Appendix AK

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Effects of Landscape and Local Habitat Attributes on Northern Goshawk Site Occupancy in Western Washington

Sean P. Finn, John M. Marzluff, and Daniel E. Varland

ABSTRACT. We quantified habitat structure, composition, and configuration at three spatial scales (39 ha nest area; 177 ha post-fledging area; 1,886 ha home range) and compared vegetative conditions with measures of northern goshawk (*Accipiter gentilis*) site occupancy at 30 historical nest sites (those containing at least one goshawk and a large stick nest when discovered) on Washington's Olympic Peninsula. Twelve of the 30 historical sites were occupied by one or more goshawks and 8 of the 12 contained a successful breeding pair. Sites that were occupied in 1 yr tended to remain occupied throughout the 3 yr study, and breeding success was strongly and positively correlated with occupancy. Occupied historical sites tended to have a high proportion of late-seral forest [>70% canopy closure of conifer species with >10% of the canopy trees >53 cm diameter at breast height (dbh)], reduced stand initiation cover, and reduced landscape heterogeneity at all three scales, but only the two larger scale models predicted occupancy successfully. Incorporating habitat attributes previously measured at finer (stand level) scales (canopy depth and percent shrub cover in the nest stand) improved our larger (landscape level) scale models of goshawk occupancy. Olympic Peninsula forest managers can promote goshawk occupancy, and therefore reproduction, by limiting the amount of early forest stand initiation cover (<20%) and landscape contrast in the home range and by maintaining potential nest stands (≥39 ha) having deep canopies and reduced shrub cover. For. Sci. 48(2):427–436.

Key Words: *Accipiter gentilis*, Geographic Information Systems, northern goshawk, scale, Washington, wildlife-habitat relationships.

THE NORTHERN GOSHAWK inhabits and breeds in forested environs throughout much of the Northern Hemisphere (Squires and Reynolds 1997). With few exceptions, the species requires a mid- to late-seral forest nest site that is often situated in a mosaic landscape. Goshawks nest in mature trees set amid a group of codominant, closed-canopied neighbors (Reynolds 1983), and this grove is contained within a larger (10–100 ha; Reynolds et al. 1992, Squires and Reynolds 1997, Penteriani 1999) homogeneous forest stand. When breeding, goshawks can be described as central place foragers, so most goshawk habitat evaluations have focused on habitat surrounding the nest, even though goshawks exploit large areas while rearing young.

Sean P. Finn, Biology Department, Boise State University, 1910 University Drive, Boise, ID 83725—Phone: (208) 424-9542; E-mail: a_gentilis@hotmail.com. John M. Marzluff, College of Forest Resources, University of Washington, Box 352100, Seattle, WA 98195—Phone: (206) 616-6883; Fax: (206) 685-0790; E-mail: corvid@u.washington.edu. Daniel E. Varland, Rayonier, 3033 Ingram St., Hoquiam, WA 98550—Phone: (360) 538-4582; E-mail: daniel.varland@rayonier.com.

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The Post-fledging Family Area [PFA (approximately 170 ha), Kennedy et al. 1994] and home range (570–3,500 ha, Squires and Reynolds 1997) are large-scale areas that likely contribute to goshawk site occupancy and reproduction. However, few accounts of goshawk habitat relationships at these scales have been published for the western United States (Reynolds et al. 1992, Johansson et al. 1994, Daw and DeStefano 2001). Empirical studies show that goshawk landscapes are usually dominated by mature sawtimber or mid- and late-seral, closed-canopy forest in the PFA and home range (Allison 1996, Daw 1997, Desimone 1997, McGrath 1997, Patla 1997). In Utah, elevation was a more efficient predictor of goshawk site use than was vegetation; however, habitat composition in the PFA correlated with goshawk presence (Johansson et al. 1994). Because these studies did not include the full extent of the goshawk's home range, or rarely identified significant linkages between goshawk presence and landscape condition, the relationship between habitat patch composition and configuration and goshawk population viability remains unclear. Despite limited empirical data, Reynolds et al. (1992) established general guidelines describing desired landscape conditions for goshawk populations in the southwestern United States.

Goshawks, like other large, mobile organisms, move quickly through their environment and probably sample available resources at a relatively coarse grain (Stern 1998). Both adults and young use an assortment of habitat types throughout the year (Kenward and Widen 1989, Hargis et al. 1994, Bosakowski et al. 1999). As a result, landscape-scale habitat use may vary greatly. In fact, goshawks should be well adapted to utilizing forest mosaics because presettlement forest landscapes were patchy due to the natural effects of topography, fire, wind, and erosion (Agee 1993). Even so, intensive forest harvest has elevated the conservation concern for goshawks in some parts of their range because these changes may cause mature forest patches to be less predictable in time and space than those produced by natural forest regeneration (Kennedy 1997, Widén 1997, DeStefano 1998).

We addressed the influence of landscape composition and configuration on goshawk occupancy (defined as one goshawk located in a historical nest site) by studying a population of goshawks breeding in mesic forest on Washington's Olympic Peninsula. Little is known about goshawks on the Olympic Peninsula (Fleming 1978, Marshall 1992), therefore we (1) estimated current occupancy and breeding rates at all historically occupied nest sites; (2) described the relationship between goshawk occupancy and habitat attributes in varying-sized landscapes beyond the nest stand; and (3) combined these results with previous analyses of within-stand measures of forest structure (Finn 2000) to provide a habitat model of goshawk use of northwestern U.S. coastal temperate rainforests at six spatial scales.

Study Area

We studied goshawks on the Olympic Peninsula in western Washington (Figure 1). The peninsula is composed of a central core of rugged mountains surrounded by almost level, forested lowlands (Franklin and Dyrness 1988). Although the presettlement landscape was largely coniferous forest, the peninsula has always been a mosaic of forest, permanent nonforest (i.e., lakes, alpine) and early successional seres resulting from natural disturbance [fire, wind, and erosion (Agee 1993)]. Over the last half-century, forest management has increased landscape heterogeneity. Forest management by various approaches has resulted in a mixture of forest stands of varied seral stages. The mosaic is further influenced by the contrasting management strategies used by the four primary landowners (Figure 1). The Olympic National Park (ONP, 365,000 ha; Holthhausen et al. 1995) conducted no commercial timber harvest, and the Olympic National Forest (ONF, 254,000 ha), currently managed under the Northwest Forest Plan for multiple uses (USDA and USDI 1994), harvested timber at relatively low levels. In contrast, the Washington Department of Natural Resources (164,000 ha) and private landowners (347,000 ha) manage primarily for timber production and harvest. Landscape cover conditions resembled a patchwork that also reflects ownership boundaries.

Methods

Occupancy and Productivity Surveys

We identified 30 locations as reliably documented goshawk breeding sites from records of goshawk activity ($n = 63$) compiled by the Washington Department of Fish and Wildlife. A reliably documented breeding site: (1) was on record in the Washington Heritage Database; (2) contained at least one goshawk when reported; and (3) contained a large stick nest at the time of the goshawk sighting. We surveyed these 30 historical nest sites (which were all occupied at least once between 1976 and 1995) at least one breeding season from 1996–1998 for goshawk occupancy using standardized aural broadcast surveys (Kennedy and Stahlecker 1993). Call stations were spaced 300 m apart on transects separated by 260 m and stations on adjacent transects were offset by 130 m to provide almost 91% broadcast coverage (Joy et al. 1994). Goshawk alarm and begging calls were amplified to approximately 85 db during surveys at appropriate intervals during the breeding season, an effective method for eliciting goshawk responses in western Washington (Watson et al. 1999). We surveyed a minimum of 170 ha surrounding 10 historical nest sites in 1996 and 314 ha (1 km radius) surrounding 20 historical nest sites in 1997–1998. Due to logistic constraints resulting from the need to survey large areas at each historical site to detect birds at alternate nest sites (Reynolds et al. 1992), we surveyed only 10–20 sites per breeding season. Because goshawks are highly mobile and tend to be secretive, we classified a historical nest site as occupied if at least one goshawk was detected visually within 1 km of a historical nest site during ≥1 survey visit. If we observed goshawks during a survey, we initiated a tree-to-tree search within a 150 m radius to find an active nest. In the absence of a confirmed breeding attempt, we continued to survey the historical site until breeding was confirmed or the survey requirements were satisfied (Finn 2000).

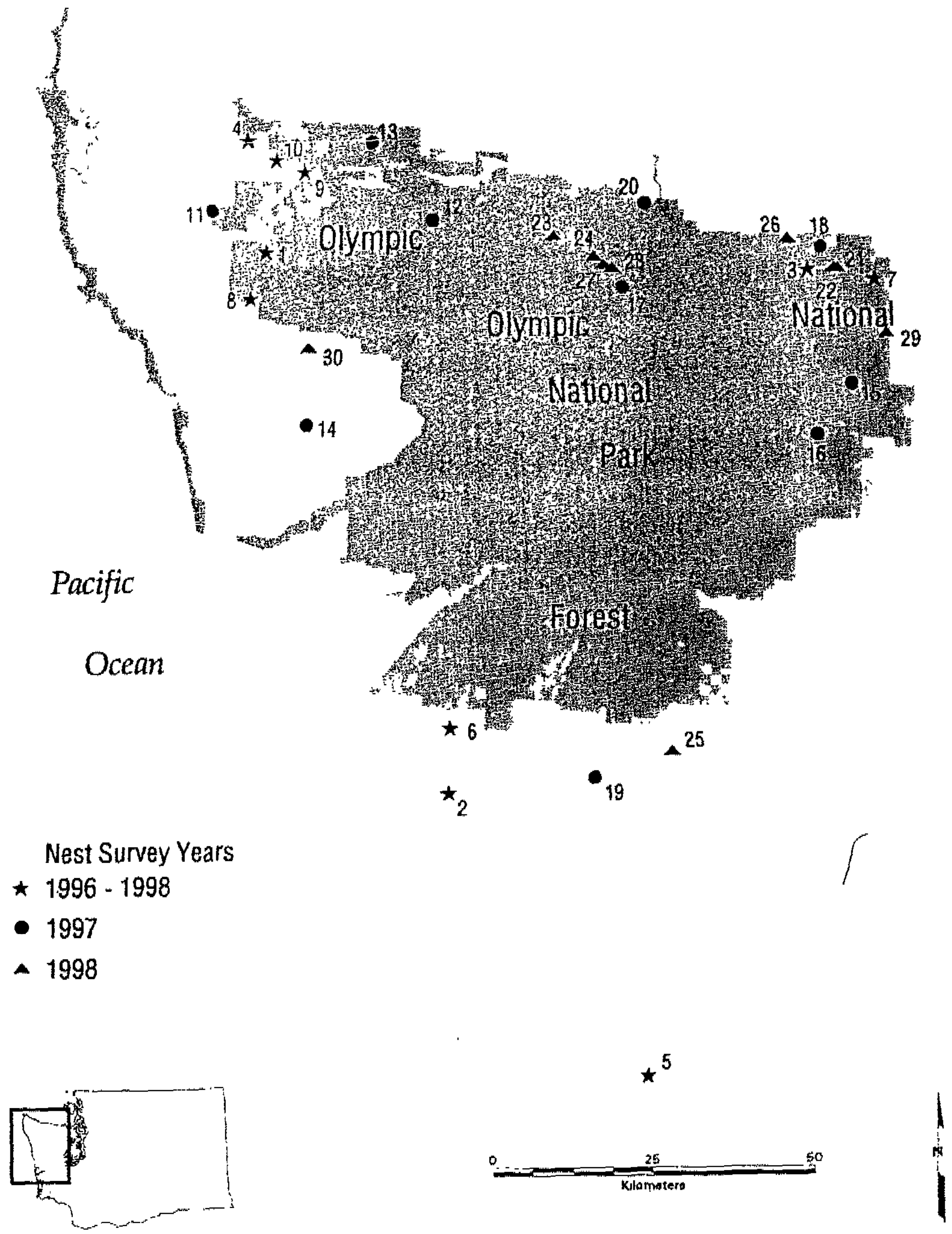

Figure 1. Historical northern goshawk (*Accipiter gentilis*) nest sites on the Olympic Peninsula, Washington, in relation to primary land ownership. All historical nests were first discovered by happenstance, between 1976–1995. We surveyed all sites for goshawk activity between 1996–1998, as indicated.

Because occupation of a given historical site can vary over time (DeStefano et al. 1994, Keane and Morrison 1994, Reynolds and Joy 1998), we surveyed 10 of the historical sites all 3 yr to assess variation in occupancy among years (the other 20 sites were each surveyed for 1 yr). Three of these ten sites were occupied every year, and three others were occupied two of the 3 yr. No site was occupied only one of the 3 yr and four of the ten sites were consistently not occupied during our study. Seventy percent of the sites maintained the same occupancy status among years, indicating that goshawk occupancy was consistent among years at sites surveyed all 3 yr (we rejected the H_0 that occupancy in 1 yr was not related to occupancy in a second year using Fisher's Exact Tests: 96–97, $P = 0.076$; 97–98, $P = 0.076$; 96–98, $P = 0.005$). Therefore, we classified all known historical nest sites in the study as "occupied" ($n = 12$) if they were occupied ≥1 yr or "not occupied during our study" ($n = 18$) if they were not occupied at least 1 yr.

Classification of occupancy based on 1 yr of surveying has the potential to result in misclassifying occupied sites as not occupied. As a result, it is possible that occupancy was actually greater than we observed. For example, we classified

14 of the 20 sites surveyed 1 yr as not occupied. However, three of the seven sites surveyed for 3 yr that were unoccupied 1 yr were also occupied another year. This suggests that 6 of the 14 sites we classified as not occupied (based on 1 yr of surveys) could in fact have been occupied in a previous or subsequent year. If we inadvertently included some occupied sites in our "not occupied" class, then our ability to detect statistical differences between habitat attributes of occupied and not occupied sites could be reduced because of increased variance in the habitat attributes of not occupied sites. Therefore, we (1) limited statistical hypothesis testing of differences among occupied and not occupied sites, (2) set $\alpha = 0.10$ for such tests to counter possible increases in variance within the not occupied class, and (3) based our management targets on the attributes of occupied sites rather than on differences between occupied and not occupied sites.

We estimated reproductive success of breeding pairs at all occupied sites ($n = 12$) during 2–3 nest site visits. We counted young as nestlings and fledglings but used the maximum number of fledglings observed as our estimate of reproduction (Marzluff and McFadzen 1996). We counted fledglings during 2–4 hr observation periods and broadcast food-begging calls to stimulate vocalizations (Finn 2000). We chose not to relate variation in breeding success to landscape attributes because some occupied sites may have been missed with our study approach.

Landscape Analysis

To quantify habitat cover classes, we used spectral analysis of 1988 and 1990 LANDSAT thematic satellite images to create a 100 m resolution raster-based habitat map that defined ten habitat cover classes (Green et al. 1993). The map was updated through 1993 to reflect changes in cover class. Map accuracy was estimated at 90–98% (Collins 1993). We reduced the original ten classes to nine by combining ecologically similar habitat types: six classes of forested habitat (late-, mid-, and early-seral stage conifer forest, stand initiation, hardwood forest, and riparian/wetlands) and three classes of nonforest habitats (ag/shrub, water/alpine, and human developed; Table 1).

We established a set of concentric circular plots over the 30 historical nest site coordinates using the GRASS 4.2.1 (Geographic Resources Analysis Support System; Baker 1997) geographic information system (GIS). Circular plots do not necessarily represent goshawk space-use in our study area (Marzluff and Varland, unpubl. data) but they can be reasonably unbiased estimates for raptors (Lehmkuhl and Raphael 1993). We examined three landscape scales that are probably important to goshawks: the nest area (area = 39 ha, radius = 350 m), the PFA (177 ha, 750 m), and the home range (1,886 ha, 2,450 m). The 39 ha nest area plots approximated our field estimate of occupied nest stand size ($n = 12$, $\bar{x} = 32.6$ ha, SE = 5.5) and home range plot size approximated the area

Table 1. Definitions and citations for explanatory landscape and local habitat variables and indices used to describe goshawk occupancy and productivity on the Olympic Peninsula, Washington.

	Definition	Citation
Landscape variables		
Late-seral forest	>70% coniferous canopy closure with >10% of canopy from trees >53 cm dbh; <75% hardwood/shrub	Collins 1993
Mid-seral forest	>70% coniferous canopy closure with <10% of canopy from trees >53 cm dbh; <75% hardwood/shrub	
Early-seral forest	<70% but >10% coniferous canopy closure (trees < 53 cm dbh); <75% hardwood/shrub	
Hardwood forest	Forest with <10% coniferous canopy closure or >70% hardwoods	
Riparian/wetlands	Mesic sites with <10% coniferous canopy closure and <70% hardwoods	
Water/alpine	Lotic or lentic water (>50m^2 in size) and glaciated mountaintops	
Stand initiation	Conifers <7 yr old, <10% coniferous canopy closure	
Ag/shrub	Agricultural plots, rangeland, and barren (nonglaciated) alpine areas	
Human developed	Areas of high use by humans	
Patch density	Number of patches per km^2	Baker and Cai 1992
Patch size	Mean size (ha) of all patches in plot	
Late-seral patch size	Mean size (ha) of late seral forest patches in plot	
Stand initiation patch size	Mean size (ha) of stand initiation patches in plot	
Patch core size	Mean size of interior cores (>100m from edge) of all patches in plot	
Late-seral core size	Mean size of interior cores (>100m from edge) of late-seral forest patches	
Patch richness	Number of different kinds (diversity) of habitat patches in plot	
Edge density	Total length of patch edge per unit (km/km^2) area in plot	
Patch shape	Index of perimeter shape relative to a circle [shape = $(0.0282 * \text{perimeter})/\text{area}^{0.5}$]	
Contrast	Describes plot texture by comparing similarity of adjacent pixels (contrast = $\Sigma_{i=1} \Sigma_{j=1}[(i-j)^2 * P_{ij}]$)	Baker and Cai 1992
Dominance index	The extent to which one or a few patch types dominate the landscape (dom. = $\ln n + \Sigma p_i \ln p_i$)	O'Neill et al. 1988
Local variables		
Canopy depth	Mean maximum overstory height – mean minimum overstory height	Avery and Burkhart 1983
Shrub cover	Mean of eight 1 m^2 samples/plot; includes sword ferns (*Polystichum* sp.)	
Medium stem density	Number of trees (38.2–63.5 cm dbh) per ha	
Distance to ridge	Closest abrupt shift in slope aspect	
Disturbance type	Index of severity of habitation disturbance (low, med, high) by humans	

used by breeding pairs of goshawks based on radio-telemetry of breeding pairs in the study area (n = 6 individuals, $\bar{x}$ = 1,913.5 ha, SE = 262.9; Marzluff and Varland, unpubl. data). The 177 ha PFA plots approximated published PFA size (170 ha; Reynolds et al. 1992, Kennedy et al. 1994). Because we used a raster-based analysis with a minimum pixel size of 50 m × 50 m, circle radii were rounded to the nearest 50 m. Using spatial analysis modules attached to the GRASS GIS (*r.le.patch* and *r.le.pixel*; Baker and Cai 1992), we described goshawk landscapes with estimates of habitat composition (cover proportion), diversity (dominance index, O'Neill et al. 1988), texture (contrast, Baker and Cai 1992), and configuration (patch shape and edge density; Table 1). Landscape attributes and indices were calculated as described by Baker and Cai (1992) and O'Neill et al. (1988). We merged the landscape data with the complementary goshawk nest site data and cross-referenced the GIS output with digital aerial photographs to check for inaccuracies. No corrections were deemed necessary.

Statistical Analysis

We estimated 20 landscape attributes (Table 1) at each of 3 spatial scales surrounding the 30 historical nest sites. We expressed the relative difference between occupied and not occupied historical sites for each habitat variable using box and whisker plots (Johnson 1999) instead of simultaneous univariate tests, because these tests can increase Type I errors (Rice 1989), and extensive hypothesis testing is inappropriate in exploratory analyses (Cherry 1998, Johnson 1999). We screened the plots to identify landscape attributes that appeared to be related to occupancy based on differences in central tendency. At each scale, we selected a subset of 6–10 variables that had statistical (approximate normal distribution, low multicollinearity) and biological (relevance to goshawks) integrity and then evaluated their usefulness as indices of goshawk site occupancy. Proportional landscape variables (i.e., percent late seral forest) were transformed (arcsine of the square root) to induce normality prior to statistical analyses (Zar 1996). We used forward-stepwise logistic regression models (PROC Logistic, SAS Inst. 1998; Hosmer and Lemeshow 1989) to explain variation in the binomial response variable (occupied vs. not occupied during our study) setting the critical value of α at 0.10 for a variable to enter the model. Significant regression models were then compared using –2 Log L values (SAS Inst. 1998).

To broaden our evaluation of the influence of habitat and spatial scale on goshawk occupancy, we incorporated local scale habitat data from Finn (2000) in our analysis. These variables, which were measured in the field using standard forest inventory techniques (Avery and Burkhart 1983), describe microscale conditions such as canopy closure, tree size, and shrub cover within the historical nest stands. The variables we used from this prior analysis are defined in Table 1.

We entered all significant variables from six uniscale analyses [nest tree (0.003 ha), vicinity (0.04 ha), stand (9-146 ha), area (39 ha), PFA (177 ha), and home range (1,886 ha)] and all possible interaction terms into multiscale regression models. We compared all significant logistic regression habitat models describing goshawk occupancy using the log-likelihood ratios (–2 Log L) of competing models (SAS Inst. 1998). Variables measured at successive scales may be autocorrelated (Holling 1992); however, we used a forward-stepwise procedure to reduce multicollinearity among predictor variables that were retained in the final models (PROC Logistic, SAS Inst. 1998; Hosmer and Lemeshow 1989). It is possible that some important variables did not enter our models because of their correlation with similar variables measured at other scales that were already in the model; however, we had already identified the importance of each variable at a single spatial scale prior to this multiscale analysis. Our interest in the multiscale analysis was to identify the relative explanatory power of variables measured at a variety of scales. Our stepwise procedure allowed us to quantify the unique contribution of habitat variables measured at many scales to the explanation of variation in goshawk occupancy.

Results

Goshawk Occupancy and Landscape Condition

Landscapes surrounding occupied historical nest sites were dominated by late-seral forest and, to a lesser degree, by mid-seral forest (Table 2). Around occupied historical sites these forests tended to have larger late-seral patch size and more uniform patch structure (i.e., contrast index, edge density) than sites not occupied during our study. These differences were most apparent with increasing spatial scale, as habitat conditions within occupied versus not occupied historical goshawk nest areas (39 ha) were more similar than were habitat conditions in PFAs (177 ha) or home ranges (1,886 ha; Tables 2, 3, 4).

The relationship between goshawk occupancy and the proportion of late-seral forest and stand initiation cover increased proportionately with increasing spatial scale. Of these, increasing stand initiation cover was most often associated with decreasing goshawk occupancy and, when combined with the contrast index, provided a significant (P = 0.02) model of site occupancy at the home range scale and a suggestive, but inconclusive (P = 0.07) model at the PFA scale (Table 5, Figure 2). Similar trends existed in the 39 ha nest areas, but regression models were inconclusive (Table 5). At larger scales (i.e., PFA and home range), the interaction between the contrast index and stand initiation cover indicated that historical sites were more likely to be occupied in landscapes with large uniform patches (low contrast) and reduced cover in the stand initiation phase (Figure 2). Goshawks occupied areas with more heterogeneity and more early stand initiation forest within their home range than within the PFA (compare Figure 2B to 2A). These models successfully accounted for occupancy at ≥75% of the historical sites. Percentage of the landscape composed of stand initiation forest was significantly lower at occupied sites at all scales except the smallest (39 ha nest area) we measured (Figure 3).

These models were further improved by incorporating local scale habitat data. Comparison of all significant uniscale models revealed that both landscape and local habitat vari-

Table 2. Landscape attributes in historical northern goshawk Nest Areas (39 ha), on the Olympic Peninsula, that were occupied ($n = 12$) and not occupied during our study ($n = 18$). Occupied sites were inhabited by ≥1 adult goshawk during at least one breeding season from 1996–1998. Landscape attributes were derived from a vegetation map provided by Collins (1993) and through spatial processing using *GRASS 4.2.1* Geographic Information System. Proportion of cover by habitat class and measures of landscape configuration are defined in Table 1.

	Occupied			Not occupied		
Landscape attributes	Mean	SE	95% CI	Mean	SE	95%CI
Late-seral forest (%)	74.55	6.65	59.5–89.1	63.96	7.13	48.9–79.0
Mid-seral forest (%)	15.32	3.91	6.7–23.9	10.21	3.84	2.1–18.3
Early-seral forest (%)	3.83	3.13	0.0–10.7	6.46	2.81	0.5–12.4
Water/ice (%)	0.23	0.23	0.0–0.7	0.0	0.0	0.0–0.0
Stand initiation (%)	6.08	3.58	0.0–14.0	13.81	5.59	2.0–25.6
Patch density (#/km^2)	8.55	1.13	6.1–11.0	10.67	1.87	6.7–14.6
Patch size (ha)	14.54	2.48	9.1–20.0	14.89	2.64	9.3–20.5
Late-seral patch size (ha)	25.58	3.01	19.0–32.2	20.40	3.25	13.6–27.3
Stand initiation patch size (ha)	0.38	0.38	0.0–1.2	4.34	1.91	0.3–8.4
Patch core size (ha)	5.58	1.69	1.9–9.3	6.09	1.76	2.3–9.8
Late-seral core size (ha)	10.58	2.08	6.0–15.2	8.50	2.02	4.3–12.8
Edge density (km/km^2)	3.18	0.65	1.75–4.61	3.74	0.69	2.29–5.19
Patch shape (index)	1.47	0.06	1.33–1.61	1.45	0.03	1.38–1.52
Patch richness (#)	2.50	0.26	1.92–3.07	2.44	0.25	1.93–2.96
Dominance index	0.30	0.07	0.14–0.46	0.21	0.05	0.11–0.31
Contrast	0.35	0.10	0.14–0.56	0.59	0.17	0.22–0.96

ables were associated with occupancy. The logistic model: logit [occupancy] = 2.43 − 0.056(stand shrub cover) − 0.049(home range stand initiation habitat * home range contrast index) correctly predicted goshawk occupancy status at 89.3% of the 30 historical sites (Hosmer and Lemeshow's [1989] $X^2 = 5.7$, $P = 0.69$, $df = 8$; Table 5).

Occupancy and Reproductive Success

Reproductive success was closely associated with occupancy (i.e., sites we labeled as occupied also had evidence of reproductive activity). We found active nests at 8 of the 12 occupied sites. Goshawks at occupied sites fledged 0–3 young/yr ($\bar{x} = 1.2$, SE = 0.23, $n = 21$). Most of the time (62%, $n = 13$ of 21 annual nesting attempts) goshawks that occupied territories also fledged young. Productivity was relatively consistent at occupied sites as well. Five of the six occupied sites we monitored for 3 yr produced fledglings in 2 of 3 yr. Across all 30 monitored sites, breeding success (categorized as 0 vs. ≥1 fledglings/yr) was strongly associated with occupancy status ($X^2 = 24.3$, $df = 1$, $P < 0.001$), therefore our measure of occupancy also indicates reproductive performance.

Discussion

General Findings and Caveats

We found that goshawks appeared to respond to habitat features at a variety of spatial scales and that habitat configuration also seemed important. We discuss these conclusions below, but advise readers to consider the following caveats. First, our study was a correlational investigation over a relatively short period of time. While we are confident that the habitat features we found associated with goshawk occupancy are indeed important drivers of occupancy, we cannot be certain. A time series study with appropriate controls that documented goshawk occupancy before and after habitat

Table 3. Landscape attributes in historical northern goshawk Post-fledging Family Areas (177 ha), on the Olympic Peninsula, that were occupied ($n = 12$) and not occupied during our study ($n = 18$). Occupied sites were inhabited by ≥1 adult goshawk during at least one breeding season from 1996–1998. Landscape attributes were derived from a vegetation map provided by Collins (1993) and through spatial processing using *GRASS 4.2.1* Geographic Information System. Proportion of cover by habitat class and measures of landscape configuration are defined in Table 1.

	Occupied			Not occupied		
Landscape attributes	Mean	SE	95% CI	Mean	SE	95%CI
Late-seral forest (%)	71.47	5.57	59.2–83.7	58.94	6.00	46.3–71.6
Mid-seral forest (%)	19.11	3.95	10.4–27.8	10.89	2.90	4.8–17.0
Early-seral forest (%)	3.86	2.45	0.0–9.2	9.29	2.72	3.5–15.0
Hardwood forest (%)	0.14	0.14	0.0–0.5	3.04	2.19	0.0–7.7
Water/ice (%)	0.05	0.05	0.0–0.1	0.47	0.36	0.0–1.2
Stand initiation (%)	5.37	2.23	0.5–10.3	16.38	4.20	7.5–25.2
Patch density (#/km2)	4.80	0.75	3.1–6.5	8.04	1.38	5.1–11.0
Patch size (ha)	33.20	7.91	15.8–50.6	26.38	9.15	7.1–45.7
Late-seral patch size (ha)	107.02	17.53	68 4–145.6	71.11	13.97	41.6–100.6
Stand initiation patch size(ha)	1.47	1.14	0.0–4.0	7.57	3.17	0.9–14.3
Patch core size (ha)	17.09	5.75	4.4–29.7	14.75	7.37	0.0–30.3
Late-seral core size (ha)	60.81	12.12	34 1–87.5	40.79	10.3	19.0–62.6
Edge density (km/km2)	3.55	0.49	2.46–4 64	4.85	0.70	3.37 - 6.34
Patch shape (index)	1 59	0.08	1 41–1.77	1.50	0.03	1.44–1.56
Patch richness (#)	3.08	0.23	2.58–3.59	3.78	0.25	3.25–4.31
Dominance index	0 43	0.08	0.23–0.63	0.40	0.05	0.29–0.52
Contrast	0 38	0.09	0.17–0 59	1.12	0.24	0.60–1.63

Table 4. Landscape attributes in historical northern goshawk Home Ranges (1886 ha), on the Olympic Peninsula, that were occupied ($n = 12$) and not occupied during our study ($n = 18$). Occupied sites were inhabited by ≥1 adult goshawk during at least one breeding season from 1996–1998. Landscape attributes were derived from a vegetation map provided by Collins (1993) and through spatial processing using *GRASS 4.2.1* Geographic Information System. Proportion of cover by habitat class and measures of landscape configuration are defined in Table 1.

	Occupied			Not occupied		
Landscape attributes	Mean	SE	95% CI	Mean	SE	95%CI
Late-seral forest (%)	63.77	4.53	53.8–73.7	50.31	4.73	40.3–60.3
Mid-seral forest (%)	17.58	3.29	10.3–24.8	13.87	2.52	8.6–19.2
Early-seral forest (%)	6.45	2.79	0.3–12.6	11.92	3.27	5.0–18.8
Hardwood forest (%)	0.62	0.39	0.0–1.5	0.79	0.62	0.0–2.1
Riparian/wetlands (%)	0.42	0.17	0.1–0.8	0.47	0.28	0.0–1.0
Water/ice (%)	0.52	0.22	0.1–1.0	0.80	0.35	0.0–1.5
Stand initiation (%)	10.64	2.95	4.1–17.1	21.30	2.76	15.5–27.1
Patch density (#/km^2)	3.66	0.52	2.5–4.8	4.96	0.79	3.3–6.6
Patch size (ha)	32.68	3.93	24.0–41.3	30.20	4.45	20.8–39.6
Late-seral patch size (ha)	456.93	155.63	114.4–799.5	235.75	96.14	32.9–438.6
Stand initiation patch size (ha)	5.02	2.03	0.5–9.5	9.46	2.78	3.6–15.3
Patch core size (ha)	17.72	2.89	11.4–24.1	15.46	3.38	8.3–22.6
Late-seral core size (ha)	314.29	112.64	66.4–562.2	170.95	81.25	0.0–342.4
Patch richness (#)	5.58	0.31	4.89–6.27	5.56	0.27	5.04–6.16
Edge density (km/km^2)	3.92	0.36	3.13–4.71	4.87	0.48	3.92–5.98
Patch shape (index)	1.58	0.02	1.53–1.64	1.58	0.03	1.53–1.65
Dominance index	0.78	0.31	0.58–0.97	0.60	0.07	0.45–0.75
Contrast	0.91	0.37	0.67–1.14	1.40	0.16	1.06–1.74

changes (e.g., Desimone 1997) would allow better inference. Second, as stated earlier, some sites may have been misclassified as "not occupied" because they were not surveyed every year and birds were missed. For this reason, we suggest that managers focus on important habitat features at occupied sites for planning and that researchers view the differences between the occupied and not occupied sites we found as hypotheses for future work, rather than definitive statistical assessments. Thirdly, although the occurrence of animals is not always indicative of a habitat's quality (Van Horne 1983), our results suggest that managing for occupancy by goshawks is also managing for successful reproduction by goshawks. This is generally the case for raptors because of limited nesting opportunities and the high cost of producing progeny (Newton 1979). Finally, our sample of only 30 historical nest sites limits our ability to broadly infer goshawk habitat relationships. However, this constitutes all of the nests reliably reported on the Olympic Peninsula and most of those known in western Washington. Therefore, our small sample is likely adequate to represent the habitat used by goshawks in western Washington.

Habitat Relationships

Goshawks on the Olympic Peninsula of Washington occupied historical sites in association with specific attributes of the landscape and local area. Goshawks nested consistently in ≥40-yr-old trees situated within mature forest stands (Finn 2000) that were surrounded predominately by late-seral forest (stands with trees >53cm dbh and other attributes, Table 1). Late-seral forest was consistently 60–75% of the landscape surrounding occupied sites at all scales that we measured (Tables 2–4). Late seral forest, by our definition, is actually quite variable in age. For example, 52% (SD = 38.5, n = 3,378, range = 40–246) of ≥40-yr-old forest stands on one private forest in the study area were classified as late seral forest. Despite using areas with up to 17% of land cover in the stand initiation stage (young regenerating clear cuts; Table 4); goshawks were most responsive to changes in stand initiation cover at the largest scales we measured (Table 5). This cover class is also negatively correlated with late-seral forest cover because an increase in stand initiation cover is generally a result of late- and mid-seral forest harvest. Either of these measures would contribute to a significant model of goshawk occupancy. However, the portion of the landscape in the stand initiation stage is a useful explanatory variable for managers because it directly relates to timber harvest targets.

The interaction of stand initiation cover and contrast index can be used to estimate acceptable levels of deviation from homogeneous forest cover for goshawks on the Olympic Peninsula. Contrast increases with heterogeneity among and between individual cover patches and is generally reduced by increasing patch size and reducing the amount of edge between different cover classes. Holding contrast constant, the odds of occupancy decreased by 12% (95% CI = 0–22%) with each 2% increase of stand initiation cover within the home range. Occupancy was unlikely if stand initiation cover exceeded 20% in the home range and 10% in the PFA (Figure 2). Likewise, if stand initiation cover within a home range exceeded 15%, the odds of goshawk occupancy further decreased by 8% (95% CI = 0–31%) with each 0.1 increase in contrast. The negative influence of increasing contrast suggests that spatially aggregating forested and nonforested patches within goshawk home ranges should contribute to goshawk conservation on the Olympic Peninsula.

Incorporating within-stand habitat data considerably improved our ability to predict goshawk occupancy of historical nest sites on the peninsula. The probability of goshawk occupancy was associated with decreasing stand initiation habitat in the landscape and decreasing shrub cover in the nest stand (Table 5). Deep forest canopy and reduced shrub and

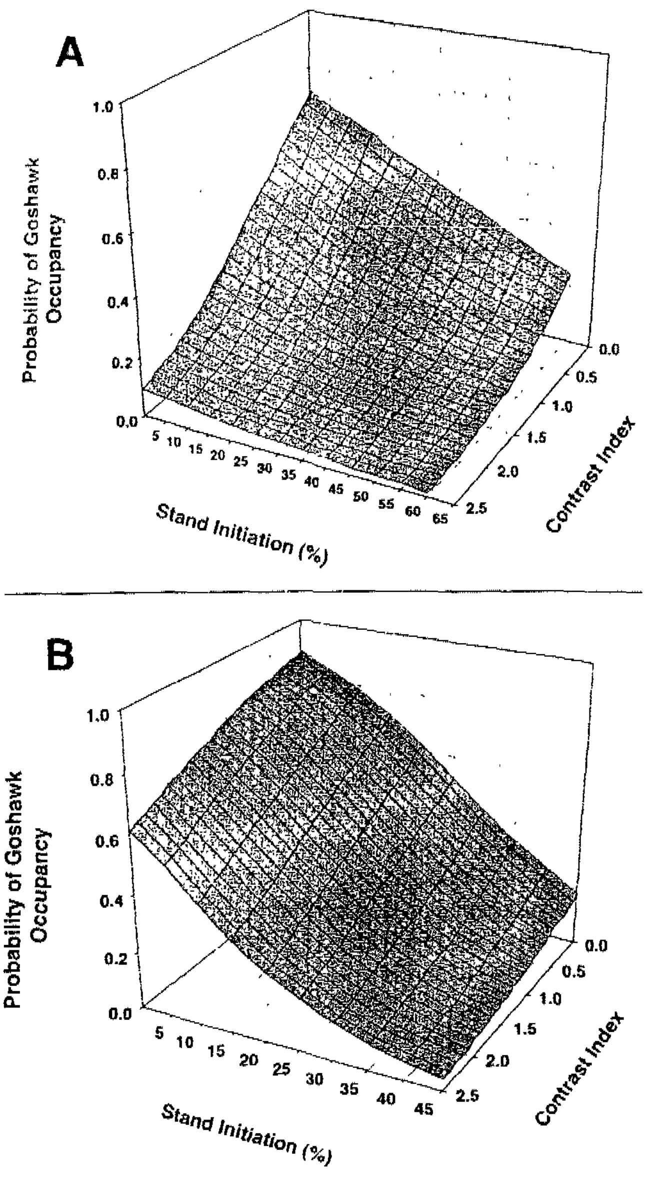

Figure 2. Contrast index interacts with the proportion of stand initiation cover to influence goshawk occupancy of historical sites on the Olympic Peninsula at both the PFA (A; 176.7 ha) and home range (B; 1885.5 ha) scales. As the proportion of stand initiation cover increases, goshawks are more likely to occupy sites with less spatial heterogeniety (less contrast).

sapling cover promote the likelihood of goshawk occupancy and therefore reproductive success within the historical nest stand (Finn 2000). Increasing stand initiation in the landscape correlates with a reduction of forest canopy cover and probably leads to increased shrub cover in stand initiation patches and ecotonal areas (Chen and Franklin 1992). Although we did not quantify fine-grained shrub cover at larger landscape scales, it may profoundly influence the availability of prey (Widén 1997) and, potentially, the suitability of an area for goshawks (DeStefano and McCloskey 1997). Reduced contrast in the landscape may also serve to reduce prey diversity by decreasing overall habitat diversity and productive habitat edges. While we cannot predict the effects our recommendations will have on all potential prey species, current data suggest that goshawks on the Olympic Peninsula forage mainly in the interiors of forest patches (including some stand initiation patches; T. Bloxton, unpubl. data). Because breeding goshawks select foraging habitat based on vegetation structure more so than prey abundance (Beier and Drennan 1997), the relationship between canopy reduction, shrub cover, and prey availability requires further study. We hypothesize that goshawks respond to some threshold of stand initiation cover, or perhaps non-late-seral forest, which may be expressed through decreased availability of prey in early seral habitats. It would be important to identify a spatial or proportional threshold if one exists.

Management Implications

Goshawks may benefit most if specific management actions are tailored to particular spatial scales. Requirements at small scales (nest site, nest stand) may be quite specific and necessitate a focused management approach to be effective. For Olympic Peninsula goshawks, this means minimizing removal of late-seral stage forest in the immediate nest vicinity (0.04 ha; Finn 2000). To promote goshawk habitat in young, dense stands at nest stand (9–146 ha; mean size, occupied stands = 33 ha) and nest area (39 ha) scales, we recommend a single, moderate-level commercial thinning (to 345–445 trees per ha) in 30- to 35-yr-old stands; this will initiate development of deep overstory canopies and low shrub cover (L. Raynes, Rayonier, pers. comm.). Furthermore, managers can provide habitat at nest stand and nest area scales by (1) not harvesting patches >1.2 ha within 350 m of historical nest sites (Table 2; 95% CI for stand initiation patch size), and (2) retaining intact late-seral forest patches (conifer stands with >53 cm dbh trees; Table 1) averaging 26 ha with approximately half (10.6 ha) of this area >100 m from an edge (late seral patch and core size, respectively; Table 2).

Requirements at larger scales (home range or PFA), however, appear to be less rigid. Goshawk needs at large scales can be met in a variety of ways that may be compatible with the needs of other species or that allow managers to balance biological and economic objectives. On the Olympic Peninsula, our results suggest that goshawk use of the landscape will be maximized where at least 54% of the home range is late-seral stage forest (Table 4; lower value of 95% CI for percentage late-seral forest) and no more than 17% is stand initiation (Table 4; upper value of 95% CI for percentage stand initiation). Reducing contrast and edge density within the home range may also increase occupancy. Harvest prescriptions that minimize inherent increases in landscape contrast surrounding historical nest sites, especially if stand initiation cover exceeds 15% of the home range, should further promote goshawk occupancy (Table 2, Figure 2).

Managing forests to create the conditions described above, if implemented across a landowner's entire holdings, would most likely be economically prohibitive for those whose primary goal is commercial timber production. Stands of late-seral forest, with trees averaging 53 cm dbh, may be produced on the Olympic Peninsula on managed forest land 40–200 yr after planting or natural regeneration, depending on the site and tree species composition (L. Raynes, Rayonier, pers. comm.). If managers of state and private lands seek to integrate the habitat needs of goshawks into their forest management decisions on the Olympic Peninsula, we sug-

Table 5. Relationships (logistic regression) between goshawk occupancy and habitat conditions at multiple spatial scales. Goshawk occupancy was determined during standardized surveys (1996–1998) around historical nest sites ($n = 30$) on the Olympic Peninsula, Washington. Nest tree, site, and stand characteristics were measured, using silvicultural methods, in the field. Nest area, PFA, and home range characteristics were derived from a GIS map. * designates an interaction of the two variables.

Scale	Variable	Intercept	Parameter Estimate	Parameter SE	Wald X^2	Wald P	Concordance (%)	−2 Log L	GOF[1] P
Home range (1,885 ha)	Stand initiation (%)								
	* Contrast index	1.06	−0.05	0.02	5.42	0.02	76.9	33.1	0.75
PFA[2] (176 ha)	Stand initiation (%)	0.39							
	* Contrast index		−0.06	0.03	3.40	0.07	75.0	33.2	0.37
Nest area (38 ha)	Stand initiation patch size (ha)	0.62	0.94	0.68	1.94	0.16	37.5	36.3	0.40
Nest stand[3] (9–146 ha)	Canopy depth (m)	−2.92	0.16	0.08	2.97	0.08			
	Shrub cover (%)		−0.06	0.03	4.13	0.04	85.6	28.0	0.34
Nest site[b] (0.04 ha)	Medium stem density	3.81	−0.27	0.18	2.40	0.12	81.8	11.4	0.60
Nest tree[b,4] (0.003 ha)	Distance to ridge (m)								
	* High disturbance	3.50	−0.01	0.01	1.45	0.22	90.9	6.3	0.19
All scales	Stand shrub cover (%)	2.43	−0.06	0.03	3.72	0.05			
	H. R. stand initiation (%)								
	* H. R. contrast index		−0.05	0.03	3.69	0.05	83.3	28.8	0.69

1 Hosmer and Lemeshow's (1989) goodness-of-fit.
2 Post-fledgling family area.
3 Data from Finn (2000).
4 $n = 11$.

gest that efforts be focused on land holdings adjacent to Olympic National Forest or Olympic National Park (Figure 1). These federal lands have late-seral forest with low contrast (larger forest patches and less edge) that should increase the attractiveness of adjacent nonfederal lands to goshawks. Nonfederal managers can also contribute to goshawk conservation by maintaining contiguous, mature forest around any known nest site. At worse, such sites would remain occupied until the members of the present pair die or disperse. These short-term gains to goshawk populations may be substantial because few birds breed in most years (Reynolds and Joy 1998). But, long-term benefits to goshawks may be especially large in areas where substantial mature forest occurs in landscapes of low contrast. On the Olympic Peninsula, these settings are most apt to occur near federal lands.

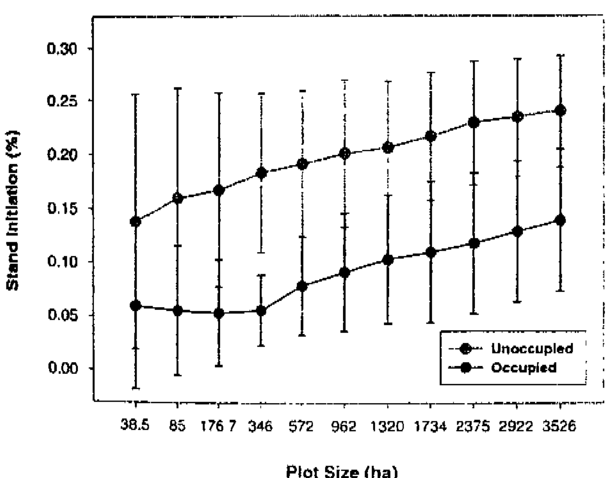

Figure 3. Occupancy of historical nest sites by goshawks is negatively influenced by the amount of stand initiation cover across landscape scales around 30 historical nest sites on the Olympic Peninsula, Washington. Error bars show 95% confidence intervals, therefore mean values for occupied sites (filled circles) are significantly different from those for unoccupied sites (open circles) if they are not included in the unoccupied site confidence intervals.

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