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DOES NORTHERN GOSHAWK BREEDING OCCUPANCY VARY WITH NEST-STAND CHARACTERISTICS ON THE OLYMPIC PENINSULA, WASHINGTON?

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ABSTRACT.—To determine stand-level habitat relationships of Northern Goshawks (*Accipiter gentilis*) on Washington's Olympic Peninsula, we surveyed all known historically-occupied sites ($N = 30$) for occupancy. We measured 45 forest-stand attributes at these sites and found, using stepwise logistic regression, that goshawks were most likely to occupy historical nest sites with high overstory depth (maximum overstory height–minimum overstory height) and low shrub cover. Forest managers can manage for high overstory depth (≥25 m) and low shrub cover (<20%) by conducting a single, moderate-level thinning (leaving 345–445 trees/ha) in young, even-aged 30–35-yr-old stands. Overstory canopy and shrub cover conditions should improve over a 5–10 yr period following thinning. Values for some habitat features (i.e., percent shrub cover, percent canopy closure, and total snags/ha) in our study were near or within the range of values reported for Spotted Owls (*Strix occidentalis*) in young forests on the Olympic Peninsula. Thus, forest management recommendations described herein may also benefit Spotted Owls.

KEY WORDS: *Northern Goshawk;* Accipiter gentilis; *logistic regression; overstory depth; shrub cover; Washington; wildlife habitat relationships, silviculture, thinning, forestry.*

VARIA LA OCUPACIÓN REPRODUCTIVA DEL AZOR CON LAS CARACTERÍSTICAS DEL SITIO—NIDO EN LA PENINSULA OLYMPIC, WASHINGTON?

RESUMEN.—Para determinar las interrelaciones del hábitat a nivel del sitio-nido para el Azor (*Accipiter gentilis*) en la península Olympic de Washington, estudiamos todos los sitios ocupados conocidos históricamente ($N = 30$). Medimos 45 atributos de los sitios en bosques y encontramos, usando regresión logística paso a paso, que estos azores probablemente ocuparon históricamente sitios nido con cubierta densa (máxima altura de la cubierta–mínima altura de la cubierta) y baja cobertura arbustiva. Los administradores de bosques puedan manejar cubiertas densamente altas (≥25 m) y baja cobertura arbustiva (<20%) llevando un simple, y moderado nivel de entresaca (dejando 345–445 árboles/ha) en plataformas jóvenes, o incluso de edades entre 30–35 años. La cubierta del dosel y las condiciones de la cobertura arbustiva deben mejorar en un periodo de 5–10 años después de la entresaca. Los valores para algunas características de hábitat (v.gr. Porcentaje de cobertura arbustiva, porcentaje de cerramiento del dosel, y total de tocones/ha) en nuestro estudio estuvieron cerca o dentro del rango de los valores reportados para *Strix occidentalis* en bosques jóvenes de la península Olympic. De esta manera las recomendaciones para el manejo de los bosques que se dan aquí, pueden beneficiar además a los búhos.
[Traducción de César Márquez]

Of critical importance to the success of an organism is its selection and use of resources. Selection among available resources may be especially important in large mobile organisms that rapidly move through extensive areas and sample available resources at a relatively coarse grain (Stern 1998). Large mobile organisms living in structurally-complex habitats may be particularly responsive to changing conditions because the various compo-

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nents of their habitat may singly or interactively affect their preferred breeding sites, thermal environment, prey abundance and distribution, vulnerability to predators, or their competitive status (Hilden 1965, Patton 1997). The Northern Goshawk (*Accipiter gentilis*; hereafter known as goshawk) is an excellent example of such an organism. Goshawks inhabit boreal and temperate forests within the Holarctic region (Squires and Reynolds 1997). Because they are highly mobile, long-lived, and can take a broad assortment of prey (Squires and Reynolds 1997, Watson et al. 1998), they are able to select among many different available habitats for breeding, roosting, foraging, and other activities.

Much research has focused on goshawk habitat use and requirements (Block et al. 1994, Squires and Reynolds 1997), primarily in response to concerns over habitat alteration (DeStefano 1998) and potential population declines (Crocker-Bedford 1998). Goshawks are described as forest generalists at large spatial scales, but are a species with narrower habitat requirements at nest sites (Squires and Reynolds 1997). At the nest-stand scale, research has shown that goshawks select stands with large-diameter trees and high canopy closure, regardless of forest type or region (DeStefano 1998).

To evaluate relationships between extant habitat and goshawk site-occupancy, we measured 45 forest characteristics in nest stands at 30 historical sites (Table 1); 29 sites were on the Olympic Peninsula and one was just south of this location (Fig. 1). Hereafter, because of the proximity of this site to the peninsula, all sites are referred to as Olympic Peninsula sites.

Our objectives were to: (1) estimate current occupancy and breeding rates at all historically occupied goshawk nest sites on the Olympic Peninsula, (2) describe the relationship between goshawk nest-stand occupancy and nest habitat attributes (see Finn et al. 2002 for descriptions at larger spatial scales), and (3) offer management recommendations based on our findings. We hypothesized that the 30 historical nest sites we identified for study would still be occupied during our study if forest conditions at these sites had not been degraded since they were first discovered. We reasoned that habitat degradation at nest sites would result in sites being unoccupied and that sites we found to be occupied would more closely resemble forest conditions at historical sites when they were used by goshawks.

STUDY AREA

The peninsula is composed of a central core of rugged mountains surrounded by more level, forested lowlands. Elevation ranges from 0–2420 m, although all known goshawk nests were restricted to elevations ranging from ca. 150–810 m. Mixed coniferous forest is the dominant vegetation over most of the peninsula although tree species, age, and composition vary along a west-east moisture gradient and from natural and anthropogenic disturbances (Franklin and Dyrness 1988, Agee 1993). Western slopes are dominated by Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), and western redcedar (*Thuja plicata*) whereas the central and eastern portions contain pure or mixed stands of western hemlock and Douglas-fir (*Pseudotsuga menziesii*), along with western redcedar and Pacific silver fir (*Abies amabilis*). Riparian and recently-disturbed areas usually contain stands of red alder (*Alnus rubra*), which may also grow in the understory or in tree gaps on older upland sites. Understory and shrub-layer densities vary widely and contain western hemlock, red alder, Pacific rhododendron (*Rhododendron macrophyllum*), sword fern (*Polystichum munitum*), and salal (*Gaultheria shallon*).

Vegetation on the Olympic Peninsula is influenced greatly by the management strategies of the four principal landowners, resulting in a mixture of forest stands of varied seral stages. The Olympic National Park (ONP, 365 000 ha, Holthausen et al. 1995) does not engage in commercial timber harvest. Under the Northwest Forest Plan, the ONP is classified as Congressionally Withdrawn (USDA and USDI 1994). The Olympic National Forest (ONF, 254 000 ha) is managed under the Northwest Forest Plan for multiple uses (USDA and USDI 1994) in which forest management now occurs at low levels in limited areas. Forest management on lands managed by the Washington Department of Natural Resources (DNR, 164 000 ha) is guided to a significant extent by a Habitat Conservation Plan (Washington State Department of Natural Resources 1997). However, the focus on these lands and on private forest lands (347 000 ha) is on commercial timber production and forest management. Forest cover conditions on the ca. 1.2 million ha of the Olympic Peninsula may be summarized by the percent of total area of each ownership class in nesting, roosting or foraging habitat for the Spotted Owl (*Strix occidentalis*) as defined by Holthausen et al. 1995: ONP—46%, ONF = 38%, DNR = 20%, and private/other non-federal = 7%.

METHODS

Occupancy at historical nest sites is an important measure of habitat suitability because goshawks usually exhibit high site fidelity (Crocker-Bedford 1990, Woodbridge and Detrich 1994, Squires and Reynolds 1997). We measured stand attributes at historical nest sites and avoided measures at random locations to eliminate the inherent bias of most use-availability studies that statistically test what is already known: that animals are nonrandomly distributed in the environment (Cherry 1998, Johnson 1999).

Occupancy Surveys. We defined 30 goshawk location records as historical nest sites after reviewing all sight records in state and federal databases. All historical nest

Table 1. Northern Goshawk survey effort at 30 historical nest sites (170 or 314 ha) on the Olympic Peninsula, Washington, 1996–98. In 1996, a 170 ha area was surveyed around each site and in 1997–98, a 314 ha area was surveyed.

		1996 No. of Visits				1997 No. of Visits				1998 No. of Visits			
Site Name/ Number[a]	Status	Courtship	Nestling	Fledgling	Total[b]	Courtship	Nestling	Fledgling	Total[b]	Courtship	Nestling	Fledgling	Total[b]
Calawah/Sitkum/12	O	2	2	1	5	2	2	1	5		3	1	4
Raney Creek/29	O	1	2	1	4	1		1	2	1	3	2	6
Dungeoness/16	O[c]			1	1	1	1	1	3	1		1	2
Burnt Mountain/2	O	3	7	1	11	3	2	1	6	1		1	2
The Hole/30	O	1	6	1	8	3	3	1	7	1		1	2
Donkey Creek/26	O	1	6	1	8	3	2	2	7	1	2	1	4
Snow Creek/18	U		2	2	4		3	1	4	1	2	1	4
Morganroth Flat/20	U	1	2	1	4	1	3	1	5		2	2	4
Swede Road/4	U	1	3	1	5		3	1	4		3	1	4
Bear Creek/3	U	2	1	1	4		3	1	4	1	2	1	4
N Fork Solduc/7	O						1	1	2				
Mount Zion/14	O						1	1	2				
Wolf Creek/11	O						2	2	4				
West Twin River/1	U						3	1	4				
Dosewallips/24	U						3	1	4				
Cook Reload/28	U						3	1	4				
Wildcat Mountain/5	U						3	1	4				
Bear Mountain/13	U						2	2	4				
Boulder Creek/9	U						3	1	4				
Iverson/6	U										2	2	4
Bowman Creek/19	O										2	2	4
Antelope Creek/15	O										2	2	4
Lillian River/17	O										1	1	2
Snahapish River/25	U									1	2	1	4
Big Canyon/23	U										2	2	4
Palo Alto/10	U										2	2	4
Bingham Creek/27	U										2	2	4
Caraco Creek/8	U										2	2	4
Dry Creek/21	U									1	1	2	4
Minnie Peterson/22	U										2	2	4

[a] See Fig. 1 for location by site number.

[b] Minimum of four visits required to meet protocol. Where <4 visits shown, occupancy was determined before protocol was met

[c] In 1996, occupancy determination was made early in nesting season by Watson (Watson et al. 1998).

sites: (1) were in the Washington Heritage Database, first located between 1976–94; (2) were occupied by at least one goshawk when reported; and (3) contained a large stick nest at the time of the goshawk sighting. Annual data on goshawk occupancy were unavailable for all of these sites, so no historical analyses were possible. We surveyed each historical nest site for goshawk occupancy using standardized aural broadcast surveys (Kennedy and Stahlecker 1993, Joy et al. 1994, Finn et al. 2002). We surveyed a minimum of a 170-ha circle surrounding 10 historical nest sites in 1996 and a 314-ha circle (1 km radius) surrounding 20 historical nest sites in 1997–98. The survey area was centered on the most recently used nest structure or, when no nest structure was found, on the UTM coordinates on record for that nest site. Because goshawks are highly mobile and tend to be secretive, we considered a historical nest site to be occupied if at least one goshawk was visually detected within 1 km of a nest during ≥1 survey visit (Finn 2000).

The protocol survey involved 4–11 survey visits where calls were broadcast from each station once during nesting, with 1–2 of these survey visits during the fledgling stage (Table 1). Call stations were 300 m apart along transects that were 260 m apart. Call stations on adjacent transects were offset by 130 m. If occupancy was determined during a survey visit, protocol surveys were discontinued but one additional site visit was made during the fledgling stage to count the number of young

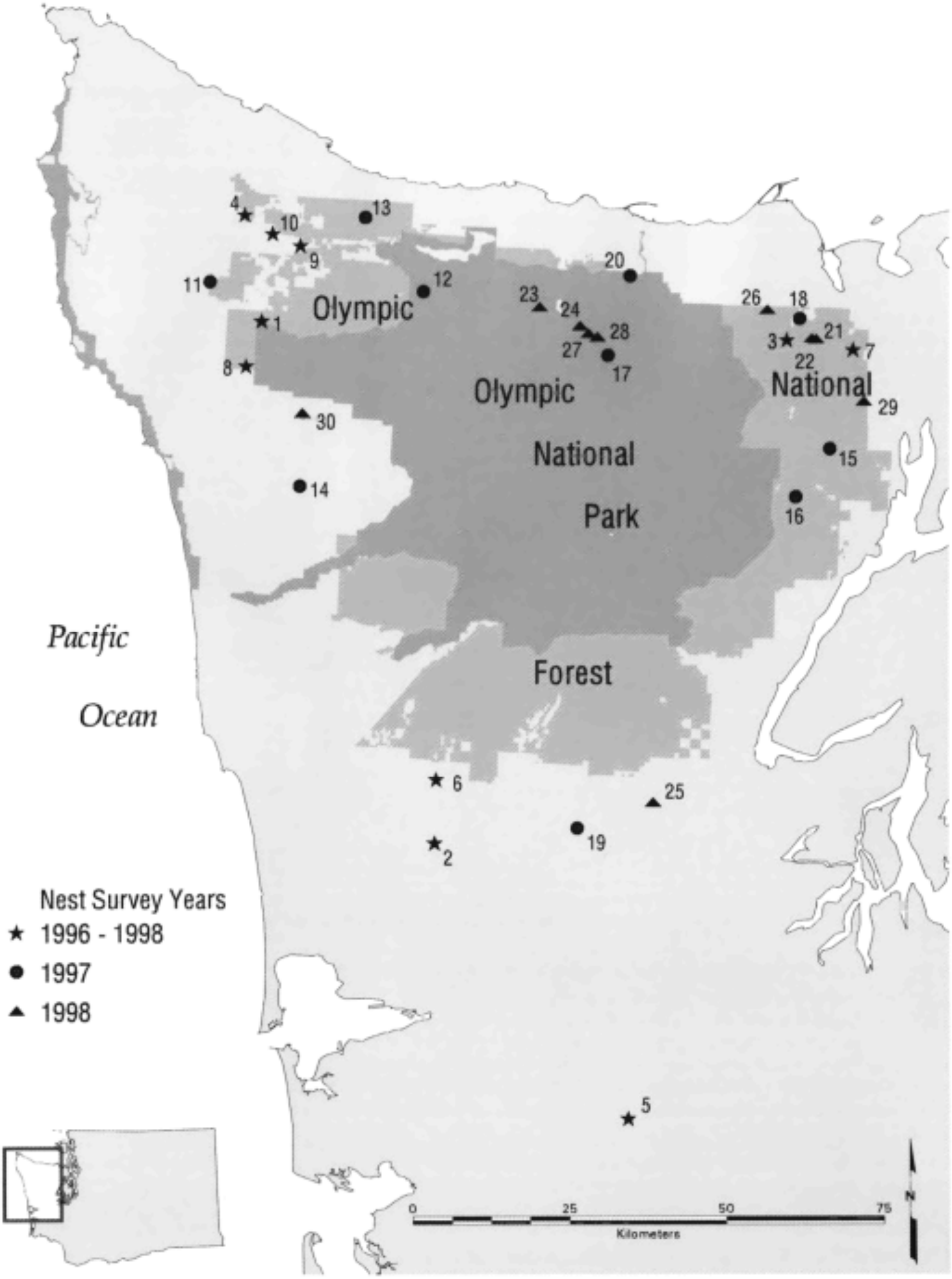


Figure 1. Location of 30 historical goshawk nest sites (170 or 314 ha) on the Olympic Peninsula, Washington. Goshawk sites outside Olympic National Park and Olympic National Forest were located on land managed by the Washington Department of Natural Resources or owned by industrial timber companies. Numbers shown are historical nest site numbers; these correspond to those identified by site name in Table 1. All historical sites were first discovered by happenstance, 1976–94. Each site was surveyed for goshawk occupancy in 1996–98, with 10 sites receiving 3 yr of surveys and 20 receiving 1 yr.

fledged. With one exception, where another research group checked on nest status (Dungeoness site in 1996; Table 1), all known nests were checked for signs of occupancy on 2–6 occasions (dependent on nest condition) during the nesting season.

Because goshawk occupation of historical sites can vary over time (DeStefano et al. 1994, Keane and Morrison 1994), we surveyed 10 historical nest sites all three years. This provided an assessment of among-year site occupancy. Seventy percent of the sites maintained the same occupancy status among any pairing of years, indicating that goshawk occupancy was consistent among years sampled (Finn et al. 2002; Table 1). Therefore, we classified all known historical nest sites on the peninsula as occupied if they were occupied ≥1 yr (N = 12) or not-occupied if they were not found occupied during any of the three survey years (N = 18).

Classifying sites as "occupied" or "not-occupied" based on one year of surveys leaves room for misclassification. Sites not occupied during the year of survey may in fact have been occupied earlier or later when no surveys occurred. To address this problem we set $\alpha = 0.10$ as the upper limit for significant differences between occupied and not-occupied sites to counter the possibility that variances were higher in our not-occupied group of stands because of misclassification. In addition, the management recommendations we provide focus on the attributes of occupied sites rather than on differences between occupied and not-occupied sites.

Habitat Analysis. To assess nest-stand habitat we measured vegetation characteristics at 30 historical nest sites. We defined the nest stand as the homogeneous forest patch surrounding a goshawk nest and delineated stands by scribing boundaries along ecotones and topographic features surrounding the nest after examining 1:12 000 orthophotographs, 1:16 000 aerial photographs, and 1: 24 000 topographic maps. Boundaries were ground-truthed in the field. Historical nest stands averaged 51.4 ha in size (range = 9–146 ha). Areas within historical nest stands where habitat alteration occurred, after goshawk occupancy and before our study, were included in our measurements of nest-stand characteristics. Thus, our habitat measurements reflect stand conditions at the time of our surveys, not conditions when the historical nest site was originally determined to be occupied by goshawks.

We measured 45 forest characteristics (Appendix 1) in 9–13 0.04-ha, systematically placed, circular plots ($\bar{x}$ = 10.5 plots/stand, SE = 0.26) in each nest stand using a modified USFS Region 6 Timber Stand Exam (USDA Forest Service 1989) and methods described by Husch et al. (1972) and Avery and Burkhart (1983). From plot center, two concentric plots were established: a variable-radius plot to sample trees >12.7 cm DBH (Diameter Breast Height, poletimber and sawtimber) and a fixed-radius plot to sample trees ≤12.7 cm DBH (saplings and seedlings).

We estimated basal area, total stem density, and stem and snag density in six size classes (12.8–38.1, 38.2–63.5, 63.6–88.9, 90.0–114.3, 114.4–139.7, and >139.8 cm) from variable radius plots (sampled using a 40 basal area factor prism). We grouped snags into a single size class (≥15.2 cm) because of the low number of snags in individual size classes. We also recorded species, DBH, total height, crown ratio, crown class, and level of mistletoe infection for each tree. Quadratic mean diameter at breast height (QDBH) was calculated as $((\Sigma\ DBH^3)/n)^{0.5}$. We used a clinometer to estimate tree heights. Crown ratio, crown class, and mistletoe abundance were estimated visually for each tree in the variable plot and then averaged for the plot. A sample of 1–3 trees of each species on each plot was cored for age and 10-yr radial growth rate. Overstory and understory canopy characteristics (i.e., overstory canopy closure, and maximum and minimum overstory heights) were estimated by averaging four measurements recorded while facing the cardinal directions. Overstory and understory canopy closure were estimated using a moosehorn (Robinson 1947). Overstory and understory height and depth were the mean of four ocular estimates of the height of live branching in the two canopy layers. We used field data to calculate stand density index (SDI, Reineke 1933) and stem density of overstory (38.2–150 cm DBH) and understory (2.5–38.1 cm DBH) trees for each nest stand. All variables were averaged per plot, then per stand.

Seedling and sapling densities were measured on a fixed-radius plot where all trees ≤12.7 cm in diameter were tallied and grouped by 2.5-cm diameter class. Mean values of height, crown ratio, crown class, and mistletoe infection were calculated for each diameter class. We estimated density and height of shrub and herb layers, and coarse woody debris (CWD) characteristics on eight 1-m^2 (Daubenmire 1959), nested plots. Plant association was assigned to all vegetation plots following Henderson et al. (1989).

Statistical Analysis. In our study, the number of predictor variables, 45, exceeded the experimental units, 30 Therefore, we first examined the relative differences between occupied and not-occupied nest sites for each variable using box-and-whisker plots (Johnson 1999). We used this approach because simultaneous univariate tests increase the Type I error rate (Rice 1989) and because the extensive hypothesis testing inherent in multiple univariate tests is inappropriate for exploratory analyses such as we undertook (Cherry 1998, Johnson 1999). We evaluated the box-and-whisker plots and identified variables with central tendencies that varied with occupancy. We selected a subset of variables that: (1) showed differences in central tendency between occupied and not-occupied sites, (2) had statistical integrity (approximate normal distribution, low multicolinearity), (3) had biological integrity (accuracy of measurement, relevance to goshawks), and (4) forest managers could effectively manage (i.e., overstory canopy closure can be managed, but percent slope cannot). The variables chosen were then evaluated as predictors of goshawk historical nest site occupancy using stepwise logistic regression models (Hosmer and Lemeshow 1989, PROC Logistic, SAS Inst. 1998) to explain variation in the binomial-response variable (occupied vs. not-occupied, $\alpha < 0.10$). We compared a main-effect model to models that included selected interaction terms to assess their significance.

RESULTS

We surveyed 10 historical sites all 3 yr (1996–98) and 20 sites during 1 yr (N = 50 annual site-sur-

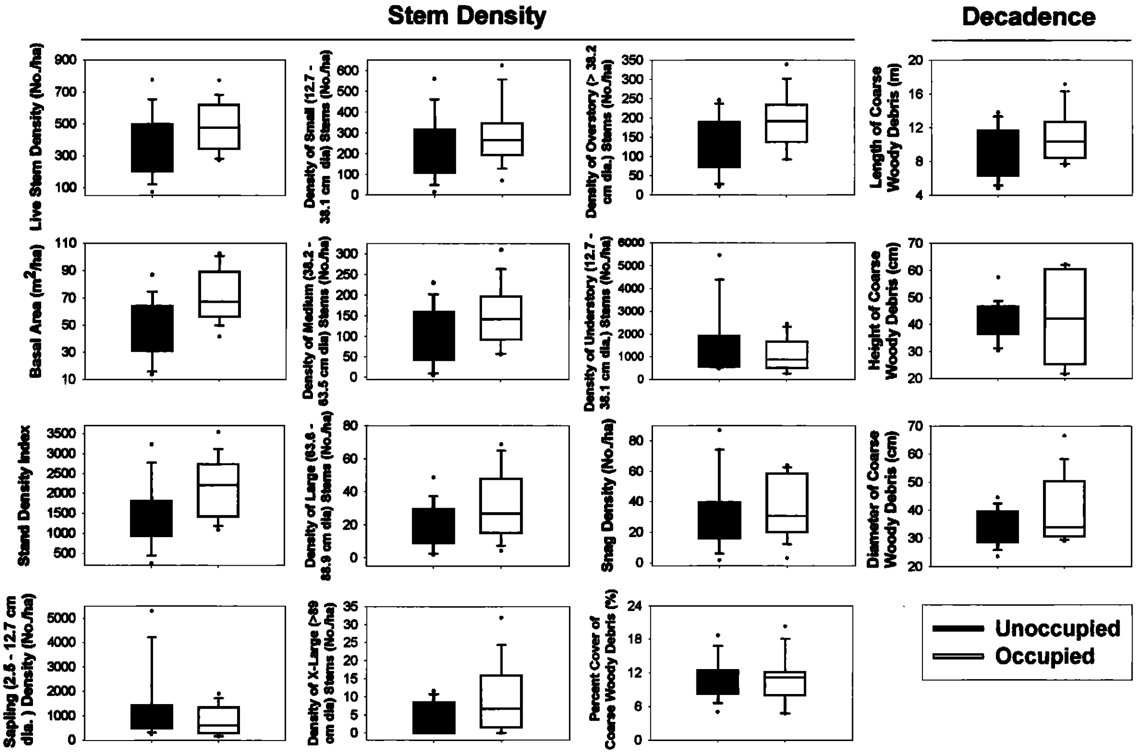


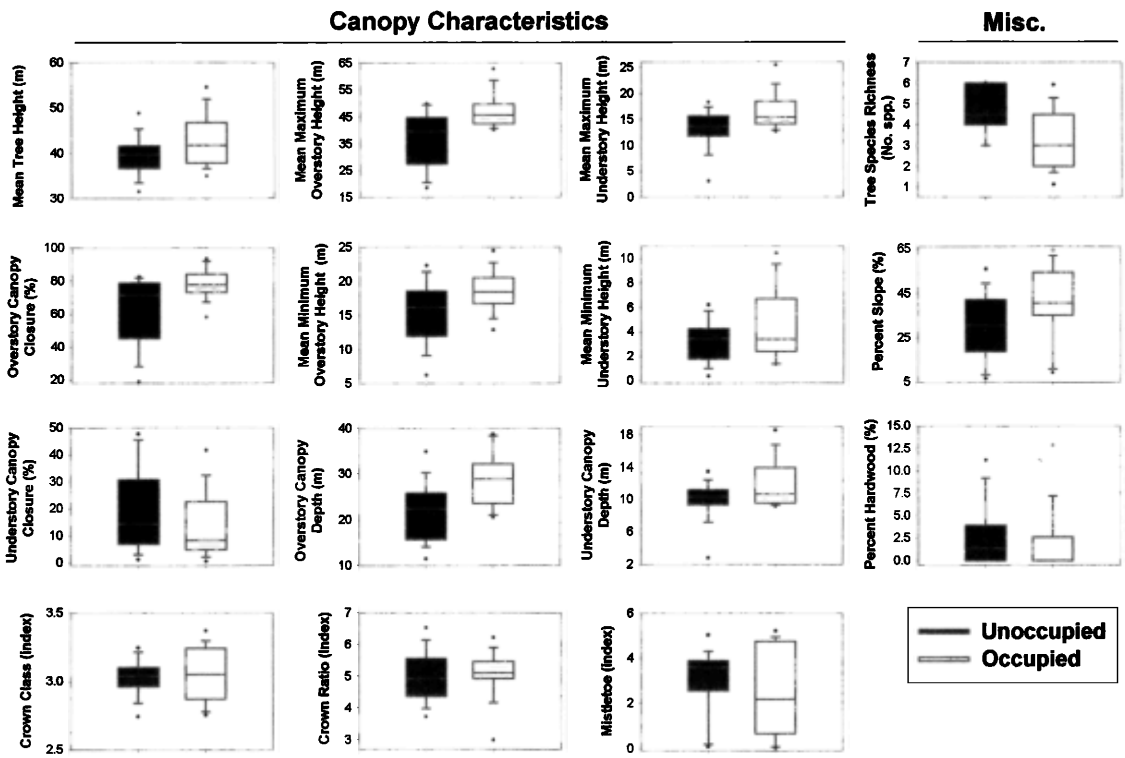
Figure 2. Habitat characteristics of goshawk nest stands (9–146 ha) at 30 historical nest sites on the Olympic Peninsula, Washington. The historical sites associated with these stands were either not-occupied (N = 18, dark boxes) or occupied (N = 12, white boxes) by goshawks, 1996–98. Boxes depict the median score and 25% and 75% quartiles. Whiskers represent the 10th and 90th percentiles and black dots represent the 5th and 95th percentiles.

veys; Table 1). We confirmed presence of goshawks during 20 of these 50 site-surveys (40% occupancy rate). At the 20 site-surveys where we observed goshawks, we saw birds during ≥2 survey visits 75% (N = 15) of the time. During the other five site-surveys that revealed occupancy, we observed an adult goshawk during one visit. In all five cases, the bird's behavior suggested it occupied the area (i.e., alarm vocalization or site tenacity during the observation). We determined that 12 of the 30 historical nest sites were occupied (Table 1). All goshawk responses were detected ≤300 m from a historical nest site location.

Stand size at historical nest sites was 9–146 ha ($\bar{x}$ = 51.4, SE = 6.4). Occupied nest stands were smaller in size ($\bar{x}$ = 32.6 ha, SE = 5.5, range = 11.6–69.3) than not-occupied nest stands ($\bar{x}$ = 63.9 ha, SE = 10.9, range = 8.7–146.2). Historical nest stands (N = 30) were composed of large ($\bar{x}$ = 57.3 cm DBH, SE = 2.4; $\bar{x}$ height = 40.8 m, SE = 1.0), mature ($\bar{x}$ = 120-yr-old, SE = 12.5) Douglas-fir and western hemlock trees, usually in association with other conifers and occasionally with a few red alders.

Compared to not-occupied nest stands, occupied nest stands tended to have deeper canopies (occupied median overstory depth = 28.9 m, not-occupied median = 21.6 m; Fig. 2) and higher canopy closure (occupied median overstory canopy closure = 77.7%, not-occupied median = 71.3%; Fig. 2). Occupied goshawk nest stands had more large-diameter trees than did not-occupied nest stands (i.e., occupied overstory stem density median = 191.9/ha, not-occupied median = 121.5/ha; Fig. 2). Occupied nest stands generally contained more timber (i.e., occupied SDI median = 2204.8, not-occupied median = 1184.2; Fig. 2) and had less shrub cover than did not-occupied stands (occupied median = 15.6%, not-occupied median = 36.9%; Fig. 2).

Overstory canopy closure, overstory canopy depth, overstory stem density, SDI, and percent



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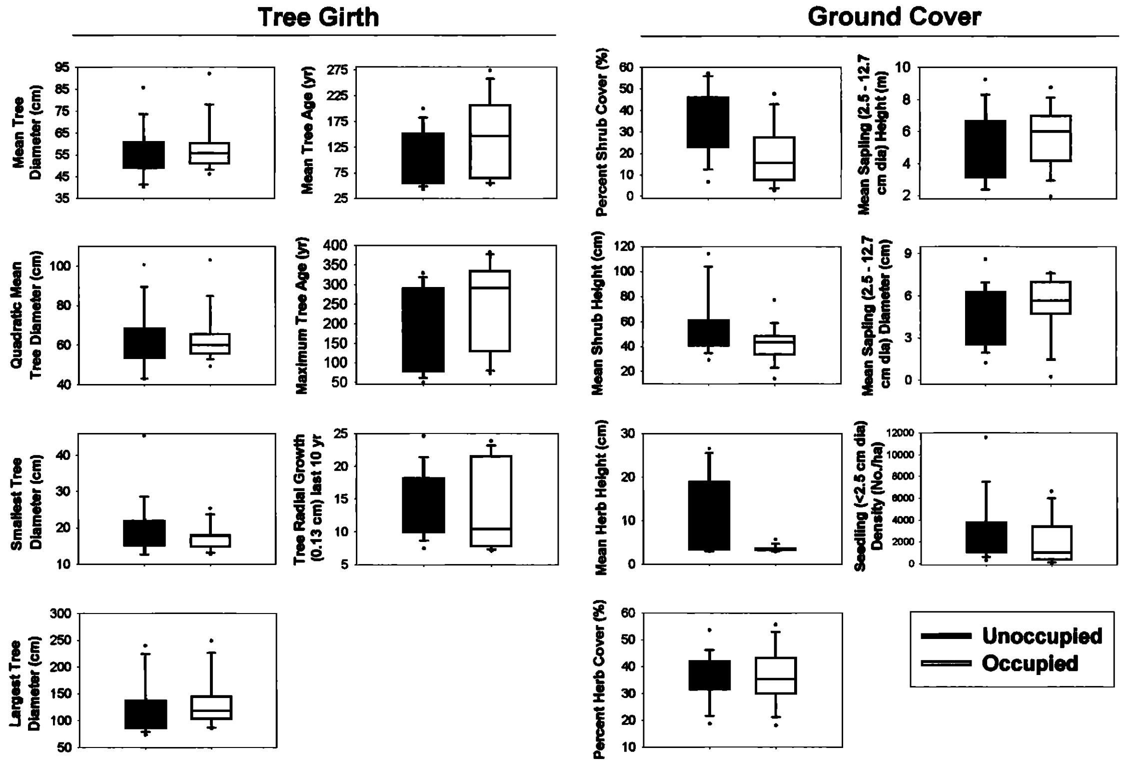
shrub cover met our variable selection criteria and were tested as predictors of goshawk nest stand occupancy. Two of these, overstory canopy depth and percent shrub cover, were useful in distinguishing between occupied and not-occupied nest stands. We found that the equation *logit* (*occupancy*) = −2.91 + 0.163 (*overstory depth*) − 0.063 (*percent shrub cover*) significantly described (overstory depth: Wald χ^2 = 2.97, P = 0.043; percent shrub cover: Wald χ^2 = 4.13, P = 0.039) and was an adequate fit (Hosmer and Lemeshow's goodness of fit = 4.087, df = 8, P = 0.850) to the data on goshawk occupancy of historical stands (Fig. 3). This model including only main effects fit the data better than did any main effects plus interaction models appraised with log-likelihood ratio criterion.

DISCUSSION

Our research indicates that occupancy of goshawk nest stands does vary with nest-stand characteristics. Our results agree with most other studies that report overstory canopy as an important feature of goshawk habitat (Squires and Ruggiero 1996, Desimone 1997, McGrath 1997, Patla 1997). These authors reported on the significance of overstory canopy closure in the nest stand but we found stand-wide overstory depth (maximum overstory height–minimum overstory height) more valuable in predicting goshawk nest-stand occupancy. Deep, dense forest canopy ($\bar{x}$ = 28.7 m, 95% CI = 24.8–32.6) may provide thermal cover (Newton 1979), protection from rain, or cover protection from predators (e.g., Great Horned Owls [*Bubo virginianus*], Reynolds et al. 1982, Squires and Reynolds 1997).

On the Olympic Peninsula, occupied nest stands typically had about 50% the shrub cover of not-occupied nest stands (Fig. 2). The odds of goshawk occupancy decreased by 47% for each 10% increase in percent shrub cover (based on the odds ratio from the logistic regression analysis). Furthermore, productive goshawk nest stands had about half the shrub cover of occupied (10.6% vs. 19.0%; Table 2).

Most other goshawk habitat studies have not reported shrub density (Speiser and Bosakowski 1987, Crocker-Bedford and Chaney 1988, Kennedy



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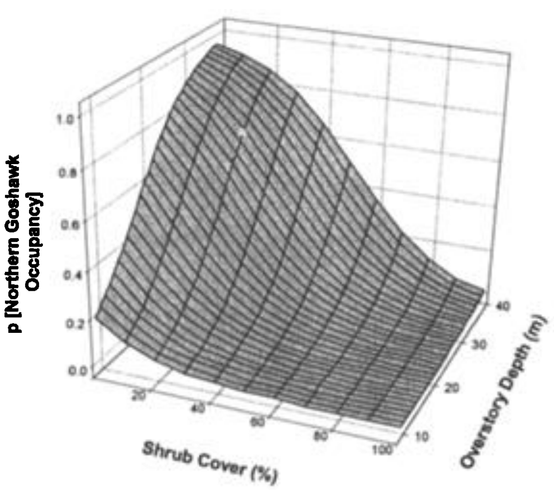

Figure 3. The probability (p) of goshawks occupying a historical nest site on the Olympic Peninsula, Washington, increases with increasing overstory depth and decreasing percent shrub cover at the nest stand scale (9–146 ha).

1988, Siders and Kennedy 1996, Desimone 1997, McGrath 1997, Penteriani and Faivre 1997) or have reported it as non-important in contributing to goshawk site occupancy (Hayward and Escano 1989, Squires and Ruggiero 1996, Patla 1997). DeStefano and McCloskey (1997), however, contend that the relative absence of goshawks from the Oregon Coast Range is due to the dense understory conditions there, which, in turn, limit prey availability. Goshawks rarely forage near their nests (Beier and Drennan 1997), so the lack of shrub cover we found in nest stands may be unrelated to prey availability. We did not measure shrub cover beyond the nest stand scale, however. At landscape scales (177-ha post-fledging area, 1886-ha home range), goshawk nest stand occupancy was predicted by a high proportion (60–75%) of late seral forest (>70% canopy closure of conifer species with >10% of the canopy in trees >53 cm DBH) and reduced landscape heterogeneity (Finn et al. 2002).

Our study may have bias because all nest sites were located opportunistically instead of as a result

Table 2. Nest stand (9–146 ha) habitat characteristics of occupied (N = 12) and productive (N = 8) historical nest sites of the Northern Goshawk on the Olympic Peninsula, Washington, 1996–98.

	Occupied[a]			Productive[b]		
Variable[c]	Mean	SE	95% CI	Mean	SE	95% CI
Mean DBH (cm)	58.8	3.7	50.6–67.0	58.2	5.4	45.5–71.0
Quadratic mean DBH (cm)	64.0	4.3	54.5–73.5	63.6	6.3	48.7–78.6
Maximum DBH (cm)	134.2	14.7	102.0–166.4	139.4	21.9	87.7–191.2
Minimum DBH (cm)	17.4	1.1	15.1–19.7	18.0	1.5	14.4–21.6
Mean tree height (m)	43.0	1.7	39.2–46.8	43.1	2.2	37.8–48.3
Crown ratio (index)	5.1	0.2	4.6–5.6	5.0	0.3	4.2–5.7
Crown class (index)	3.1	0.1	3.0–3.2	3.0	0.1	2.9–3.2
Mistletoe (index)	2.5	0.6	1.2–3.8	1.8	0.6	0.5–3.1
Radial growth (cm)	1.7	0.3	1.2–2.3	1.9	0.3	1.1–2.6
Mean tree age (yr)	147.4	22.8	97.2–197.6	128.9	25.4	68.7–189.0
Maximum tree age (yr)	247.6	33.0	175.1–320.1	229.2	37.0	141.7–316.7
Mean sapling DBH (cm)	5.3	0.7	3.9–6.7	5.1	1.0	2.7–7.4
Mean sapling height (m)	5.7	0.6	4.4–7.0	5.7	0.8	3.8–7.5
Overstory canopy closure (%)	78.4	2.9	72.1–84.7	79.0	4.1	69.3–88.8
Minimum overstory height (m)	18.6	0.9	16.6–20.6	19.9	1.0	17.6–22.2
Maximum overstory height (m)	47.3	2.0	42.9–51.7	47.0	2.7	40.6–53.4
Overstory depth (m)	28.7	1.8	24.8–32.6	27.1	2.3	21.7–32.4
Understory canopy closure (%)	13.7	3.7	5.6–21.8	13.9	5.1	1.8–26.0
Min. understory height (m)	4.6	0.9	2.7–6.5	5.8	1.0	3.2–8.3
Maxi. understory height (m)	16.5	1.1	14.1–18.9	16.6	1.5	13.1–20.2
Understory depth (m)	11.9	0.9	9.9–13.9	10.9	0.7	9.1–12.6
Percent shrub cover (%)	19.0	4.2	9.7–28.3	10.6	2.5	4.8–16.4
Mean shrub height (cm)	41.9	4.7	31.7–52.1	39.9	4.2	29.9–49.9
Percent herb cover (%)	36.5	3.2	29.5–43.5	5.0	4.2	25.1–44.9
Mean herb height (cm)	3.6	0.2	3.1–4.1	3.4	0.2	3.1–3.8
CWD cover (%)	11.0	1.3	8.1–13.9	12.7	1.5	9.0–16.3
CWD height (cm)	42.1	4.8	31.6–52.6	45.0	5.6	31.9–58.2
CWD length (m)	11.0	0.9	9.0–13.0	11.5	1.3	8.3–14.6
CWD DBH (cm)	40.6	3.6	32.7–48.5	41.2	5.1	29.2–53.2
Slope (%)	40.5	5.0	29.5–51.5	42.5	5.7	28.9–56.0
Aspect (degrees)	269.9	26.3	218.4–321.3	294.5	63.5	170.1–58.9
Basal area (m^2/ha)	71.4	5.9	58.5–84.3	68.5	5.7	55.0–81.9
Sapling den. (No./ha)	797.3	180.8	399.4–1195.2	831.3	259.3	218.1–1444.6
Small stem density (No./ha)	286.6	41.9	194.4–378.8	297.2	63.8	146.3–448.1
Med. stem density (No./ha)	151.0	22.5	101.6–200.4	146.4	23.4	91.2–201.7
Large stem density (No./ha)	39.1	7.7	22.2–56.0	32.5	8.1	13.3–51.8
Ex.-large stem den. (No./ha)	2.3	1.4	0.0–5.3	2.4	2.0	0.0–7.0
Understory stem den. (No./ha)	1083.9	219.8	600.0–1567.8	1128.5	320.9	369.6–1887.4
Overstory stem den. (No./ha)	192.5	21.9	144.2–240.8	181.3	22.6	127.9–234.8
Live stem density (No./ha)	485.4	47.4	381.0–589.8	488.0	67.9	327.4–648.6
Stand density index	2136.0	223.1	1644.9–2627.1	2107.1	317.6	1355.9–2858.3
Tree species richness (No.)	3.2	0.4	2.2–4.2	3.1	0.5	1.9–4.3
Percent hardwood (%)	1.9	1.2	0.0–4.4	1.2	0.6	0.0–2.7
Snag density (No./ha)	35.8	6.0	22.6–49.0	40.0	6.7	24.2–55.8
Seedling (No./ha)	2031.0	657.8	583.3–3478.7	2671.5	911.8	515.1–4827.9

[a] 12 sites: eight productive (where ≥1 young fledged) and four occupied with no productivity.
[b] Eight productive sites.
[c] See Appendix 1 for descriptions of habitat variables.

of systematic searches of the full range of goshawk habitat (Squires and Reynolds 1997, Daw et al. 1998). Our sample included all of the nests reliably reported on the Olympic Peninsula over an 18-yr period, 1976–94. Thus, though our sample is small, it is likely adequate to represent goshawk habitat use by goshawks on the Olympic Peninsula. Furthermore, Daw et al. (1998) compared goshawk nest stand habitat in stands found opportunistically with those found by systematic searches in Oregon and found no differences in two key habitat variables, large tree density and canopy cover. Their sample of opportunistically-located nests included nests found by individuals searching for goshawk nests with a preconceived notion of goshawk habitat preferences (i.e., searching likely habitat). Nests in our study, however, were found by individuals whose reasons for being in the field varied greatly (i.e., hikers, Marbled Murrelet (*Brachyramphus marmoratus*) surveyors, foresters conducting timber cruises) and who, in nearly all cases, were focused on activities other than finding goshawk nests. The Daw et al. (1998) study provides empirical evidence that the method we employed for identifying historic nest sites was adequate.

While we provide useful information on the characteristics distinguishing between occupied versus not-occupied nest stands, we recognize that site occupancy is not necessarily indicative of quality habitat (Van Horne 1983, Vickery et al. 1992). We believe our occupancy surveys are good indicators of habitat quality for goshawks because, in our study, nest-stand occupancy and reproduction were closely correlated (Finn 2000, Finn et al. 2002). Young successfully fledged from eight of 12 occupied sites. Moreover, only one of the 10 sites we surveyed every year was consistently occupied, but never produced fledglings.

Small-scale (e.g., nest tree, nest vicinity) habitat influences on occupancy of goshawk nest stands were not identified in our study (Finn 2000). Thus, forest managers should focus on stand scale (this paper) and landscape scale (Finn et al. 2002) habitat management for goshawks.

MANAGEMENT IMPLICATIONS

Goshawk nest stand size in our study averaged 32.6 ha in occupied historical sites and 63.9 ha in not-occupied historical sites, which is within the range of 10–100 ha reported by Squires and Reynolds (1997) for goshawk nest stands across North America. We recommend that managers who seek to address nest stand level habitat needs tailor stand size after the ranges reported here.

Our research indicates that goshawk nest-stand habitat may be provided on the Olympic Peninsula by managing stands to create deep overstory canopies and low shrub cover (Table 2, Figs. 2 and 3). Long et al. (1983) and Bailey (1996) report that large crowns can be created in dominant and codominant trees by thinning stands at 20–50 yr of age. Thinning reduces crown competition, thereby enhancing crown development and tree diameter growth. Thinning, however, allows more light to reach the forest floor which also promotes understory growth (Hayes et al. 1997, Thysell and Carey 2000). Hayes et al. (1997) indicated that thinning to moderate densities facilitates crown development but limits development of understory because the canopy closes rapidly.

To accelerate the development of deep overstory canopies in young even-aged stands, we recommend that a single moderate-level thinning take place in stands 30–35 yr of age. On the Olympic Peninsula and elsewhere in western Washington and Oregon, moderate-level thinning would result in retention of 345–445 trees/ha where heavy thinning would result in retention of 148–247 trees/ha (L. Raynes pers. comm.).

To promote deep overstory canopies at the onset of stand initiation, planting a mixture of shade tolerant (i.e., western hemlock) and intolerant (i.e., Douglas-fir) tree species at 3–4 m spacing is recommended (ca. 1000 trees/ha, L. Raynes pers. comm.). Spacing trees farther apart will reduce crown competition and may result in excessive canopy depth (L. Raynes pers. comm.), therein creating inadequate flight space for goshawks. A single, moderate-level thinning of the trees remaining in the stand (there will be some mortality) at 30–35-yr-old across the range of diameter classes, as opposed to thinning a specific diameter class, would promote deeper forest canopies as the stand develops; this is because more growing space is available, particularly for the larger trees (L. Raynes pers. comm.).

Once thinning has occurred, overstory canopy development and a concomitant reduction in shrub cover would occur over a 5–10 yr period. After this, stands would likely be suitable for goshawk nesting for as long as they were retained. Mean tree age of occupied nest stands in our study was 147 yr (N = 12, SD = 71.3, range = 51–275).

The four youngest occupied stands were 50–70-yr-old while the four oldest were 200–275-yr-old.

We suggest that it is not stand age per se that is important to goshawk nesting, instead it is the habitat elements associated with older stands (this study: deep overstory canopy, low shrub cover, Squires and Reynolds 1997, DeStefano 1998: large trees with high canopy closure). The extent to which these features can be created in younger-aged stands will make forest management for goshawks more economically practicable. Other silvicultural prescriptions may work as well as those we suggest or may be more appropriate, depending on site conditions. Currently, most stands on the Olympic Peninsula are managed on a 40–50 yr rotation (L. Raynes pers. comm.), due primarily to a re-tooling of local sawmills to handle smaller-diameter logs.

The importance of old forest attributes to the Northern Spotted Owl, which also inhabits western Washington forests and is sensitive to habitat loss, is well known (Gutierrez et al. 1995, Horton 1996, Irwin et al. 2000). Goshawks, however, use a broader range of forest structural stages than do Northern Spotted Owls (DeStefano 1998). We found goshawks nesting in stands as young as 51 yr, and Bosakowski et al. (1999) report on goshawks nesting in 40–54-yr-old managed stands in western Washington.

In research on Northern Spotted Owl use of young forest habitat on the Olympic Peninsula, Buchanan et al. (1999) report values for some habitat features important to Northern Spotted Owls (i.e., total snags/ha, percent shrub cover, percent canopy closure, and coarse woody debris cover) that are near or within the range of values we found for these same features for goshawks (Table 2). Thus, forest management as described herein may also benefit Northern Spotted Owls.

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Appendix 1 Variable names, sampling approaches and definitions for 45 habitat variables measured at 30 historical Northern Goshawk nest sites on the Olympic Peninsula, Washington, 1996–98.

NAME	SAMPLING APPROACH	DEFINITION	REFERENCE
Mean DBH[a] (≥12.8 cm)	DBH tape	Tree girth (/ 3.1415) taken 1.37 m from ground, outside bark.	
Quadratic mean DBH (QDBH)	DBH tape	QDBH = $((\Sigma\ DBH^2)/n)^{0.5}$; alternate estimator of mean cross-sectional area of trees.	Husch et al. 1972
Maximum DBH	DBH tape	Largest diameter tree in sample.	
Minimum DBH	DBH tape	Smallest diameter tree (≥12.7 cm).	
Mean tree height	Clinometer	PLOTHT = $D^b\ (\tan\alpha_1 + \tan\alpha_2)$ averaged per nest site and stand.	Husch et al. 1972
Crown ratio	Ocular	Proportion of bole w/live stems (9 classes representing 10% increments).	USDA 1989
Crown class	Ocular	Position of tree crown relative to neighboring canopy.	
Mistletoe (*Phoradendron* sp.) index	Ocular index	Index: 0 = none, 6 = heavy measured per tree, averaged per nest site and stand.	
Radial growth	Increment borer, ruler	Most recent 10 annual rings measured to nearest 1.3 mm.	USDA 1989
Mean tree age	Increment borer	1st 1–3 trees/species/plot bored; age then averaged per nest site and stand.	
Maximum tree age	Increment borer	Oldest tree in stand.	
Mean sapling DBH	DBH tape	Trees from 2.5–12.7 cm diameter. Fixed plot, average diameter of all stems.	
Mean sapling height	Ocular	Trees from 2.5–12.7 cm diameter. Fixed plot, average height of all stems.	
Overstory canopy closure	Moosehorn	Sum of 4 estimates from center of plot in cardinal directions; averaged per stand.	Robinson 1947
Minimum overstory height	Ocular average	Mean of 4 estimated in cardinal directions; averaged per plot.	
Maximum overstory height	Ocular average	Mean of 4 estimated in cardinal directions; averaged per plot.	
Overstory depth	Ocular average	Maximum overstory height − Minimum overstory height.	
Understory canopy closure	Moosehorn	Sum of 4 estimates from center of plot in cardinal directions; averaged per stand.	Robinson 1947
Minimum understory height	Ocular average	Mean of 4 estimated in cardinal directions; averaged per plot.	
Maximum understory height	Ocular average	Mean of 4 estimated in cardinal directions; averaged per plot.	
Understory depth	Ocular average	Maximum understory height − Minimum understory height.	
Percent shrub cover	1 m square plot	Mean of 8 1-m^2 samples/plot; includes sword fern (*Polystichum* sp.)	

Appendix 1. Continued.

NAME	SAMPLING APPROACH	DEFINITION	REFERENCE
Mean shrub height	Ocular average	Mean of 8 1-m^2 samples/plot.	
Percent herb/grass/forb cover	1 m square plot	Mean of 8 1-m^2 samples/plot.	
Mean herb/grass/forb height	Ocular average	Mean of 8 1-m^2 samples/plot.	
Coarse woody debris (CWD) cover	1 m square plot	Mean of 8 1-m^2 samples/plot; coarse woody debris included all wood >10.2 cm diameter.	
CWD height	Ocular average	Mean height above ground for all coarse woody debris. A measure of floor heterogeneity.	
CWD length	Steel tape	Mean length of all coarse woody debris.	
CWD DBH	Ocular average	Mean DBH of boles tallied as coarse woody debris.	
Slope	Clinometer	1 estimate per plot averaged per stand.	
Aspect	Compass	1 estimate per plot, averaged per stand. Analyzed using Rayleigh's R statistic.	
Basal area (stems >12.7 cm)	40 BAF[c] prism	Number of trees in plot * BAF [40]/plot.	Husch et al. 1972
Stand density index (SDI)	40 BAF prism	SDI = LSTEMDEN[d] * $(QDBH/25)^{1.6}$; Estimate of stem density based on tree size.	Reineke 1933
Live stem density (stems >12.7 cm)	40 BAF prism	Stem density estimated for 7 diameter classes (D1–D7) from polyareal sample.	Husch et al. 1972
Small stem density (DCLS)	40 BAF prism	DCLS = D1 (2.5–12.6 cm DBH) + D2 (12.7–38.1 cm DBH).	
Medium stem density (DCLM)	40 BAF prism	DCLM = D3 (38.2–63.5 cm DBH).	
Large stem density (DCLL)	40 BAF prism	DCLL = D4 (63.6–88.9 cm DBH).	
Extra-large stem density (DCLXL)	40 BAF prism	DCLXL = D5 + D6 + D7 (≥89.0 cm DBH).	
Understory stem density (UDEN)	40 BAF prism	UDEN = SAPL + DCL1 + DLC2; density of stems ≤38.1 cm DBH.	
Overstory stem density (ODEN)	40 BAF prism	ODEN = Σ (DCL3 through DCL7); density of stems 38.2–150.0 cm DBH.	
Sapling density (SAPL)	Fixed radius plot	Stems 2.5–12.6 DBH. Plot radius varied between stands (1.1–8.0 m); held constant within stands.	USDA 1989
Seedling density	Fixed radius plot	Stems <2.5 cm DBH. Plot radius varied between stands (1.1–8.0 m); held constant within stands.	
Snag density (>15.2 cm DBH)	40 BAF prism	Estimated for all diameter classes combined.	
Tree species richness	Tally	Discrete count of species with stems >12.7 cm diameter.	
Percent hardwood	Tally	(Angiosperm stems/total stems) * 100.	
Stumps	Estimate	Stump abundance, size and weathering estimated by plot. Stands classed *post-hoc*.	
Stand stage	Ocular	Canopy tree successional structure.	Oliver and Larson 1990
Habitat association	Key	Floral species composition.	Henderson et al. 1989

[a] DBH = diameter breast height.
[b] D = horizontal distance to tree.
[c] BAF = basal area factor
[d] LSTEMDEN = large stem density