TEMPORAL PATTERNS OF NORTHERN GOSHAWK NEST AREA OCCUPANCY AND HABITAT: A RETROSPECTIVE ANALYSIS

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ABSTRACT.—We studied occupancy and habitat associations of Northern Goshawks (*Accipiter gentilis*) at nest areas in south-central Oregon in 1992–94. We surveyed 51 pre-1992 nest areas (i.e., historical breeding areas first discovered during 1973–91) for goshawks and used aerial-photograph interpretation to document forest cover conditions and changes over time between areas that were occupied by goshawks and those where we did not detect goshawks (no-response sites). We also surveyed for new nests during 1992–94. Of 38 occupied nests first found in 1992–94 (i.e., post-1992 nest areas), 86% (33/38) were in mid-aged (mean stand DBH 23–53 cm, <15 trees/ha >53 cm DBH) or late (≥15 trees/ha >53 cm DBH; mean stand DBH >53 cm) closed (>50% canopy closure) structural-stage forest. Occupancy of historical (pre-1992) nest areas by goshawks was 29% (15/51). Of 46 pre-1992 nest areas that we examined for habitat change, 15 were occupied by goshawks in 1994 and had more mid-aged closed and late closed forest in 12-, 24-, 52-, 120-, and 170-ha circular areas centered on nest locations than did 31 no-response areas. There was no difference in the amount of late closed and mid-aged closed forest in pre-1992 nest areas compared with occupied pre-1992 nest areas. A logistic regression model for all occupied nest areas confirmed that late closed and mid-aged closed forest variables were important indicators of forest conditions that supported breeding pairs. Goshawks were more likely to persist in the historical nest areas that had about 50% of mature and older closed-canopy forest within the 52-ha scale. We recommend retaining existing late closed, late open, and mid closed structure within 52-ha scale of the nest site. Moreover, late closed and mid closed structure combined should not fall below 50% within the 52-ha scale and should exceed 40% within the 170-ha scale surrounding the nest site. To optimize conditions for breeding goshawks, we recommend retaining large trees (>53 cm DBH) to help preserve stand integrity, maintain closed canopies, and provide connectivity to alternative nest sites within nest areas.

KEY WORDS: *Northern Goshawk; Accipiter* gentilis; *habitat; historical nest areas; landscape change; Oregon.*

PATRONES TEMPORALES DE OCUPACIÓN DE ÁREAS DE NIDIFICACIÓN Y HÁBITAT DE *ACCIPITER GENTILIS*: UN ANÁLISIS RETROSPECTIVO

RESUMEN.—Estudiamos la ocupación y las asociaciones de hábitat de *Accipiter gentilis* en áreas de nidificación del centro-sur de Oregon entre 1992 y 1994. También censamos 15 áreas de cría históricas descubiertas entre 1973 y 1991 (i.e., nidificación pre-1992), y usamos fotografías aéreas para documentar las condiciones de cobertura de bosque y cambios en el tiempo entre áreas que estaban ocupadas por esta especie y áreas en las que no la detectamos (sitios sin respuesta). También realizamos censos para buscar nidos nuevos entre 1992 y 1994. De 38 nidos activos encontrados por primera vez entre 1992 y 1994 (i.e. nidificación post-1992), el 86% (33/38) se encontró en bosques de sucesión media (promedio de DAP 23–53 cm, <15 árboles/ha >53 cm DAP) o bosques cerrados antiguos (≥15 árboles/ha >53 cm DAP; promedio de DAP >53 cm; >50% de cobertura del dosel). La ocupación de las áreas de nidificación históricas (pre-1992) por parte de *A. gentilis* fue del 29% (15/51). De 46 sitios de cría pre-1992 para los cuales evaluamos los cambios en el hábitat, 15 estuvieron ocupados en 1994 y presentaron mayor cantidad de bosques cerrados de edad media y bosques antiguos en áreas circulares de 12, 24, 52, 120 y 170 ha centradas en sitios en donde se ubicaban nidos, que 31 sitios sin respuesta. No existió

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diferencia en la cantidad de bosques cerrados de edad media y bosques antiguos entre áreas de nidi-ficación pre-1992 en comparación con las áreas ocupadas pre-1992. Un modelo de regresión logística que incluyó todas las áreas de nidificación ocupadas confirmó que las variables de los bosques cerrados de edad media y sucesión tardía fueron indicadoras importantes de las condiciones del bosque propicias para las parejas reproductivas. Las aves presentaron mayor probabilidad de persistir en las áreas de nidificación histórica que presentaban aproximadamente el 50% de bosques maduros antiguos de dosel cerrado a la escala de 52 ha. Recomendamos mantener la estructura de bosques antiguos cerrados y abiertos y bosques de edad media cerrados en las 52 ha circundantes a los sitios de nidificación. Además, la estructura combinada de bosques cerrados antiguos y de edad media no debe caer por debajo del 50% a la escala de 52 ha y no debe exceder el 40% en la escala de las 170 ha circundantes a los sitios de nidificación. Para optimizar las condiciones para la nidificación de A. gentilis, recomendamos man-tener árboles grandes (>53 cm DAP) para ayudar a preservar la integridad de los bosques, mantener doseles cerrados y proveer conectividad entre sitios de nidificación alternativos ubicados en las mismas áreas de cría.

[Traducción del equipo editorial]

The ability of breeding pairs of Northern Goshawks (*Accipiter gentilis*; hereafter, goshawks) to persist in intensively managed and selectively harvested forests over time is largely unknown. Evidence suggests tree harvest impacts nest site selection (Crocker-Bedford 1990, Penteriani and Faivre 2001), use (Woodbridge and Detrich 1994), and ultimately nesting persistence (Crocker-Bedford 1995). Penteriani and Faivre (2001) examined logging disturbance and habitat change over a limited time (6–11 yr) in a European shelterwood harvest regime, but the effects of habitat alteration in western North American forests are not fully understood. Mature forest, consisting of large trees (diameter at breast height [DBH] >50 cm) and closed canopy cover (>50%), was demonstrated to be preferred by breeding goshawks for nest sites in western North America (e.g., Hayward and Escano 1989, Bull and Hohmann 1994, Squires and Ruggiero 1996, Daw and DeStefano 2001, McGrath et al. 2003).

There has been concern and debate that goshawk populations in western North America may be declining in response to habitat alteration and loss of these forests (Kennedy 1997, DeStefano 1998, Smallwood 1998, Crocker-Bedford 1998). Using aerial photographic records of timber harvest areas (Reutebuch and Gall 1990) on the Fremont National Forest and adjacent private forest lands dating from 1969–92, we evaluated temporal changes to forest structure around goshawk nests during 1992–94. Our objectives were to: (1) determine if a random sample of historical goshawk nest areas (i.e., nests first found in 1973–91) were occupied in 1994, (2) document post-1992 forest conditions and quantify change in forest cover on his-

torical nest areas, and (3) compare 1994 forest cover between historical nest areas that were occupied by goshawks between 1992 and 1994 to those historical nest areas where presence of goshawks was not detected.

STUDY AREA

Research took place on the Fremont National Forest (FNF) and the Klamath Tree Farm of the Weyerhaeuser Company in south-central Oregon, encompassing >5000 km². Elevations ranged from 1200–2200 m. Ponderosa pine (*Pinus ponderosa*), white fir (*Abies concolor*), and lodgepole pine (*P. contorta*) were the dominant commercial tree species. Generally, large expanses of lodgepole pine interspersed with small stands of pure ponderosa pine on higher ground dominated the northern half of the study area; dry mixed-conifer stands (white fir, incense cedar [*Libocedrus decurrens*], ponderosa pine, and sugar pine [*P. lambertiana*]) dominated the southern half of the study area. Douglas-fir (*Pseudotsuga menziesii*) was rarely encountered or absent, and most adjacent private lands had extensive ponderosa pine plantations. Natural forest openings consisted of xeric rocky flats, which contained sagebrush (*Artemisia* spp.) and bitterbrush (*Purshia tridentata*) near ponderosa pine and mixed-conifer stands, and moist meadows, which were typically associated with lodgepole pine and had a vegetative cover of sedges (*Carex* spp.), sagebrush, and willow (*Salix* spp.) next to perennial streams or springs. The landscape was a mosaic of forest cover types, containing two large burned areas from the 1950s and 1992, natural openings, and human-created openings. Dominant silvicultural practices on Forest Service lands were partial harvest, selective removal, and shelterwood treatments in mixed-conifer and ponderosa pine. All forest management terms used in this paper follow Helms (1998). Regeneration (clearcut) harvest was more typical in lodgepole pine habitat, although observational data and Forest Service records (Fremont National Forest Supervisor's Office, Lakeview, OR U.S.A.) documented that regeneration harvest occurred in mixed conifer and mature ponderosa pine types. Private land management was dominated by mostly early seral and some mid-seral plantations of *P. ponderosa*

in large clearcuts or past overstory removal with few scattered large seed trees. Forest Service management, regulated timber harvest and aggressive fire suppression dates back >50 yr; selective railroad logging took place around 1920 (Hopkins 1979, Laudenslayer et al. 1989). Regional historical accounts state that ponderosa pine stands were typically composed of large trees with a mean DBH of 40–70 cm and basal area (BA) ranging from 13 to 23 m^2/ha (Munger 1917), stands rarely encountered in managed forests during our study.

METHODS

We defined *nest site* as the tree containing the occupied nest or the mapped location of the historically occupied nests and ≤1 ha around the location. A *nest area* for this study was the area that we surveyed out to 1000 m (about 300 ha), centered on a nest site. We defined post-1992 nest areas as occupied (breeding) nest areas first discovered during our study, which was conducted during 1992–94. Historical nest areas were defined as pre-1992 nest areas if they were first discovered occupied 1973–91 by Forest Service or Weyerhaeuser personnel, or other researchers. Occupied nest areas were areas we surveyed during 1992–94, where at least one adult goshawk was present or actively nesting. For purposes of habitat-change comparisons in 1994, occupied nest areas were a subset of the historical pre-1992 nest areas that were found occupied in 1994. No-response areas were a subset of pre-1992 nest areas surveyed in 1994 that had no detections.

Goshawk Nest Area Occupancy Surveys. We compiled a list of historical goshawk nest area locations from original data collected by Reynolds (1975, 1978), U.S. Forest Service (unpublished data, Fremont National Forest, Lakeview, OR U.S.A.), and Weyerhaeuser Company (unpublished data, Klamath Tree Farm, Klamath Falls, OR U.S.A.) and evaluated each dataset based on quality of documentation (e.g., written reports, legal and area descriptions, mapped locations), observer reliability (e.g., biologist or experienced observer), and number of years the nest area was documented as occupied. Nest records were included if there was adequate documentation of a goshawk attending a nest structure, incubating, or if fledglings or nestlings were present at the nest site. Locations meeting the above criteria were mapped, and forest cover type was validated by aerial photograph or field examination before surveys commenced. We stratified sites into one of three forest cover types: dry mixed-conifer, ponderosa pine (<20% other tree species), and lodgepole pine (<20% other tree species).

We broadcast conspecific vocalizations to elicit responses from nesting goshawks or fledglings from late May to early August 1992–94 (Kennedy and Stahlecker 1993, Joy et al. 1994). Surveys were centered on the last known occupied historical nest location, with at least 35–40 calling stations per survey area (see below), spaced 320 m apart and staggered on adjacent and parallel transect belts. To ensure coverage of potential nest areas, we examined the literature for estimates of inter-nest distances between alternative nest sites (273 m in the Klamath NF, California [Woodbridge and Detrich 1994]; 266 m [Reynolds et al. 1994], and 489 m [Reynolds and Joy 1998] in Arizona; and 432 m in Utah [Dewey et al. 2003]), sizes

of post-fledging family areas (PFA; ca. 168 ha, Kennedy et al. 1994), and the effective auditory range of the megaphone (≥150 m; Joy et al. 1994; S. Desimone unpubl. data). Based on this information, we established our survey area size as a circle with an approximate 1000-m radius centered around the nest location (ca. 40 stations). This resulted in a search area of about 300 ha, nearly twice the area of mean PFA size reported by Kennedy et al. (1994). If a response was detected, we immediately searched the vicinity for an occupied nest. For those surveyed areas where there were no detections during the nestling period (first survey), we resurveyed the area at least once in July–August during the fledgling period using the same stations so that each "no-response" area was visited and surveyed at least twice in a season. We also conducted systematic and opportunistic searches (DeStefano et al. 1994a, Daw et al. 1998) for new goshawk nests (i.e., post-1992) during May–August 1992–94. When surveying a known occupied nest area from the previous survey season (i.e., 1992 or 1993), we used multiple observers to conduct a silent search at the last known occupied site to minimize disturbance. If there were no detections, we extended the search pattern by radiating out from the nest tree while using a combination of intermittent taped broadcast calls near the nest and regularly spaced calling stations. These areas had the same level of survey effort as the systematic searches: about 300 ha around the last known occupied nest.

Vegetation Sampling. We used 1:12 000 and 1:15 800 scale aerial photographs to describe and classify historical (1969–91) forest vegetation conditions and post-1992 conditions, obtained from the U.S. Forest Service and Weyerhaeuser Company for years 1969, 1972, 1976, 1978, 1980, 1983, 1988, and 1992 (the most recent available) for reference stands. Harvest inventory data from the Fremont National Forest were used to update 1988 and 1992 photos to 1994 conditions.

We used a 3× Dietzgen stereoscope to delineate cover in an 11% random sample (25 of 227) of reference stand polygons representing the range of forest conditions and habitats on the 1992 photographs. The variable-plot vegetation sampling method (Bell and Dilworth 1988) was used to verify the condition of these reference polygons on the ground. We sampled 7–11 plots ($\bar{x}$ = 8.1 plots/ reference polygon, SD = 1.8), 160 m apart, on a transect located through the longest axis of the habitat polygon or in parallel transects if the polygon was >300 m wide. Plots were measured for basal area (BA) using a 20-factor (ft^2/acre, later converted to m^2/ha) wedge prism at plot center to sort trees into diameter classes. We recorded DBH for all count trees by combining plots within a stand to determine trees/ha (TPH) and BA for each forest structure class. The stem count per sample point multiplied by the BA factor equaled the total BA occupied by tree stems on a per ha basis (Bell and Dilworth 1988). We followed the U.S. Forest Service Region 6 Vegetation Structural Stage (VSS) guidelines for general forest cover type descriptions in eastern Oregon (U.S. Department of Agriculture 1994).

We used two non-forest categories (open wet [moist meadows] and open dry [xeric flats]) and four forest structure categories (late, mid-age, early, very-early), combined with two canopy closure classes (≤50% or

Table 1.   Forest structure classification for aerial photograph interpretation on the Fremont National Forest and adjacent private lands in Oregon U.S.A., based on mean tree diameter at breast height (DBH), mean canopy closure, and trees per ha (TPH) ≥53 cm DBH (USDA 1994). Very early stage was forest regeneration or clearcut.

FOREST STRUCTURE	DBH (cm)	CANOPY CLOSURE (%)	TPH ≥53 cm
Late closed	>53	>50	≥15
Late open	>53	≤50	≥15
Mid-aged closed	23–53	>50	<15
Mid-aged open	23–53	≤50	<15
Early closed	12–23	>50	none
Early open	12–23	≤50	none
Very early	≤12	<50	none

>50%), to identify and delineate vegetative cover on aerial photographs. Stands were then typed into forest vegetative cover classes based on total BA of trees per diameter class and TPH >53 cm (Table 1). We defined canopy closure as the amount of sky obscured by tree foliage and branches as measured by a Lemmon spherical densitometer (Vales and Bunnell 1985). Canopy measurements were taken 5 m from plot center in four cardinal directions, averaged, and mean percent canopy closure was calculated from all plots for the polygon.

Following reference plot validation, all remaining habitat on photographs within a 170-ha circle around nest locations was delineated into vegetative cover polygons based on the validated reference plots and assigned vegetation structure categories. When 1994 photographs were not available, the 1994 Fremont National Forest Harvest Inventory (U.S. Forest Service, Fremont NF, Lakeview, OR U.S.A.) was used to update the habitat condition. A 19% (N = 102) random sample of polygons (N = 546), stratified by general forest cover type, was ground-verified using the same variable-plot sampling method outlined for reference stands. We assessed stand-typing accuracy by constructing an error matrix to determine the accuracy of our photograph interpretation (Desimone 1997).

To delineate historical forest conditions, we used U.S. Forest Service and Weyerhaeuser Company aerial photographs (1:12 000, 1:15 800, and 1:24 000 scales) that represented stand conditions present in the year of the last known occupied nest. We extrapolated our reference set results to type stands into vegetative structure classes on the remaining historical photographs. All completed polygons were transferred to 1:24 000 scale U.S. Geological Survey (USGS) quadrangle maps using a zoom transfer scope (Bausch and Lomb Corporation, Rochester, NY U.S.A.) and digitized into a Geographic Information System, where area was calculated for each habitat polygon.

Annual Variation in Occupancy. We estimated annual variation in occupancy by resident pairs of western North American goshawks by examining data from five other study areas (Table 2). We then compared the mean annual occupancy rates of goshawks from these five study areas to our findings for post-1992 nest areas and pre-1992 (historical) nest areas assessed in 1994. Annual occupancy was defined as the mean (SE) annual percent of occupied areas. We assumed (1) territory occupancy was determined using similar survey techniques with equal effort (Joy et al. 1994, Reynolds et al. 1994, Woodbridge and Detrich 1994, Kennedy 1997) and (2) little or no major stand disturbance or habitat alteration occurred within territories since discovery (S. Dewey, P. Kennedy, R. Reynolds, and B. Woodbridge pers. comm.). An occupied territory was defined by all researchers as ≥1 adult goshawk present in or near the nest on ≥2 separate occasions during the breeding season and in-

Table 2.   Mean occupancy rates of Northern Goshawk nest areas (NA) among six concurrent studies in the western U.S., including occupied nest areas found on the Fremont National Forest (NF) and adjacent private lands 1992–94, Oregon, U.S.A. (this study). Occupancy is defined as a territory used regularly by at least one adult goshawk during the breeding season. The first year a nest was discovered is not included in the calculations.

STUDY AREA	SOURCE	NA	MEAN	SE	YEARS[a]
Kaibab NF, AZ	R.T. Reynolds pers. comm.	32	0.72	0.05	4–5
New Mexico	Kennedy 1997	22	0.74	0.07	4–11
Klamath NF, CA	Woodbridge and Detrich 1994	26	0.74	0.01	5–9
Utah	Kennedy 1997	26	0.75	0.06	4–7
Malheur NF, OR	S.K. Daw pers. comm.	33	0.66	0.02	2–4
Fremont NF, OR	This study	20	0.79	0.04	2

[a] Number of years of occupancy data for known nests in the study area.

cluded pairs attempting to nest (Reynolds et al. 1994, Woodbridge and Detrich 1994, Kennedy 1997).

Habitat Change Analysis. Using nest tree locations as nest area centers, we established five different radius categories of 12, 24, 52, 120, and 170 ha. These areas had biological or managerial significance: 12 ha was recommended as a minimum nest area size for goshawks (Reynolds 1983, Reynolds et al. 1992); 24 ha was the size of goshawk habitat areas designated on the Fremont NF to protect nesting stands (U.S. Department of Agriculture [USDA] 1989); 52 ha was about the mean size of the aggregate of alternative nest areas associated with the primary nest area of goshawks nesting in the Klamath NF in northern CA (Woodbridge and Detrich 1994); 120 ha was the area of old-growth habitat allocated for management of Pileated Woodpeckers (*Dryocopus pileatus*) on the Fremont NF (USDA 1989); and 170 ha was the size of the goshawk PFA (Reynolds et al. 1992, Kennedy et al. 1994).

We conducted comparisons at both "disk" (12, 24, 52, 120, and 170 ha) and "ring" (the area between the 12–24, 24–52, 52–120, and 120–170 ha disks) scales. Disks represent cumulative effects as scale increases, since smaller disks are included within the larger disks. Rings were tested individually so that influence of inner disks was removed (Ramsey et al. 1994, McGrath et al. 2003).

We examined how forest structure around historical nest sites changed over time by calculating the % change for each vegetation cover (forest and non-forest) variable (equation 1):

$$\%\text{Change} = [(Area_{1994} - Area_{HISTORIC})/ \quad (1)$$
$$Area_{HISTORIC}] \times 100$$

where $Area_{1994}$ is the area of a cover category for 1994, and $Area_{HISTORIC}$ is the area of the same cover category in the year the site was last known to be occupied. This calculation was made for each of the paired sites for all scales of disks and rings. We used Wilcoxon signed-rank test for paired comparisons to test for changes in forest cover between pre-1992 and post-1992 conditions and Kruskal-Wallis one-way analysis of variance by ranks followed by multiple comparison tests for least significant difference (LSD) to test for differences in forest cover among pre-1992, pre-1992 occupied, and pre-1992 no-response nest areas (Conover 1980; JMP Statistical Software version 3.1, SAS Institute, Cary, North Carolina, U.S.A).

Logistic Regression Model. We wanted to know the likelihood of predicting the suitability of historical nest areas by considering the amount of area of each vegetation structure category (forest and non-forest) around occupied and no-response sites. Thus, we constructed a logistic regression model (Hosmer and Lemeshow 1989, Ramsey et al. 1994) using the binary response variable of occupied ($Y = 1$) or no-response ($Y = 0$) by goshawks in a historical nest area in 1994. The importance of a particular habitat variable was determined by a stepwise analysis (PROC LOGISTIC; SAS Institute, Inc., 1992). The alpha for entry level (p_E) of the variable to be considered for the model was 0.15 because we wanted to detect possible trends in the event of a nonsignificant P-value. Models were run for each of the five disks and four rings. The full model included all explanatory habitat variables (equation 2):

$$\text{logit P (Y)} = B_0 + B_1 \times \text{VeryEarly}$$
$$+ B_2 \times \text{EarlyClosed}$$
$$+ B_3 \times \text{EarlyOpen}$$
$$+ B_4 \times \text{MidClosed}$$
$$+ B_5 \times \text{MidOpen}$$
$$+ B_6 \times \text{LateClosed}$$
$$+ B_7 \times \text{LateOpen}$$
$$+ B_8 \times \text{OpenWet}$$
$$+ B_9 \times \text{OpenDry} \quad (2)$$

where B_0 is constant, and B_1 through B_9 are the coefficients. The model was run in *logit P(1)* mode (stepwise descending) to calculate odds ratios for significant variable(s) associated with a nest area being occupied (i.e., $Y = 1$). Interaction terms were evaluated in the final model.

RESULTS

Nest Area Surveys. During 1992–94, we found 38 occupied goshawk nest areas (15 pre-1992 and 23 post-1992) that composed our sample of nests for vegetation analysis. Of the 51 pre-1992 nest areas we reexamined, 10 had evidence of nesting and five more had goshawks present, for a total of 15 historical occupied nest areas. Twelve of the 15 occupied nest areas were contained wholly on Forest Service ownership, two were on Weyerhaeuser land, and one was mixed ownership. Of 36 no-response areas, 23 were on Forest Service, 11 on Weyerhaeuser, and two were mixed ownership. We removed five nests from the historical sample for our vegetation analysis because of inadequate photographic records. Therefore, of the remaining 46 pre-1992 nest areas surveyed to protocol, 15 were occupied, and 31 were no-response areas. Number of nestlings per nest was similar for pre-1992 areas occupied in 1994 and post-1992 nests (1.5 ± 1.2 [$N = 10$] and 1.4 ± 1.0 [$N = 18$] young/nest, respectively).

Annual Variation in Territory Occupancy. Of 38 occupied nest areas, we were able to consistently survey 20 for at least two seasons from 1992–94; these had a mean annual occupancy rate of 79% (SE = 4; Table 2). This was similar to the mean annual occupancy rates from five other concurrent studies in the western U.S. (73%, SE = 2, for Arizona, California, New Mexico, Utah, and Oregon; Table 2). Occupancy of all historical (pre-1992) nest areas surveyed in 1994 was 29% (15/51), which was significantly different from the occupan-

cy rate for post-1992 areas (χ^2 = 12.4, 1 df, P = 0.0004) and substantially lower than reported in the literature (Table 2).

For post-1992 nest areas, mean inter-alternative nest distance was 245 m (SE = 48, N = 23; no data for private lands). This was comparable to the inter-alternative nest distances reported in the literature (Reynolds et al. 1994, Woodbridge and Detrich 1994, Dewey et al. 2003).

Habitat Typing. Overall typing accuracy based on ground verification of reference polygons was 80%. Mid-age and late categories were 80–90% for reference polygons (Desimone 1997); we thought this was an acceptable rate to proceed with the analysis (Lillesand and Kiefer 1994). Our highest classification accuracies were for dry open and wet open non-forest categories (100% each) from reference polygons, followed by late open and late closed forest structure (90% each), mid-aged open (84%), and mid-aged closed forest (80%). Early open and early closed forest structure was least accurately classified(67% and 69%, respectively).

Forest Cover Distribution. For post-1992 nest areas, 25 of 42 (60%) occupied nest trees were within late closed forest structure, and 11 of 42 (26%) were in mid-aged closed structure. Distribution of post-1992 and pre-1992 nest sites was similar among the three forest cover types: 56% versus 47% in mixed conifer, 24% versus 28% in lodgepole pine, and 20% versus 25% in ponderosa pine, respectively.

Habitat Change Analysis. Mean percent change of the seven forest-structure categories (Table 1) for pre-1992 nest areas over time occurred in all scales (i.e., five disks and four rings) (see Desimone 1997: Tables 11 and 12 for details). For disks, the largest increases were in the amounts for very-early (642%, SE = 93%) and early open (238%, SE = 17%) categories. The largest decreases over time were in the late open (−54%, SE = 3%), late closed (−49%, SE = 1%), and mid closed (−30%, SE = 3%) categories. The magnitude of the percent change decreased with increasing scale; for example, increase in very-early cover went from 742% to 640% to 435% at 12-, 52-, and 170-ha disk scales, respectively, while decreases in late open cover went from −58% to −56% to −47% for 12-, 52- and 170-ha scales, respectively. Similar results were noted for rings, although at lower magnitudes.

In Figure 1, we presented late closed, early open, and very-early structural stages because they rep-
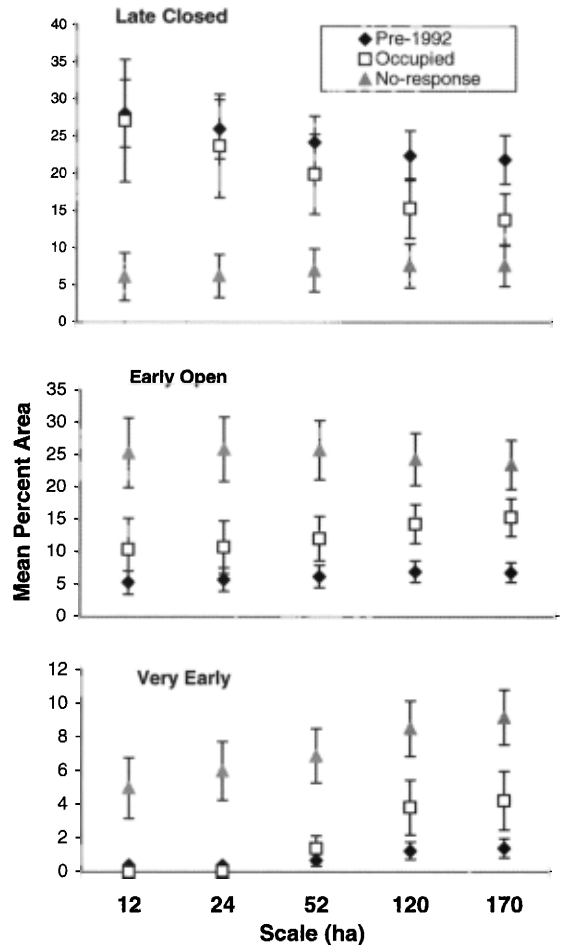

Figure 1.   Mean (SE) area of late closed, early open, and very early structural stages among 5 circular analysis scales surrounding 46 historical (pre-1992; first discovered during 1973–91) goshawk nest sites in south-central Oregon, U.S.A.; 15 were occupied by goshawks and 31 had no evidence of occupancy in 1994. See text and Table 1 for further description of forest structure categories.

resented most confidence in correctly classifying habitat types, and therefore most confidence in detecting a decrease in area of highest suitable habitat (late closed) and an increase in area of known non-nesting habitat (early open and very early). For the 12-, 24- and 52-ha scales, mean percent late closed forest at all occupied nest areas in 1994 remained nearly the same as at pre-1992 areas (i.e., no significant difference). However, mean percent late closed forest at no-response areas was about
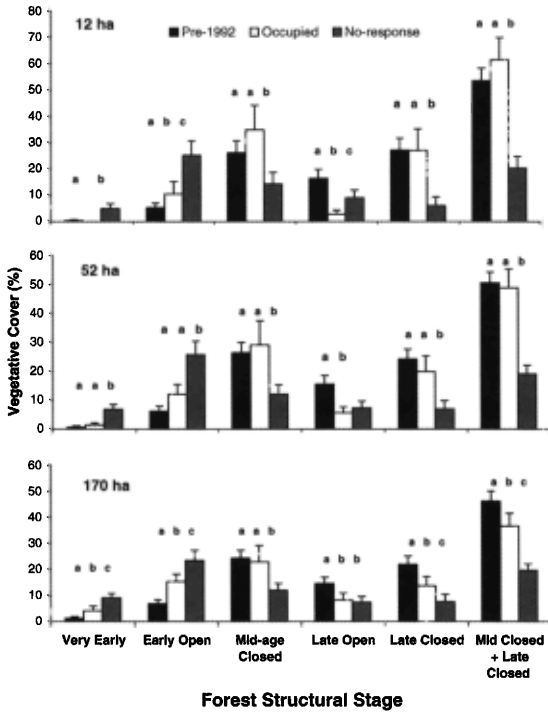
Figure 2. Mean (SE) distribution of forest structural stage categories (plus a combination of mid-aged and late closed canopy forest) at 12-, 52-, and 170-ha scales surrounding 46 historical (pre-1992—first discovered during 1973–91) goshawk nest sites in south-central Oregon, U.S.A.; 15 were occupied by goshawks and 31 had no evidence of occupancy in 1994. We omitted the 52- and 120-ha data because results were similar. See text and Table 1 for further description of forest structure categories. Difference in grouped means assessed by Kruskal-Wallis test ($\alpha = 0.05$). Within each group, Fisher's test of least significant difference for multiple comparisons was used; pairs within each forest structure stage not significantly different share common letters.

one-fourth to one-fifth the amount of late closed at pre-1992 and occupied pre-1992 areas (Fig. 1). With increasing scale, the mean proportion of early open structure at no-response nest areas was 4–5 times greater than pre-1992 nest areas, and over twice that of occupied pre-1992 areas (Fig. 1). The mean proportion of very early stage increased with increasing scale and was 4–6 times greater at 12-, 24- and 52-ha scales for no-response areas than pre-1992 and occupied pre-1992 areas (Fig. 1). For 120- and 170-ha scales, mean proportion of very early was about half that in occupied compared to

no-response areas; pre-1992 areas had about 1/8th that of no-response areas.

No-response areas ($N = 31$) showed significant changes in the general distribution of forest structure compared to all pre-1992 areas and also differed significantly from occupied pre-1992 areas for 12-, 52- and 170-ha disk scales (Kruskal-Wallis test, all $P < 0.0454$; Fig. 2). Histograms for 24- and 120-ha scales were not presented, as patterns in results were similar but intermediate in values between their adjacent scales. Mean proportion of area was significantly different for late closed forest, mid-aged closed forest, early open forest, and very early among pre-1992, occupied pre-1992, and no-response areas (LSD for pairs of means, $P < 0.05$). The greatest single change in a category was in the mean amount of late closed forest in pre-1992 ($\bar{x} = 22$–27% among all disk scales) and no-response areas ($\bar{x} = 6$–8%, all disks; Kruskal-Wallis, $P < 0.0003$).

At the 52-ha scale, the mean percent area of late closed forest (20%) for occupied pre-1992 areas remained similar to historical pre-1992 areas (24%; Fig. 2). Less than half of the mean area of mid-aged closed forest that once existed in pre-1992 areas (25%) occurred in no-response areas (12%). This corresponded with an increase in mean percent mid-aged open forest in no-response (24%) compared to the occupied pre-1992 areas (15%). In no-response areas, mean percent area of early open canopy forest was >4 times the historical mean (pre-1992) amount, and more than twice that of occupied pre-1992 areas (LSD test of means, $P < 0.05$). Very early mean percent area was significantly greater in no-response than occupied pre-1992 areas (LSD test of means, $P < 0.05$; Fig. 2). We point out comparisons at the 52-ha scale because it represents, in theory, the aggregate of alternative nest sites for a nesting area, and the persistence of goshawk use or occupancy appears to be correlated with higher amounts of mature forest at about this scale (Woodbridge and Detrich 1994).

Logistic Regression Model of Forest Structure Association. For post-1992 occupied nest areas, both late and mid-aged closed variables were associated with the 52-ha disk model (drop in Deviance $\chi^2 = 9.5$; 1 df; $P < 0.01$) and the 24–52 ha ring model (drop in Deviance $\chi^2 = 20.7$; 1 df; $P < 0.01$), as described by the reduced model (Equation 3):

Table 3. Results of stepwise logistic regression analysis for occupied ($Y = 1$) goshawk nest areas ($N = 15$), Fremont National Forest and adjacent private lands, Oregon, U.S.A., 1994. Stepwise entry level was at $\alpha = 0.15$. Scales emanate from territory centers; ring size is the area between two concentric disk areas. Parameter estimates are natural log (ln) of odds ratios. The interaction term (late closed $\times$ mid-aged closed) was not significant ($P = 0.23$).

Disk Size[a] (ha)	Variable	Parameter Estimate	SE	Wald χ^2	P-value	Odds Ratio Estimate	95% Confidence Interval of Odds Ratio
12	Intercept	−83.9333	24.4576	11.7771	0.0006	—	—
	Late closed	0.4771	0.1650	8.3594	0.0038	1.611	0.1537–0.8005 (1.166–2.227)
	Mid-aged closed	0.3344	0.1157	8.3554	0.0038	1.397	0.1076–0.5612 (1.114–1.753)
24	Intercept	−46.5816	13.664	11.6205	0.0007	—	—
	Late closed	0.2660	0.0947	7.8850	0.005	1.305	0.0804–0.4516 (1.084–1.571)
	Mid-aged closed	0.1729	0.0616	7.8829	0.005	1.189	0.0522–0.2936 (1.054–1.341)
52	Intercept	−21.9700	6.3879	11.8290	0.0006	—	—
	Late closed	0.1131	0.0401	7.9426	0.0048	1.120	0.0345–0.1917 (1.035–1.211)
	Mid-aged closed	0.0818	0.0307	7.1046	0.0077	1.085	0.0216–0.1420 (1.022–1.155)
Ring Size[b] (ha)							
12–24	Intercept	−85.3932	25.1893	11.4925	0.0007	—	—
	Late closed	0.5126	0.1798	8.1303	0.0044	1.670	0.2109–0.9366 (1.235–2.551)
	Mid-aged closed	0.3175	0.1215	6.8264	0.009	1.374	0.0984–0.5913 (1.103–1.806)
24–52	Intercept	−33.9116	10.7673	9.9193	0.0016	—	—
	Late closed	0.1754	0.0691	6.4489	0.0111	1.192	0.0533–0.3301 (1.055–1.391)
	Mid-aged closed	0.1423	0.0579	6.0437	0.0140	1.153	0.0376–0.2719 (1.038–1.313)

[a] Forest structure classes were not significantly associated with the 120- and 170-ha disk scales.
[b] Forest structure classes were not significantly associated with the 52–120 and 120–170 ring scales.

$$logit\ (1) = B_0 + B_1\ (\text{late closed}) + B_2\ (\text{mid-aged closed}) \quad (3)$$

There was a strong association between nest area occupancy and both late closed and mid-aged closed forest at the 12, 24, and 52 ha scales (Table 3). At the 12-ha nest area scale, the odds that a site was occupied increased by 61% (odds ratio 1.61) for each unit (1 ha) increase of late closed forest habitat, while holding the mid-aged closed forest variable constant. For each unit increase of mid-aged closed forest habitat, the odds that a site was occupied increased by 37% (odds ratio 1.37), while holding the late closed forest variable constant.

The reduced model was also significant for the 12–24 and 24–52 ha rings. The stepwise descending model procedure did not yield a significant model for any variables associated with occupied sites for 120 or 170 ha disks, or for 52–120 and 120–170 ha rings. The interaction term (*late closed* $\times$ *mid-aged closed*) of the reduced model for disks was not significant ($\chi^2 = 43.1$; 1 df; $P = 0.23$).

DISCUSSION

Not all goshawk territories may be occupied in all years (Detrich and Woodbridge 1994, Reynolds et al. 1994), and even in the absence of human-caused habitat alteration, some territories can be

expected to be lost due to natural (e.g., stand se-
nescence, disease, fire) changes in the forest over
time (Graham et al. 1994). Mean annual occupan-
cy of goshawk nesting areas in six studies across the
western U.S. (concurrent with this study) were con-
sistently in the 65–80% range over 2–11 yr of study.
An occupancy rate of 29% (15/51) of the historical
nest areas on our study area in 1994 is low by com-
parison. The low occupancy rate may be due in
part to attrition of some suitable nest areas due to
natural disturbance over time; one fire partially
burned two nest areas in our study. It is also pos-
sible that our goshawk surveys did not extend out
far enough to include some of the alternative nests
used. Recent data from Arizona suggests that about
67% of goshawks move to alternative nest locations
every year and that a 1000 m broadcast calling ra-
dius accounted for about 95% of the alternative
nest attempts (R. Reynolds unpubl. data). If these
findings are applied to our study, we likely missed
about 5% of all alternative nests in our study.

Like many raptors, individual goshawk pairs may
not breed every year, and determining trends in
territory occupancy using 2 yr survey data is ten-
tative (DeStefano et al. 1994a). Pairs not nesting
in a given year, but still occupying the nest area,
are difficult to find when surveys are conducted
after courtship (Dewey et al. 2003). However, we
searched large areas (>300 ha) multiple times
around each historical nest location during a pe-
riod when local weather conditions were not par-
ticularly inclement for the region and when gos-
hawk productivity was relatively high: 74% (17/23)
of nests on the Fremont NF and 91% (20/22) of
nests on the nearby Malheur National Forest suc-
cessfully fledged young in 1994 (S. Rickabaugh, S.
Danver, and S. Daw unpubl. data). Other studies
in eastern Oregon and Washington reported simi-
lar high occupancy and nest success levels for 1994
(McGrath et al. 2003; S. Finn unpubl. data). In ad-
dition, Kostrzewa and Kostrzewa (1990) reported
that weather did not affect the density of territorial
goshawk pairs over an 8-yr period in Europe, but
was an influential limiting factor to breeding suc-
cess. Thus, we concluded that the low occupancy
rates of the historical nest areas were not attributed
to low detectability, although we could not com-
pletely rule this out as a possibility.

The difference in forest structure between post-
1992 occupied and no-response nest areas was
compelling. Late structural stage forest, especially
with canopy cover >50%, was much more preva-

lent around occupied than no-response nest areas.
Conversely, very early and early structural stage for-
est was much more prevalent in no-response than
occupied nest areas. Our results indicated that late
forest structure declined by 20–50%, and very early
and early forest structure increased by >400%
around no-response nests. These trends were de-
tectable at all scales, but were strongest at the
smaller scales (12 and 52 ha) and decreased with
increasing scale. Although we do not have detailed
history of stand management for all cases, the ob-
served difference in habitat is attributed to levels
of timber harvest, which we verified by photo-
graphic evidence and field examination. The loss
of large trees (>53 cm DBH) and a reduction in
canopy cover to <50% appeared to influence nest
area occupancy. Penteriani and Faivre (2001) and
Penteriani et al. (2002) found that nest sites (ca.
0.8 ha) around the nest tree altered by more than
30%, either by selective tree harvest (shelterwood)
or windthrow, caused goshawk pairs to change lo-
cations to new nest stands. The general conclu-
sions reached by Penteriani and Faivre (2001) and
Penteriani et al. (2002) on habitat disturbance
were consistent with our results: goshawks were ab-
sent from nest areas where there was ≥30% mean
decrease in late and mid closed forest (12-ha scale)
compared to the pre-1992 condition. Our data
showed that this pattern was consistent at larger
(12–52 ha) scales as well.

Our results suggested that nest area habitat al-
teration (loss of nesting habitat) was the most likely
reason for the low occupancy rates of historical
nest areas in 1994. The habitat alteration was likely
the result of timber harvest (documented by aerial
photographs), which reduced the proportion of
late and mid-aged forest with high canopy closure
and increased the proportion of very early and ear-
ly open forest conditions within 52 ha (scale of lo-
gistic model significance) of goshawk nests.

Management practices for nesting habitat pro-
tection on the Fremont NF were limited during
1973–91, ranging from no protection (unrestricted
harvest) of nest areas to 12-ha no-harvest buffers
around nests during the breeding season (Reyn-
olds 1983, USDA 1993). In 1983, the Fremont
National Forest Plan established several 24-ha gos-
hawk habitat management areas. However, condi-
tions on most of these management areas ranged
from early successional forests (unsuitable to mar-
ginal for nesting habitat) to mid-aged forest with
only small patches of late-successional forest. Some

goshawk management areas were reassigned or re-located in subsequent years to achieve timber harvest objectives (K. Palermo and W. Watkins, Fremont NF, pers. comm., S. Desimone unpubl. data).

The photographic record revealed that little or no long-term habitat protection was implemented for the 31 no-response areas as of 1994. All were historical sites that had some portions within 52 ha of the nest site harvested during or after the historical nesting season. In contrast, most goshawk territories in the western U.S. study areas we reviewed (Table 2) had little or no habitat loss from timber harvest practices since discovery by the researchers and had yearly monitoring programs that documented relatively high occupancy rates (B. Woodbridge, P. Kennedy, R. Reynolds, and S. Dewey pers. comm.). This further supported our conclusion that timber harvest was a determining factor leading to significantly lower occupancy rates in the no-response nest areas compared to the occupied areas.

Nest area fidelity (as indexed by occupancy rates) is likely to be higher in good quality habitats as compared to poor quality habitats. This may be advantageous because there is an increased likelihood of nesting success where they may have been successful before (Newton 1979, Newton and Wyllie 1992, Rosenfield and Bielefeldt 1996). Our results suggest nest areas with >50% proportion of older and larger structural classes may be higher quality nest areas than areas dominated by younger seral stages (Woodbridge and Detrich 1994, Finn et al. 2002). Detrich and Woodbridge (1994) and Reynolds et al. (1994) reported that 70–75% of banded goshawks occupied the same nest area in successive years, which was similar to findings for Cooper's Hawks (*A. cooperii*; Rosenfield and Bielefeldt 1996) and Eurasian Sparrowhawks (*A. nisus*; Newton and Wyllie 1992). Although anecdotal, in 1992–94 we found an occupied nest in each of two nest areas that were both within 100 m of their respective historical nest site in nest areas that received special protection as old growth management areas in the early 1980s (Fremont NF unpubl. data); these sites were first found 20 yr earlier by Reynolds (1975).

In Arizona, Reynolds and Joy (1998) reported that over a 6-yr period, 92% of breeding male and 79% of breeding female goshawks had fidelity to their territories and mates. However, in extreme conditions such as food stress (Newton 1979) or in disturbed habitats (Woodbridge et al. 1988, Bosa-kowski et al. 1993, Woodbridge and Detrich 1994, Crocker-Bedford 1995), there is evidence to suggest that species with strong site fidelity might behave differently. Bosakowski et al. (1993) reported five of six Cooper's Hawk nest sites were abandoned and not reused in the year following clearing of adjacent forests and human encroachment within a range of 40–500 m of the nest site. Hargis et al. (1994) postulated that monitoring site fidelity of breeding goshawks might provide a valuable indicator of the quality of the surrounding home range. If specific habitats needed for foraging and development of fledglings are subjected to habitat alteration outside nest areas (defined as >12 ha in Hargis et al. [1994]), hawk pairs might vacate even though individual nest sites (i.e., ≤12 ha) are being protected (Woodbridge et al. 1988, Bosakowski et al. 1993, Hargis et al. 1994, Woodbridge and Detrich 1994, Crocker-Bedford 1998).

To infer that goshawk populations have declined on our study area is beyond the scope of this study. It is possible that goshawks not found in our historical no-response nest areas in 1994 had relocated to more suitable areas elsewhere. However, in these no-response nest areas, forest structural conditions were significantly altered from past timber harvest, suggesting that habitat quality had been substantially reduced, which precluded goshawks from occupying those nest areas (i.e., out to the 300-ha surveyed area in our study) through time.

Our results indicated that pre-1992 nest areas still occupied by goshawks in 1994 had >50% of their mean area in mid closed + late closed forest within the 52-ha scale (Fig. 2), and most resembled their historical photograph conditions. Moreover, late forest (i.e., late closed and late open) structure was most predominant in occupied nesting areas at the 12-ha scale for all forest cover types examined, supporting studies in Oregon (Moore and Henny 1983, Bull and Hohmann 1994, Daw and DeStefano 2001), northern California (Woodbridge and Detrich 1994), and elsewhere (Reynolds et al. 1982, 1994, Crocker-Bedford and Chaney 1988, Hayward and Escano 1989, Siders and Kennedy 1996, Squires and Ruggiero 1996). In 1994, only 2–8% of the forested area in the Fremont NF was composed of ponderosa pine or pine-associated, late structured, old forest (Henjum et al. 1994). Because of the decline of areas of contiguous large and old trees (>50 cm DBH or >150 yr of age; Henjum et al. 1994), late-successional and old ponderosa pine forest has become an in-

creasingly threatened forest ecosystem in North America (Noss et al. 1995).

Implications of Vegetative Cover Loss. A mosaic of vegetative cover best describes goshawk nest areas (i.e., 170 ha) on the Fremont and private lands we examined. For a goshawk population to persist in this mosaic, sufficient breeding habitat must exist to promote positive net reproduction (Rosenzweig 1985, Urban and Shugart 1986). Although recent analyses of goshawk demography in the U.S. reported no evidence of population trends (DeStefano et al. 1994b, Kennedy 1997), forest management activities such as intensive harvest and road building, as well as human development in the last 50–100 yr have changed the forest mosaic proportions to a far greater degree than natural disturbance regimes. In recent decades, for example, older forest has been harvested at a more rapid rate than it can develop (USDA 1993, Henjum et al. 1994, DellaSalla et al. 1995). The accelerated pace of habitat change has greatly increased the proportion of early successional forest and resulted in a skewed distribution favoring younger age classes compared to what was present historically in our study area (Henjum et al. 1994, 1996, Noss et al. 1995, Weyerhaeuser Corporate Photographic Archives unpubl. data). The net effect is that suitable nesting and foraging habitat for goshawks is reduced (McCarthy et al. 1989, DellaSalla et al. 1995, Henjum et al. 1996), and positive net reproduction of goshawks and other species that use older forests is potentially affected.

Our results lend evidence to the hypothesis that long-term occupancy of nest areas is correlated with larger proportions of mature forest (Woodbridge and Detrich 1994) and indicates that substantial amounts of late and mid-aged closed forest were important to the continued use of historical nest areas by goshawks. Significant differences in the amounts of mid-age closed and late closed forest between historical (pre-1992) and occupied (post-1992) nest areas were not apparent in 1994 at the 52-ha scale (Fig. 1, 2), suggesting that relatively intact forest structure resembling historical conditions contributes to its persistent use by goshawks. However, there was a slight significant difference at the 170-ha scale for late closed and mid closed + late closed habitat. We could not predict the response of goshawks to limited alterations of habitat (e.g., thinning, light selection harvest). However, tree harvest prescriptions that create large areas with sparse cover are potentially detri-

mental to nest area occupancy in our study area, especially if the percent of open canopy forest (i.e., very early, early open, mid open, late open) is >34% (mean) of the 52-ha scale or >44% (mean) of the 170-ha scale (Fig. 2).

Management Implications. Our results showed that the presence of late and mid-aged closed forest (combined, 60% and 48% within the 12-ha and 52-ha scale, respectively) were important to the continued use of historical nest areas by goshawks. We recommend a no-harvest zone within the 12-ha around nest sites and discourage further cutting of large trees within the 52 ha. These recommendations would help to preserve stand integrity, maintain closed canopies, promote connectivity to alternative nest stands, and maximize conditions for breeding goshawk pairs to persist. Retaining existing mid-aged closed and late closed forest structure to levels of >50% at the 52-ha scale and >40% within the 170-ha scale, as well as managing to promote this structure in the future, would also likely benefit goshawks. Based on our results, we also recommend that about 10–20% of the surrounding forest structure outside the nest site be in very early or early open categories with the lesser amounts in the smaller scales (12 and 24 ha; Fig. 1). Management within the 170-ha scale should be limited to light thinning or carefully prescribed burning of overstocked stands outside of the breeding season (October–February) to promote mature, uneven-aged stand development. This could also improve foraging opportunities for goshawks by removing some of the dense understory of shade tolerant conifers.

Finally, logistic regression analyses suggest that habitat alteration that reduces the proportion of mature closed-canopy forest, and which is subsequently replaced by early successional forest, reduces the probability of an area as a potential nesting habitat for breeding goshawks, supporting McCarthy et al. (1989). More severe alterations (clearcuts and moderately high alteration, partial removal of stands resulting in <50% canopy closure) increase the likelihood of goshawks not reoccupying areas due to deterioration in the quality of potential nest-areas.

vision. We are indebted to E. Beck, C. Carstarphen, J.
Citta, S.K. Daw, A. Krawarik, J. Mauer, M.T. McGrath,
M.A. McLeod, C.D. Schelz, and K.H. Schmidt for field-
work and data collection and the personnel and staff of
the U.S. Forest Service and Weyerhaeuser Company for
providing information on goshawks, land access, and ae-
rial photographs. T. Hershey, P. Cooler, and D. Rau of
the Fremont National Forest provided logistical support,
the GIS data summary and final habitat maps. We thank
R.J. Steidl for assistance with data analyses and reviewers
D.A. Boyce, P.L. Kennedy, and D.E. Varland who helped
improve the manuscript.

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