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Abstract approved:

Eric D. Forsman

The northern goshawk (*Accipiter gentilis*) is a species of concern in the western United States due to its association with mature structural stage forests. I employed a use-versus-availability study design to quantify the vegetative, physiographic, and landscape variables associated with goshawk breeding habitat selection in the San Juan Mountains of southwestern Colorado. This region of Colorado is characterized by high elevations and dominated by spruce-fir forests. I documented 41 goshawk nest territories on the Rio Grande and San Juan National Forests and compared them to random sites. I constructed logistic regression models at multiple spatial scales and employed Akaike's Information Criterion (AIC) to select the most parsimonious models. Of the models evaluated for the nest-site-scale analysis, there were four top competing models that all contained canopy closure and crown basal height as explanatory variables. Two of the four competing models also contained slope, and two contained the presence of aspen. Increased canopy closure, higher crown basal height, and flatter slopes increased the relative odds of a site being used for nesting. The presence of at least one aspen tree within the stand increased the relative odds of use by more than 5 times. The multi-scale

model set contained two top competing models. In both models, greater canopy closure, higher understory crown basal height, and greater distance to edge increased the odds of goshawk use. Model results suggested that it was 59% less likely that a goshawk would select a site centered on a spruce-fir stand than one centered on other available forest types. In southwestern Colorado, stands with high probability of use by goshawks included areas of mature structural stage forest with canopy closure $\geq 40\%$, open understory, slope $\leq 20\%$, located ≥ 200 meters from a non-forest edge. Additionally, mixed conifer and spruce-fir stands containing $\geq 10\%$ aspen canopy cover were more likely to contain goshawk nests.

Northern Goshawk Breeding Habitat Selection within High-elevation Forests of Southwestern Colorado

by
Cheron L. Ferland

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Cheron L. Ferland, Author

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DEDICATION

I dedicate this thesis to the two greatest loves of my life:

my parents –

Denise and David Orden.

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Introduction

The northern goshawk (*Accipiter gentilis*) is a large forest hawk that nests in mature and old structural stage forests (Moore and Henny 1983, Speiser and Bosakowski 1987, Hayward and Escano 1989). Since mature and old forests are also a valuable resource for humans, goshawks have become a topic of debate, the center of litigation, and the focus of much research. In fact, goshawks are approaching the celebrity-status of the northern spotted owl (*Strix occidentalis*), the poster-child for old-growth forests.

Goshawks are a species of concern due to possible population declines and the potential for forest management to either negatively or positively influence the species (Reynolds 1983, Kennedy 1988, Crocker-Bedford 1990). During the past 15 years, the USDI Fish and Wildlife Service has been petitioned three times to list goshawks under the Endangered Species Act. Each time the petition has been denied, in large part due to lack of data. However, the USDI Fish and Wildlife Service did place the goshawk on the Category 2 list of the Endangered Species Act in 1991 and several regions of the USDA Forest Service classify the goshawk as a "sensitive" species.

Because the goshawk is a species of concern and there is little data on the distribution and nesting habitat of goshawks in Colorado, more research is warranted on this elusive species. Goshawk breeding habitat has been studied in several portions of the North American range of the species and researchers have found that nest sites are typically characterized by moderate slopes, older structural stage forests, relatively high canopy closure, and open understories (Reynolds et al. 1982, Moore and Henny 1983, Speiser and Bosakowski 1987, Hayward and Escano 1989). Although the values of nest site attributes vary among forest types and regions, the patterns are similar throughout North America (Reynolds et al. 1982, Moore and Henny 1983, Hayward and Escano 1989, Squires and Ruggiero 1996, Daw et al. 1998, McGrath et al. 2003). However, scant nest site information is available for goshawks nesting within the Rocky Mountains. One ecological region of particular interest is the San Juan Mountains of southwestern Colorado. This region contains some of the highest elevation goshawk habitat in North America as well as a large percentage of spruce-fir forest. Very little information is available on the characteristics of goshawk nest sites in these high elevation areas, and even less information is available on goshawks nesting in spruce-fir forests. In fact, prior to this study, many local biologists and land managers in Colorado thought that goshawks did not nest in spruce-fir forests, even though nearly 50 percent of the forest in the San Juan Mountains is spruce-fir. This impression was due in part to a historical notion that goshawks in the San Juan Mountain region prefer to nest in aspen trees, a notion that was reinforced by data from Montana concluding that goshawks avoided nesting in spruce-fir forests (Clough 2000). Squires and Ruggiero (1996) emphasized the need for determining the importance of spruce-fir forests to nesting goshawks in the Rocky Mountain region. Additionally, understanding the specific habitat conditions that goshawks select for nesting in the San Juan Mountains will allow local biologists to recognize what constitutes goshawk breeding habitat and also to predict where goshawks are likely to nest.

I hypothesized that goshawk nesting in the San Juan Mountains would be associated with the same vegetative structural and physiographic characteristics that have been documented in previous studies, especially relatively high canopy closure and basal area, open understories, and mature and old structural stage forests (Reynolds et al. 1982, Moore and Henny 1983, Hayward and Escano 1989, Squires and Ruggiero 1996, Daw et al. 1998, McGrath et al. 2003). I also tested the hypothesis that goshawks prefer aspen trees for nesting. And, while goshawks do utilize spruce-fir forests for nesting, I hypothesized that use of such forests was less than expected relative to availability. Additionally, I examined landscape pattern features that potentially influence habitat selection by goshawks including: distance from the nearest non-forest edge, amount of edge per unit area, and proportion of all forest and mature structural stage forest surrounding the nest.

Objectives

My primary objective was to determine vegetative, physiographic, and landscape pattern characteristics associated with goshawk nest sites within the study area. My secondary objective was to determine the importance of spruce-fir forests in goshawk nest selection in southwestern Colorado.

Study Area

My study area included the San Juan and Rio Grande National Forests which are adjacent to each other, but on opposite sides of the Continental Divide in the southern Rocky Mountain ecoregion (Figure 1, Bailey 1998). These two forests encompass approximately 19,600 km^2 (1,960,000 ha), including the San Juan, La Garita, Cochetopa, and Sangre de Cristo mountains. Elevations range from 1,900–

Figure 1. Rio Grande and San Juan National Forests (San Juan Mountains) study area, Colorado USA

4,350 m and precipitation averages 25-50 cm annually, with 25-75% in the form of snow, depending on elevation.

The terrain is mountainous, with forested vegetation dominated by Engelmann spruce (*Picea engelmannii*) - subalpine fir (*Abies lasiocarpa*), aspen (*Populus tremuloides*), ponderosa pine (*Pinus ponderosa*), and mixed conifer forests. Mixed conifer forests are comprised of Douglas-fir (*Pseudotsuga menziesii*), with varying amounts of limber pine (*Pinus flexilis*), white fir (*Abies concolor*), bristlecone pine (*Pinus longaeva*), lodgepole pine (*Pinus contorta*), blue spruce (*Picea pungens*), Engelmann spruce, subalpine fir, ponderosa pine, and aspen.

Resource management activities within the study area include timber harvesting, mining, cattle and sheep grazing, firewood cutting, and prescribed burning. The area is also heavily used by recreationists for activities such as off-road vehicle use, motorized and non-motorized trail biking, horseback riding, hiking, camping, auto touring, hunting, fishing, skiing, and snowmobiling.

The forested portion of the study area is largely contiguous and includes five wilderness areas: Weminuche (199,282 ha), Sangre de Cristo (91,648 ha), South San Juan (64,262 ha), La Garita (52,149 ha), and Lizard Head (16,671 ha). These wilderness areas occupy 20% of the study area.

Terminology

Habitat - the collection of biotic and abiotic factors that produce occupancy by goshawks (Andersen et al. 2005).

Mature habitat structural stage forest – as defined by the Rio Grande National Forest, consists of forests in which the dominant overstory trees are > 23 cm DBH. These forests are further subdivided based on canopy closure, into stands averaging > 70% canopy closure, stands averaging 40-70% canopy closure, and stands averaging < 40% canopy closure (USDA Forest Service 2004). Hereafter referred to as "mature forest."

Post-fledging family area (PFFA) – the core area used by the female and containing the nest and adjacent forest used by older fledglings until the young are no longer dependent on the adults for food (Reynolds et al. 1992).

Preference - the likelihood that a resource will be selected if offered on an equal basis with others (Johnson 1980).

<u>*Sapling-pole habitat structural stage forest*</u> - as defined by the Rio Grande National Forest, consists of forests in which the dominant overstory trees are 5-23 cm DBH. These forests are further subdivided based on canopy closure, into stands averaging > 70% canopy closure, stands averaging 40-70% canopy closure, and stands averaging < 40% canopy closure (USDA Forest Service 2004). Hereafter referred to as "sapling-pole forest."

<u>*Selection*</u> - the process in which an animal chooses a resource (Johnson 1980).

<u>*Territory*</u> – for purposes of this study is defined as: the circular area surrounding an active nest with a diameter equal to the mean distance of nests from the nearest neighboring territories. Assumed to be the approximate area defended by a pair of nesting goshawks.

Methods

Study Design

Wildlife habitat investigators must select a scale, or multiple scales, of analysis appropriate to the ecology of the organism (Morrison et al. 1998). Animals select resources in a hierarchical fashion that Johnson (1980) classified into four "orders" of selection, corresponding to the geographic range of the species (first order), the home range (second order), general features, such as a forest stand within the home range (third order), and specific features such as the structural attributes of the nest tree or foraging locations or items (fourth order). The relevant characteristics of selection may be different at each of these levels (Johnson 1980, Wiens 1981, Orians and Wittenberger 1991), thus the level or scale of investigation influences the definitions of availability and hence the resulting patterns (Wiens 1989).

I employed a use-versus-availability design (Manly et al. 2002) to evaluate the hypothesis that goshawks selected nest sites based on vegetative, physiographic and/or landscape attributes. Johnson (1980) defined habitat selection as the process in which an animal chooses a resource. This definition implies choice, rather than random or opportunistic placement. Thus, many studies assess selection by comparing sites that are used (e.g. nest sites) to random sites within the study area, which essentially represent the conditions available.

The 41 nests used in my analysis were all known to have been active at least once between 1995 and 2005 and were located through a combination of methods including systematic random sampling, project surveys, opportunistic observations, and historic records. Though most of the nests were not located during random surveys, I considered them to be representative of goshawk nest sites within the study area.

Goshawks build from one to nine nests per territory and often alternate nests annually (Squires and Reynolds 1997, Reynolds et al. 2005). To maintain statistical independence, I used only the most recently active nest from each territory for analysis.

I evaluated breeding habitat selection by comparing the composition of forests in circles centered on nest trees and random sites within the study area. For these analyses I used four different circle sizes, as follows: 1) a 16-m radius plot (0.10 ha) corresponding to the nest site, 2) a 514-m radius plot (83 ha) corresponding to the McGrath et al. (2003) post-fledging area (PFA); 3) a 736-m radius plot (170 ha) corresponding to the traditional post-fledging family area (PFFA) of Reynolds et al.

(1992); and 4) a 1,500-m radius plot (707 ha) corresponding to the "theoretical" territory. I hypothesized that each of these scales was ecologically relevant to goshawks. Similar scales have been used in other studies of habitat selection by breeding goshawks (Daw 1997, Joy 2002, McGrath et al. 2003)

The McGrath et al. (2003) PFA scale (83 ha) is an empirical estimate of the area of concentrated use by the fledglings in the two-month period after they leave the nest, prior to natal dispersal. In contrast to the PFFA, this estimated area of use does not include the movements of the adult female. I chose to use this scale based on the fact that McGrath et al. (2003) found the habitat model that best discriminated between nests and random sites in their study encompassed 83 ha surrounding the nest. Additionally, this scale is only slightly larger than the mean area used by goshawk fledglings during the post-fledging period on Vancouver Island, British Columbia (59 ha; McClaren et al. 2005).

The PFFA scale (170 ha) represents an area of concentrated use by the family from the time the young leave the nest until they are no longer dependent on the adults for food. The traditional PFFA size, often utilized by land managers, is based on mean estimates derived by Reynolds et al. (1992) and Kennedy et al. (1994).

Reynolds et al. (2005) defined a breeding territory as an area that may or may not be defended against conspecifics, but used by a single pair of goshawks during a breeding season. Since I did not track goshawk movements in this study, I defined a theoretical territory scale with radius of 1,500 m (707 ha) which represents half of the average nearest neighbor distance reported in other studies where intensive goshawk monitoring and tracking has occurred ((3.0 km ± 0.83 SD in Arizona (Reynolds et al. 1994); 3.3 km ± 0.3 SE in California (Woodbridge and Detrich 1994)).

To evaluate selection, I randomly selected 41 points within the study area to compare to the 41 nest sites. The random points were selected from the universe of any forested habitat within the study area boundary. If the random point did not fall within a forested area, it was discarded and the next point was evaluated until the target number of random points was obtained.

Because I wished to answer the question, "Given a suitable nest tree, what other characteristics distinguish goshawk use from non-use?" random points were centered on the nearest tree with limbs capable of supporting a goshawk nest. Trees at random points were called "surrogate" nest trees.

Habitat Variables Quantified

During the 2002-2005 breeding seasons, I quantified vegetative and physiographic characteristics at nest and random sites using a combination of field measurements and digital map calculations (Table 1). These characteristics were selected not only on the basis of their ability to describe forest structural characteristics, but also for their ease of use by forest managers, as well as their importance in the goshawk literature.

Slope, aspect, forest type, canopy closure, basal area, habitat structural stage, and crown basal height were measured in the field. Elevation was derived from digital 1:24,000 USGS topographic quads in Terrain Navigator Pro, version 6.03 (Maptech, Amesbury, MA). Aspen canopy cover was derived directly from the San Juan and Rio Grande National Forest geographic information system (GIS) vegetative data layer

Table 1. Descriptions of physiographic, vegetative, and landscape variables used to model northern goshawk breeding habitat in the San Juan Mountains of southwestern Colorado (2002-2005).

Acronym	Description	Unit
Physiographic Variables		
Elevation	Elevation above sea level at nest/surrogate tree measured on 1:24,000 digital maps	m
Slope	Slope averaged from measurements taken with a clinometer uphill and downhill of the nest/surrogate tree perpendicular to contour of the slope	%
Aspect	Aspect measured with a compass from nest/surrogate tree perpendicular to the contour of the slope	degrees
Vegetative Variables		
FT	Forest type surrounding nest/random site	categories
CC	Canopy closure averaged from four measurements taken with a moosehorn densiometer in four cardinal directions at 15 meters from the nest/surrogate tree	%
AspenCC	Canopy cover of aspen trees within nest/random site forest per GIS	%
BA	Basal area measured with a 10-factor prism from nest/surrogate tree	m^2 ha^{-1}
HSS	Habitat structural stage per visual assessment of canopy closure and average tree size within view of site center to correspond with USDA Forest Service, Region 2, Habitat Structural Stages (USDA Forest Service 2004)	categories
CBH	Crown basal height, or mean height to first live limb averaged from measurements on five trees, including nest/surrogate tree plus four trees located 10 meters from site center in four cardinal directions. Measured with clinometer	m
Landscape Variables		
dEdge	Distance from site center to edge of nearest non-forest patch ≥ 1 ha	m
FOR83	Proportion forest within 83 ha circle surrounding site center[a]	Proportion
FOR170	Proportion forest within 170 ha circle surrounding site center[a]	Proportion
FOR707	Proportion forest within 707 ha circle surrounding site center[a]	Proportion
MF83	Proportion mature habitat structural stage forest within 83 ha circle	Proportion
MF170	Proportion mature habitat structural stage forest within 170 ha circle	Proportion
MF707	Proportion mature habitat structural stage forest within 707 ha circle	Proportion
ED83	Amount of edge per 83 ha area surrounding site center	m ha^{-1}
ED170	Amount of edge per 170 ha area surrounding site center	m ha^{-1}
ED707	Amount of edge per 707 ha area surrounding site center	m ha^{-1}

[a]Non-forest included the following categories constituting ≥ 1 ha: clearcuts, seedling forests, water, meadows, shrublands, grasslands, bare ground, and rock

"R2VEG". Within R2VEG, canopy cover of the three dominant tree species is quantified for each stand polygon. Distance to the nearest non-forest edge was measured on 1:12,000 digital aerial photographs in Terrain Navigator Pro, version 6.03 (Maptech, Amesbury, MA). Any transition from forest to a non-forest patch ≥ 1 hectare constituted an edge. Non-forest included the following categories constituting ≥ 1 ha: recent clearcuts, seedling stands (i.e. trees < 5 cm DBH), water, meadows, grassland, shrubland, bare ground, and rock.

Landscape pattern characteristics were derived from the San Juan and Rio Grande National Forest GIS vegetative data layer using the Patch Analyst 3.1 extension in Arcview 3.3 (ESRI, Redlands, CA, USA). I computed the proportion of all forest, proportion of mature structural stage forest, and proportion of edge per unit area at each scale beyond the nest site.

The San Juan and Rio Grande National Forest GIS vegetative layer was originally constructed from photo interpretation of 1:24,000-scale aerial photographs dating from 1989-1998. Cover type polygons were manually digitized and the minimum polygon mapping unit size for vegetation was 2 hectares and at least 48 meters wide. Field visits with visual assessment of random and nest sites indicated that the accuracy of the GIS map layers was 96% for forest type and 87% for habitat structural stage.

Prior to data analysis, aspect was converted from degrees to quadrants. Aspects on slopes ≤ 10% were classified "no aspect effect".

Statistical Analysis

I calculated univariate statistics (means, medians, and standard errors) and examined distribution plots for each variable. Variables exhibiting kurtosis and/or skewness > |2| were transformed onto a normalizing scale prior to tests. I performed univariate analyses comparing nest sites ($n = 41$) and random sites ($n=41$). For each quantitative variable, I computed two-sample t-tests ($\alpha = 0.05$) to determine if the means differed significantly. For each categorical variable, I compared goshawk nest sites to random sites using Bonferroni simultaneous confidence intervals ($\alpha = 0.10$) to test the hypothesis that goshawks used nest site habitat in proportion to availability (Marcum and Loftsgaarden 1980).

To assess habitat selection, I used an information theoretic approach and developed two sets of *a priori* multiple logistic regression models based on my hypotheses and ran them in PROC LOGISTIC (SAS Institute 2002). In all models, goshawk nest presence was the dependent variable. Prior to model development, I derived correlation coefficients for each combination of variables to assess multicollinearity. When pairs of variables were strongly related (Pearson's correlation coefficient $r \geq |0.60|$), only one was included in the model.

Model selection was based on an information-theoretic approach and included the use of Akaike's Information Criteria corrected for small sample size (AIC_c). I used the difference in AIC_c between each candidate model and the model with the lowest AIC_c (ΔAIC_c) to rank models (Burnham and Anderson 2002). Models within 2 AIC_c of the top model were considered competitive. I also used odds ratios to evaluate the strength of specific effects within competitive models.

The first set of models was constructed to evaluate fourth order selection at the nest site using logistic regression (PROC LOGISTIC, SAS Institute 2002) to compare nest sites to random sites. The 16 models in this set included combinations of the physiographic and vegetative characteristics as independent variables. My hypothesis was that the most influential variable would be canopy closure, in combination with slope and open understories (i.e. high crown basal height). Thus, I constructed models that included combinations of these parameters and also included single variable models and the null model for comparison. Additionally, I believed that the presence of even one aspen tree, whether within an aspen stand or a conifer stand, would increase the odds of goshawk use. To investigate this relationship, I included an "Aspen" indicator variable in some models to indicate the presence or absence of ≥ 1 aspen tree in the plot. The best variables in this model set were used as a base model for my multiple spatial scale analysis.

To assess selection at multiple spatial scales, I developed a second set of models that included the base model from the nest-site-scale analysis in combination with the landscape attributes, to determine the best landscape characteristic and scale that distinguished nest sites from random sites. I began with the nest-site-scale base model in order to determine the landscape variable that was best at discriminating selection, given ideal nest site conditions. I used logistic regression (PROC LOGISTIC, SAS Institute 2002) to evaluate a total of 26 models, including single variable models and the null model. I hypothesized that the amount of mature structural stage forest surrounding nest sites would be important and would be positively associated with goshawk use. Also, since goshawks are often associated with interior forests, I predicted that distance to edge would be positively associated with goshawk nest use, and that lower edge density (i.e. amount of edge per unit area) would have a significant positive influence on goshawk nest area selection. Since I wished to evaluate the relative odds of goshawks selecting nest sites in spruce-fir forests, I added a spruce-fir indicator variable ("Spruce"), to several models, indicating whether or not the forest surrounding the nest/surrogate tree was spruce-fir. The Spruce indicator variable was not included in models containing variables at scales larger than 83 ha (PFA) since it was evident from the univariate analyses that the relative importance of predictor variables diminished beyond this scale.

Results

Univariate Analysis

Of the 41 goshawk nests selected for analysis, 66% were in aspen trees, 22% were in ponderosa pine, 7% were in Engelmann spruce, and 5% were in lodgepole pine (Figure 2). Nests in aspen were generally positioned within a major fork of the tree; however several were positioned on a lateral branch within 5 meters of the trunk. Nests in conifers were positioned on lateral branches within 0 to 5 meters of the trunk.

Forests surrounding nest trees were almost equally distributed among forest types, with nests in aspen forests outnumbering nests in other types (Figure 3). In contrast, forests surrounding random locations were most commonly located in spruce-fir forests (Figure 3). Bonferroni confidence intervals revealed that spruce-fir forests were used for nesting significantly less than expected based on availability (Table 2).

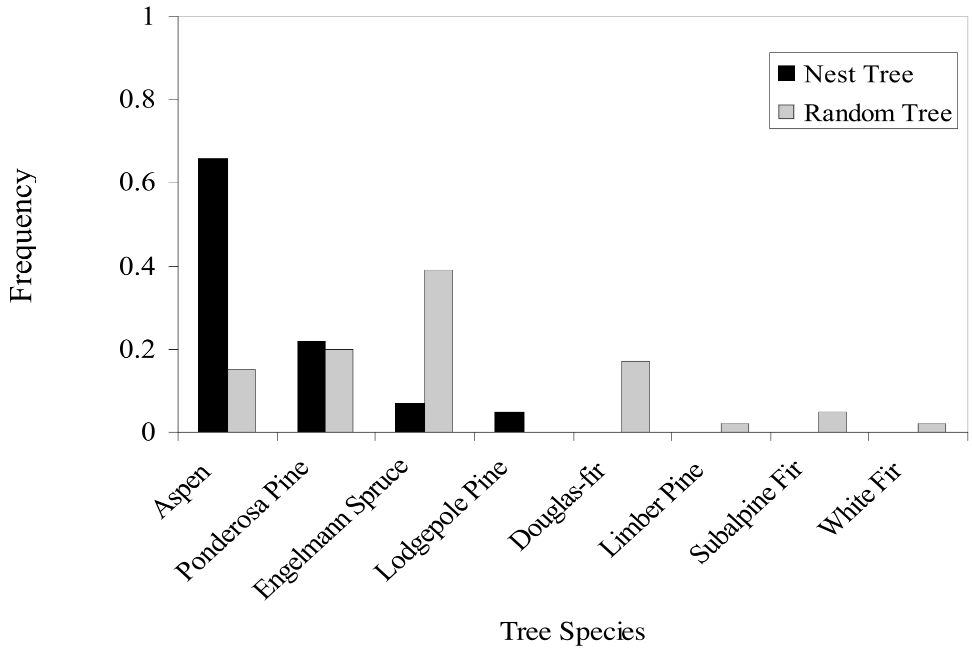


Figure 2. Frequency of occurrence of northern goshawk nest trees (n=41) and random trees (n=41) in the San Juan Mountains of southwestern Colorado (2002-2005).

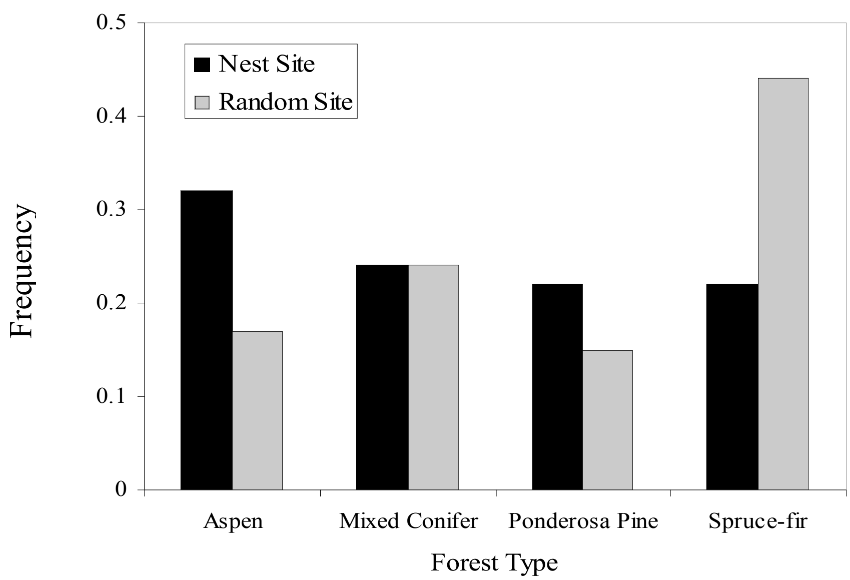


Figure 3. Frequency of occurrence of goshawk nest trees (n = 41) and random trees (n = 41) in different forest types in the San Juan Mountains of southwestern Colorado (2002-2005)

Table 2. Bonferroni 90% simultaneous confidence intervals for forest type at northern goshawk nest sites (n = 41) and random sites (n = 41) in the San Juan Mountains of southwestern Colorado (2002-2005). Bonferroni-adjusted $\alpha = 0.0125$.

Forest type	Proportion of observed nests (P_o)	Proportion of random sites (P_e)	Difference ΔP $(P_o - P_e)$	90% simultaneous confidence intervals on difference (ΔP)
Aspen	0.32	0.17	0.15	$-0.009 \leq \Delta P \leq 0.302$
Ponderosa pine	0.22	0.15	0.07	$-0.067 \leq \Delta P \leq 0.214$
Spruce-fir	0.22	0.44	-0.22	$-0.390 \leq \Delta P \leq -0.049$[a]
Mixed conifer	0.24	0.24	0.00	$-0.156 \leq \Delta P \leq 0.156$

[a]Used significantly less than expected based on availability

Of the 41 goshawk nests, 37 (90%) were in mature forests with canopy closure ≥ 40%, 3 (7%) were in mature forests with canopy closures < 40 %, and 1 (2%) was in a sapling-pole forest with canopy closure < 40% (Figure 4). The distribution of nest trees was significantly different than expected, with more nest trees than expected in mature forests with canopy closure ≥ 40%, fewer nest trees than expected in mature forests with canopy closure < 40%, and no difference from the expected proportion in sapling-pole forests (Figure 4, Table 3).

Mean crown basal height was 7 m higher in nest sites than in random sites (Table 4). Aspect at nest sites differed from expected. Sites on flat terrain (i.e. no aspect effect) were used significantly more than expected, whereas sites on north, south, east, and west aspects were used in proportion to availability (Table 5). Mean percent canopy closure and mean basal area of trees was significantly greater at nest sites than at random sites (Table 4). Of the 41 nest trees, 38 (93%) were on sites that had canopy closure > 40%, while only 27 (66%) random trees were on sites with canopy closure > 40%.

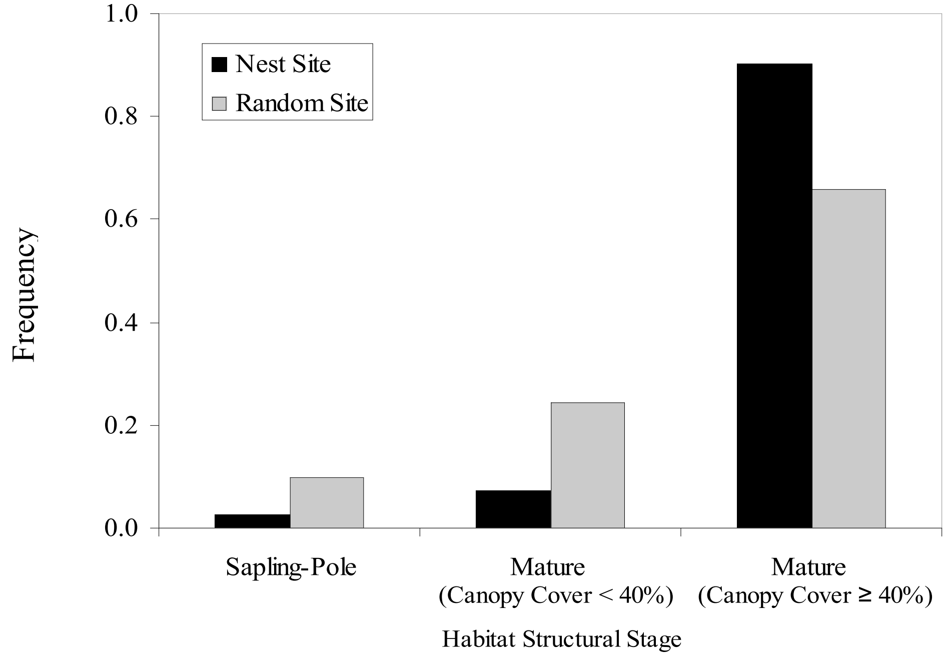


Figure 4. Proportion of goshawk nest trees (n = 41) and random trees (n = 41) in different forest structural types in the San Juan Mountains of southwestern Colorado (2002-2005).

Table 3. Bonferroni 90% simultaneous confidence intervals for habitat structural stage at northern goshawk nest sites (n=41) and random sites (n=41) in the San Juan Mountains of southwestern Colorado (2002-2005). Bonferroni-adjusted $\alpha = 0.0167$.

Habitat Structural Stage	Proportion of observed nests (P_o)	Proportion of random sites (P_e)	Difference ΔP $(P_o - P_e)$	90% simultaneous confidence intervals on difference (ΔP)
Sapling-pole	0.02	0.10	-0.07	$-0.160 \leq \Delta P \leq 0.014$
Mature (Canopy closure < 40%)	0.07	0.24	-0.17	$-0.303 \leq \Delta P \leq -0.038$[a]
Mature (Canopy closure ≥ 40%)	0.90	0.66	0.24	$0.094 \leq \Delta P \leq 0.394$[b]

[a]Used significantly less than expected based on its availability.
[b]Used significantly more than expected based on its availability.

Mean percent canopy cover contributed by aspen trees in nest sites was 70% in aspen forest, 18% in mixed conifer forest, 11% in spruce-fir forest, and 0% in ponderosa pine forest (Table 4, Figure 5). The average canopy cover of aspen did not differ between nest sites and random sites in ponderosa pine forests or aspen forests, but in mixed conifer and spruce-fir forests, nests were located in forests that had significantly more aspen canopy cover than did random sites (Figure 5).

Table 4. Mean values for vegetative, physiographic, and landscape variables surrounding 41 northern goshawk nest sites and 41 random sites on the Rio Grande and San Juan National Forests, Colorado (2002–2005). P-values are from two-sample *t*-tests on untransformed data unless otherwise noted.

	Goshawk nest sites (n=41)			Random sites (n=41)			
Variable	Mean	SE	Range	Mean	SE	Range	P-value
Crown Basal Height (m)	13	0.9	2-23	6	0.9	1-20	**< 0.001**
Basal area (m^2 ha^{-1})	35	1.7	18-64	26	2.3	7-64	**0.003**
Canopy closure (%)	73	3.1	16-98	55	4.2	6-100	**0.001**
% Aspen canopy cover	29	5.0	0-94	15	4.2	0-90	**0.041**[a]
Aspen forest[b]	70 (n=13)	6.0	16-94	70 (n=7)	7.0	35-90	0.926[a]
Ponderosa pine forest[c]	0 (n=9)	0.4	0-4	0 (n=6)	0.3	0-2	0.968[a]
Spruce-fir forest[d]	11 (n=9)	2.5	4-25	6 (n=18)	2.0	0-30	**0.029**[a]
Mixed conifer forest[e]	18 (n=10)	4.3	0-40	4 (n=10)	1.6	0-15	**0.005**[a]
Slope (%)	16	2.0	0-58	29	3.0	0-68	**< 0.001**
Elevation (m)	2788	48.6	2121-3306	2934	52.5	2324-3505	**0.044**
Distance to edge (m)	466	51.3	70-1351	185	27.3	3-681	**< 0.001**[a]
All forest - 83 ha[f]	0.85	0.0	0.61-1.00	0.85	0.0	0.16-0.99	**< 0.001**[g]
All forest -170 ha[f]	0.84	0.0	0.53-0.99	0.85	0.0	0.28-0.99	**< 0.001**[g]
All forest - 707 ha[f]	0.83	0.0	0.47-0.98	0.76	0.0	0.42-0.98	**0.053**
Mature forest - 83 ha[f]	0.70	0.0	0.01-0.99	0.64	0.0	0.08-0.99	0.344
Mature forest - 170 ha[f]	0.68	0.0	0.05-0.99	0.64	0.0	0.12-0.99	0.443
Mature forest - 707 ha[f]	0.60	0.0	0.16-0.95	0.62	0.0	0.11-0.99	0.665
Edge density - 83 ha[h]	20	3.6	0-93	50	7.7	0-265	**< 0.001**
Edge density - 170 ha[h]	34	4.2	0-109	32	5.9	0-158	**0.001**[a]
Edge density - 707 ha[h]	35	4.0	4-129	34	3.9	1-101	0.197[a]

[a] P-value for square root transformed data
[b] Percent aspen canopy cover within aspen forest types
[c] Percent aspen canopy cover within ponderosa pine forest types
[d] Percent aspen canopy cover within spruce-fir forest types
[e] Percent aspen canopy cover within mixed conifer forest types
[f] Proportion of area
[g] P-value for arcsine transformed data
[h] m ha^{-1}

Table 5. Bonferroni 90% simultaneous confidence intervals for aspect at goshawk nest sites (n = 41) and random sites (n = 41) in the San Juan Mountains of southwestern Colorado (2002-2005). Bonferroni-adjusted $\alpha = 0.01$.

Aspect	Proportion of observed nests (P_o)	Proportion of random sites (P_e)	Difference ΔP ($P_o - P_e$)	90% simultaneous confidence intervals on difference (ΔP)
North	0.17	0.15	0.02	$-0.108 \leq \Delta P \leq 0.157$
East	0.15	0.24	-0.10	$-0.241 \leq \Delta P \leq 0.046$
South	0.12	0.24	-0.12	$-0.262 \leq \Delta P \leq 0.018$
West	0.10	0.22	-0.12	$-0.255 \leq \Delta P \leq 0.011$
No aspect effect	0.46	0.15	0.32	$0.173 \leq \Delta P \leq 0.461$[a]

[a] Used significantly more than expected based on its availability.

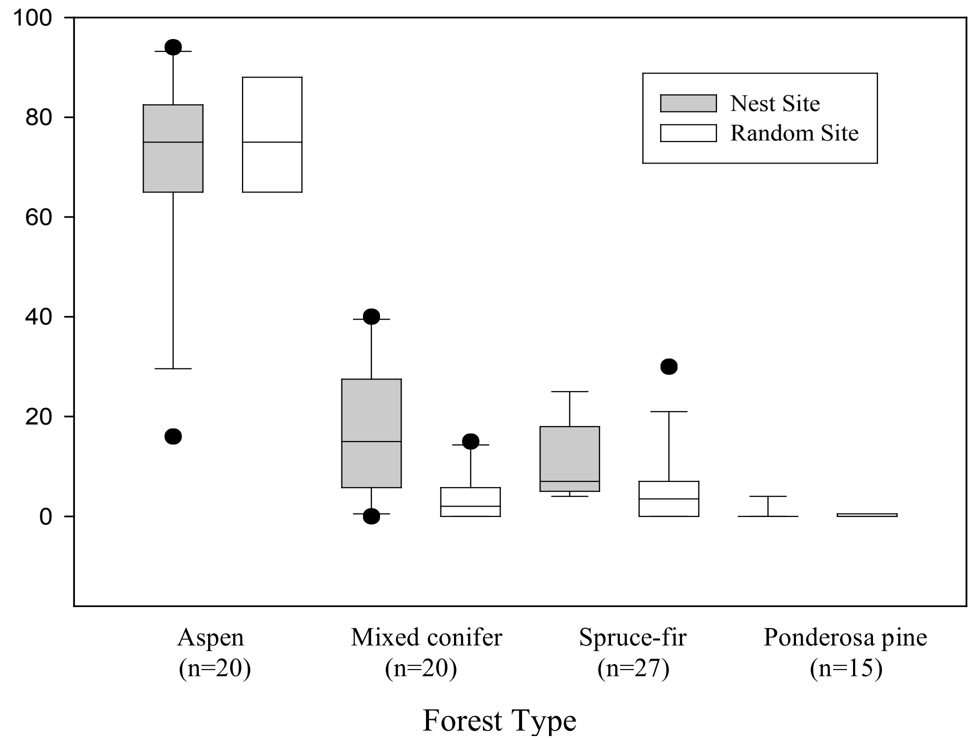


Figure 5. Percent canopy cover of aspen in forests surrounding goshawk nest sites (n = 41) and random sites (n = 41) in the San Juan Mountains of southwestern Colorado (2002-2005). Lines within the boxes represent the median, outer tails are first and third quartiles, and dots are outliers.

Mean percent slope and mean elevation at goshawk nests were significantly lower than at random locations (Table 4). Twenty-seven of 41 nests (66%) were on slopes < 20%, while only 13 (32%) of 41 random sites were on slopes < 20%.

Both mean and median distance to the nearest non-forest edge was greater for nest trees than for random locations (Table 4, Figure 6). Additionally, comparison of mean edge density indicated a consistent trend towards lower edge density in nest sites than in random sites at all scales, although the difference was significant only at the PFA and PFFA scales (Table 4). Figure 7 provides a visual representation of the minimum, mean, and maximum edge density in nest sites and random sites at the PFA scale.

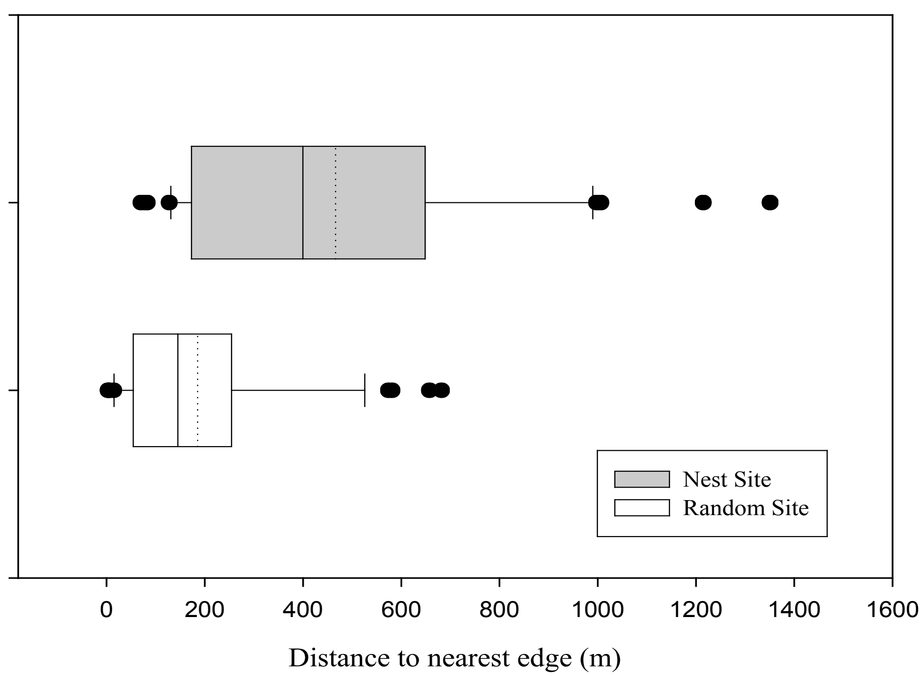
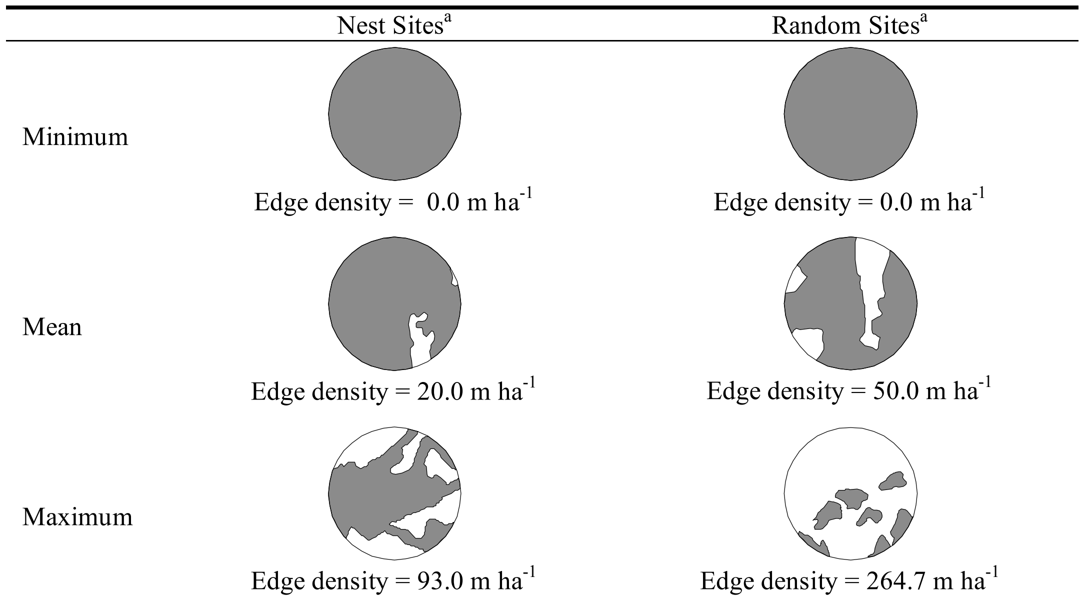


Figure 6. Box plots of distance to nearest non-forest edge (m) from northern goshawk nest trees (n = 41) and random trees (n = 41) in the San Juan Mountains of southwestern Colorado (2002-2005). The solid and dotted lines within box plots represent the median and mean, respectively. Outer tails are first and third quartiles and dots are outliers.



[a] Shaded region is forestland, white is non-forest

Figure 7. Examples of landscape pattern in 83 ha (PFA) circles surrounding goshawk nest sites (n = 41) and random sites (n = 41) with minimum, mean, and maximum amounts of edge density (m ha^{-1}) in the San Juan Mountains of southwestern Colorado (2002-2005).

The proportion of area covered by all forest types was significantly greater in nest sites than in random sites at the PFA and PFFA scales, but not at the territory scale (Table 4, Figure 8). When the frame of reference was restricted to mature forest, there was a higher proportion of mature forest in PFA and PFFA circles surrounding nest sites, but it was not significant. Additionally, there was a slightly smaller proportion of mature forest surrounding nest sites at the territory scale versus random sites (Table 4, Figure 8).

Logistic Regression Models

Of the 16 models evaluated for nest-site analysis, there were 4 competing models with AIC_c values within 2 units of the most parsimonious model (Table 6). All

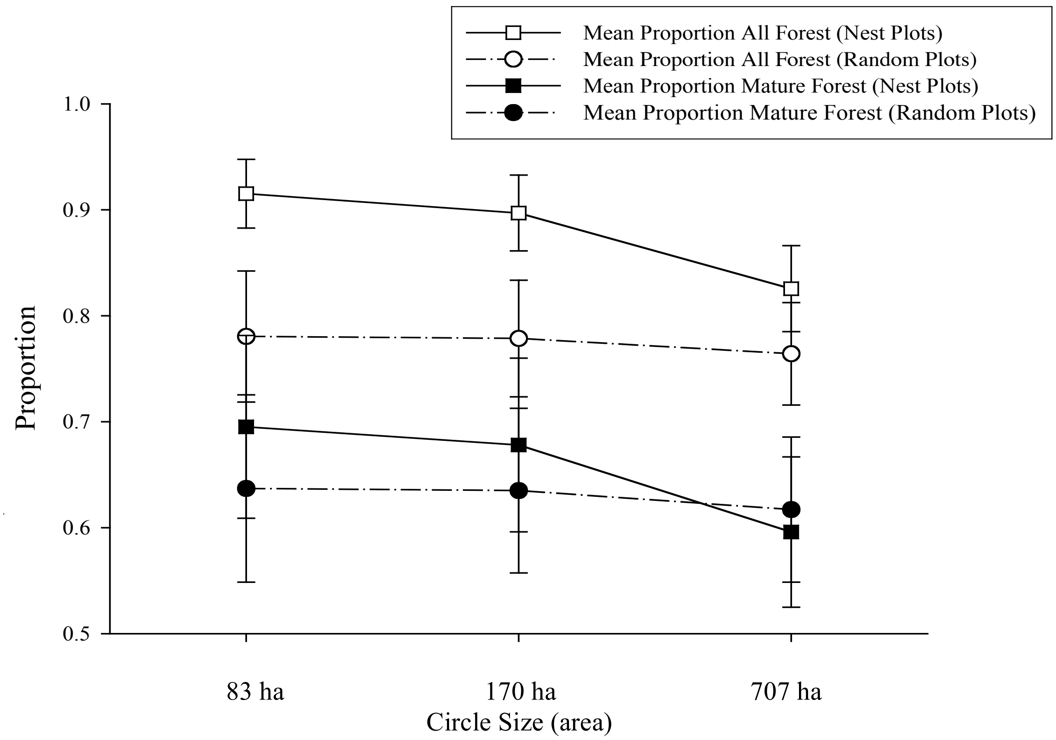


Figure 8. Mean proportions of all forest and mature forest within circles of different size surrounding northern goshawk nests (n = 41) and random sites (n = 41) in the San Juan Mountains of southwestern Colorado (2002-2005).

four of the top models included canopy closure and crown basal height as explanatory variables. Two also contained slope, and two contained the presence of aspen. These four models accounted for 92% of the cumulative Akaike weights (w_i). In all of the top models, increased canopy closure and higher crown basal height increased the odds of goshawk use, and neither of the confidence intervals for the parameter estimates included zero. Holding all other variables constant, the relative odds of a 0.10-ha site being a nest site increased by 4% with each 1% increase in canopy closure (Odds ratio = 1.04, 95% C.I. = 1.02-1.08). Thus, a site with 70% canopy closure would be 40%

Table 6. Results of logistic regression analysis of vegetative and physiographic characteristics at northern goshawk nest sites (0.10 ha plot) in the San Juan Mountains of southwestern Colorado (2002-2005). The model deviance (-2log(l)), number of parameters (k), AIC$_c$, difference in AIC$_c$ (ΔAIC$_c$), and the weight of evidence in favor of model i being the actual Kullback-Leibler best model in the set (w_i), are given for all models. AIC$_c$ is Akaike's information criterion adjusted for small sample size. Model acronyms are defined in Table 1. θ denotes a model

Model Structure	-2log(l)	k	AIC$_c$	ΔAIC$_c$	w_i
θ *0.04*(CC) + *0.10*(CBH) + *0.85*(Aspen[a])	79.14	4	85.29	0.00	0.34
θ *0.04*(CC) + *0.14*(CBH)	81.53	3	85.60	0.31	0.29
θ *0.04*(CC) + *0.10*(CBH) - *0.01*(Slope) + *0.87*(Aspen[a])	78.49	5	86.74	1.45	0.16
θ *0.04*(CC) + *0.14*(CBH) - *0.01*(Slope)	80.97	4	87.12	1.83	0.13
θ *0.05*(CC) + *1.35*(Aspen[a])	84.48	3	88.55	3.27	0.07
θ *0.17*(CBH)	92.19	1	94.21	8.93	0.00
θ *0.05*(CC)	92.84	1	94.86	9.58	0.00
θ *0.14*(CBH) + *0.60*(Aspen[a])	90.80	3	94.88	9.59	0.00
θ *0.05*(CC) – *0.02*(Slope)	90.93	3	95.00	9.71	0.00
θ *0.17*(CBH) – *0.01*(Slope)	91.55	3	95.63	10.34	0.00
θ *0.14*(CBH) – *0.14*(Slope) + *0.62*(Aspen[a])	90.06	4	96.21	10.92	0.00
θ *0.05*(CC) + *0.01*(AspenCC)	92.17	3	96.24	10.95	0.00
θ *1.23*(Aspen[a])	104.22	2	106.24	20.95	0.00
θ *0.02*(AspenCC)	106.02	1	108.04	22.76	0.00
θ - *0.02*(Slope)	111.98	1	114.00	28.72	0.00
θ *Null Model*	184.45	1	186.47	101.19	0.00

[a] Indicator variable for the presence or absence of ≥ 1 aspen tree within stand surrounding site.

more likely to contain a goshawk nest than a site with 60% canopy closure, holding all other variables constant. Likewise, the relative odds of a site being a nest site increased by 10% for each 1-meter increase in crown basal height, holding other variables in the model constant (Odds ratio = 1.10, 95% C.I. = 1.01-1.22). Conversely, slope and the presence of aspen had little effect on the relative odds of a site being used for nesting. The coefficient for the slope variable indicated a negative correlation but was very small. A 1% decrease in slope increased the relative odds of goshawk use by 1% (Odds ratio = 0.99, 95% C.I. = 0.95-1.02). The odds ratio estimate for the aspen indicator variable was 5.46 (95% C.I. = 0.49-61.47). This can be interpreted to mean that the presence of at least one aspen tree within the stand increases the relative odds of use of the stand for nesting by more than 5 times. However, there is a wide confidence interval on this estimate which contains 1, providing weak evidence of any effect.

The multi-scale model set included two competing top models, both of which contained canopy closure, crown basal height, and distance to edge as explanatory variables (Table 7). The second ranked model also contained the spruce-fir indicator variable. These two models accounted for 100% of the Akaike weights. There was little support for models that included edge density, amount of all forest, or amount of mature forest, and there was no indication that plot scale had much influence. In both of the top models, greater canopy closure, higher crown basal height, and greater distance to edge increased the odds of goshawk use, and the confidence interval for the parameter estimates of crown basal height and distance to edge did not include zero. Based on the model with spruce-fir as an indicator variable, it was 59% less likely that a goshawk would select a site centered on a spruce-fir forest than one centered on the other available forest types, holding all else equal (Odds ratio = 0.59, 95% C.I. = 0.14-2.52). However, the 95% confidence interval on the odds ratio estimate provided weak evidence of any effect. In the top ranked models, a canopy closure increase of 1% increased the relative odds of goshawk use by 1% (Odds ratio = 1.01, 95% C.I. = 0.98-1.04) and a 1-meter increase in crown basal height increased the relative odds of goshawk use by 26% (Odds ratio = 1.26, 95% C.I. = 1.12-1.43). For every 100 meters further from an edge, relative odds of goshawk use increased by 60% (Odds ratio =

Table 7. Results of logistic regression multi-scale model selection from analysis of vegetative, physiographic, and landscape characteristics at northern goshawk nest sites in the San Juan Mountains of southwestern Colorado (2002-2005). The model deviance (-2log(l)), number of parameters (k), AIC_c, difference in AIC_c (ΔAIC_c), and the weight of evidence in favor of model i being the actual Kullback-Leibler best model in the set (w_i), are given for all models. AIC_c is Akaike's information criterion adjusted for small sample size. Model acronyms defined in Table 1. θ denotes a model

Model	-2log(l)	k	AIC_c	ΔAIC_c	w_i
θ *0.01*(CC) + *0.23*(CBH) + *0.006*(dEdge)	62.49	4	71.01	0.00	0.70
θ *0.01*(CC) + *0.22*(CBH) + *0.006*(dEdge) - *0.27*(Spruce[a])	61.93	5	72.72	1.71	0.30
θ *0.02*(CC) + *0.16*(CBH) - *0.03*(ED83)	75.33	4	83.85	12.84	0.00
θ *0.02*(CC) + *0.14*(CBH) + *7.11*(FOR83) - *0.53*(Spruce[a])	73.59	5	84.38	13.37	0.00
θ *0.02*(CC) + *0.16*(CBH) + *6.26*(FOR83)	76.19	4	84.71	13.70	0.00
θ *0.02*(CC) + *0.15*(CBH) + *5.08*(FOR170)	78.55	4	87.07	16.06	0.00
θ *0.02*(CC) + *0.16*(CBH) - *0.02*(ED170)	79.79	4	88.31	17.30	0.00
θ *0.17*(CC) + 0.17(CBH)	84.80	3	91.10	20.09	0.00
θ *0.19*(CBH)	87.22	2	91.37	20.36	0.00
θ *0.02*(CC) + *0.16*(CBH) + *2.03*(FOR707)	83.74	4	92.26	21.25	0.00
θ *0.02*(CC) + *0.18*(CBH) - *1.01*(MF707)	84.12	4	92.64	21.63	0.00
θ *0.02*(CC) + *0.17*(CBH) + *0.59*(MF83)	84.44	4	92.96	21.95	0.00
θ *0.02*(CC) + *0.17*(CBH) - *0.005*(ED707)	84.58	4	93.10	22.09	0.00
θ *0.02*(CC) + *0.17*(CBH) + *0.40*(MF170)	84.67	4	93.19	22.18	0.00
θ *0.02*(CC) + *0.15*(CBH) + *0.95*(MF83) - *0.43*(Spruce[a])	82.58	5	93.37	22.36	0.00
θ *0.02*(CC) + *0.15*(CBH) + *0.95*(ED83) - *0.43*(Spruce[a])	82.58	5	93.37	22.36	0.00
θ *0.005*(dEdge)	90.99	2	95.14	24.13	0.00
θ *6.21*(FOR83)	98.67	2	102.82	31.81	0.00
θ -*0.03*(FOR83)	98.97	2	103.12	32.11	0.00
θ *5.90*(FOR170)	100.76	2	104.91	33.90	0.00
θ *0.03*(CC)	101.62	2	105.77	34.76	0.00
θ -*0.02*(ED170)	104.09	2	108.24	37.23	0.00
θ - *0.51*(Spruce[a])	109.14	2	113.29	42.28	0.00
θ Null Model	113.68	1	115.73	44.72	0.00
θ *0.78*(MF83)	112.75	2	116.90	45.89	0.00
θ *0.69*(MF170)	113.07	2	117.22	46.21	0.00

[a] Indicator variable for whether or not the site was centered in a spruce-fir forest.

1.006, 95% C.I. = 1.003-1.010).

Discussion

Vegetative and physiographic conditions at goshawk nest sites in the San Juan Mountains of southwestern Colorado were similar to conditions found in other North American studies of goshawks. Goshawk nest sites in this study were characterized by open understories, moderate slopes, relatively high canopy closure and basal area, and were located away from forest edges.

San Juan Mountain goshawk nest sites were found in mature forests of all forest types represented on the study area including spruce-fir. Nests were in aspen, ponderosa pine, Engelmann spruce, and lodgepole pine trees. Goshawk nest tree selection is most certainly a function of the presence of a suitable substrate capable of supporting a large stick nest (0.3-1 meter diameter). Beebe (1974) stated that goshawks would nest in any species of tree as long as the tree provided a secure anchorage for the nest. Deciduous trees with forked branches or coniferous trees with whorled branching are suitable nest trees (Reynolds et al. 1982, Speiser and Bosakowski 1989). Thus aspen trees provide ideal nest platforms and were the primary nest tree species in 66% of the territories within the study area. In the San Juan Mountains, aspen occurs as a co-dominant in mixed conifer and spruce-fir forests as well as in large monotypic forests. Occasionally it also occurs in narrow linear stands adjacent to creeks, wet meadows, or other flooded areas. In three instances in this study, goshawks nested in aspen nest trees in small, narrow aspen stands within a larger mosaic of ponderosa pine forest. Could this be a function of “culture” or what Newton (1979) calls “local tradition” whereby goshawks are imprinted on the nest tree species they are born in and then as adults seek out a similar nest tree? Speiser and Bosakowski (1987) reported that goshawks in New York and New Jersey nested primarily in deciduous hardwoods (82%), despite a substantial number of conifers at nest sites. There is little doubt that aspen is an important nest tree for goshawks in the San Juan Mountains because the presence of even one aspen tree in mixed conifer or spruce-fir forests increased the probability of nesting by a factor of five. Additionally, the proportion of aspen canopy cover in mixed conifer and spruce-fir forests at goshawk nest sites was significantly higher than at random sites. Spruce-fir forests containing goshawk nest sites had twice as much mean aspen canopy cover as random sites and mixed conifer forests had four times as much. Ponderosa pine forests on the other hand were fairly monotypic and contained few aspen trees.

My analysis suggested that spruce-fir forests provided less suitable nest sites for goshawks than forests of aspen, ponderosa pine and mixed conifer. However, the fact that 9 out of 55 nest sites that I found were in spruce-fir forests indicates that spruce-fir forests may be important to the conservation of goshawks, especially in regions like the San Juan Mountains, where it is the dominant forest type. Thus, I agree with Squires and Ruggiero (1996) that more work is needed to better document the use of spruce-fir habitat by goshawks. I also think it is important for managers to realize that the old notion that goshawks do not nest in spruce-fir forests in the Rocky Mountains is wrong, and needs to be replaced with a more enlightened view. The low proportion of documented nests within spruce-fir forests could be due to a number of factors, including prey availability, and tree and forest structure. Spruce-fir forests occur at high elevations where winter conditions and persistent snowpack in the late winter and early spring may limit both abundance and availability of prey. Additionally, Joy (2002) and Clough (2000) suggested the typically dense understories of spruce-mixed forests might limit access to prey, thereby negatively influencing the probability of goshawk nesting. Likewise, Engelmann spruce and subalpine fir trees both tend to have downward sloping branches that do not provide good nest support.

My results indicated that goshawks preferred to nest in forests with open understories (i.e. high crown basal height) and moderate to high canopy closure. Similar patterns have been reported in most other studies of goshawk breeding habitat (Table 8). Crown basal height in my study was 7 meters higher at nest sites than at random sites and crown basal heights were from 1 to 4 meters higher at nest sites than random sites in other studies (Table 8). High crown basal height in combination with moderate to high canopy closure is correlated with open understories. Goshawks tend to hunt in the ground-shrub and shrub-canopy zones of forests (Reynolds and Meslow 1984), and it has been suggested that dense shrub understories, such as those found in the Coast Range of Oregon, can limit goshawk access to prey and hence use of an area for breeding (Reynolds and Meslow 1984, DeStefano and McCloskey 1997). However, access to prey may not be driving nesting habitat selection at the nest site scale since there is little evidence that goshawks actually hunt in their immediate nest area (Richard T. Reynolds, USDA Forest Service, personal communication). Rather, the selection of a nest tree in an area with an open understory may be influenced by the need for dominance/defense of the nest area (Newton 1979).

Most studies in the United States have found that mean canopy closure at goshawk nests ranges from 60-95% and is significantly greater than available sites

(Siders and Kennedy 1994). However, the absolute value is dependent on the forest type. For instance, Reynolds et al. (1982) found goshawk nest sites in areas with canopy closure as low as 10% and in eastern California, mean canopy closure around the nest on the Inyo National Forest was only 31% (Table 8). However, in all studies, the mean canopy closure at nest sites was higher than what was available. In this study 93% of nest sites had canopy closure ≥ 40%. R.T. Reynolds (personal communication 2006) suggests that 40% canopy closure should be the minimum management target for goshawk nesting habitat in most regions of North America. Additionally, Desimone and DeStefano (2005) found that altering historical goshawk nest stands to < 50% canopy closure increased the likelihood of goshawks not re-occupying the stand.

Canopy closure, basal area, and understory conditions are highly correlated with each other and one or all are commonly used to quantify goshawk nest site characteristics. Hayward and Escano (1989) found that high canopy closure at nest sites was the most uniform habitat characteristic for goshawks nesting in Idaho and western Montana. While McGrath et al. (2003) gave a convincing argument for using basal area versus canopy closure as a predictor variable in habitat models, I found that single variable logistic regression models resulted in lower AIC_c values for basal area than for canopy closure. Thus I chose canopy closure as the proxy variable in my habitat models.

Though mean elevation at nest sites was significantly lower than at random locations based on statistical tests, the mean difference was only 146 meters, which

Table 8. Habitat characteristics surrounding northern goshawk nest sites and random sites ($\overline{X}$ ± SE).

Variable	Nest sites		Random sites		Source
	n	$\overline{X} + SE$	n	$\overline{X} + SE$	
Crown basal height (m)					
Wyoming	39	10 ± 1.0	33	7 ± 0.5	Squires and Ruggiero 1996, 174
Idaho/Wyoming	26	15 ± 0.6	26	11 ± 0.8	Patla 1997, 119
Montana	19	9 ± 0.5	30	8 ± 0.6	Clough 2000, 43
France	50	11 ± 0.4	50	8 ± 0.3 m	Penteriani et al. 2001, 162
SW Colorado	41	13 ± 0.9	41	6 ± 0.9	This study
Canopy closure (%)					
Idaho/Montana	17	80 ± 2.7			Hayward and Escano 1989, 477
NE California	20	31 ± 2.3	102	21 ± 1.5	Hargis et al. 1994, 72
Wyoming	39	67 ± 2.0	33	60 ± 3.8	Squires and Ruggiero 1996, 174
Wisconsin	37	82 ± 2.9			Rosenfield et al. 1998, 193
California	35	70 ± 3.1	291	41 ± 1.2	Keane 1999, 121
Montana	19	67 ± 1.7	30	58 ± 2.3	Clough 2000, 43
E Oregon/Washington	82	53 ± 1.7	82	33 ± 1.7	McGrath et al. 2003, 25
Northern Arizona	41	46 ± 1.9			La Sorte et al. 2004, 309
SW Colorado	41	73 ± 3.1	41	55 ± 4.2	This study
Slope (%)					
NE California	20	12 ± 2.5	102	10 ± 1.3	Hargis et al. 1994, 72
New York/New Jersey	16	21 ± 4.5	70	19 ± 1.5	Bosakowski and Speiser 94, 74
Wyoming	39	11 ± 1.0	33	16 ± 2.0	Squires and Ruggiero 1996, 174
Wisconsin	37	14 ± 2.6			Rosenfield et al. 1998, 193
California	35	24 ± 3.0	291	18 ± 0.9	Keane 1999, 121
Montana	19	29 ± 3.1	30	30 ± 3.1	Clough 2000, 32
E Oregon/Washington	82	23 ± 1.9	82	25 ± 2.2	McGrath et al. 2003, 25
Northern Arizona	41	21 ± 2.4			La Sorte et al. 2004, 309
SW Colorado	41	16 ± 2.0	41	29 ± 3.0	This study
Distance to edge (m)					
New York/New Jersey	16	264 ± 29.2	70	238 ± 25.1	Bosakowski and Speiser 94, 47
Montana	19	299 ± 41.8	30	371 ± 168	Clough 2000, 32
Idaho/Wyoming	26	327 ± 68	26	172 ± 62	Patla 1997, 119
France	50	1002 ± 147	50	629 ± 60	Penteriani et al. 2001, 162
SW Colorado	41	466 ± 51.3	41	185 ± 27.3	This study

may not be biologically significant. A change in elevation of 146 meters is not likely to cause a significant effect on the structural characteristics of forest habitat based on differing climactic and/or geologic conditions.

Although goshawks occasionally nest on steep slopes, most of the nests in my study and in other studies have been located on moderate to flat slopes. In fact, two-thirds of goshawk nests in this study were on sites with slope ≤ 20%. In other North American studies, mean slope ranged from 11% in wyoming to 29% in Montana, and was often lower than mean slope at random sites (Table 8). Goshawk nest site use, as quantified, can be interpreted in light of the ecology of a large forest hawk adapted to a sub-canopy world. Steep slopes, which are not typically used, can inhibit both subcanopy flight and dominance views below the canopy. Additionally, trees on steep slopes are often smaller and perhaps less suitable for supporting large nests.

In my study, goshawks used all aspect categories in proportion to their availability except for the no-aspect effect category (i.e. sites with slopes ≤ 10%), which was used significantly more than expected. Some studies have reported that goshawks prefer nesting on northern exposures (Moore and Henny 1983, Hall 1984, Hayward and Escano 1989), but others have detected no preference (Crocker-Bedford and Chaney 1988, Kennedy 1988). In two instances I did find goshawks nesting on xeric south slopes. Perhaps aspect has been misrepresented in studies that did not take into account the fact that gentle slopes (i.e. ≤ 10%) have virtually no aspect effect at all and a literal interpretation of aspect on these sites would potentially overemphasize the role of aspect in nest site selection.

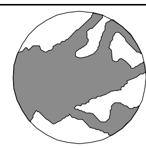
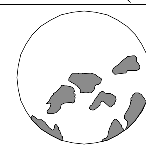
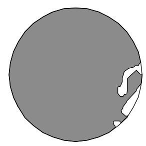
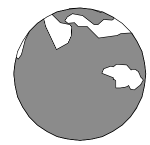
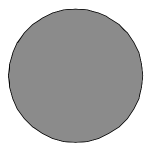
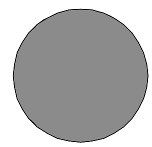
In my study, and in most other studies that have been conducted on goshawks, nests tended to be located further from edges than random locations (Table 8). The only exception I found was Clough (2000), who found that nest sites were located closer to an edge than random sites, but not significantly so (Table 8). These results suggest that goshawks avoid areas near large openings when selecting nests. In my study, the mean distance from goshawk nest sites to the nearest non-forest edge was more than twice as far as distance to edge for random plots. Penteriani et al. (2001) reported that nests were, on average, 60% further from an edge than were random plots and Patla (1997) reported that nest sites were 50% further from an edge than were random sites (Table 8).

I predicted that edge density would be lower within circles surrounding goshawk nest sites than random sites since goshawks are typically an interior, forest-nesting species. Edge density in circles surrounding nest sites in my study was less than half the density at random sites within the PFA and PFFA and was one third less at the territory scale. Finn et al. (2002, 432) reported that, in the Olympic peninsula of Washington, mean edge density at the PFFA scale of occupied goshawk nest sites was 35.5 ± 4.9 m ha^{-1}, versus 14 ± 4.2 m ha^{-1} in my study.

I predicted that landscapes surrounding goshawk nest sites would contain a significantly higher proportion of mature forest than random sites and that this would strongly influence nesting habitat selection. However, this was not the case. Circles surrounding goshawk nests did contain significantly higher proportions of all forest than random sites at increasing spatial scales, but the proportion of mature forest in circles surrounding nest sites was not significantly higher than at random sites. The mean proportion of mature forest for all three scales was high (0.60 – 0.70; Table 4), but there was a wide range of variation. This result lends support to DeStefano's (1998) argument that goshawks are a facultative old/mature forest species, rather than an old forest obligate. Others have suggested that old forest may also be important in the PFFA (Kennedy et al. 1994, Daw 1997) and have found that old forest becomes less prevalent, and possibly less important, at increasing distances from the nest; partially as a result of increasing heterogeneity with increasing scale (Daw 1997, Desimone 1997, McGrath 1997).

While the proportion of mature forest in circles surrounding nest sites was not significantly different than at random sites, the minimum proportion of all forest in circles surrounding nest sites was much higher than at random sites within PFA circles - 0.61 versus 0.16, respectively (Figure 9). At the PFFA scale, the minimum proportion of all forest in circles surrounding nest sites was nearly twice that of random sites (0.53 versus 0.28, respectively; Table 4). And at the territory scale, the minimum proportion of all forest was nearly identical between nest sites and random sites (0.47 versus 0.42, respectively; Table 4). This pattern could indicate a minimum threshold of all forest at the PFA scale for goshawk nesting in the San Juan Mountains, whereby 83 ha landscapes containing < 60% forest cover are not likely to be selected by goshawks for nesting. At increasing distance, the minimum threshold decreases, but is still 47% at the 707 ha scale. These results corroborate the findings of Desimone and DeStefano (2005) who concluded that goshawks were more likely to persist in historical nest areas in south-central Oregon that had a minimum combined coverage of 40% late seral and mid seral forest, within the 170 ha area surrounding goshawk nest sites.

Landscape fragmentation is a relative concept and a relevant topic in relation to the nesting ecology of forest accipiters. Recent studies comparing habitat characteristics around goshawk nests to random sites at multiple spatial scales have

	Proportion all forest at goshawk nest sites (83 ha) [a]	Proportion all forest at random sites (83 ha) [a]
Minimum	 0.61	 0.16
Median	 0.96	 0.85
Maximum	 1.00	 0.99

[a] Shaded region is forestland, white is non-forest

Figure 9. Minimum, median, and maximum representations of landscape pattern surrounding 41 goshawk nest sites and 41 random sites at the 83 ha (PFA) scale in the San Juan Mountains of southwestern Colorado (2002-2005).

suggested that goshawk habitat can be discriminated from random sites by a larger proportion of large-diameter, old, closed-canopy forests at scales between 83 ha (PFA; McGrath et al. 2003) and 170 ha (PFFA; Daw and DeStefano 2001). Additionally, Finn et al. (2002) reported that occupied historic goshawk nests had a greater proportion of late structural stage forest with high canopy closure, less forest initiation cover, and reduced landscape heterogeneity at the 177 ha and 1,886 ha scales, than at similar scales around unoccupied historic nests. These studies reinforce the notion that there is an association between large patches of mature forest and goshawk nesting but it is important to put them in the context of their relative "available" landscapes. The forested portions of the San Juan Mountains are largely contiguous with some small and large meadows, waterways, lakes, rock outcrops, and alpine tundra creating openings in the forest. There is only a limited amount of timber harvesting and nearly 20% of the area is classified wilderness area. The largely contiguous forest in the San Juan Mountains contrasts with other regions, such as Europe, where goshawks have adapted to increasingly fragmented landscapes. For instance, Kenward (1996) found that in portions of Europe, the species reaches its highest densities in sub-boreal (temperate and more southerly) regions where forests are fragmented by creation of farmland. Another example of goshawks persisting in highly fragmented landscapes is in the high elevation regions of Nevada where goshawks nest within small ($\overline{X}$ = 24.9 ± 21.9 ha), isolated aspen patches (Younk and Bechard 1994).

Although individual variables such as canopy closure, basal area, structural stage, and topographic position might each uniquely contribute to selection (McGrath et al. 2003), it seems reasonable to assume that nest selection is triggered by a gestalt perception of the environment that incorporates several factors simultaneously (Lack 1933). My logistic regression analysis of nest-site selection indicated that canopy closure, crown basal height, slope, and the presence of aspen trees discriminated between goshawk and random sites in southwestern Colorado. While canopy closure, crown basal height, and the presence of aspen trees positively influenced the likelihood of goshawk nesting, slope negatively influenced it. At larger spatial scales, canopy closure, crown basal height, and distance to edge were the variables that best discriminated between goshawk nest sites and random sites. These variables also positively influenced the probability of nesting. The pattern and proportion of forested vegetation at larger scales beyond the nest site became less discriminating with distance from the plot center in a heterogeneous landscape.

There were several potentially confounding factors in my study. First, nest sites were not located via random sampling, and thus, may not represent the population. Although it is encouraging that a number of studies have suggested little difference between goshawk nests sites found via random versus non-random methods (Patla 1997, Daw et al. 1998, Rosenfield et al. 1998), it is still necessary to at least acknowledge that location of nests by non-random methods could be a problem. Second, it is possible that the use of only one nest per territory in my analysis may not have captured all of the variation present in alternate nest sites.

A third potentially confounding factor is the lack of complete knowledge of the location of all goshawk territories in the study area. Territoriality is assumed to strongly influence the spatial distribution of nests among breeding pairs of goshawks and Reich et al. (2004) pointed out that this type of intra-specific behavior is a necessary component of any habitat model involving breeding birds. I did not know where all goshawk territories were on my study area, and thus could not incorporate territoriality into my models. Therefore, my results may overemphasize the significance of habitat conditions in breeding habitat selection. Additionally, if a large number of random study area plots fell within existing goshawk territories, then results could be invalid.

A fourth potentially confounding factor is that goshawk nests may not be as easy to locate in conifer forests as in aspen, which could create a negative bias that would indicate that spruce-fir is less used than it really is. Lastly, because I was not able to conduct a rigorous assessment of GIS accuracy, it is possible that parameters calculated from GIS maps contained errors that would confound my results.

Since this study was retrospective and involved neither randomization nor random sampling, inferences are limited both temporally and spatially to the San Juan Mountain sites included in this study and the relationships mentioned here may not apply to other areas.

Conclusions

Goshawks in the San Juan Mountains of southwestern Colorado select for nest site characteristics that are similar to characteristics selected by goshawks throughout the range of the species in North American. They nest in a broad range of forest types, and prefer nest sites within mature forests containing relatively high canopy closure and basal area, open understories, and moderate or flat slopes away from forest edges. Aspen trees provide ideal nest platforms and are often selected for nesting.

Goshawks do nest in mature spruce-fir forests with high canopy closure and open understories, but they often select an aspen as the actual nest tree. Biologists with limited survey funding and/or time can prioritize goshawk surveys to include areas of mature forest with canopy closures $\geq$ 40%, open understories, slopes $\leq$ 20%, at least 200 meters from a non-forest edge. Additionally, mixed conifer and spruce-fir forests containing $\geq$ 10% aspen cover are more likely to contain goshawk nests. Though these vegetative, physiographic, and landscape conditions may represent high probability nesting habitat, any forest with a tree capable of supporting a goshawk nest does provide an opportunity for nesting, thus search effort should include these areas as well. Managers in the San Juan Mountains who want to improve forest conditions for goshawks should maintain mature structural stage forests with a minimum canopy closure of 40% and also retain at least 50% of a territory-sized area in forest.

An important thing to consider is that many non-habitat-related phenomena influence habitat selection in birds, including nest predation, competition, intra- and inter- specific competition and attraction, and food limitation (Newton 1979). Additionally, population density and demographics may have a major effect on which habitats are used or unused (Rotenberry and Wiens 1980). All of these factors were beyond the scope of this study, but likely contribute to habitat selection. Additionally, the scale of analysis in this study did not extend beyond the theoretical territory and it is likely there are additional important patterns of landscape relationships, especially at the home range scale, influencing selection.

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Appendices

Appendix A. Nest chronology, productivity, and diet of northern goshawks in the San Juan Mountains of southwestern Colorado

Understanding local nesting chronology is important for surveying, monitoring, and managing northern goshawk nest sites and/or territories. Breeding goshawks center their activities around a nest for approximately 7 months out of a year. Courtship activity begins in early March and fledglings can remain in the nest area until the end of September (Squires and Reynolds 1997).

Nest monitoring was conducted on active goshawk nests within the Rio Grande and San Juan National Forests of southwestern Colorado in 2003 (n=2) and 2004 (n=11) to determine nesting chronology and productivity. On average, four visits were made to each nest during the breeding season (March – September) in order to count and age young as well as to estimate dates of incubation, hatching, and fledging.

According to Squires and Reynolds (1997), courtship typically begins around the 1st of March and eggs are layed in late April or early May but this chronology may be delayed by cold, wet springs. Incubation generally lasts 28-32 days and the nestling period lasts from 35-42 days. Juvenile goshawks usually leave the nest when they are about 40-days-old but this can vary by sex. Fledglings often remain in the PFFA for up to 8 weeks after leaving the nest (Squires and Reynolds 1997).

The estimated dates of onset of incubation, hatching, and fledging reported here are based on a 30-day average incubation period. Nestling goshawks that were 28-days-old or older were assumed to have fledged. As Brian Woodbridge (USDI Fish and Wildlife Service, personal communication) points out, this assumption is justified by the fact that accurate determination of the number of fledglings produced at goshawk nests is made difficult by the variability in fledging dates and behaviors of

Appendix A, Table 1. Estimated dates of onset of incubation, hatching, and fledging in the Rio Grande and San Juan National Forests, southwestern Colorado, during the 2003 and 2004 goshawk breeding seasons. "RGNF" = Rio Grande National Forest; "SJNF" = San Juan National Forest.

Goshawk territory	Estimated incubation onset	Estimated hatch date	Estimated fledge date	No. hatch	No. fledge	Comments
2003 Breeding Season						
Alder Creek (RGNF)	18-May	17-Jun	28-Jul	2	2	On July 17th, there was fresh evidence of someone climbing the nest tree with a mechanical device. Suspect it had occurred within previous 24 hours. One fledgling was out of the nest and the other was capable of branching so suspect they escaped capture.
Indian Creek (SJNF)	13-May	12-Jun	22-Jul	2	2	
2004 Breeding Season						
Alder Creek (RGNF)[a]	26-Apr	26-May	5-Jul	2	2	This territory was also active in 2002.
California Gulch (RGNF)[a]	27-Apr	27-May	6-Jul	3	2	On July 18th there was evidence that the nest tree had been climbed (appeared to be a large cat) and there was one dead fledgling about 100 meters downhill from the nest. On July 23rd and Aug 12th there was one live fledgling in the nest area. This territory was also active in 2002.
Dorsey Creek (RGNF)[a]	30-Apr	30-May	Unk	1	Unk	There was one 16-day old chick seen on June 16th and only an empty nest on July 19th and July 27th so it's not certain if this chick survived and fledged.
Dyers Creek (RGNF)	Unk	N/A	N/A	N/A	N/A	Nest failed during incubation period. Witnessed incubation from May 3rd - June 9th but she had abandoned nest by the June 23rd visit. Climbed and retrieved 3 unhatched goshawk eggs
Long Lost (RGNF)	Unk	Unk	Unk	≥1	≥1	This nest/territory was discovered on Aug 12th. The nest had successfully fledged at least one fledgling that was still in the area but there was no way to determine the nest chronology or total productivity.
Stone (RGNF)[a]	1-May	31-May	Unk	3	3	There were three 30-day old chicks seen June 29th and only an empty nest on subsequent visits on July 23rd and August 10th so assume hatchlings fledged and dispersed or went undetected.
Lime Creek (SJNF)[a]	9-May	8-Jun	18-Jul	4	4	Detected only 3 fledglings on last visit but all 4 were seen in the nest on a prior visit and were at least 28-days-old.

[a]Active nests included in chronology/productivity estimates

Appendix A, Table 1. (Continued)

Goshawk territory	Estimated incubation onset	Estimated hatch date	Estimated fledge date	No. hatch	No. fledge	Comments
Willow Creek (RGNF)	Unk	N/A	N/A	N/A	N/A	Nest failed during incubation period (or early in nestling period). Witnessed incubation from April 28th - May 31st but she had abandoned nest by June 16th visit. Climbed into nest and could not find evidence of eggs or dead chicks.
Millwood #9 (SJNF)[a]	27-Apr	27-May	6-Jul	2	2	
Jackson (SJNF)[a]	25-Apr	25-May	4-Jul	2	2	
Indian Creek (SJNF)[a]	28-Apr	28-May	Unk	2	2	There were two 28-30 day old chicks seen on June 25th but only an empty nest on July 25th. Assumed hatchlings fledged and dispersed early or went undetected.
Porcupine Creek (SJNF)	Unk	Unk	Unk	>=1	0	This nest/territory was discovered on June 24th. The nest had failed with no sign of adults and one dead, desiccated hatchling under the tree. The nestling's age of death was 14-17 days but there was no way to determine how long it had been dead.
Kenney Flats (SJNF)	Unk	N/A	N/A	N/A	N/A	Nest failed during incubation period. Witnessed incubation on May 28th but there was only an empty nest on June 24th visit.

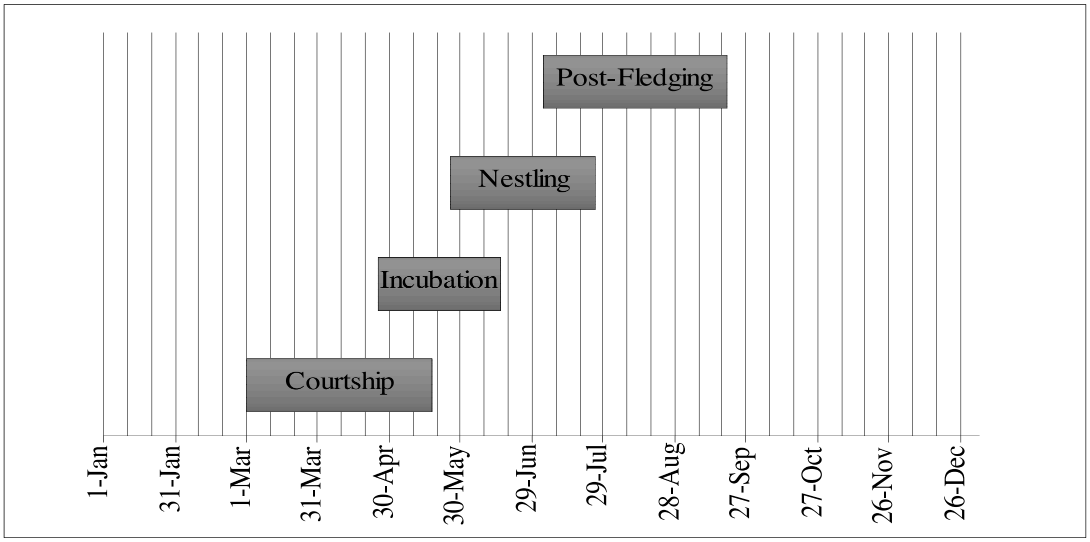
[a]Active nests included in chronology/productivity estimates

male and female fledglings. Male goshawks may leave the nest up to 10 days earlier then females, and fledglings may or may not return to the nest to roost and feed. Thus, if productivity data are desired, it is preferable to use counts of large nestlings (24-30 days old) as a surrogate for actual number fledged.

Three (27%) of the eleven active nests that were intensively monitored in 2004 failed during incubation thus were not included in the estimates of nesting chronology. The cause of failure was not known. Biologists climbed two of the three failed nest trees after abandonment. One nest contained 3 un-hatched eggs and the other contained no sign of eggs or chicks. Disturbance by goshawk observers is unlikely to have been a cause of failure since visits were of short duration (average of 15 minutes) and the female goshawks remained on their nests and only one out of the three even vocalized. Additionally, Squires and Reynolds (1997) report that disturbance associated with research has little impact on nesting birds. More likely causes of failure include: first-breeding-year females with limited experience; low prey availability; limited hunting success by male tasked with providing food for himself as well as the incubating female; and/or weather extremes such as high winds and/or rain which may have caused extreme thermodynamic stress on the incubating female and/or eggs/chicks. In fact, in 2004, there was an unusual number of days with localized high winds (> 15 mph) during late April and May in the San Juan Mountains. There was also greater rainfall and lower temperatures than usual during the incubation/early hatchling period in 2004.

The onset of incubation occurred almost two weeks earlier in 2004 than in 2003. In 2004, seven of the eight monitored nests began incubation between 26 April and 01 May (Appendix A, Table 1). One began slightly later - 09 May. Conversely, in 2003, the two nests monitored began incubation on 13 May and 18 May (Appendix A, Table 1).

Goshawk productivity was measured as the mean number of fledglings per active nest. Goshawks typically produce only one clutch per year of 2 to 4 eggs. A nest was considered "successful" if nestlings were observed within 2 weeks of the normal fledging age of 42 days (i.e. > 28 days old). Reproductive success was



Appendix A, Figure 1. Range of dates encompassing courtship, incubation, nestling, and post-fledging periods for northern goshawks in the San Juan Mountains, Colorado (2003-2004).

actually higher in 2003 ($\overline{X}$ = 2.00 fledglings/active nest) than in 2004 ($\overline{X}$ = 1.55 fledglings/active nest), when 4 out of 11 nests failed (Appendix A, Table 2). Squires and Reynolds (1997) report the number of young per clutch and pair is highly variable across North American goshawk studies. In my study, overall nest success, or the percentage of nests that fledged young, was 100% in 2003 and 64% in 2004 (Appendix A, Table 2).

The 2003 breeding season was an extremely poor nesting year for goshawks in the southwestern United States. Active nests were found at only 2 of 30 (6.7%) goshawk territories in the San Juan and Rio Grande National Forests. Similarly low nesting rates were experienced in other parts of the southwest in 2003 (Reynolds et al. 2005). Annual variation in goshawk reproduction is associated with variation in prey and weather (Keane 1999, Salafsky et al. 2005) and 2003 was the fourth year of an

Appendix A, Table 2. Northern goshawk productivity and territory occupancy in the Rio Grande (RGNF) and San Juan National Forests (SJNF), southwestern Colorado, 2003-2004.

	No. active nests monitored	No. territories checked	Nesting rate[a]	No. fledglings	No. successful nests	Average no. fledglings per active nest	Nest success (%)
2003							
RGNF	1	12		2	1	2.00	100
SJNF	1	18		2	1	2.00	100
Total	2	30	6.7	4	2	2.00	100
2004							
RGNF	6	17		7	3	1.12	50
SJNF	5	16		10	4	2.00	80
Total	11	33	33.3	17	7	1.55	64

[a]Percent active territories/territories checked

extended drought in Colorado. Studies by Wiens et al. (2006) and Keane (1999) have illustrated a wide annual variation in reproduction. For instance, the proportion of territorial pairs with active nests varied from 7-86% on the Kaibab Plateau in Arizona (Wiens et al. 2006). Thus, annual variation in reproductive activity is to be expected in the San Juan Mountains as well.

Prey items associated with goshawk nests were collected in 2002, 2003, and 2004 in order to determine at least a sample of the prey types consumed by goshawks in the San Juan Mountains. Prey remains were collected from underneath active nests, from plucking posts near active nests, and from castings (pellets) around active nests within 15 territories and identified to species when possible. Eleven species of birds, five species of mammals, as well as insects were present in diets of San Juan Mountain goshawks during the study period (Appendix A, Table 3).

Appendix A, Table 3. Species of prey remains found in association with 15 different active northern goshawk nests in the San Juan and Rio Grande National Forests, southwestern Colorado (2002-2004).

Species	Common Name
Birds	
Ceryle alcyon	Belted kingfisher
Chordeiles minor	Common nighthawk
Colaptes auratus	Northern flicker
Cyanocitta stelleri	Steller's jay (fledglings and adults)
Dendragapus obscurus	Blue grouse
Nucifraga columbiana	Clark's nutcracker (fledglings and adults)
Perisoreus canadensis	Gray jay (fledglings and adults)
Pica hudsonia	Black-billed magpie
Sphyrapicus thyroideus	Williamson's sapsucker
Turdus migratorius	American robin
Zenaida macroura	Mourning dove
	Robin-sized bird
Mammals	
Lepus americanus	Snowshoe hare (juveniles and adults)
Spermophilus lateralis	Golden-mantled ground squirrel
Spermophilus variegates	Rock squirrel
Tamiasciurus hudsonicus	Pine squirrel
Thomomys spp.	Pocket gopher
	Unknown rabbit
Insects	
	Unknown beetle

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Appendix B. Photographs of northern goshawk nest sites in the San Juan Mountains of southwestern Colorado

Northern goshawk nest sites in aspen forests

Appendix B, Figure 1. Alder Creek northern goshawk nest site in mature aspen stand, Rio Grande National Forest, southwestern Colorado (2003).

Appendix B, Figure 2. California Gulch northern goshawk nest site in mature structural stage aspen forest, Rio Grande National Forest, southwestern Colorado (2004).

Northern goshawk nest sites in aspen forests

Appendix B, Figure 3. Dorsey Creek northern goshawk nest site in mature structural stage aspen forest, Rio Grande National Forest, southwestern Colorado (2004).

Appendix B, Figure 4. Stone northern goshawk nest site in mature structural stage aspen forest, Rio Grande National Forest, southwestern Colorado (2004).

Northern goshawk nest sites in ponderosa pine forests

Appendix B, Figure 5. Jackson northern goshawk nest site in mature structural stage ponderosa pine forest, San Juan National Forest, southwestern Colorado (2005).

Appendix B, Figure 6. Kenney Flats northern goshawk nest site in mature structural stage ponderosa pine forest, San Juan National Forest, southwestern Colorado (2005).

Northern goshawk nest sites in spruce-fir forests

Appendix B, Figure 7. Heart Mountain northern goshawk nest site in mature structural stage spruce-fir forest, Rio Grande National Forest, southwestern Colorado (2003).

Appendix B, Figure 8. Long Lost northern goshawk nest site in mature structural stage spruce-fir forest, Rio Grande National Forest, southwestern Colorado (2005).

Northern goshawk nest sites in mixed conifer forests

Appendix B, Figure 9. Lime Creek northern goshawk nest site in mature structural stage mixed conifer forest, San Juan National Forest, southwestern Colorado (2005).

Appendix B, Figure 10. Porcupine Creek northern goshawk nest site in mature structural stage mixed conifer forest, San Juan National Forest, southwestern Colorado (2004).