor Research 32:189–194.

Salafsky, S. R., T. Reynolds, and B. R. Noon. 2005. Patterns of temporal variation in goshawk reproduction and prey resources. Journal of Raptor Research 39:237–246.

Smithers, B. L., C. W. Boal, and D. E. Andersen. 2005. Northern goshawk diet in Minnesota: an analysis using video recording systems. Journal of Raptor Research 39:264–273.

Speiser, R., and T. Bosakowski. 1987. Nest site selection by northern goshawks in northern New Jersey and southeast New York. Condor 89:387–394.

Spiegelhalter, D. J., N. Best, B. P. Carlin, and A. Van der-Linde. 2002. Bayesian measures of model complexity and fit (with discussion). Journal of the Royal Statistical Society, Series B 64:583–639.

Squires, J. R., and P. L. Kennedy. 2006. Northern goshawk ecology: an assessment of current knowledge and information needs for conservation and management. Studies in Avian Biology 31:8–26.

Squires, J. R., and R. T. Reynolds. 1997. Northern goshawk (*Accipiter gentilis*). Pages 24–32. *in* A. Poole, and F. B. Gill, editors. The birds of North America, number 298. The American Ornithologists' Union, Washington, DC, USA: and The Academy of natural Sciences, Philadelphia, Pennsylvannia, USA.

Stearns, F. W. 1949. Ninety years change in a northern hardwood forest in Wisconsin. Ecology 30:350–358.

Steele, M. A. 1998. *Tamiasciurus hudsonicus*. Mammalian Species 586:1–9.

Tyrrell, L. E., and T. R. Crow. 1994. Structural characteristics of old-growth hemlock-hardwood forests in relation to age. Ecology 75:370–386.

United States Department of Agriculture Forest Service [USDA]. 2004*a*. Chequamegon-Nicolet National Forest 2004 Land and Resource Management Plan. R9-CN-FP. U.S. Department of Agriculture, Rhinelander, Wisconsin, USA.

United States Department of Agriculture Forest Service [USDA]. 2004*b*. Chequamegon-Nicolet National Forest Final Environmental Impact Statement (and Appendices) to accompany the 2004 Land and Resource Management Plan. R9-CN-FEIS and R9-CN-FEIS APPENDICES. U.S. Department of Agriculture, Rhinelander, Wisconsin, USA.

Widén, P. 1997. How, and why, is the goshawk (*Accipiter gentilis*) affected by modern forest management in Fennoscandia? Journal of Raptor Research 31:107–113.

Wisconsin Department of Natural Resources [WDNR]. 2010. Wisconsin wildlife reports. <http://dnr.wi.gov/org/land/wildlife/harvest/harvest.htm> Accessed 11 Jan 2011.

Woodbridge, B., and P. J. Detrich. 1994. Territory occupancy and habitat patch size of northern goshawks in the southern Cascades of California. Pages 83–87. *in* W. M. Block, M. L. Morrison, and M. H. Reiser, editors. The northern goshawk: ecology and management. Studies in Avian Biology 16, University of California Press, Berkeley, CA.

Woodbridge, B., and D. D. Hargis. 2006. Northern goshawk inventory and monitoring technical guide. General Technical Report WO-71. U.S. Department of Agriculture, Forest Service, Washington, DC, USA.

Woodford, J. E., C. A. Eloranta, and K. D. Craig. 2008. Nest monitoring and prey of northern goshawks in Wisconsin. Passenger Pigeon 70:171–179.

Associate Editor: Marc Bechard.