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ECOLOGY AND HABITAT OF BREEDING NORTHERN GOSHAWKS IN THE INLAND PACIFIC NORTHWEST: A SUMMARY OF RESEARCH IN THE 1990S

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Abstract. During the 1990s, we conducted research on the distribution, productivity, and habitat relationships of Northern Goshawks (*Accipiter gentilis*) in eastern Oregon and Washington. Our research was initiated primarily in response to concerns raised about the status of Northern Goshawks in the western US, and coincided with early attempts to list the species as threatened or endangered under the Endangered Species Act and the publication of management guidelines for goshawks in the southwestern US. To develop baseline information on the status, distribution, and habitat relationships of goshawks in eastside forests (i.e., east of the Cascade Mountain Range) in the Pacific Northwest, we established study areas on three national forests in eastern Oregon in 1992, adding a fourth study area in central Washington in 1994. We focused on the breeding season and nesting habitat because of its primary importance to goshawk ecology and the logistical feasibility of finding nests. Density of breeding pairs ranged from 0.03–0.09/100 ha, and annual productivity ranged from 0.3–2.2 young fledged/nest. Goshawks selected forest stands with trees of larger diameter and greater canopy closure for nesting than available in the landscape. Occasionally nests could be found in large trees in open-canopied stands. As distance increased from the nest site, forest type and structure became more heterogeneous and the prevalence of older-seral-stage forest declined. Dry or wet openings were present in most territories, often within close proximity to nest stands. Goshawks ate a variety of mammalian and avian prey. Mammal species made up a larger portion of prey biomass on two of the national forests, but avian species appeared to be more prevalent in the diet of goshawks in the most northern study area. We recommend that the existing management guidelines for goshawks in the Southwest form a basis for management in the inland Pacific Northwest, particularly with regard to nested spatial concepts, emphasis on management of prey, and the use of silviculture to promote the development and replacement of old growth or late-seral-stage forest. Our research and management recommendations can be used in concert with the Southwestern management guidelines to establish a mix of vegetation structural stages to support goshawk populations, their prey, and other forest wildlife species specifically for the inland Pacific Northwest.

Key Words: *Accipiter gentilis*, density, diet, nests, habitat, inland Pacific Northwest, management recommendations, Northern Goshawk, Oregon, Washington.

ECOLOGÍA Y HÁBITAT DE REPRODUCCIÓN DEL GAVILÁN AZOR EN EL INTERIOR DEL NOROESTE PACÍFICO: UN RESUMEN DE INVESTIGACIÓN SOBRE LA DÉCADA DE LOS NOVENTA

Resumen. Durante la década de los noventa, conducimos investigación sobre la distribución, productividad, y relaciones del hábitat del Gavilán Azor (*Accipiter gentilis*), en el este de Oregon y de Washington. Nuestra investigación fue iniciada principalmente en respuesta a las preocupaciones acerca del estatus de los Gavilanes Azor en el oeste de Estados Unidos, lo cual coincide con los intentos recientes de enlistar a la especie como amenazada o en peligro, bajo el Acto de Especies en Peligro, así como con la publicación de las pautas para el manejo de gavilanes en el suroeste de los Estados Unidos. Para desarrollar información de arranque dele stado, distribución, y relaciones del hábitat de los gavilanes de bosques del lado este (ej. este de la Cordillera Montañosa de la Cascada) en el Noroeste Pacífico, establecimos áreas de estudio en tres bosques nacionales en el este de Oregon en 1992, agregando una cuarta área de estudio en el centro de Washington en 1994. Nos enfocamos en la temporada de reproducción y en el hábitat de anidación, debido a la primordial importancia en la ecología del gavilán y a la viabilidad logística de encontrar nidos. La densidad de parejas reproductoras osciló de 0.03–0.09/100 ha, y la productividad anual osciló de 0.3–2.2 volantones por nido. La densidad de parejas reproductoras tuvo un rango de 0.03-0.09/100 ha, y la producción anual tuvo un rango de 0.3–2.2 volantones/nido. Los gavilanes para anidar, seleccionaron áreas boscosas con árboles de mayor diámetro y mayor cierre de copa, de lo que había disponible en el paisaje. Ocasionalmente, nidos pudieron ser encontrados en árboles grandes con copas abiertas. Conforme la distancia del sitio del nido incrementaba, el tipo de bosque y la estructura se volvía más heterogénea y la preponderancia de bosque en estado seral decayó. Zonas abiertas secas o húmedas estuvieron presentes en casi todos los territorios, a menudo con una estrecha proximidad a los nidos. Los gavilanes comieron una variedad de presas mamíferas y aves. Las especies mamíferas conformaron una porción mayor de la biomasa de presas, en dos de los bosques nacionales, pero las especies de aves parece que prevalecieron más en la dieta de los gavilanes en la parte más al norte del área de estudio. Recomendamos que las guías existentes para el manejo de los gavilanes en el Suroeste, formen una base para el manejo en el interior del Noroeste Pacífico, particularmente respecto a los conceptos espaciales de anidación, énfasis en manejo de presa, y la utilización de silvicultura para promover el desarrollo y el reemplazo de bosque de viejo crecimiento o de estado seral tardío. Nuestra investigación y nuestras recomendaciones de manejo pueden ser utilizadas, en concertación con las guías de manejo del Suroeste, para establecer una mezcla de fases en la estructura de la vegetación, para sostener las poblaciones de gavilán, sus presas, y otras especies silvestres de bosque, específicamente para el interior del Noroeste Pacífico.

In 1992, we began studies on the breeding ecology and habitat relationships of Northern Goshawks (*Accipiter gentilis*) in eastern Oregon. In 1994, we expanded our research to include parts of eastern Washington. This research was initiated because the distribution of nesting pairs and the status of the population in the Pacific Northwest were largely unknown but of concern because of the potential effects of timber harvest on the structure of forest stands (Marshall 1992). This paper represents a synthesis and summary of these findings: some information has been published previously and is cited appropriately, while additional information has not been published and is presented herein.

During the two–three decades before our studies, most of the research and management attention for forest wildlife in the Pacific Northwest was focused west of the Cascade Mountain range in the temperate rainforests of western Oregon and Washington and northwestern California (e.g., Thomas et al. 1990, Forest Ecosystem Management Assessment Team 1993, USDA Forest Service 1993b). The Northern Spotted Owl (*Strix occidentalis caurina*) was a major species of concern because of its close association with late-seral-stage forest (old growth) and the potential impact of extensive and intensive timber harvesting on owl populations on both public and private lands (DeStefano 1998). In 1990, however, attention focused on timber harvesting and another species of forest raptor in a different region of the country—the Northern Goshawk in the southwestern US (Crocker-Bedford 1990). This prompted heightened interest in the goshawk throughout its range in the western US, including forests east of the Cascade range in the inland Pacific Northwest. The USDA Forest Service (USFS) developed management recommendations for Northern Goshawks in the forests of the Southwest (Reynolds et al. 1992). Other regions of the country were obviously interested in the recommendations put forth by Reynolds et al. (1992), but it was unclear if these guidelines would be entirely appropriate for forest management outside of the Southwest.

Reynolds et al. (1992) review of the status of goshawks, especially the potential impact of timber harvest on nesting and reproduction, directed the design of our research. Specifically, we focused on locating nests and making nests the center of habitat studies. We built on the spatial concepts put forth by Reynolds et al. (1992), who specified three nested spatial components used by breeding goshawks: (1) a 10–12 ha nest area, composed of one or more forest stands or alternate nests; (2) a 120–240 ha postfledging area (PFA), which is an area around the nest used by adults and young from the time of fledging, when the young are still dependent on the adults for food, to independence (Kennedy et al. 1994); (3) and a foraging area that comprises the balance of the goshawks' home range, which Reynolds et al. (1992) estimated as 1,500–2,100 ha based on averages from previous studies.

Our objectives were to: (1) determine the distribution, density, and productivity of nesting goshawks in the coniferous forests of eastern Oregon, (2) examine forest structure and vegetative characteristics around goshawk nests at several scales, including the nest stand (10–12 ha) and an area approximating the PFA (170 ha), (3) determine the historic distribution of nests and potential effects of timber harvest and landscape change, (4) model effects of changes in forest structure as a result of timber harvest to the distribution of goshawk nests, (5) describe goshawk-prey relationships and diet, and (6) evaluate the appropriateness of the southwest management guidelines for the inland Pacific Northwest. Aspects of objectives 1–4 were presented in theses by Daw (1997), Desimone (1997), and McGrath (1997) and several publications; this information is summarized. Information on goshawk-prey relationships and diet and the efficacy of the southwest management guidelines for the Pacific Northwest are newly presented in this paper.

METHODS

Study Areas

We examined Northern Goshawk populations on federal and private lands in four areas of eastern Oregon and Washington: southern, east-central, and northeastern Oregon and central Washington. In southern Oregon, research occurred on all districts of the Fremont National Forest and surrounding lands of the Klamath Province of the Weyerhaeuser Corporation, encompassing >5,000 km^2. In general, large expanses of lodgepole pine (*Pinus contorta*) interspersed with small stands of ponderosa pine (*Pinus ponderosa*) on higher ground and wet meadows on lower ground dominated the northern half of the study area, while dry, mixed conifer stands interspersed with xeric rocky flats with sagebrush (*Artemisia* spp.) and bitterbrush (*Purshia tridentata*) dominated the southern half. Large blocks of pine plantation were common on Weyerhaeuser lands.

In east-central Oregon, research was conducted on the Bear Valley Ranger District of the Malheur National Forest, encompassing about 1,500 km^2. This area was characterized by a mix of forest types including ponderosa pine on dry slopes, ponderosa pine and Douglas-fir (*Pseudotsuga menzeseii*) stands on more moist sites, and mixed conifer stands including some Douglas-fir, grand fir (*Abies grandis*), western larch (*Larix occidentalis*), and lodgepole pine on north slopes. Small openings including wet and dry meadows and dry rocky flats were common, and the district surrounded a large, open, flat valley (about 240 km^2) dominated by sagebrush and grasses.

In northeastern Oregon, research was conducted on all districts of the Wallowa-Whitman National Forest, as well as lands administered by Boise Cascade Corporation and R-Y Timber Company, encompassing >5,500 km^2. A mosaic of forest stands occurred throughout this area, including ponderosa pine, lodgepole pine, grand fir, and subalpine fir (*Abies lasiocarpa*) as well as mixed conifer stands of ponderosa pine, Douglas-fir, grand fir, and western larch.

In central Washington, research was conducted on lands surrounding the community of Cle Elum, including the Cle Elum Ranger District of the Wenatchee National Forest and lands managed by the Washington Department of Fish and Wildlife, Plum Creek Timber Company, and Boise Cascade Corporation, encompassing about 3,000 km^2. Conifer associations included Pacific silver fir (*Abies amabilis*), subalpine fir, grand fir, western larch, Engelmann spruce (*Picea engelmannii*), white pine (*Pinus monticola*), lodgepole pine, ponderosa pine, Douglas-fir, western red cedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*) (Franklin and Dyrness 1973).

All study areas were mosaics of various-aged forest stands, dry and wet openings, and burns. The climate in eastern Oregon and Washington was dry, with cold winters providing the majority of precipitation as snowfall. Topography was typically moderately sloped hills and ridges with some deeply-cut drainages in the south to highly variable topographic relief including moderate to steep slopes and high mountain peaks in the north. Elevations generally ranged between 900–3,000 m. Silvicultural practices included a variety of even-aged (e.g., clear-cut and shelter-wood harvests) and uneven-aged (e.g., thinning from below, overstory removal, and group selection) management techniques.

Nest Locations and Productivity

We established five survey areas for goshawk nests on the Fremont, Malheur, and Wallowa-Whitman National Forest, which we called density study areas (DSA; DeStefano et al. 1994a). These DSAs ranged from about 9,000–13,000 ha and were composed of forest types representative of the dominant forest tree species on each national forest. Within each DSA, we broadcast taped goshawk calls to elicit a response from goshawks and used the protocol recommended by Kennedy and Stahlecker (1993) and Joy et al. (1994) to search for all goshawk nests in 1992–1994 (DeStefano et al. 1994b, Daw et al. 1998). We made repeated searches of each DSA to locate every territory. In addition, we also located nests opportunistically outside of the DSAs during other field activities, or had nest locations reported to us by wildlife and timber survey crews (Daw et al. 1998).

We visited nests in late July and counted nestlings either just before or just after fledging. A successful nest was any nest that produced more than_one fledgling. Nesting phenology dates were based on back-dating from estimated weekly development of juveniles based on plumage characteristics and fledging dates (Boal 1994).

Historic Nest Sites

In 1994, we compiled a list of 102 previously known or historic goshawk territories from the Fremont National Forest and surrounding lands from original data collected by Reynolds (1975, 1978), Reynolds and Wight (1978), Reynolds et al. (1982), the USFS, and Weyerhaeuser Corporation, dating from 1973–1991 (Desimone 1997). We evaluated the credibility of these reported nest locations based on accompanying documentation (e.g., written reports, legal descriptions, and mapped locations), reliability of observers, and number of years the site was known to be active. Records of historic nest sites were only included if there was a confirmed report of young or an incubating goshawk noted in the report. After evaluation of associated documentation, we compiled a list of credible territory locations. These nest locations were then stratified into one of three principal forest cover types, including dry-mixed conifer, ponderosa pine, and lodgepole pine, and a stratified random sample was selected for field survey. We surveyed these sites according to protocol. Searches were conducted ≥2 times during May–August 1994, were centered on the last known nest location, and extended out in a 1,000-m-diameter circle from the last recorded nest location. We classified each nest site as goshawk present, if a goshawk was detected and we had confirmed evidence of nesting, or no response, if no goshawk was detected.

Habitat Characteristics

We measured forest structure and other habitat elements in goshawk breeding territories in Oregon and Washington at several scales, represented by circles of increasing size, all of which were centered on nest trees or random trees (Lehmkuhl and Raphael 1998). Scales ranged from 12–170 ha and had biological or management significance (Daw 1997, Desimone 1997, McGrath 1997). For example, 12 and 170 ha represented the nest and PFA sizes, respectively, recommended by Reynolds et al. (1992) for goshawks in the Southwest, while 24 ha was designated as a management unit for goshawk nests on some forests in eastern Oregon at the time of our study. Woodbridge and Detrich (1994) recommended 52 ha to encompass clusters of nests sites used in different years by a single pair, and 120 ha was an area used for Pileated Woodpecker (*Dryocopus pileatus*) management in some forests in eastern Oregon.

For our earlier studies (Daw 1997, Desimone 1997), we classified forest structure based on current guidelines provided by individual forests (USDA Forest Service 1994a). Forest structure was based on mean diameter at breast height (dbh), density of trees, and amount of canopy cover (Table 1). We also include dry openings (e.g., grass or sagebrush meadows), wet openings (e.g., riparian corridors flanked by wet meadows), and roads (arterial which were paved, collector which were well-used gravel, and local which were sporadically used unpaved). For the latter study (McGrath 1997, McGrath et al. 2003), we used the four stand stages recommended by Oliver and Larson (1996:148), who defined stand initiation as the stage characterized by young trees of various species colonizing the site following disturbance; stem exclusion as the absence of seedlings and saplings with the onset of self thinning and the beginning of crown class differentiation into dominant and subordinate species; under story reinitiation as colonization of the forest floor by advanced regeneration and continued over story competition; and old growth as the irregular senescence of over story trees and recruitment of under story trees into the overstory.

Forest structure was delineated on aerial photographs, and a portion was ground-verified (Daw 1997, Desimone 1997, McGrath 1997). We then compared the habitat variables around nest sites to random points in a use-versus-availability framework among the different scales (Marcum and Loftsgaarden 1980, Manly et al. 1993). We performed use-versus-availability tests in three different ways during the course of our research: (1) at historic nest sites on the Fremont National Forest and surrounding private lands (Desimone 1997), (2) at current (1992–1994) nest stands and surrounding PFA-sized areas around nests on the Malheur National Forest (Daw 1997), and (3) at multiple scales around current nests on national forests and private lands in eastern Oregon and central Washington (McGrath 1997). Details of methods are described in these theses and resulting publications (Daw et al. 1998, Daw and DeStefano 2001, McGrath et al. 2003).

Table 1. Forest stand classification characteristics used during studies of Northern Goshawk historic nest sites, currently occupied nest stands, and post-fledging areas in eastern Oregon, based on USDA Forest Service (1994a) designations for tree size (diameter at breast height [dbh]) and canopy closure (Daw 1997, Desimone 1997).

Forest vegetation structure	dbh (cm)	Crown closure (%)	Trees per ha ≥53 cm dbh
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	Not applicable
Early open	12–23	<50	Not applicable
Very early	≤12	<50	Not applicable

Diet and Prey Relationships

We collected goshawk pellets and plucking remains opportunistically during 1992–1994 on the Fremont National Forest, 1992–1996 on the Malheur National Forest, and 1992–1993 on the Wallowa-Whitman National Forest. Each sample was collected between June and September beneath a goshawk nest or plucking post. A sample consisted of all remains collected at the same site on the same day. Fur, feathers, and skeletal remains were separated by picking apart dry pellets and other remains. Mammal and bird remains were compared to study skins and skeletons in collections at Oregon State University, Corvallis, and The University of Arizona, Tucson. We also used a dichotomous key (Verts and Carraway1984) to identify small mammal skeletal remains. A prey item was counted only if it was absolutely not part of other identified prey in the same sample; no attempt was made to estimate prey numbers by counting individual hairs, feathers, or bone fragments within a sample, because they are of little value for counting prey (Marti 1987). Prey were classified into 14 categories and summarized as percent composition and biomass for each study area. Biomass was calculated by multiplying the number of each prey item by the mean weight of that item (DeStefano and Cutler 1998).

Terminology and Statistical Analyses

We classified goshawk nest locations based on occupancy (modified after Postupalsky 1974). An occupied territory was any territory where goshawks attempted to breed, independent of success, where evidence such as an incubating or brooding female, nestlings or fledglings, or eggshell fragments was confirmed. A current territory was any territory first found during the course of our field studies (1992–1994), while an historic territory was any confirmed territory that was initially found during 1973–1991 (the years before our field studies). A successful nest was any nest from which more than one young fledged (Steenhoff and Kochert 1982).

We used chi-square, two-sample t-tests of homogeneity, or Wilcoxon signed-rank tests to compare proportional use of forest structural categories between nest stands and random stands (Zar 1996). For multiple scales (circles) around nests, we used logistic regression with forward stepwise variable selection to test for habitat associations (Hosmer and Lemeshow 1989, Daw 1997, McGrath et al. 2003). Variables were either square-root or natural log transformed when necessary, and included in the model at $P \leq 0.10$ (Daw 1997, Desimone 1997, McGrath 1997). Our binary response variable was coded as either nest (1) or random (0, i.e., not nest), and the effect of explanatory variables was to increase or decrease the odds of a nest occurring. We report $\bar{x} \pm$ SE and considered variables to be significant at $P \leq 0.10$.

RESULTS

Density, Phenology, and Productivity

During 1992 and 1993, we found 20 and 30 occupied goshawk territories in our DSAs, respectively (Table 2; DeStefano et al. 1994a). Nest densities ranged from 0.026–0.088 territories/100 ha, and varied among DSAs and between years. Nesting phenology was similar on all three national forests in Oregon—goshawks laid eggs in late April to early May, eggs hatched during late May and early June, and young fledged from late June–late July. Productivity ranged between 0.3–2.2 fledglings per nest and varied within each forest and between years (Table 3; DeStefano et al. 1994a). However, there was an apparent but weak latitudinal trend in productivity in both years, with productivity declining from south (Fremont National Forest) to north (Wallowa-Whitman National Forest) (Table 3).

Table 2. Density of breeding Northern Goshawks in eastern Oregon,1992–1993 (from DeStefano et al. 1994a).

		1992			1993		
National forest	Primary forest cover	Area searched (ha)	Nests	Nest density (per 100 ha)	Area searched (ha)	Nests	Nest density (per 100 ha)
Fremont	Lodgepole	8,780	4	0.046	12,960	8	0.062
	Mixed conifer				10,627	4	0.038
Malheur	Ponderosa pine	9,046	8	0.088	9,046	6	0.066
	Mixed conifer				10,519	9	0.086
Wallowa-Whitman	Mixed conifer	11,396	8	0.070	11,396	3	0.026

TABLE 3. PRODUCTIVITY OF BREEDING NORTHERN GOSHAWKS IN EASTERN OREGON,1992–1993 (FROM DESTEFANO ET AL. 1994A).

		1992			1993		
National forest	Primary forest cover	$\bar{x}$	SE	N	$\bar{x}$	SE	N
Fremont	Lodgepole	2.2	0.75	6	2.2	1.08	6
	Mixed conifer				0.3	0.76	3
Malheur	Ponderosa pine	1.9	0.57	10	0.3	0.72	6
	Mixed conifer				1.6	0.89	7
Wallowa-Whitman	Mixed conifer	1.0	0.71	9	0.7	0.76	3

HABITAT RELATIONSHIPS FOR HISTORIC NEST SITES

We compiled a list of 102 historic goshawk territories on the Fremont National Forest and surrounding private lands. Of these, 72 reports were deemed credible. We surveyed for the presence of goshawks at 51 of these sites and categorized vegetation structure around 46 (five sites did not have adequate photographic records) (Desimone 1997).

In 1994, 15 of 51 (29%) historic sites were occupied by adult goshawks. These occupied sites (N = 15) had more mid-aged closed forest (Table 1) and late closed forest (Table 1) than no-response sites (N = 31) in the 12 ha around each nests (Desimone 1997).

Combined mid-aged and late-closed forest comprised 49% (se 7%) of the forest cover in 12 ha around historic occupied nests, versus 19% (SE = 3%) for historic no-response nests (Kruskal-Wallis, P ≤0.045; Desimone 1997). Among current nest sites (i.e., those nests first found during our study in 1992–1993 on the Fremont National Forest; N = 38), 86% were in mid-aged or late structural stage forest with >50% canopy closure in the 12 ha around the nest.

HABITAT RELATIONSHIPS FOR NEST STANDS AND PFAS

On the Malheur National Forest, we compared forest stands that contained goshawk nests to random forest stands without nests at two scales, stand-level (12–50 ha) and PFA-sized (170 ha) circles (Daw 1997, Daw and DeStefano 2001). Both nest stands and random stands were similar in size (103 ± 20 ha and 137 ± 19 ha, respectively; t = 1.23, 54.6 df, P = 0.22). Nests were not distributed among forest stands in the same proportion as stands were available. Late seral-stage forest with large trees and dense canopy cover was used by goshawks for nesting more than it was available, while mid-aged forest was used less (P = 0.03). Stands with open canopies (<50% cover) were used in proportion to availability, but overall use was rare; only two of 22 nests were in open-canopied stands.

At a broader perspective, nest stand attributes within 1 ha of 82 goshawk nests on four national forests (including the Malheur National Forest) and private lands in eastern Oregon and Washington were compared with available habitat at 95 random sites (McGrath 1997, McGrath et al. 2003). Canopy closure, estimated at 43 points within 1 ha of each site, averaged 53% (SE = 1.7, range = 14–89%) around goshawk nests, and 33% (SE = 1.7, range = 3–74%) at random sites. Additionally, canopy closure around the 82 goshawk nest sites was normally distributed about the mean of 53% (P >0.05; Shapiro-Wilk statistic for a test of normality, PROC UNIVARIATE [SAS 1988]). Goshawk nests were not distributed proportionately among the four stages of stand development (i.e., stand initiation, stem exclusion, under story re-initiation, old growth; χ^2 = 19.8, 3 df, P <0.0001). Stem exclusion was used significantly more than expected based on its availability, and stand initiation was used significantly less than expected. Under story re-initiation and old growth stands were used in proportion to their availability in the landscape (McGrath 1997, McGrath et al. 2003).

The forest in PFA-sized circles around goshawk nests was a mix of structural stages. Dense canopy, mid-aged forest was most prominent (37%), followed by dense canopy, late forest (29%), and early forest or regenerating clearcuts (3%) (Daw 1997). All PFA-sized circles contained wet openings ($\bar{x}$ = 7.0 ± 1.2 ha), and 12 of 22 PFA-sized circles contained dry openings ($\bar{x}$ = 3.0 ± 0.7 ha). Dry openings were more prevalent around nests than random points (χ^2 = 3.2, 1 df, P = 0.08), and the presence of dry openings increased the odds of a nest occurring 2.5 times (P = 0.08) (Daw 1997).

HABITAT RELATIONSHIPS FOR MULTIPLE SCALES

McGrath (1997) and McGrath et al. (2003) built on the sample of nests collected on the three national forests in eastern Oregon and added a fourth study area in central Washington. For this analysis, we used 82 goshawk nests and 95 random points, and analyzed forest structure within 1 ha of nest sites and at landscape scales of 10, 30, 60, 83, 120, 150, and 170 ha. The analyses and results were extensive and are reported by McGrath et al. (2003) and can be summarized as follows: (1) by examining goshawk habitat relationships at multiple spatial scales across several study areas, we detected unifying spatial patterns and structural conditions surrounding goshawk nesting habitat, (2) the ability to discriminate goshawk nest sites from available habitat decreased as landscape scale increased, and different factors influenced goshawks at different scales, (3) the presence and arrangement of forest structural types interacted to influence site suitability for nesting, (4) at the 1-ha scale, the stage of stand development (i.e., stand initiation, stem exclusion, understory reinitiation, old growth; Oliver and Larson 1996), low topographic position, and tree basal area reliably discriminated between nests and random sites, (5) low topographic position and basal area were more influential than stand structure, (6) at the landscape scale, modeling indicated that conditions at different scales interact to influence selection of habitat for nesting, (7) a core area exists surrounding goshawk nests in which stem exclusion and understory reinitiation stands with canopy closure ≥50% served as apparent protection against potentially detrimental effects associated with more open forest, and (8) among several models tested, the model that best discriminated between nests and random sites encompassed 83 ha surrounding the nest and incorporated habitat characteristics from multiple scales nested within that range. This model had a cross-validated classification accuracy of 75%. Positive correlations were found between fledging rate and tree basal area within 1 ha of the nest ($F_{1, 77} = 2.89$, $P = 0.041$), and between fledging rate and the percentage of landscape occupied by stem exclusion stands of low canopy closure (i.e., <50%) at landscape scales ≥60 ha ($F_{1, 77}$; $0.041 \leq P \leq 0.089$).

Diet and Prey Relationships

We found 153, 197, and 30 unique prey items below nests or at plucking sites on the Fremont, Malheur, and Wallowa-Whitman national forests, respectively (Table 4). By frequency, both birds and mammals comprised about 50% each of goshawk remains from the Fremont and Malheur national forests; birds comprised 60% and mammals 40% on the Wallowa-Whitman National Forest. Prey from the Fremont National Forest was dominated by Northern Flickers (*Colaptes auratus*) (17%) and tree squirrels (*Tamiasciurus* spp., *Tamias townsendii*, and *Glaucomys sabrinus*) (15%). Prey from the Malheur National Forest was dominated by Northern Flickers (20%), American Robins (*Turdus migratorius*)

Table 4. Percent composition and estimated biomass of prey items of Northern Goshawks from three national forests in eastern Oregon (from DeStefano and Cutler 1998).

	Fremont (1992–1994) N = 153		Malheur (1992–1996) N = 197		Wallowa-Whitman (1992–1993) N = 30	
Species	% composition	% biomass	% composition	% biomass	% composition	% biomass
Rabbit/hare	6.6	27.6	6.6	20.8	0.0	0.0
Ground squirrel	7.2	6.3	11.7	13.9	3.3	5.1
Tree squirrel	15.0	13.3	9.1	10.1	3.3	3.1
Unidentified squirrel	2.6	2.0	8.6	7.9	0.0	0.0
Pocket gopher [a]	3.3	3.2	0.0	0.0	3.3	3.7
Other mammals	1.3	0.9	4.1	0.6	13.3	1.3
Unidentified small mammal	11.8	12.7	7.1	9.2	20.0	24.4
Total mammals	47.8	66.0	47.2	62.5	39.9	37.5
American Robin [b]	5.2	2.1	11.7	5.5	6.7	3.0
Owl	2.0	1.4	1.5	1.3	0.0	0.0
Woodpecker	6.5	2.2	1.5	1.3	3.3	1.2
Northern Flicker [c]	17.0	12.3	20.3	17.6	10.0	8.2
Steller's Jay [d]	8.5	4.4	5.6	3.5	3.3	2.0
Other birds	5.9	7.1	4.1	2.2	23.3	38.6
Unidentified birds	7.2	4.5	8.1	6.1	13.3	9.5
Total birds	52.2	34.0	52.8	37.5	59.9	62.5

[a] *Thomomys* spp.
[b] *Turdus migratorius.*
[c] *Colaptes auratus.*
[d] *Cyanocitta stelleri.*

(12%), and ground squirrels (*Spermophilus* spp.) (12%). Prey from the Wallowa-Whitman National Forest was dominated by Northern Flickers (10%) and American Robins (7%).

By biomass, birds comprised about 35% and mammals 65% of prey items from the Fremont and Malheur national forests; that trend was reversed for the Wallowa-Whitman National Forest (65% birds and 35% mammals) (Table 4). Rabbits (*Sylvilagus* spp.) and hares (*Lepus* spp.) contributed most to biomass of prey from the Fremont and Malheur national forests, although these larger prey were apparently consumed relatively infrequently. Tree squirrels and Northern Flickers made up 13% and 12% of total biomass, respectively, on the Fremont National Forest, while ground squirrels and Northern Flickers made up 15% and 14%, respectively, on the Malheur National Forest. Unidentified birds and small mammals made up 39% and 24%, respectively, on the Wallowa-Whitman National Forest.

DISCUSSION

Our information on the density and productivity of Northern Goshawks only spanned a few years, and thus is inadequate to fully address questions related to the status and population ecology of this species. Longer studies will more adequately provide information on life history parameters (DeStefano et al. 1994b, 1995), but our studies provide at least estimates of breeding densities and productivity over a fairly broad geographic area for a point in time. This information is also useful for comparative purposes, especially when assessing management plans that have been developed for other regions of the goshawk's range, and also stimulates some hypotheses and speculation. For example, densities of nesting goshawks may vary among forest types, with more nests per unit area in ponderosa pine than lodgepole pine.

For the historic nest-site phase of our research, our goal was to examine potential effects of long-term habitat alteration on the distribution of breeding Northern Goshawks based on changes in forest structure over three decades. We determined whether historic territories (i.e., those occupied ≥1 season during 1973–1991) were still occupied, documented changes in forest cover in historic territories between 1973–1994, and compared present conditions of forest vegetation between historic nest sites that were currently occupied and those where goshawks were not detected (no-response sites). Goshawks were more likely to be found in historic territories having a high percentage (about 50%) of mid-aged and late succession forest in closed-canopied conditions. Again, long-term studies will be necessary to fully assess the impact of extensive and intensive timber harvest on goshawk populations, but it appeared on the Fremont National Forest, and likely other parts of the inland Northwest, that a reduction in large trees and canopy cover, either through short-term, high-volume logging or repeated entry into stands over time, reduced the suitability of those stands for occupancy by breeding goshawks.

Our examination of the forest structure around goshawk nests showed selection for forest stands with larger trees and denser canopy than available in the surrounding landscape, which is a consistent finding for breeding goshawks throughout the western US (Squires and Reynolds 1997). Nest sites were often associated with wet or dry openings in the forest. Occasionally, goshawk nests were found in large trees in more open-canopied stands. As distance from the nest increased, so did the mixture of forest types and structure. Dense canopy and late seral stage structure was clearly important at landscape scales close to the nest, but decreased in relative abundance with distance from the nest (Daw and DeStefano 2001, McGrath et al. 2003). In general, Northern Goshawk nesting habitat became less distinguishable from the landscape with increasing area. These results are not surprising considering the heterogeneous landscape and scarcity of remaining large patches of older forest in eastern Oregon and Washington, conditions that are common throughout much of the forested lands in the western US (USDI Fish and Wildlife Service 1998c). Our spatial modeling also showed that timber harvest can be managed to maintain or enhance goshawk nest site suitability over time in the inland Northwest, and that a non-harvest strategy can in some cases be just as detrimental to nesting habitat as can be aggressive, maximum-yield forestry (McGrath et al. 2003). Active management may be required to counteract recent historical changes in the dynamic nature of forests such as fire suppression, overstocking of pole-sized trees, and insect outbreaks (Graham et al. 1994b, McGrath et al. 2003). Further, habitat management based on exclusionary buffers should be re-evaluated in light of the way different habitat factors interact across spatial scales (McGrath et al. 2003). Designation of buffers of a specific size around goshawk nests forces a predetermined restriction on all forest types, which may not be appropriate among different forest types (e.g., ponderosa pine vs. lodgepole pine stands), gives the impression that management is not required beyond the buffer, and ignores the spatial interactions that may be occurring among scales (e.g., nest stand, PFA, and foraging area).

Given the results from Desimone (1997), and the association between occupancy at historic sites and landscape composition, we see an avenue for the implementation of habitat models from McGrath et al. (2003) to maintain or enhance goshawk nesting habitat in an adaptive management context, while monitoring occupancy and productivity over time. Implementation of the models in a management context should be done in a deliberate manner, and be viewed as an experiment. We also offer the caveat that these models were developed in the interior Pacific Northwest, and may not be applicable to other regions or climatic conditions. McGrath et al. (2003) provide several examples of model applications at several landscape scales.

Goshawks in eastern Oregon preyed upon a wide variety of birds and mammals. Lagomorphs, tree and ground squirrels, Northern Flickers, and American Robins were important prey, based on both frequency in prey remains and estimated biomass. The relative importance of these species in the diet of goshawks could change with differences in relative abundance of prey over time (Watson et al. 1998) or as the structure of the forest is altered by succession, fire, or timber harvest (Reynolds et al. 1992). However, many of these or similar common species are likely important sources of energy for goshawks throughout much of their range in North America, and are listed in Reynolds et al. (1992).

The relatively small amount of prey collected from the Wallowa-Whitman National Forest is inadequate for fully assessing diets of goshawks on that forest. However, the results from this forest compared to the Fremont and Malheur national forests stimulate some speculation as to the relationship of prey availability, diet, and productivity of Northern Goshawks in western forests (DeStefano and McCloskey 1997, Watson et al. 1998). Birds appeared to make up a larger portion of the diet in the northernmost forest, the Wallowa-Whitman—about 60% birds and 40% mammals by frequency and biomass. Prey remains on both the Fremont and Malheur were about 50:50 for birds and mammals by frequency and about 35:65 by biomass. Productivity (number of fledglings per nest) may be lower on the Wallowa-Whitman National Forest (0.85 ± 0.74) compared to the Malheur National Forest (1.3 ± 0.73) and Fremont National Forest (1.6 ± 0.86). Birds in general contributed lower biomass than mammals, and high numbers of small birds such as flickers and robins, compared to larger prey such as grouse and hares, in the diet may correlate to lower productivity in goshawks in any part of their range. The relationship of nutrition to reproductive output and survival of young in raptors is well documented (Ward and Kennedy 1994, 1996). Our data only show this relationship weakly, if at all, but this does underscore the importance of quality as well as quantity of prey in the diet. Larger biomass prey, such as lagomorphs and even squirrels and grouse, likely contributes to higher productivity of goshawks. In regions of the goshawk's range where breeding pairs rely heavily on small birds for prey, such as southeast Alaska and the Olympic Peninsula of Washington, productivity is often low (Finn et al. 2002b). Given the importance of prey abundance and availability in the current version of the goshawk management guidelines (Reynolds et al. 1992), further study on prey biomass, energetics involved in capture, and productivity of nesting goshawks would be interesting and warranted.

Goshawks can also be quite adaptable in the types of cover in which they hunt. Studies have shown that goshawk spend large amounts of time hunting in late-seral-stage forest (Bright-Smith and Mannan 1994, Beier and Drennan 1997). This was likely the case in eastern Oregon as well, but we did commonly observe goshawks hunting in the broad open sagebrush valley adjacent to the Malheur National Forest, and occasionally flying back into the forest with ground squirrels, which made up a measurable portion of prey remains from this forest (12% by frequency and 14% by biomass).

We believe that the management recommendations for goshawks developed by Reynolds et al. (1992) for the southwestern US have major application for the inland Pacific Northwest. The nested spatial concept, consisting of alternate nest sites of 10–12 ha, within a post-fledging area (PFA) of 170 ha, within a home range of a few to several thousand hectares, is based on the ecology of breeding goshawks and provides a framework for addressing habitat needs at multiple scales. The mixture of cover types among these three spatial scales, as well as across landscapes the size of national forests as outlined by Reynolds et al. (1992) for the Southwest, should be applicable to other regions of the goshawks' geographic range. Reynolds et al. (1992) present desired amounts and spatial patterns of various vegetation structural stages (VSS) to provide a mix of cover types for goshawks and their prey, and to promote old-growth development and replacement. These recommended VSS should be reviewed for the inland Pacific Northwest in light of McGrath et al. (2003). One important caveat is that conservation of existing late-seral-stage forest and silvicultural treatments aimed at promoting the development of forest with old-growth characteristics (e.g., large trees, multi-layered stories, high-canopy volume, abundant and well distributed logs and snags) (Sesnie and Bailey 2003), should be of highest priority, as this is the forest seral stage most under-represented in the inland Pacific Northwest (Everett et al. 1993, Henjum 1996). There may be potential for management of the understory reinitiation stage to promote old growth characteristics in this region. Early successional stage forest and openings are well represented, but managers in eastern Oregon and Washington could focus on the size, distribution, and spatial arrangement of these forest patches and openings, with the southwest management guidelines and McGrath et al. (2003) as templates.

The focus on providing habitat for a variety of goshawk prey, as put forth by Reynolds et al. (1992), is also very appropriate and applicable to the Pacific Northwest. Managing for a diversity of prey species will not only help ensure a variety of prey for goshawks, especially when the periodic abundance of some species is low, but will also move us closer to management for biodiversity. What is most needed now is the systematic implementation and careful documentation of management procedures on the ground and long-term monitoring of the results, with changes made as necessary in an adaptive management framework (Long and Smith 2000).

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