

# Does forest structure affect reproduction of northern goshawks in ponderosa pine forests?

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## Summary

**1.** Many management prescriptions are based on ecological hypotheses; evaluating empirical support for these hypotheses can improve management. There has been considerable dispute about the potential response of the northern goshawk to three management-driven forest structures in ponderosa pine forests of the south-western United States: (i) the structure recommended by US Forest Service's goshawk guidelines, designed to increase the abundance of 14 goshawk prey species and thus benefit goshawks; (ii) preferred foraging habitat as suggested by empirical evidence that goshawks forage selectively in areas with abundant large trees and dense canopy closure, rather than areas of highest prey abundance; and (iii) presettlement (i.e. prior to Euro-American settlement) structure characterized by clumps of large trees, canopy closure < 40% and dense herbaceous understorey, which could have negative effects on goshawks.

**2.** To evaluate empirical support for hypotheses that goshawk reproduction is affected by each of these three forest structures, we measured forest structure in a 1215-ha nest-centred circular area in each of 13 goshawk breeding areas on the Apache–Sitgreaves National Forest, Arizona. The breeding areas were selected to span the full range of productivity (fledglings per year monitored) over the previous 9-year period.

**3.** Forest structure had a moderate effect on goshawk productivity ( $r^2 \leq 0.46$ ). Contrary to expectation, goshawk productivity decreased with increasing similarity to the goshawk guidelines.

**4.** Goshawk reproduction was not correlated with resemblance of the breeding area to preferred foraging habitat or resemblance to presettlement forest conditions.

**5. Synthesis and applications.** Because the goshawk guidelines may not improve goshawk reproduction, the Forest Service should reconsider its decision to apply the guidelines to most forested lands in Arizona and New Mexico. Managers should evaluate empirical support routinely for the major ecological hypotheses that underlie forest prescriptions.

**Key-words:** *Accipiter gentilis*, ecological restoration, forest management, forest structure, *Pinus ponderosa*, reproductive success, vegetative structural stage

## Introduction

The northern goshawk *Accipiter gentilis* L. is a species of concern in Arizona (Arizona Game and Fish Department, undated) and a US Forest Service sensitive species in Region 3 (US Forest Service 1993a). The goshawk population in the western United States was evaluated for listing under the Endangered Species Act in 1992 and 1998 (US Fish & Wildlife Service 1998). Concern over the status of the goshawk prompted the US Forest Service to develop management recommendations for National Forests in Arizona and New Mexico (Reynolds

*et al.* 1992; referred to hereafter as 'goshawk guidelines'). In 1996, the goshawk guidelines were incorporated into amendments of all Forest Plans in these two states (US Forest Service 1995, 1996). The amendments require the goshawk guidelines to be implemented on all Forest Service forestlands that are not managed for Mexican spotted owls (*Strix occidentalis lucida*). A fundamental assumption of the goshawk guidelines is that the 'goshawk is a forest habitat generalist that uses a variety of forest types, forest ages, structural conditions, and successional stages' (Reynolds *et al.* 1992: 1). Reasoning that 'if goshawk populations are a barometer of their prey populations, then forest management should feature prey habitats', Reynolds *et al.* (1992) prescribed a forest structure that

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should provide abundant populations of 14 prey species. Following Reynolds *et al.* (1992), we use the term forest structure to include descriptors such as tree density, diameter distribution, canopy closure, numbers of snags and logs and basal area.

Greenwald *et al.* (2005) provide an alternative concept of ideal goshawk habitat. Their review of habitat use studies in North America (11 of 12 published after the goshawk guidelines) suggests that goshawk foraging locations within their home ranges are characterized by many large [ $> 40\text{-}6\text{ cm}$  diameter at breast height (d.b.h.)] trees and dense ( $> 40\%$ ) canopy closure, but that goshawks do 'not select stands with the greatest prey abundance' (Greenwald *et al.* 2005: 120). Although none of the studies reviewed by Greenwald *et al.* (2005) hypothesized that goshawk reproduction or survival would be highest in goshawk breeding areas with many large trees and dense canopy closure, this is a reasonable hypothesis from these observations.

In these same south-western forests, ecological restoration of ponderosa pine (*Pinus ponderosa*) and pine-oak (*Quercus* species) forests has been proposed to reverse changes to forest structure and function caused by a century of livestock grazing, fire suppression and timber harvest, and to reduce the risk of stand-replacing wildfires (Covington & Moore 1994). Accordingly, managers in the region are proposing treatments to restore conditions that prevailed prior to Euro-American settlement. Compared to current forest structure, these presettlement conditions are characterized by lower basal area, stem density and canopy closure, and a larger fraction of the landscape dominated by large trees (Fulé, Covington & Moore 1997; Mast *et al.* 1999; Fulé *et al.* 2002; Waltz *et al.* 2003). Concern that presettlement forest structure will affect goshawk populations adversely is one of the main issues raised by environmental advocacy groups opposed to implementation of restoration treatments (US Fish and Wildlife Service 1998).

Managers would benefit from an empirical assessment of how these three alternative forest structures would affect goshawks. Although direct experiments would be ideal, managers would have to assign randomly a statistically useful number of goshawk territories to required treatments and controls, and it would take decades to implement treatments and monitor goshawk response. We chose a less direct but more expedient approach by correlating goshawk reproduction with similarity of goshawk breeding areas to each of these three alternative forest structures.

Several previous studies have related stand characteristics to goshawk reproduction (Crocker-Bedford 1990, 1995; Ward, Ward & Tibbets 1992; Patla 1997; Finn, Marzluff & Farland 2002). Although each of these studies provided useful information about how reproduction varies with one or more forest trait, no study addressed these particular forest structures directly or compared empirical support for alternative hypotheses. Furthermore, these studies were limited to relatively short monitoring periods: 3–7 years per territory (Patla 1997) or 1–3 years per territory (all other studies). Monitoring reproduction for  $> 3$  years is appropriate because

goshawk reproduction in western North American landscapes fluctuates widely among years, probably driven by changes in weather and prey abundance (Kennedy 1997; Krüger & Lindström 2001; McClaren, Kennedy & Dewey 2002). One possibility is that forest structure affects reproduction only during years of high fledging success, other years being so poor that the influence of habitat is obscured. For example, Bloxton (2002) observed that goshawk reproduction virtually ceased in La Niña years (years of low precipitation in western North America driven by cold ocean temperatures in the equatorial Pacific), overriding habitat effects. Alternatively, forest structure might influence reproduction only in years of poor reproduction; for example, Krüger & Lindström (2001) observed that in good years all goshawk territories had high productivity with little variation among breeding areas.

To address these issues, we related goshawk nest productivity over a 9-year period to forest structure in landscapes around 13 goshawk breeding areas in ponderosa pine and pine-oak forests on the Apache–Sitgreaves National Forest in Arizona. Our objective was to assess how reproductive success of goshawks varied with similarity of goshawk breeding areas to three alternative forest structures (goshawk guidelines, preferred foraging habitat, presettlement conditions) over a time span that included a range of climatic conditions typical of the South-western United States.

## Methods

### STUDY AREA

We studied goshawks on the Black Mesa and Lakeside Ranger Districts of the Apache–Sitgreaves National Forest in east-central Arizona. The study area is part of the Mogollon Plateau, an area dominated by basaltic and limestone type soils that forms the uplifted southern edge of the Colorado Plateau and is dominated by ponderosa pine. Elevations in the study area ranged from 1768 to 2417 m (mean 2134 m). In these breeding areas, silverleaf oak (*Q. arizonica*), pinyon pine (*P. edulis*), alligator juniper (*Juniperus deppeana*) and Utah juniper (*J. osteosperma*) frequently co-occurred with ponderosa pine, especially at lower elevations or on south-facing slopes. At higher elevations and in steep canyons, co-dominant species were Douglas fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), and aspen (*Populus tremuloides*). Gambel oak (*Q. gambelii*) and New Mexico locust (*Robinia neomexicana*) were common understory tree species throughout. Annual precipitation at the nearest weather station (Show Low Airport, 2102 m elevation) averaged 39.9 cm during 1993–2002, with driest years in 2002 (24.5 cm) and 1996 (31.4 cm), and relatively wet years in 1993 (53.4 cm), 1994 (50.7 cm) and 1997 (46.6 cm).

Our research activities occurred within a 1215-ha circle (radius 1967 m) from the geographical centroid of each area's known nest locations. To avoid the implication that these circles correspond exactly to goshawk territories, we use the term 'goshawk breeding areas' to refer to these circular areas.

None of the goshawk breeding areas in our study experienced timber harvest in  $> 8\%$  of the breeding area (mean 2.8%, range 0–7.6%) during 1993–2002. Thus we believe that the goshawk reproduction we observed was not affected by disturbance or other short-term effects of timber harvest.

## MONITORING GOSHAWK REPRODUCTION

During 1993–2002, the Arizona Game and Fish Department, US Forest Service (USFS) and Northern Arizona University collaborated to monitor northern goshawks in the study area. Each year, we first visited each historic northern goshawk breeding area in April and May to determine occupancy and locate any active nest. An historic breeding area was a nest site or cluster of nests where an incubating goshawk was observed at least once during the previous 3 years. If occupancy was not confirmed at historic nest sites, we conducted visual searches within a 1.6 km radius around the centroid of known nests, excluding pinyon–juniper woodlands, meadows or other treeless areas. Following USFS South-western Region's northern goshawk inventory protocols (Kennedy & Stahlecker 1993; Joy, Reynolds & Leslie 1994), we also broadcast conspecific recordings to elicit responses from northern goshawks. Playback tapes provided by the USFS included both the adult 'alarm' call and the female 'wail' call. The alarm call was used from June to early July (nestling period) and the wail call was used from late July to early September (fledgling period). Because Woodbridge & Detrich (1994) found 95% of alternative nests within 800 m of the last known nest, we placed 24 calling points uniformly throughout an 800-m radius area around previous nest sites. If we could not verify nesting activity in an occupied area early in the season, we conducted a second survey during the fledgling dependency period (August). We spent up to 7 person-days searching a breeding area before considering it unoccupied.

An area was considered occupied if a pair of goshawks were inferred to use the area during at least part of the breeding season, based on presence of a new or refurbished nest, an adult bird at or near a nest on  $\geq 2$  occasions, or fresh mutes, moulted feathers and prey remains around a nest structure (Ingraldi 1999). A nest was considered active if we observed a female goshawk in incubation posture, at least one fresh egg or egg shell fragments or fledgling or juvenile northern goshawks (Ingraldi 1999). Active nests were visited at least once every 10 days to monitor status and productivity.

A nest was deemed successful if at least one nestling survived to 100% of fledgling age (39 days old; Steenhof 1987). Ages were determined using Boal's (1994) photographic guide, or by the observed number of days since hatching. Productivity was measured as number of nestlings that survived at least 39 days, unless there was subsequent evidence that the nestlings did not fledge.

We used fledglings per year monitored (occupancy rate times productivity per occupied nest) as a measure of reproductive success. Nest productivity is a problematic measure because it considers only nest areas where pairs are present and initiate breeding but ignores intermittent use or early abandonment of lower quality sites (McClaren *et al.* 2002). Krüger & Lindström (2001) found that breeding pairs of goshawks occupied progressively poorer breeding sites as number of breeding pairs increased, i.e. only the best sites were occupied in years with few nesting attempts. Fledglings per year monitored incorporates both measures. Similarly, Wiens & Reynolds (2005: 210) found that the number of fledglings produced per adult goshawk over a 10-year period was 'a reliable index of fitness' (which they defined as recruitment to the breeding population). We did not use data for the first year each breeding area was discovered because by definition an area with a newly discovered nest could not be classified as unoccupied.

From all 46 goshawk breeding areas known and monitored annually for all or part of 1993–2002, we excluded 18 breeding areas because > 50% of the breeding area was dominated by either pinyon–juniper or mixed conifer vegetation types and four breeding areas at which major disturbance (campground construction,

timber harvest in > 10% of the area during the 10-year period) occurred during the monitoring period. Because most goshawks in this region nest in forests dominated by ponderosa pine, we confined our attention to breeding areas in that forest type. We then selected the five most productive and five least productive breeding areas, and selected three areas randomly with intermediate productivity. For these 13 areas, we calculated fledglings produced per breeding area (see Table S1 in Supplementary material).

## MEASURING FOREST STRUCTURE

After the 10 years of monitoring, when all nest locations had been determined, we measured forest structure in each of the 13 breeding areas. We mapped one sample point per 4.05 ha (10 acres) throughout each breeding area (~300 points per breeding area), assigned each point a Universal Transverse Mercator (UTM) location, and used global positioning system (GPS) units to locate each point on the ground.

Based on radio-telemetry studies, Reynolds *et al.* (1992) posited three key components to a goshawk home range: nest areas (73 ha divided among three alternate nest areas and three replacement areas); a post-fledgling family area (170 ha near the nest used by the female and fledglings from incubation through juvenile dispersal); and a foraging area (2185 ha of additional foraging area for the male goshawk). Areas close to the nest may have a different influence on goshawk reproduction than do more distant areas. Thus we evaluated forest structure in two areas: a circular area centred on the geographical centroid of the breeding area's nest locations, and a larger annulus around this circle. The 243-ha circle (radius 880 m, ~60 sample points) was intended to encompass the nest areas and post-fledgling family area; for brevity we refer to this circle as the Central Zone of a goshawk breeding area. The annulus was the area within a circle of radius 1967 m, excluding the Central Zone, and thus encompassed 972 ha (~240 sample points) of the foraging area closest to the nest; we refer to this area as the Foraging Band. Totalling 1215 ha, these areas represent half of a 2430-ha home range for a pair of breeding goshawks (Reynolds *et al.* 1992; Kennedy *et al.* 1994). Funding limitations precluded sampling additional breeding areas, or the entire foraging area.

We collected forest stand data at each point, using USFS intensive (Level I) stand examination procedures (US Forest Service 1993b). At each sample point we placed three concentric plots: (1) variable-radius plot utilizing a 10 basal area factor (BAF) prism within which we recorded d.b.h., height and species for each live tree; (2) 0.405-ha (1-acre) circular plot within which we tallied all snags > 25.4 cm d.b.h. and logs > 25.4 cm at midpoint; and (3) a 0.00405-ha (0.01-acre) fixed circular plot within which we tallied all seedlings and saplings < 12.7 cm d.b.h. Our minimum size thresholds for tallying snags and logs correspond to snag and log definitions in Reynolds *et al.* (1992).

After calculating basal area by species, we used USFS algorithms to calculate three derived variables at each point: forest type, canopy closure class and dominant diameter class. We recognized 10 forest types [non-forest, ponderosa pine, oak, pinyon–juniper (PJ), aspen, mixed conifer, pine–oak, pine–PJ, oak–PJ and PJ–oak] based on the basal area of each tree species with respect to thresholds defined by Eyre (1981) and US Fish and Wildlife Service (1995: 52–58). We estimated canopy closure class from percentage of a theoretical maximum Stand Density Index (SDI) for each forest type using the USFS algorithm (McTague & Patton 1989; US Forest Service 1993b) and maximum SDI values for each forest type proposed by Long (1985). Canopy closure class boundaries were 40% canopy closure (corresponding to 30% maximum SDI), 50% canopy closure

**Table 1.** Reference forest structures that might affect goshawk reproduction or survival in ponderosa pine forests of the South-western United States. We hypothesized that goshawk reproduction would increase as a goshawk breeding area increasingly resembled the goshawk guidelines or preferred foraging habitat, but would decrease with increasing resemblance to presettlement conditions. Unless otherwise labelled, percentages are percentage of landscape area. VSS: Vegetative Structural Stages

Forest structure	Description		
	243-ha Central Zone	972-ha Foraging Band	Source
Goshawk guidelines I <sup>a</sup>	7% VSS class <sup>b</sup> 1; 7% VSS 2; 14% VSS 3; 14% VSS 4 with > 50% canopy closure; 58% VSS 5–6 with > 50% canopy closure ≥ 4.9 snags ha <sup>-1</sup> and ≥ 7.4 logs ha <sup>-1</sup>	10% each VSS <sup>b</sup> 1 and 2; 20% each VSS 4, 5, and 6 with > 40% canopy closure ≥ 4.9 snags ha <sup>-1</sup> and ≥ 7.4 logs ha <sup>-1</sup>	Reynolds <i>et al.</i> (1992)
Goshawk guidelines II <sup>a,d</sup>	VSS diameter distribution as above, but no requirements for canopy closure, snags, or logs		Reynolds <i>et al.</i> (1992)
Preferred foraging habitat	50° large (> 40.6 cm d.b.h.) trees ha <sup>-1</sup> Canopy closure > 40%		Greenwald <i>et al.</i> (2005)
Pre-settlement conditions	2% VSS 1, 8% VSS 2, 14% VSS 3, 16% VSS 4, 28% VSS 5, 32% VSS 6 69% basal area < 11 m <sup>2</sup> ha <sup>-1</sup> , 14% basal area 11–16 m <sup>2</sup> ha <sup>-1</sup> , 11% basal area 16–25 m <sup>2</sup> ha <sup>-1</sup> , 5% basal area > 25 m <sup>2</sup> ha <sup>-1</sup> 83% canopy closure < 40%, 10% canopy closure 40–60%, 7% canopy closure > 60%		Unweighted mean of frequency distributions for each variable in Fig. 1

<sup>a</sup>Central Zone prescription is the area-weighted average of Reynolds *et al.* (1992) prescriptions for the 73-ha nest areas and 170-ha post-fledging family area. <sup>b</sup>VSS 1: 0–3 cm d.b.h.; VSS 2: 3–13 cm d.b.h.; VSS 3: 13–30 cm d.b.h.; VSS 4: 30–46 cm d.b.h.; VSS 5: 46–61 cm d.b.h.; VSS 6: > 61 cm d.b.h. VSS of each plot is class with plurality of basal area, regardless of species. <sup>c</sup>Greenwald *et al.* (2005) and references cited therein did not specify an optimal number of large trees/ha, but all the studies cited therein suggested that the optimum was probably higher than any density we observed in a goshawk breeding area. Specified value (50) is 20% larger than the highest mean density we observed in a goshawk breeding area. The results of our analyses did not vary when we tried ideal values ranging up to 100 (an implausibly high value for this region). <sup>d</sup>Reduced model built to avoid the risk of spurious results due to: (a) calculated canopy closure classes could differ from true canopy classes, and (b) only small fractions of each breeding area met snag and log targets.

(corresponding to 39% of maximum SDI) and 60% (corresponding to 47% maximum SDI). We recognized six diameter classes, designated 1–6, corresponding to the Vegetative Structural Stages (VSS) used in USFS Region 3 (Reynolds *et al.* 1992; see Table 1, footnote b). Finally, we created four classes for basal area such that each class contained 25% of our sample points, namely 0.09–11 m<sup>2</sup> ha<sup>-1</sup>, 11–16 m<sup>2</sup> ha<sup>-1</sup>, 16–25 m<sup>2</sup> ha<sup>-1</sup> and > 25 m<sup>2</sup> ha<sup>-1</sup>.

#### CALCULATING SIMILARITY OF BREEDING AREAS TO REFERENCE CONDITIONS

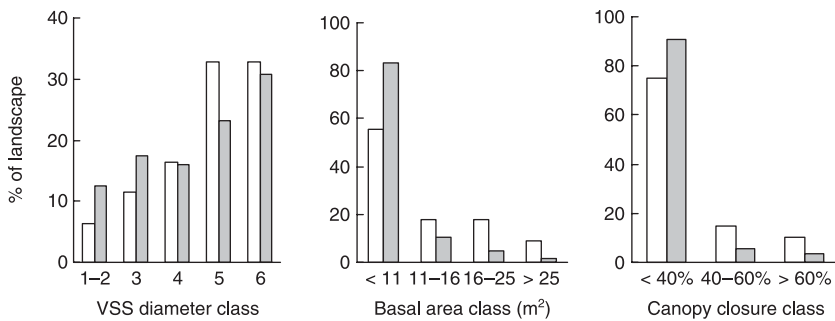
We used percentage similarity,  $S$  (Bray & Curtis 1957; Ludwig & Reynolds 1989) as an index of how each breeding area matched reference forest structures.  $S$  is scaled from 0% (no similarity) to 100% (complete similarity). Although designed originally to calculate similarity between communities or species assemblages,  $S$  can also be used to quantify similarity between sampling units and reference conditions that share a common set of descriptor variables.  $S$  is calculated as  $2W/(A + B)$ , where  $W = \sum \min(X_j, X_k)$ ,  $A = \sum X_j$  and  $B = \sum X_k$ . In our case the  $X$ s were variables such as percentage of total area dominated by trees of a particular diameter class or with at least 4.9 large snags per ha.  $X_j$  values are the observed values in a goshawk breeding areas and  $X_k$  values are the value for the same variable under the reference condition.

We calculated how well each goshawk breeding area resembled each of four reference forest structures (Table 1), including two versions of the goshawk guidelines, an empirical estimate of presettlement forest structure and an estimate of preferred foraging habitat. Reynolds *et al.* (1992) developed the goshawk guidelines by identifying

14 goshawk prey species, reviewing the literature on habitat selection by these species, and interpreting the literature on habitat use by these 14 species in terms of six tree diameter class (Table 1, footnote b), canopy closure and numbers of snags and logs. This process yielded recommendations that nesting habitat should be dominated by trees > 46 cm d.b.h. with canopy closure > 50%, that the post-fledging family area should be dominated by the larger diameter classes with canopy closure > 50%, and the foraging area should be dominated by larger diameter classes with canopy closure > 40% (details in Table 1).

Our first model for the goshawk guidelines reflected the distribution of diameter classes, canopy closures, snags and logs recommended by Reynolds *et al.* (1992). The second version reflected only the distribution of diameter classes recommended by Reynolds *et al.* (1992). We developed this simpler model for two reasons. First, we did not measure canopy closure directly in the field, but calculated it using a Forest Service algorithm (US Forest Service 1993b), which introduced unknown errors into our estimates of canopy closure class. Secondly, most goshawk breeding areas had far fewer snags and logs than recommended by Reynolds *et al.* (1992), such that all goshawk breeding areas were about equally dissimilar from the goshawk guidelines with regard to these characteristics. This uniform dissimilarity could mask importance of differences among breeding areas in tree diameter distributions.

Our reference forest structure for preferred foraging habitat was based on interpretation of 12 studies of foraging habitat summarized by Greenwald *et al.* (2005). These studies suggest that ideal foraging habitat is a landscape with an average of 50 large trees ha<sup>-1</sup> and 100% of the landscape with canopy closure > 40% (details in Table 1, footnote c).



**Fig. 1.** Frequency distributions of Vegetative Structural Stage diameter classes, basal area classes and canopy closure classes in presettlement conditions at 79 plots near Grandview Point, Arizona, 250 km from our study area, and 143 plots near Mount Trumbull, Arizona (dark bars, 450 km from our study area). We used the unweighted mean of each pair to estimate presettlement conditions. Data provided by P. Z. Fulé (Northern Arizona University, unpublished).

**Table 2.** Alternative models of forest structure effects on goshawk reproduction.  $F$ ,  $S$  refers to percentage similarity (Bray & Curtis 1957); subscripts CZ and FB refer to the Central Zone and Foraging Band, respectively, of a goshawk breeding area

Hypothesis	Model
Resemblance of CZ and FB to forest structure prescribed in the goshawk guidelines improves goshawk reproduction	$F = B_0 + B_1 \times S_{GG,CZ} + B_2 \times S_{GG,FB}$ ; $B_1, B_2 > 0$ , where $S_{GG}$ = similarity to Goshawk Guidelines I in Table 1
Resemblance of CZ to forest structure prescribed in the goshawk guidelines improves goshawk reproduction	$F = B_0 + B_1 \times S_{GG,CZ}$ ; $B_1 > 0$
Resemblance of CZ and FB to diameter distribution prescribed in the goshawk guidelines improves goshawk reproduction	$F = B_0 + B_1 \times S_{GGdiam,CZ} + B_2 \times S_{GGdiam,FB}$ ; $B_1, B_2 > 0$ , where $S_{GGdiam}$ = similarity to Goshawk Guidelines II in Table 1
Resemblance of CZ to diameter distribution prescribed in the goshawk guidelines improves goshawk reproduction	$F = B_0 + B_1 \times S_{GGdiam,CZ}$ ; $B_1 > 0$
Increased amount of preferred foraging habitat in CZ and FB improves goshawk reproduction	$F = B_0 + B_1 \times S_{PFH,CZ} + B_2 \times S_{PFH,FB}$ ; $B_1, B_2 > 0$ , where $S_{PFH}$ = similarity to preferred foraging habitat in Table 1
Increased amount of preferred foraging habitat in CZ improves goshawk reproduction	$F = B_0 + B_1 \times S_{PFH,CZ}$ ; $B_1 > 0$
Resemblance of CZ and FB to presettlement forest structure decreases goshawk reproduction	$F = B_0 + B_1 \times S_{presett,CZ} + B_2 \times S_{presett,FB}$ ; $B_1$ and $B_2 < 0$ , where $S_{presett}$ = similarity to presettlement conditions in Table 1
Resemblance of CZ to presettlement forest structure decreases goshawk reproduction	$F = B_0 + B_1 \times S_{presett,CZ}$ ; $B_1 < 0$

Our reference forest structure for presettlement conditions was based on reconstructed conditions at two sites in Arizona, one near Grandview Point on the south rim of the Grand Canyon (Fulé *et al.* 2002) and one near Mount Trumbull (Waltz *et al.* 2003). In both cases, dendroecological methods (Fritts & Swetnam 1989) were applied to current evidence (old-growth trees, stumps, logs and other signs of tree removal) to estimate forest conditions prior to livestock grazing, fire suppression and logging (1870 at Mount Trumbull, 1887 at Grandview). P. Z. Fulé (Northern Arizona University) provided the raw data that we used to recreate frequency distributions of basal area, dominant diameter class and canopy closure (Fig. 1). These were the only available data on presettlement conditions in nearby ponderosa pine and pine-oak forests. Soil types in these two areas were derived from the same parent materials (basalt, calcareous sandstone and limestone) as those in our study area. Because the two sites had similar distributions for each variable measured, we used the mean of the two distributions as the reference condition.

#### EVALUATING EMPIRICAL SUPPORT FOR ALTERNATIVE MODELS

For each set of reference conditions, we built two models that related goshawk reproduction (number of fledglings fledged per

year monitored) to the percentage similarity of a goshawk breeding area to that reference forest structure. One model related reproduction only to conditions in the Central Zone; the second model had an additional term for the influence of the Foraging Band (Table 2).

We used an information-theoretic approach adjusted for small sample size [Aikake's information criterion (AIC<sub>c</sub>); Burnham & Anderson 2002] to evaluate empirical support for each of the eight models. Because this approach will always identify the model with the best support, even when no model is well supported, we report only models that met minimal thresholds of  $\Delta AIC_c < 5.0$  and adjusted  $r^2 > 0.10$ . We compared empirical support among the eight models.

#### Results

The 13 goshawk breeding areas varied in their percentage similarity to reference forest structures (see Table S2 in Supplementary material). The Central Zones of breeding areas were on average 32% similar (range 21–56%) to the forest structure recommended by the goshawk guidelines. When only the diameter distribution recommended by the guidelines was considered, average percentage similarity

**Table 3.** Models relating goshawk reproduction to the percentage similarity of a breeding area to a reference forest structure, for 13 goshawk breeding areas monitored 1993–2002 on the Apache–Sitgreaves National Forest, Arizona. Only models with  $\Delta\text{AIC}_c < 5$  and  $r^2 > 0.10$  are shown. Eight models were tested

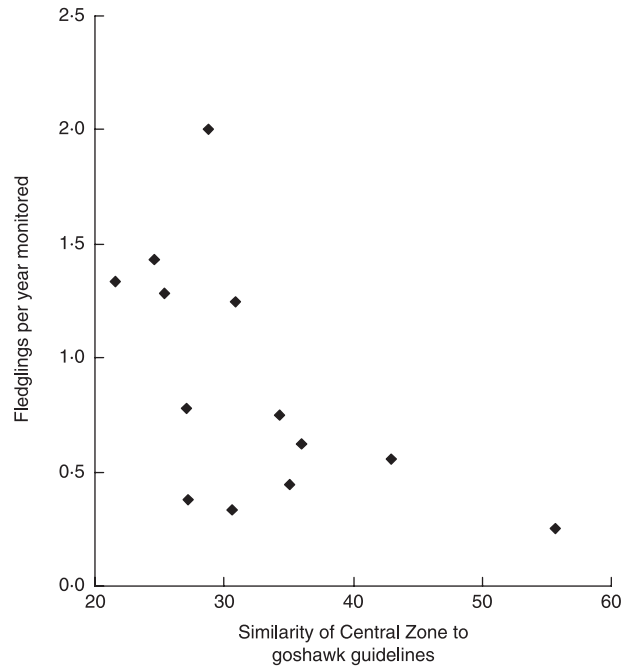
Model <sup>a</sup>	Reference forest structure	$\Delta\text{AIC}_c$	$r^2$	Standardized coefficient	
				CZ	FB
2	Goshawk guidelines	0.0	0.45	-0.67	NA
4	Diameter distribution of goshawk guidelines	1.3	0.39	-0.40	NA
1	Goshawk guidelines	4.3	0.45	-0.64	-0.04

<sup>a</sup>Model number from Table 2.

increased to 50% (range 32–82%). The Foraging Band of a breeding area was somewhat more similar to the goshawk guidelines, averaging 43% similarity (range 26–57%) for the full prescription and 71% (range 53–85%) for the diameter distribution only. Percentage similarity between breeding areas and preferred foraging habitat averaged 65% in both the Central Zone and Foraging Band. Goshawk breeding areas were about 30% similar to presettlement conditions, with no Central Zone or Foraging Band exceeding 38% similarity.

Three of the four models relating goshawk reproduction to the goshawk guidelines were supported by the data (Table 3), including two models that included only effect of forest structure in the Central Zone, and one model that included effects of both the Central Zone and the Foraging Band. Contrary to expectation, however, goshawk breeding areas that resembled most closely the forest structure prescribed by the goshawk guidelines tended to have lower goshawk productivity (Table 3, Fig. 2). This negative influence was most pronounced for forest conditions in the Central Zone, for which a 1 standard deviation (SD) increase in percentage similarity was associated with a half SD decrease in productivity. The similarity of the Foraging Band to the goshawk guidelines had a negative association with goshawk productivity in only one model, but the coefficient was close to zero (Table 3). In light of these surprising results, we examined models for the three worst years of goshawk reproduction (1997, 2001 and 2002), as well as the three best years of goshawk reproduction (1995, 1996 and 1998; details in Table S1 of Supplementary material). In both cases the same models were supported, and the sign and size of standardized coefficients were similar to those observed across all 9 years. No  $r^2$  value exceeded 45% (Table 3).

No model relating goshawk reproduction to ideal foraging habitat or to presettlement forest structure was supported by the data. Because our linear models could be insensitive to non-linear trends we examined scatterplots, which confirmed the lack of association between fledgling success and these two forest structures in either the Central Zone or Foraging Band.



**Fig. 2.** Mean number of goshawk fledglings per year monitored decreased with increasing similarity to the goshawk guidelines for  $n = 13$  territories monitored on the Apache–Sitgreaves National Forest, Arizona over 9 years ( $r^2 = 0.45$ ).

## Discussion

### A PRIORI HYPOTHESES

None of the expected associations between goshawk reproduction and forest structure were confirmed. There was no evidence of increased goshawk reproduction in breeding areas that resembled preferred foraging habitat, or of decreased reproduction in forest structure more similar to presettlement conditions.

The strongest pattern was that, contrary to our hypothesis, production of fledglings decreased as the breeding area's similarity to the goshawk guidelines increased. Why did goshawk reproduction not increase with similarity to the goshawk guidelines? One possibility is that Reynolds *et al.* (1992) estimated inaccurately forest conditions that maximize prey abundance. Their procedure involved three key decisions or interpretations, each of which was subject to uncertainty (Arizona Game and Fish Department 1993). First, Reynolds *et al.* (1992) gave each prey species equal weighting in their analysis, despite differences among prey species in biomass, abundance and contribution to goshawk diet, and despite the fact that six of the 14 species are unavailable in winter. Secondly, Reynolds *et al.* (1992) interpreted primary literature to estimate whether each species was found in low, moderate or high abundance in each VSS canopy closure class. These interpretations were necessarily subjective because the primary literature did not use VSS as an independent variable and because the three abundance classes were not defined explicitly. Thirdly, Reynolds *et al.* (1992) translated tallies of the number

of species scoring 'high' and 'medium' in each VSS class into optimal percentages of the landscape in each class. Although Reynolds *et al.* (1992) discussed and interpreted these tallies thoughtfully, others (e.g. Arizona Game and Fish Department 1993) interpreted these same data as supporting a prescription with larger fractions of the landscape dominated by larger trees and denser canopy closures. Errors at each step in the process could have synergistic effects that compromised this conceptual model.

Another possibility is that Reynolds *et al.* (1992) erred in their fundamental assumption that goshawks are habitat generalists and prey specialists that thrive best in a landscape with abundant prey. Drennan & Beier (2003) and Greenwald *et al.* (2005) questioned this assumption and emphasized evidence that goshawks are prey generalists and habitat specialists.

Finally, the goshawk guidelines use a forest descriptor (VSS) that has never been evaluated rigorously for its utility as a descriptor of wildlife habitat (although it was developed originally for this purpose: Thomas 1979). To the extent that VSS is an inappropriate descriptor it would contribute to statistical noise in our analyses, but such noise is unlikely to cause the negative correlation we observed.

Our results offer no support for the alternative hypothesis that reproductive success increases in breeding areas with increasing percentage of ideal foraging habitat. Empirical studies of foraging locations selected by goshawks in the western United States (summarized by Greenwald *et al.* 2005) were remarkably consistent in documenting that goshawks use forest structures characterized by relatively dense canopy and many large trees, but do not use sites with higher prey abundance. Goshawks in France also seem indifferent to prey abundance but partial to large trees and high crown volumes (Penteriani, Faivre & Frochot 2001). Because these forest conditions did not improve goshawk reproduction, we speculate that perhaps these forest conditions are associated positively with demographic parameters that we did not measure, such as reproductive life span, or adult or post-fledging survival.

Presettlement forest structure (< 250 stems ha<sup>-1</sup>, < 40% canopy closure, < 1 large snag and < 1 large log per ha; Fulé *et al.* 2002; Waltz *et al.* 2003) differs markedly both from preferred habitat and from the recommendations of the goshawk guidelines. Thus we expected that similarity to this structure would be correlated negatively with goshawk reproduction. Our results do not support this notion. However, no goshawk breeding area was > 39% similar to restored conditions, and we caution against extrapolating our results to the effects of large-area restoration treatments.

The three forest structures we examined had only moderate influence on goshawk productivity. Two other studies, using different forest traits, found little influence of forest structure on reproductive success of northern goshawks in the western United States. Joy (2002) found that proportions of six vegetation types did not differ between 56 higher-productivity and 44 lower-productivity goshawk territories in a 9-year study in northern Arizona. Patla (1997) observed no effect of percentage mature forest on goshawk occupancy or goshawk productivity per occupied nest, and attributed this result to the fact that all

territories had high (> 60%) percentage mature forest with little inter-territory variation. The most regularly occupied territories in her study were characterized by relatively greater proportions of mature forest cover. Patla (1997) also observed a small positive effect of sage-scrub openings on occupancy and reproduction ( $r^2 = 0.22$ ) and speculated that prey production was relatively high in those openings.

The low correlations we observed may be related to the fact that our circular areas did not necessarily correspond to areas of most intense goshawk use. None the less, we believe the 1215-ha circular areas we sampled included most areas used by breeding goshawk parents and fledglings during the breeding season. On the nearby Coconino National forest, mean home range size (95% harmonic mean) during the breeding season was 840 ha for 23 females and 1341 ha for 12 males (Hall 2001). Similarly, our 880-m radius Central Zone probably includes areas most important to juveniles and adult females during the fledgling dependency period. Kennedy *et al.* (1994) reported that 96% of the locations of fledglings were within 800 m of the nest during the first 4 weeks of the juvenile dependency period, decreasing to 76% in the last 4 weeks. However, these home range areas are not circular, and goshawks use areas within their home range non-uniformly (Kennedy *et al.* 1994; Beier & Drennan 1997).

#### WHAT MAKES SOME GOSHAWK BREEDING AREAS MORE PRODUCTIVE THAN OTHERS?

Like Krüger & Lindström (2001), we observed that some goshawk breeding areas consistently produced more fledglings than others. The contrary findings of McClaren *et al.* (2002) may reflect their use of fledglings per active nest as the response variable, ignoring differences in occupancy rates among breeding areas. However, if forest structure does not drive productivity, what does? Plausible hypotheses include prey abundance, disturbance, weather patterns and parenting ability of goshawk breeders.

Prey abundance was correlated with year-to-year variation in reproduction for goshawk populations studied for 4–10 years in the western United States (Doyle & Smith 1994; Keane 1999; Salafsky, Reynolds & Noon 2005) and Sweden (Tornberg, Korpimäki & Byholm 2006), but was uncorrelated with goshawk population growth in a 24-year time-series in Germany (Krüger & Lindström 2001). Based on the three US studies, we believe that prey abundance is a major driver of year-to-year variation in reproduction for goshawk populations in the western United States. A reasonable hypothesis is that prey abundance also drives reproductive variation among goshawk breeding areas. To our knowledge, no study has tested this hypothesis.

Disturbance levels, such as number of roads, traffic volume on roads or trails, amount of residential development, timber harvest and research activity (e.g. nest checks, nest surveys) could also affect goshawk reproduction. These disturbances were relatively constant across our 13 breeding areas, but we believe that an unauthorized camping area did cause abandonment of one breeding area that had been consistently

productive before intensive camping began near the nest stand.

Weather patterns, such as spring and summer precipitation, are correlated with between-year variation in goshawk reproduction (Kostrzewa & Kostrzewa 1990; Patla 1997; Penteriani 1997; Ingraldi 1999; Bloxton 2002; Fairhurst & Bechard 2005). However, for such effects to account for variation among goshawk breeding areas, the breeding areas would have to experience different weather patterns. We do not believe this was the case on our study area.

Finally, our most productive breeding areas may have reflected qualities of the breeding pairs rather than forest structure within the breeding area. However, given a mean reproductive life span of 2 years (Wiens & Reynolds 2005), several generations of high-quality parents would have to use a given breeding area to create high productivity over 9 years of observations. Until a researcher devises a method to measure parenting ability independently from nest success, it would be difficult to design a study to test this hypothesis rigorously.

#### MANAGEMENT IMPLICATIONS

The goshawk guidelines were conceived as an approach to management that would address the needs of multiple species (goshawks and 14 prey species) and meet other forest objectives (Reynolds *et al.* 1992). Compared to the years when production of fibre and ungulates drove forest management, the guidelines marked a big step towards ecosystem management and conservation of all native species. However, the assumptions behind the guidelines remain a set of largely untested hypotheses. Despite small sample size and the use of an observational rather than experimental approach, we found a moderate negative correlation between goshawk productivity and the forest structure prescribed by the guidelines. This calls into question the purported benefit to goshawks. Studies have not yet addressed response of the 14 prey species.

These results raise questions about the decision (US Forest Service 1996) to implement the goshawk guidelines on most Forest Service lands in Arizona and New Mexico. In (1993, the Arizona Game and Fish Department (1993: 62) recommended that the Forest Service 'identify areas... which reflect the desired future conditions identified in the [goshawk guidelines, and] ... monitor these areas to see if goshawks and the 14 targeted prey have responded as expected'. Our study suggests that goshawks did not respond as expected, and the monitoring and adaptive management approach recommended in 1993 is equally important today.

More broadly, many prescriptions for managing forests and other wildlands are based on ecological hypotheses. Managers should evaluate empirical support for the ecological hypotheses that are being applied to large landscapes. Careful allocation of areas to prescription and control sites, adequate replication and long-term monitoring are essential to evaluate empirical support in the most rigorous fashion. Observational studies such as ours can be a fast and relatively inexpensive alternative.

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## Supplementary material

The following supplementary material is available for this article.

**Table S1.** Reproductive history of the 13 goshawk breeding areas 1993–2002.

**Table S2.** Percentage similarity to reference conditions and productivity for the 13 goshawk breeding areas.

This material is available as part of the online article from: <http://www.blackwell-synergy.com/doi/full/10.1111/j.1365-2664.2007.01409.x>

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**Table S1.** Reproductive history of  $n = 13$  northern goshawk breeding areas monitored 1993-2002 on the Apache-Sitgreaves National Forest, Arizona. % active = percentage of years in which goshawks nested in the breeding area, FYM = mean fledglings/year across all years monitored. FYA = mean fledglings/year across years a breeding area was active. Because a breeding area could not have been unoccupied in the year it was first discovered, we excluded the first year of monitoring from calculations of % active, FYM, and FYA. With the data in Tables S1 and S2, you can repeat our analyses, or examine patterns for any of the three measures of reproductive success for any subset of years.

Territory	Reproductive Status of Breeding Area by Year <sup>a</sup>										All years		
	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	% active	FYM	FYA
Alder	X	X	2	0	U	3	3	U	3	1	71	1.4	2.0
Aniceto Knoll	X	X	X	X	X	2	2	3	P	P	50	1.3	2.5
Blevins	X	1	2	0	0	1	U	U	U	U	50	0.4	0.8
Danish Hollow	2	3	0	0	P	P	P	P	U	P	33	0.3	1.0
Grama Draw	1	U	3	2	P	P	2	P	U	U	33	0.8	2.3
Hart Canyon	X	X	X	X	X	X	2	2	2	2	100	2.0	2.0
Heber Hollow	1	P	2	1	P	3	0	2	2	2	78	1.3	1.7
Hidden	P	0	0	3	U	U	0	0	U	1	67	0.4	0.7
Little Brushy	X	X	2	1	2	2	2	2	U	0	86	1.3	1.5
Los Burros	X	P	P	P	0	P	3	3	U	U	38	0.8	2.0
Timber Mesa	P	0	P	2	0	1	2	P	P	0	67	0.6	0.8
Town Draw	X	2	1	1	U	U	0	P	U	U	38	0.3	0.7
Willow Wash	X	2	2	2	U	U	1	P	U	U	38	0.6	1.7
Mean fledglings ( $n =$ 13 breeding areas) <sup>b</sup>	n.a.	0.60	1.11	1.09	0.18	0.91	1.25	0.92	0.54	0.46			
Mean fledglings ( $n =$ 47 breeding areas) <sup>b</sup>	n.a.	0.49	0.69	0.67	0.24	0.68	0.53	0.46	0.28	0.21			

<sup>a</sup> X = not monitored (not yet discovered); U = unoccupied (no evidence of goshawk presence); P = adult goshawks present, but no evidence of nesting; numerals = number of fledglings from a nest at which incubation was observed.

<sup>b</sup> Breeding area status from year of nest discovery was censored from the calculation. Present (P) and apparently unoccupied (U) were treated as zeros for this calculation. Year-to-year variation was similar between the 13 sampled territories and all 47 monitored territories ( $R^2 = 0.69$ ).

**Table S2.** Percentage similarity (S) to reference conditions and productivity for  $n = 13$  northern goshawk breeding areas monitored 1993-2002 on the Apache-Sitgreaves National Forest, Arizona. Subscripts: CZ = Central Zone of a goshawk breeding area, FB = Foraging Band, GG = forest structure recommended in the goshawk guidelines, GGDIA = diameter distribution recommended in the goshawk guidelines, PFH = forest structure characteristic of preferred foraging habitat, PRE = pre-settlement forest structure. With the data in Tables S1 and S2, you can repeat our analyses, or examine patterns for any of the three measures of reproductive success for any subset of years.

Territory	$S_{GG,CZ}$	$S_{GG,FB}$	$S_{GGDIA,CZ}$	$S_{GGDIA,FB}$	$S_{PFH,CZ}$	$S_{PFH,FB}$	$S_{PRE,CZ}$	$S_{PRE,FB}$
Alder	24.6	40.4	45.3	75.5	79.4	83.5	21.9	26.9
Aniceto Knoll	30.9	52.9	45.9	79.1	61.0	68.8	24.2	29.2
Blevins	27.2	44.2	44.0	66.1	63.0	49.2	33.4	37.6
Danish Hollow	30.6	47.2	57.8	80.1	77.4	71.8	27.6	31.1
Gramma Draw	27.1	38.5	33.4	66.5	50.0	59.1	36.6	34.6
Hart Canyon	28.8	36.2	50.6	69.3	66.2	52.4	32.3	36.1
Heber Hollow	21.5	26.1	32.0	52.5	54.8	56.2	37.5	38.1
Hidden	35.1	40.9	54.0	69.8	67.9	67.7	29.6	25.1
Little Brushy	25.3	37.3	41.7	68.4	76.3	74.7	18.5	23.9
Los Burros	34.3	44.3	47.5	66.8	72.8	75.3	26.0	28.0
Timber Mesa	43.0	57.3	56.8	85.0	43.1	60.1	33.3	34.4
Town Draw	55.7	48.5	81.9	71.2	76.4	75.3	26.0	27.0
Willow Wash	36.0	41.8	57.6	77.7	54.1	52.3	34.9	37.5
Mean	32.3	42.7	49.9	71.4	64.8	65.1	29.4	31.5