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FINAL REPORT

Demography and habitat characteristics of Northern Goshawks on the Apache-Sitgreaves National Forest 1993-2000

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CHAPTER I

Population Viability Analysis of Northern Goshawks in east-central Arizona

Abstract. Status of the Northern Goshawk (*Accipiter gentilis*) was recently reviewed by the U.S. Fish and Wildlife Service (USFWS) to determine whether or not the species should be listed as threatened or endangered west of the 100th meridian in the continental U.S. Lack of adequate demographic data was a reason cited by USFWS in its recommendation not to list (USFWS 1998). Because of this, I monitored demographic vital rates of Northern Goshawks in 44 breeding territories on the Apache-Sitgreaves National Forest for seven years (1993-1999). We developed a stage-structured, stochastic population viability analysis (PVA) model which incorporated goshawk nesting activity rate, fecundity rate, pre-adult survivorship rates, and adult survivorship rate. The model specified the initial number of individual females per stage class (0-1, 1-2, 2-3, >3 years old), initial number of floaters (non-territorial females), and number of years to project the population (e.g., 50 or 100 years). Given a seven-year mean (±SD) nesting activity rate of 48% ± 13, fecundity rate of 0.46 ± 0.14, first year female survivorship rate of 43% ± 16, and adult female survivorship of 80% ± 5, projected lambda over 100 years was 0.87 ± 0.04 95% CI. Sensitivity analysis showed that adult survivorship had the greatest effect on trajectory of the population. Values of key demographic parameters suggest that goshawk reproduction was not sufficient to balance local mortality during the study period, and that the local population would decline in the absence of immigration. However, model results only reflected demographic parameters estimated during a relatively short period characterized by atypical weather patterns (prolonged drought). Thus, it is uncertain whether model results reflect a short-term phenomenon or long-term trend. The greater the number of years I observed the model's demographic input parameters, the more precise were estimates of lambda. This underscores the need for long-term (>10 yrs.) estimates of demographic parameters. Among territories that were monitored at least four years (*n*=42), 10 produced 52% of all fledglings and 55% of female fledglings. The ability to identify highly productive territories may be a valuable tool when managing for viability of this species.

INTRODUCTION

The Northern Goshawk (*Accipiter gentilis*) is afforded special status in Arizona and was recently evaluated for potential listing under the federal Endangered Species Act in the western United States (USFS 1993, USFWS 1998, AGFD *in prep*). Kennedy (1997) did not recognize western North America as a distinct Northern Goshawk population and concluded that there was no strong evidence to support the argument that the species is declining within the United States. However, given the affinity of Northern Goshawks for nesting and foraging areas with high canopy closure and high density of large trees (Beier and Drennan 1997, Squires and Reynolds 1997), timber management practices may negatively impact Northern Goshawks. Concern over the status of the Northern Goshawk prompted the U. S. Forest Service (USFS) to develop and implement management guidelines (Reynolds et al. 1992) across the southwestern U.S.

Maguire and Call (1993) and a recent status review (USFWS 1998) concluded that scarcity of demographic information precluded a meaningful population viability analysis (PVA) for Northern Goshawks. A PVA projects population trajectory or extinction risk over time (Shaffer 1981, Gilpin and Soule 1986, Shaffer 1990). A PVA may also allow managers to determine if a local population is functioning as a sink or source. A sink population does not produce enough young to replace adult mortality and is maintained by continued immigration (Pulliam 1988, Faaborg et al. 1993). In contrast, a source population produces enough young to compensate for adult mortality, while providing a surplus of emigrants.

The purpose of this study was to estimate population viability of Northern Goshawks and evaluate how the number of years that demographic parameters are observed influences the mean and variance of key demographic parameters and population viability. Specific objectives were to: 1) estimate adult and post-fledging survival rates; 2) estimate percent of nests active, percent of active nests that produce young, primary sex ratio, and fledglings per nest; and 3) model the status and population trend of Northern Goshawks on the Apache-Sitgreaves National Forest in east-central Arizona.

STUDY AREA

The study area encompasses the Black Mesa and Lakeside ranger districts on the Sitgreaves portion of the Apache-Sitgreaves National Forests (Fig. 1). The Sitgreaves portion of the Forest is located on the Mogollon Plateau and encompasses approximately 330,300 ha. Elevation ranges from 1768 to 2417 m. Annual precipitation occurs in two seasons, with snow storms in January through March and summer rains in July through September. Soil parent materials are dominated by volcaniclastic deposits, Kaibab limestone, and Coconino sandstone (Darton 1965).

Since European settlement, the Apache-Sitgreaves National Forest has been intensively managed, with much of the area grazed by livestock and used for timber production. Like many National Forest lands in the southwestern U.S., the Apache-Sitgreaves National Forest is currently dominated by stands of younger age class ponderosa pine (*Pinus ponderosa*) (Garrett and Soulen 1999). Most ponderosa pine stands on level terrain have been logged, with steeper slopes of canyons and drainages receiving less logging impact.

A wide range of vegetation communities occur within the study area (Brown 1994). The Mogollon Rim edge is dominated by deep drainages with mixed-conifer communities of Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor)* and ponderosa pine, with pockets of aspen (*Populus tremuloides*), New Mexican locust (*Robinia neomexicana*), and

Gambel oak (*Quercus gambelii*). Ridgetops are generally dominated by ponderosa pine forest. As elevation decreases to the north, ponderosa pine forest transitions to a woodland dominated by alligator juniper (*Juniperus deppeana*), Utah juniper (*J. osteosperma*) and Colorado pinyon pine (*P. edulis*). As elevation decreases further, a Plains Grassland community develops, dominated by blue grama (*Bouteloua gracilis*), sand dropseed (*Sporobolus cryptandrus*), and fourwing saltbush (*Atriplex canescens*).

METHODS

DEMOGRAPHIC PARAMETERS

To find nesting territories, field crews followed the USFS Southwestern Region's Northern Goshawk inventory protocol (Kennedy and Stahlecker 1991), which uses conspecific playback recordings to solicit responses from Northern Goshawks. A tape developed and provided by the USFS included both the adult "alarm" call and the female "wail" call. The adult alarm call was used during the nestling period (June to early July). The wail call was used during the fledgling-dependency period (late July to early September). Tapes were played on a cassette recorder that amplified the call.

In each year from 1993 to 1999, I first visited historical Northern Goshawk breeding areas in April and May to determine occupancy and reproductive status. An historical breeding area is a nest site or a collection of alternative nests in close proximity where breeding activity was previously documented, with the minimum requirement being the observation of an incubating bird. If historical nests were not occupied, crews searched suitable habitat within a 1600 m radius around the last known occupied nest. Suitable nesting habitat included all forested areas except pinyon-juniper woodlands, meadows, and areas defoliated by forest fires (Squires and Reynolds 1997). I visited all occupied non-active territories again in August (fledgling dependency period) in a follow-up attempt to locate active nests. I used conspecific playback recordings within an 800 m radius of the last known active or refurbished nest. Approximately 95% of alternate nests found within a territory in northern California were < 800 m apart (Woodbridge and Detrich 1994). A total of 24 call points were uniformly distributed 300 m apart within this 800 m boundary.

I considered a breeding area occupied if a pair of goshawks were known or inferred to use the area during at least part of the breeding season, based on presence of: 1) a new or refurbished nest; 2) an adult bird at or near a nest structure on two or more occasions; or 3) fresh mutes, molted feathers, and prey remains at a nest. A nest was determined to be active if I observed: 1) a female Northern Goshawk in incubation posture; 2) at least one fresh egg or eggshell fragments; or 3) young Northern Goshawks. I visited active nests periodically during the breeding season (approximately late April through early August) to monitor status and productivity.

The study area contains approximately 200,300 ha of potential nesting habitat (i.e, Montane Conifer Forest type, Brown 1994). Based upon distribution of nest sites (approximately 5.1 km apart), and subtracting areas defoliated by forest fires or occupied by urban development, I used an estimated maximum of 60 territories in the PVA model.

Ages of nestlings were determined using a photographic guide produced by Boal (1994). I deemed an active nest successful if at least one nestling fledged. I climbed active goshawk nests and banded nestlings with USFWS aluminum leg bands when birds were between 30 and 40 days of age. Standard morphological measurements were taken, including: tarsus dorsal/ventral, tarsus lateral, hallux length, beak depth, culmen length, and weight. I used these measurements to determine sex of nestlings (Ingraldi *in prep*). I estimated fledgling sex ratios from broods where sex of all young was determined. I define fecundity as the mean number of female fledglings produced per breeding female.

To assess first year survivorship rates, crews affixed backpack style satellite transmitters (Microwave Telemetry, Inc.), equipped with a mortality sensor, to young female Northern Goshawks, >36 days old (Boal 1994). The complete transmitter package weighed approximately 35 grams, <5% of body mass of each female tagged. Each transmitter was programmed to transmit signals every five days, thereby extending battery life to approximately 62 weeks. Transmitter data were processed by Service Argos, Inc. (Landover, Maryland). Transmitter signals were received by polar-orbiting NOAA weather satellites, and locations were calculated by Argos from Doppler-shifts of signal frequency (Fancy et al. 1988). Ideemed fledglings independent from their parents when they spent > 3 consecutive days > 2 km from the nest site (Kennedy et al. 1994).

Crews captured all unbanded breeding females when nestlings were >10 days old, using a dho-ghaza trap baited with a live Great Horned Owl (*Bubo virginianus*) (Bloom 1987). Crews fitted adult Northern Goshawks with individually numbered colored plastic bands (Haggie Engraving, Crumpton, MD), and USFWS leg bands. Each year, I attempted to resight birds within breeding territories and unmarked birds were captured and marked. I monitored adult females because the primary sex ratio in this population is skewed toward males, suggesting that females may be the limiting sex, and because males were more difficult to resight.

ANALYSIS

I used the Kaplan-Meier estimator (White and Garrott 1990) to calculate survival rates for juvenile female goshawks telemetered in 1995-1997. The Kaplan-Meier procedure is designed for data sets that include censored individuals, i.e., individuals for which contact was lost (e.g., the transmitter failed) and therefore fate is uncertain. I used a log-rank test to test for differences in survival between years (Pollock et al. 1989).

I performed a series of goodness-of-fit tests within the program RELEASE (Burnham et al. 1987) to determine if adult female mark and resight data met assumptions of time-dependent Cormack-Jolly-Seber models (Cormack 1964, Jolly 1965, Seber 1965). Two important assumptions of Cormack-Jolly-Seber models are that each animal has the same probability of resighting and that marked animals have equal probability of survival. I used program MARK (White and Burnham 1999) to estimate adult female survivorship based on the Cormack-Jolly-Seber model. I examined four models (annual survivorship varied and probability of resighting was constant, annual survivorship was constant and probability of resighting varied, both varied, and both were constant) to evaluate whether annual survivorship and probability of resighting varied among years. I used Akaike's Information Criteria (AIC), which is a numerical measure based on the deviance and the number of parameters in a model (the lower the deviance and the fewer the model parameters, the "better" the AIC), to select among competing models (Lebreton et al. 1992). The mark resighting method does not distinguish between mortality and permanent emigration from a study area, and therefore underestimates survival rates.

POPULATION VIABILITY MODEL

I developed a stochastic stage structured model in Microsoft Visual Basic™, using mathematical and graphics macros available in Microsoft Excel™ (Appendix 1a, b and c).

Using the mean and standard deviations of the demographic input parameters (i.e., nesting activity rate, fecundity rate, and stage specific survivorship rates) for each year, the model randomly chose a value from a normal distribution with specified mean and standard deviation and then calculated number of survivors per stage from a binomial distribution, with number of trials equal to number of individuals in the age class or number of active nests. Sub-adult (1 and 2- year-olds) survivorship rates were set equal to those of adults, and first age of reproduction was set at three years. At each time step, the model recorded population size and lambda. Adult females in excess of the maximum number of territories were considered non-territorial "floaters" with a survival rate equal to that of adults. I performed 100 simulations of 100 years each and recorded mean lambda value (N_{t+1} / N_t) and mean population size for each simulation. I deemed the population extinct when the number of breeding females fell below 10, because the model exhibited rapid inflation in the variance of lambda when number of breeding females were <10.

I performed sensitivity analysis on each demographic parameter (survivorship, nesting activity, and fecundity rates) by altering estimated mean values ±10%, ±20%, and ±30% (Burgman et al. 1993). One demographic parameter was altered at a time, therefore interactions among parameters were not evaluated. I also modeled population viability using means and standard deviations of demographic input parameters estimated from years 1993-1996, 1993-1997, 1993-1998 and 1993-1999 to evaluate influence of adding years to the data set.

Density (breeding density or numbers of individuals) has been shown to influence both survivorship (Begon et al. 1996) and fecundity rates (Sinclair 1989, Ferrer and Donazar 1996). I modeled density dependence in reproduction through a ceiling on the number of breeders (i.e., the maximum number of breeding territories was set to 60), but did not incorporate density dependence in survivorship because saturation of neighboring territories would have little effect on survivorship of territorial adult birds. Similarly, I used density independent fecundity rates on the basis of field data, which showed no decrease in fecundity with an increase in the number of breeding birds (Fig. 2).

I estimated environmental variation in demographic parameters by removing sampling variation from total observed variation (Gould and Nichols 1998). Sampling variance for binomial demographic parameters (e.g., survival, activity and fecundity rates) was estimated from binomial probability distributions (Zar 1984:369- 379).

For comparison, I used the software package RAMAS/metapop (Akcakaya 1994) to assess population viability. Fundamental differences between my model and that of RAMAS/metapop were: 1) initial population size was 102 in RAMAS/metapop (60 breeding females, 24 0-year-olds [fledglings], 10 one-year-olds, 8 two-year-olds) and 132 in the constructed model (same number of individuals per cohort as RAMAS/metapop plus 30 non-territorial "floating" females); 2) my model had a ceiling of 60 breeding females; 3) my model used nesting activity rate as a factor contributing to number of fledglings produced; and 4) my model tracked a pool of non-breeding females that can move into the breeding population. In contrast, RAMAS/meta had a ceiling type of density dependence that "killed" all floaters.

RESULTS

DEMOGRAPHIC PARAMETERS

Over the seven-year period 1993 to 1999, mean activity rate of 45 territories was 48% ± 15% SD (± 13% SD when sample variance was removed) (Table 1). Of 128 total nesting attempts, 40 failed, yielding a 31% ± 16 SD mean failure rate among active nests over the course of study.

From 88 successful broods over the seven years, 165 fledglings were produced (Table 2). Among territories monitored at least four years (*n*=42), 10 produced 52% of all fledglings and 55% of female fledglings. Mean number of fledglings produced per active nest was 1.26 ± 0.38 SD, with 1.87 ± 0.14 SD fledglings produced per successful nest. Although number of fledglings produced per active nest fluctuated (0.54-1.66), the number of fledglings produced per successful nest remained relatively constant, between 1.67 and 2.0. Mean fecundity rate was highly variable from year to year (0.23-0.78), with mean of 0.46 ± 0.18 SD (± 0.14 SD when sample variance was removed). Combining years, 89 male fledglings (64%) to 51 female fledglings (36%) produced a sex ratio (male:female, 1.75:1) that differed from a 1:1 sex ratio ($\Pi^2 = 10.31$, *d.f.* = 1, $P = 0.0013$).

Forty-two adult female goshawks were marked over the seven-year period. Assumptions of the Cormack-Jolly-Seber model were met (overall goodness-of-fit, $\Pi^2 = 6.27$, *d.f.* = 9, $P = 0.71$). My comparative models indicated that survivorship was constant among time periods, but probability of resighting varied among years (Table 3). Therefore, environmental variance in adult survival rate was estimated as zero in the PVA models. Estimated annual mean survivorship rate for adult female Northern Goshawks was 80% ± 0.05 SD (95% CI 68% to 88%).

Survivorship rates for fledgling female Northern Goshawks showed no difference between 1995 and 1996 (log-rank test, $\Pi^2 = 0.113$, *d.f.* = 1, $P = 0.74$). I could not test for differences in fledgling survivorship rates between year 1997 and 1995 or 1996 because only two fledglings were tagged in 1997. Pooling across years, annual survivorship rate of 16 female fledglings was 43% ± 16 SD (Fig. 3). During the course of the study, seven confirmed mortalities occurred; cause of death (starvation) was determined in only one case. This confirmed case of starvation occurred in the second week of the independent period. The other nine transmitters were censored because they failed within the expected battery life span. I observed no fledgling mortality after the 31st week post fledgling, until the last transmitters failed (the 52nd week).

POPULATION VIABILITY ANALYSIS

A mean lambda value of 0.87 ± 0.02 SE for Northern Goshawks was estimated over the seven-year period. Because the 95% confidence limits (0.83 to 0.91) did not encompass 1, a population with these demographic parameters for 100 years would decline in the absence of immigration. The model projects the number of breeding females falling below 10 at 24 years (Fig. 4), with the total population falling below 16 individuals. Sensitivity analysis showed that adult survivorship had the greatest effect on lambda (i.e., the linear regression curve possessed the greatest slope) and that nesting activity rate was also influential (Fig. 5). The greater number of years I observed the model's demographic input parameters, the more precise was my estimate of lambda (Table 4). The RAMAS/metapop model produced a lambda of 0.93 ± 0.005 SE (95% confidence limits of 0.92 to 0.94).

DISCUSSION

REPRODUCTIVE PARAMETERS

Nesting success often is overestimated in studies with seasonal nest searches, because nests failing early in a season are less likely to be detected than are successful nests (Mayfield 1961, Johnson 1979, Steenhof and Kockert 1982). However, Reynolds and Joy (1998) found that past estimates of nesting success from monitoring traditional Northern Goshawk territories differed by no more than 3% in any year compared with the Mayfield method, suggesting that such bias is negligible. Therefore, this suggests that my nest search protocol would have no potential bias in underestimating nest failures. By 1995, 89% of nesting territories had been located, therefore this potential bias from missing nesting attempts that failed early on was low during 1996 to 1999. Occupancy rate is a poor indicator of Northern Goshawk population status, because detecting territory occupancy for Northern Goshawks is influenced by the amount of search time, experience of field personnel, and difficulty of the terrain. Success rate and number of fledglings per active nest are better indices of the reproductive status of a population, given an adequate sample size. Nest success and mean number of fledglings per active nest were lower than most rates reported west of the 100th meridian (Table 5). Fragmentation of suitable foraging and nesting habitat, low prey populations, or dry weather conditions during the study (Ingraldi and Rosenstock *in review*) may be reasons for these lower reproductive rates. On average, I monitored 39 territories per year, which exceeds the minimum estimate of 35 Northern Goshawk nesting territories needed to precisely estimate nest productivity and nesting success on the Kaibab Plateau in northern Arizona (Reynolds and Joy 1998).

Mean number of fledglings per successful nest on the Apache-Sitgreaves National Forest was just below that found in other studies of Northern Goshawks in the western United States (Table 5). Number of fledglings per active nest also was below average, which was reflected in lower than average nest success (Table 5). Number of fledglings produced per successful nest is a more meaningful measure of productivity of a population than is the number of fledglings produced per active nest (Steenhof 1987). The latter statistic is influenced by failures due to extraneous and unpredictable factors, such as the loss of a nest tree to windthrow. In contrast, number of fledglings per successful nest more directly reflects experience of breeding birds (usually related to age) or quality and availability of prey (Newton 1979). The relatively low nest success rate (69%) suggests that some territories may have been attractive to nest in, but were not suitable to produce young, or that detrimental abiotic factors (e.g., high precipitation) during critical times in the nesting cycle may be influencing nest success (Ingraldi and Rosenstock *in review*).

Because 10 nesting territories produced >50% of all fledglings and 50% of female fledglings, decreasing habitat quality within these territories may have long-term impacts on the viability of Northern Goshawks within the study area. Similarly, on the Kaibab Plateau, 20% of nesting territories contributed 80% of overall fledgling production (R. Reynolds, Rocky Mountain Research Station, pers. comm.).

SURVIVORSHIP

I observed two major periods of mortality after fledgling birds became independent. The first mortality period was 3-7 weeks after fledgling independence and the other occurred in January (Fig 3.). The mortality episode during the early independent period may have been caused by young inexperienced birds searching for areas to winter and landing in habitat with limited prey or high concentrations of predators. The mortality episode occurring in January may have been caused by low temperatures and deep snow that commonly occur at this time in ponderosa pine vegetation cover type. In addition, availability of prey for Northern Goshawks may decrease in winter due to hibernation, torpor, or migration of many prey species.

High variance associated with my survival estimate of fledgling birds was most likely due to the low number of birds monitored. Pollock et al. (1989) estimated that 20 individuals need to be tracked at one time to obtain a precise survival estimate using the Kaplan-Meier estimator. My estimate of fledgling survivorship was lower than four other studies (2 in North America, 2 in Scandinavia), which estimated first year survivorship rates in Northern Goshawks (Table 6). Survival rates were lower in Europe than in New Mexico. Comparisons made between survivorship rates of Northern Goshawks in the U.S. and Europe (where they are legally killed to protect game birds) must be questioned. But of 220 Northern Goshawks (114 male and 106 female) radio tagged in Europe by Kenward et al. (1993), only 15 were shot.

My estimated annual survivorship for adult females (80%) fell within the 70% to 87% range reported by other studies (Table 7). I observed lower survivorship rates for adult females than did Reynolds and Joy (1998) on the Kaibab Plateau during 1991-1996. This difference may be due to more favorable weather conditions in the early1990s (Ingraldi and Rosenstock *in review*), larger areas of forest stands with old-growth attributes on the Kaibab Plateau, or that there was a greater proportion of larger trees on the Kaibab Plateau.

The mark-resight method yields poor estimates of adult survivorship, because only a small proportion of marked birds are resighted, particularly in years when nesting activity rate is low. This was evident in that my resighting probabilities varied greatly among years (mean 62%, range 38%-100%), reflecting annual changes in number of breeding pairs and, therefore, opportunities for resighting birds. Although I could not confirm that my data violated the assumption of equal catchability, I believe that adult females occupying more productive territories were marked more often than were females from territories with low nesting activity rates. This would upward bias my estimate of survivorship, if birds from more productive territories live longer. Finally, higher resighting probabilities yield more precise estimates of survival (Pollock et al. 1990), thus my low resighting probabilities may justify caution when using the survivorship estimate in my population viability analysis model.

POPULATION VIABILITY ANALYSIS

My PVA model made several important assumptions, including that sub-adult survivorship was equal to that of adults, and that survivorship was density independent. Subadults (1- and 2-year olds) likely have survival rates intermediate between those of 0-year olds and adults. If so, my model over-estimated lambda. Although my data could not demonstrate density dependence in survival or reproduction rates, such relationships probably do exist (Sinclair 1989, Begon et al. 1996). If so, my model overestimated the width of the confidence interval on lambda. Also, demographic estimates over the seven years of study may not have adequately represented inherent variation in those parameters. However, if the demographic parameters I observed over the seven year period were to persist, my model suggests that Northern Goshawks will not continue to occupy the Apache-Sitgreaves National Forest without immigration of birds into the study area. Northern Goshawks are a mobile species (Squires and Reynolds 1997), and the Apache-Sitgreaves National Forest is part of a larger contiguous forest of ponderosa pine in central Arizona. Therefore, at times of low reproductive performance or episodes of high adult mortality, connectivity with a larger population of Northern Goshawks may assist in buffering any local fluctuations in these demographic parameters. Consequently, the Apache-Sitgreaves National Forest may be a "sink" habitat (Pulliam 1988) for Northern Goshawks.

Commercially available PVA models, such as RAMAS/metapop, do not provide for the flexibility needed to model certain raptor populations (e.g., the inability to reflect non-territorial birds of breeding age). This lack of model flexibility may be the reason for the discrepancies in estimated lambdas. The RAMAS/metapop output would lead one to believe that the study population is not as dire as my model predicts, but it nonetheless showed a declining population.

Adult survivorship rate was the most important parameter influencing population growth rate. This finding is consistent with previous analys indicating that adult survivorship is more important than is fledging success for population viability of peregrine falcons (*Falco peregrinus*); (Wooton and Bell 1992), northern spotted owls (*Strix occidentalis caurina*); (Noon and Biles 1990) and lesser kestrels (*Falco naumanni*) (Hiraldo et al. 1996). Although my estimate for survival rate may be inaccurate (as discussed above), this parameter would have to be about 88% or greater to maintain a lambda of 1, other demographic parameters being equal (Fig. 5A).

Finally, the low survivorship and reproductive performance may reflect the fact that the Apache-Sitgreaves National Forest is on the southern edge of the range of *A. g. atricapillus*. Population density tends to be greatest near the center of the range and lower toward the boundaries, because resources are often scarce and/or environmental conditions approach tolerance limits at a species's geographic fringe (Brown 1984). Also, direct and indirect effects of climate often seem to be important in the persistence of marginal populations (Hoffmann and Blows 1994). This is especially important given that environmental factors may affect demographic rates of northern goshawk populations (Widen 1997, Ingraldi and Rosenstock *in review*).

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Table 1. Status and number of Northern Goshawk territories monitored on the Apache-Sitgreaves National Forest, Arizona, 1993-1999.

Variable	Year							Mean (SD)
	1993	1994	1995	1996	1997	1998	1999	
Territories monitored	26	33	39	42	42	44	45	38.7 (6.9)
Active territories	18	11	26	22	13	19	19	18.3 (5.1)
Activity rate[1]	0.69	0.33	0.66	0.52	0.31	0.43	0.42	0.48 (0.15)
Occupied territories	25	27	33	30	20	23	25	26.1 (4.3)
Occupancy rate[2]	n/a[4]	0.82	0.85	0.71	0.48	0.52	0.55	0.66 (0.16)
Unoccupied	n/a[4]	6	6	12	22	21	20	14.5 (7.5)
Failed nests	1	3	12	6	7	4	7	5.7 (3.5)
Failure rate[3]	0.06	0.27	0.46	0.27	0.54	0.21	0.37	0.31 (0.16)

[1]Number of active territories / total number of territories monitored.

[2]Number of occupied territories / total number of territories monitored.

[3]Number of failed territories / number of active territories.

[4]n/a = not applicable because first year of study.

Table 2. Productivity of Northern Goshawk territories monitored on the Apache-Sitgreaves National Forest, Arizona, 1993-1999.

	Year							
Variable	1993	1994	1995	1996	1997	1998	1999	Mean (SD)
Total no. fledglings	30	16	27	28	10	30	24	23.6 (7.7)
No. male fledglings	10	9	17	16	7	17	13	12.7 (4.1)
No. female fledglings	9	3	10	8	3	10	8	7.3 (3.0)
No. fledglings of unknown sex	11	4	0	4	0	3	3	----
Fledglings/active nest	1.66	1.45	1.04	1.27	0.54	1.58	1.26	1.26 (0.38)
Fledglings/succ. nest	1.76	2.00	1.93	1.75	1.67	2.00	2.00	1.87 (0.14)
Sex ratio[1]	1.1:1	3:1	1.7:1	2:1	2.3:1	1.7:1	1.6:1	1.75:1 [3]
Fecundity[2]	0.78	0.36	0.38	0.41	0.23	0.58	0.47	0.46 (0.18)

[1] Males:female.

[2] Number of fledgling females produced per breeding female (i.e., active nests). The fecundity calculation incorporates the number of fledglings of unknown sex in proportion to the sex ratio from the current year.

[3] The sex ratio for the pooled number of males / females (89/51) from all years.

Table 3. Capture-recapture models used to estimate survival rate of adult female Northern Goshawks on the Apache-Sitgreaves National Forest in east-central Arizona, 1993 - 1999. The low AIC value for the first model below suggests the best model fit.

Model	Deviance	No. parameters	AIC	Mean survivorship rate (± SE)
Survival rate constant, probability of resighting varies with year	57.747	6	161.77	0.80 ± 0.05
Survival rate and probability of resighting varies with year	50.507	9	161.99	0.77 ± 0.07
Survival rate varies with year, probability of resighting is constant	62.47	5	163.72	0.77 ± 0.08
Survival rate and probability of resighting is constant	71.720	2	166.72	0.79 ± 0.05

Table 4. The number of years of observation had profound influences on the long-term expected value of lambda, and on adult survivorship (the most influential demographic parameter in our PVA).

Years of observation	Duration (yrs.)	Nesting activity rate (mean ± SD)	Fecundity rate (mean ± SD)	Adult female survivorship (mean ± SD)	Estimated lambda (95% CI)
1993-1996	4	0.55 ± 0.14	0.48 ± 0.17	0.70 ± 0.09	0.77 (0.69-0.85)
1993-1997	5	0.50 ± 0.16	0.43 ± 0.18	0.74 ± 0.07	0.82 (0.76-0.88)
1993-1998	6	0.49 ± 0.14	0.46 ± 0.16	0.75 ± 0.07	0.84 (0.80-0.88)
1993-1999	7	0.48 ± 0.13	0.46 ± 0.14	0.80 ± 0.05	0.87 (0.83-0.91)

Table 5. Productivity of Northern Goshawk populations west of the 100th meridian.

Location	Year	No. active nests[1]	No. successful nests[2]	Mean no. fledglings / active nest	Mean no. fledglings / successful nest	Nest success (%)[3]	Source
E. Arizona	1993-99	128	88	1.29	1.88	69	This Study
N. Arizona	1988-90	NA	NA	1.68	2.00	82	Zinn & Tibbitts 1990
N. Arizona	1991-96	273[4]	224[4]	1.55[4]	1.88[4]	82[4]	Reynolds & Joy 1998
SE Arizona	1993-94	14	11	1.50	1.90	79	Snyder 1995
California	1981-83	181	164[4]	1.71	1.89[4]	91[4]	Bloom et al. 1986
Arizona	1990-92	22	20	1.90	2.20	91	Boal & Mannan 1994
California	1987-90	23	18	1.39	1.77	78	Austin 1993
New Mexico	1984-88	16	NA	0.94	2.14	NA	Kennedy 1989
Oregon	1992	12	10	1.2	1.40	83	Bull & Hohmann 1994
Oregon	1992-93	50	NA	1.28[4]	N/A	N/A	DeStefano et al. 1994
C. Arizona	1990-91	NA	23	N/A	1.72	N/A	Dargan 1991
Alaska	1971-73	33	NA	2.00	2.70	N/A	McGowan 1975
Alaska	1991-96	56	53[4]	1.90	2.00[4]	95[4]	Titus et al. 1997
California	1984-92	84	73[4]	1.93	2.22[4]	87[4]	Woodbridge & Detrich 1994
Oregon	1969-74	48	NA	1.70	N/A	90	Reynolds and Wight 1978
Mean[6]	----	----	----	1.59	1.99	86	----

[1]An active nest is where at least an egg was laid or inferred to be laid by a female (e.g., a bird seen in incubation posture). [2]A successful nest fledged at least one young. [3]Nesting success is the proportion of active territories that successfully produced young. [4]Estimated from data presented. [5]Mean nesting success. [6]Excluding this study.

Table 6. Estimated post-fledging survivorship calculated for Northern Goshawks in previous studies. We used satellite transmitters to estimate survivorship, all other studies but Haukioja and Haukioja (1970) used radio-tagged birds. Time monitored survivorship is the proportion surviving the number of months indicated (i.e., rates are not annualized).

Location	Year	Time monitored survivorship (SE)	Annualized survivorship	N	Mos. post fledging[1]	Source
E. Arizona	1995-97	.43 (0.06)[2]	.41	16	11.5	This Study
N. New Mexico	1992	.91 (0.09)[3]	.81	12	5.5	Ward & Kennedy 1996
N. New Mexico	1992	.93 (0.06)[4]	.85	15	5.5	Ward & Kennedy 1996
N. New Mexico	1993	1.0 (0.0)[3]	1	9	7	Ward & Kennedy 1996
N. New Mexico	1993	.67 (0.27)[4]	.50	3	7	Ward & Kennedy 1996
Alaska	1992-93	.50 (N/A)	.16	14	4.5	Titus et al. 1994
Gotland, Sweden	1980-87	.86 (N/A)	.55	220	3	Kenward et al. 1993
Gotland, Sweden	1980-87	.69 (N/A)	.48	220	6	Kenward et al. 1993
Gotland, Sweden	1980-87	.52 (N/A)	.52	220	12	Kenward et al. 1993
Fennoscandia, Europe	1950-66	.37 (N/A)[5]	.37	552	12	Haukioja & Haukioja 1970

[1]The number of months monitored after fledging.

[2]Calculated survivorship for females only.

[3]Treatment in supplemental feeding experiment.

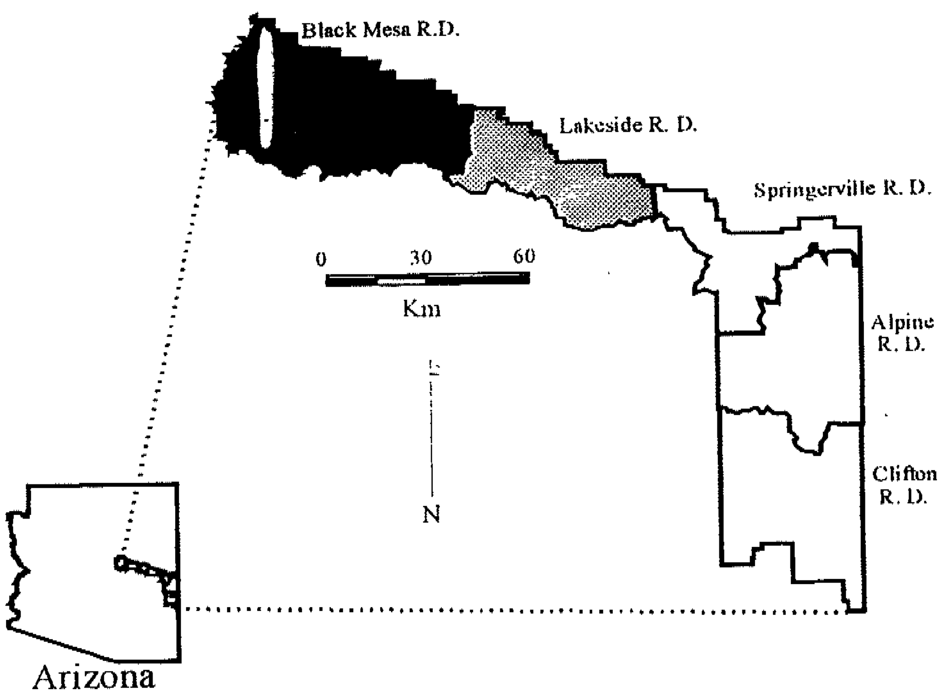
[4]Control in supplemental feeding experiment.

[5]Estimated from banding.

Table 7. Estimated mean survivorship rates for adult female Northern Goshawks in previous studies.

Location	Year	Survivorship (SE)	N	Source	Method
Cen. Arizona	1993-1999	0.80 (0.05)	42	This Study	Mark-resight
N. Arizona	1991-1996	0.87 (0.05)	99	Reynolds and Joy 1998	Mark-resight
N. California	1983-1992	0.70 (0.10)	40	DeStefano et al. 1994	Mark-resight
N. New Mexico	1984-1995	0.86 (0.09)[1]	45	Kennedy 1997	Mark-resight
Gotland, Sweden	1980-1985	0.79 (N/A)	132	Kenward 1993	Radio tracking
Alaska	1992-1996	0.72 (N/A)[1]	39	Iverson et al. 1996	Radio tracking
Fennoscandia, Europe	1950-1966	0.86 (N/A)[1]	552	Haukioja and Haukioja 1970	Band returns

[1] Annual survivorship reported for adults (male and female combined).



Black Mesa R.D.
Lakeside R. D.
Springerville R. D.
Alpine R. D.
Clifton R. D.
0 30 60
Km
N
Arizona

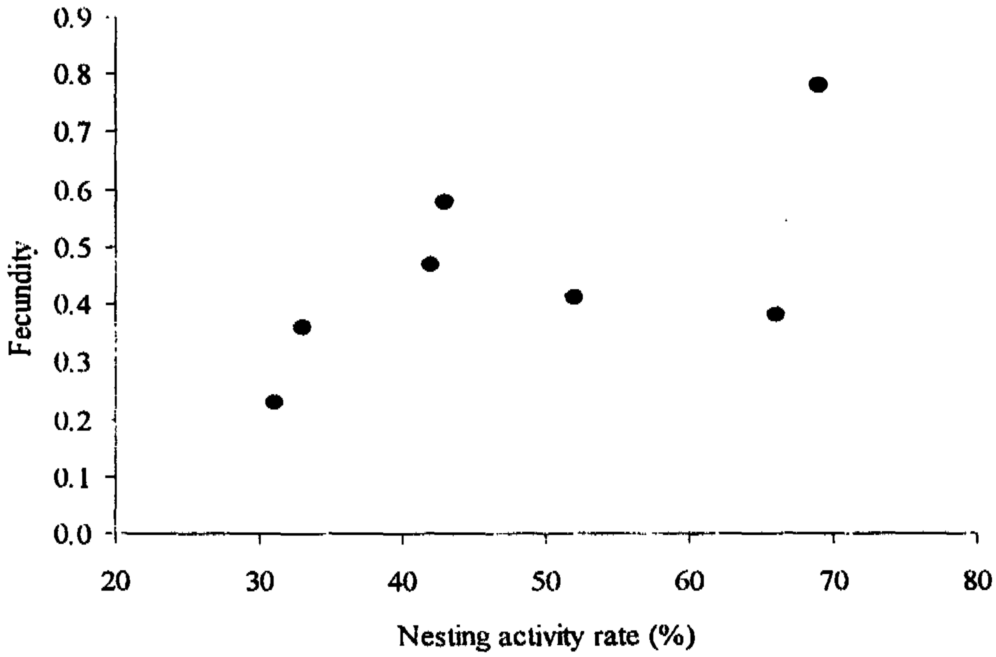


Figure 1. Northern Goshawk study area includes the Black Mesa and Lakeside ranger districts of the Apache-Sitgreaves National Forest, in east-central Arizona.

Figure 2. Nesting linear regression of activity rate plotted against fecundity rate ($r^2 = 0.37$, $P = 0.14$) for Northern Goshawks nesting on the Apache-Sitgreaves National Forest, Arizona 1993-1999.

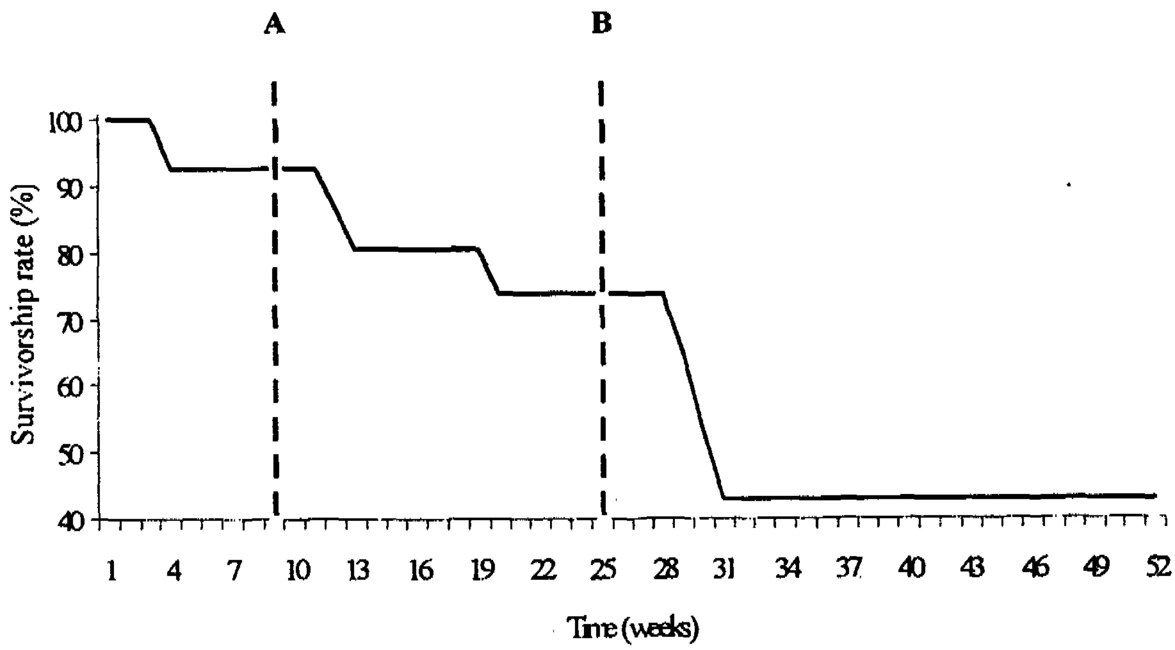


Figure 3. Kaplan-Meier estimate of first year survivorship estimated from 16 fledgling Northern Goshawk females tagged with satellite transmitters on the Apache-Sitgreaves National Forest, Arizona, 1995-1997. The vertical line marked A depicts the average time when fledglings became independent from their parents and vertical line B is approximately mid-December when the inclement winter weather usually begins.

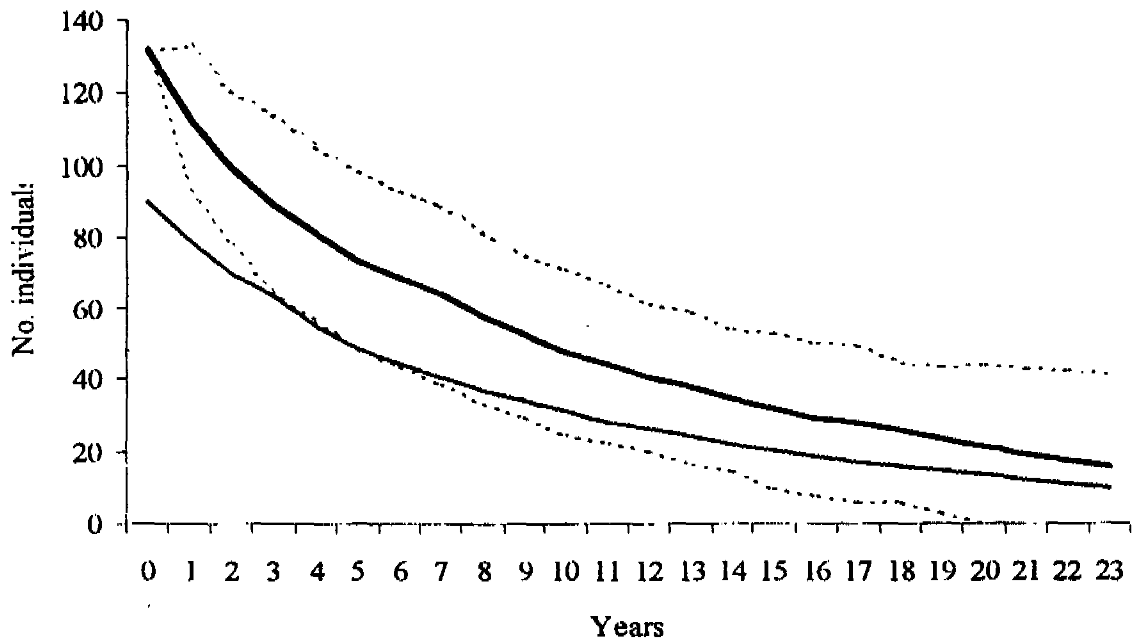


Figure 4. Projections of the total number of females population and number of breeding female Northern Goshawks estimated from a population viability analysis program (see text) and using estimated demographic parameters collected on the Apache-Sitgreaves National Forest, Arizona, 1993-1999. The heavy solid line represents the mean total population and the dashed lines represent the 95% CI. The light solid line represents the mean number of females of breeding age.

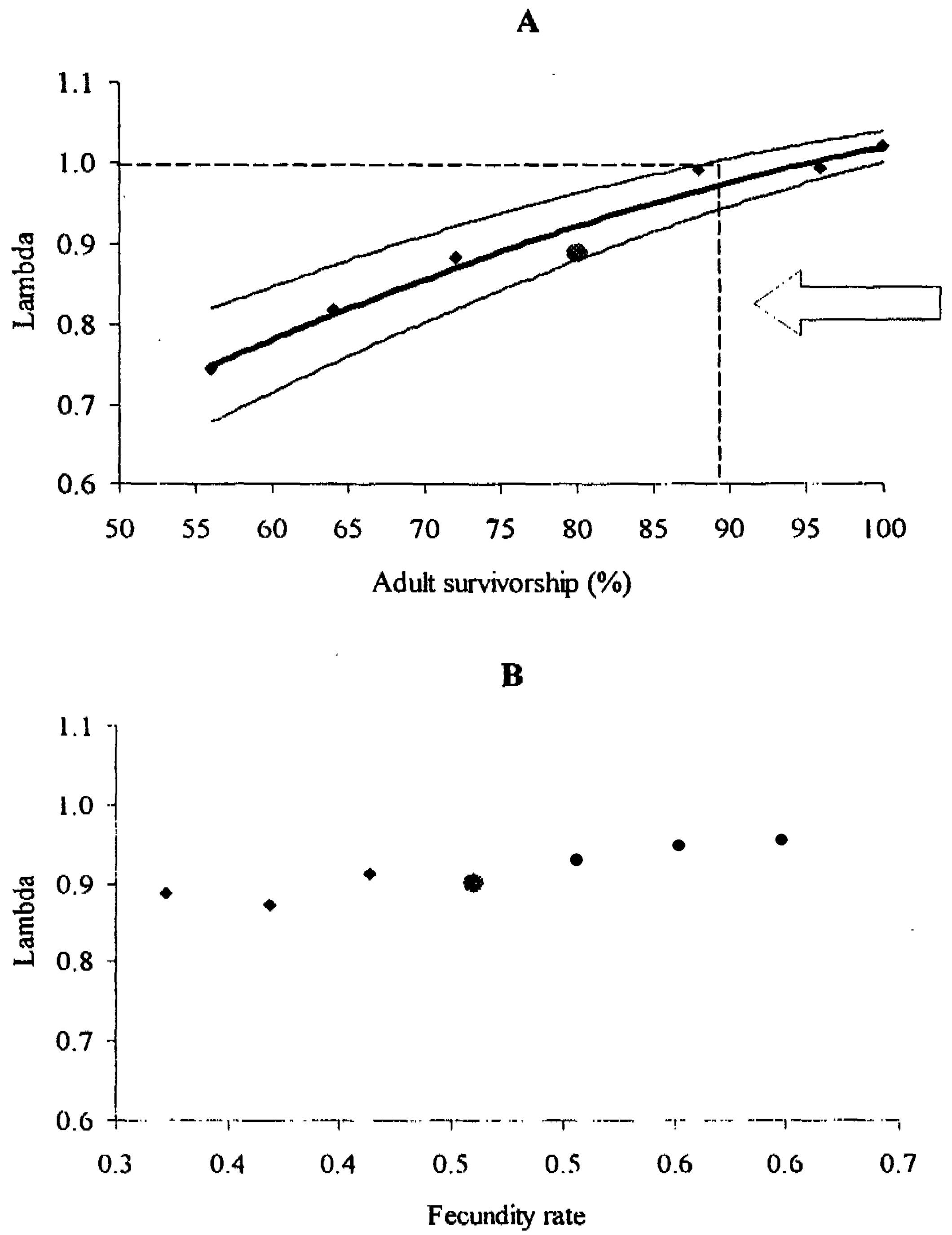


Figure 5A, B, C, and D. Sensitivity analysis of the population viability model's demographic input parameters estimated from a population of Northern Goshawks on the Apache-Sitgreaves National Forest, Arizona, 1993-1999. The points represent deviance of 10%, 20% and 30% from the estimated value (circle). In figure A, the heavy solid curve is a fitted second degree polynomial to the mean lambdas and the light lines represent the 95% CI. Adult survivorship ∃88% would yield a stable population.

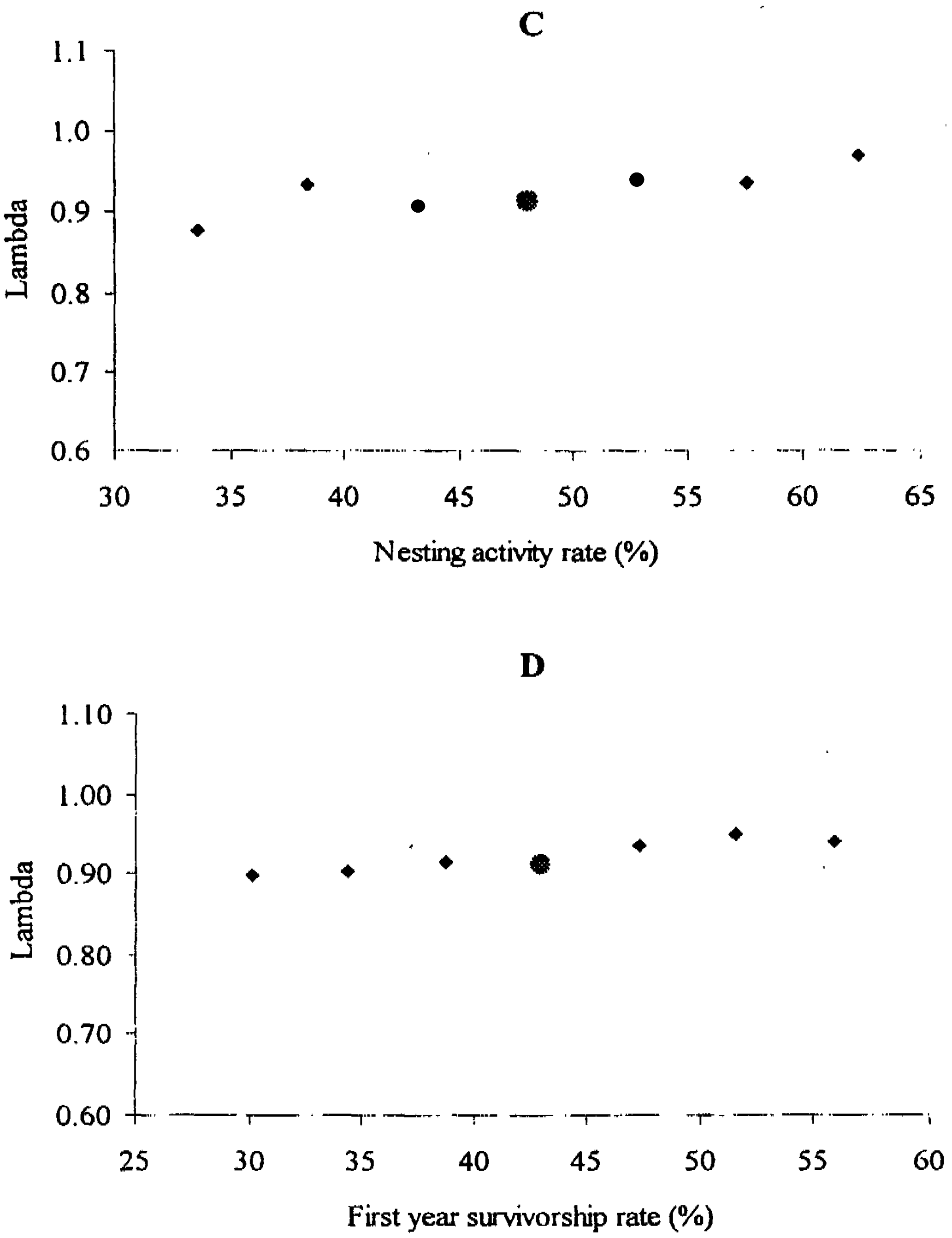


Figure 5A, B, C, and D. Continued.

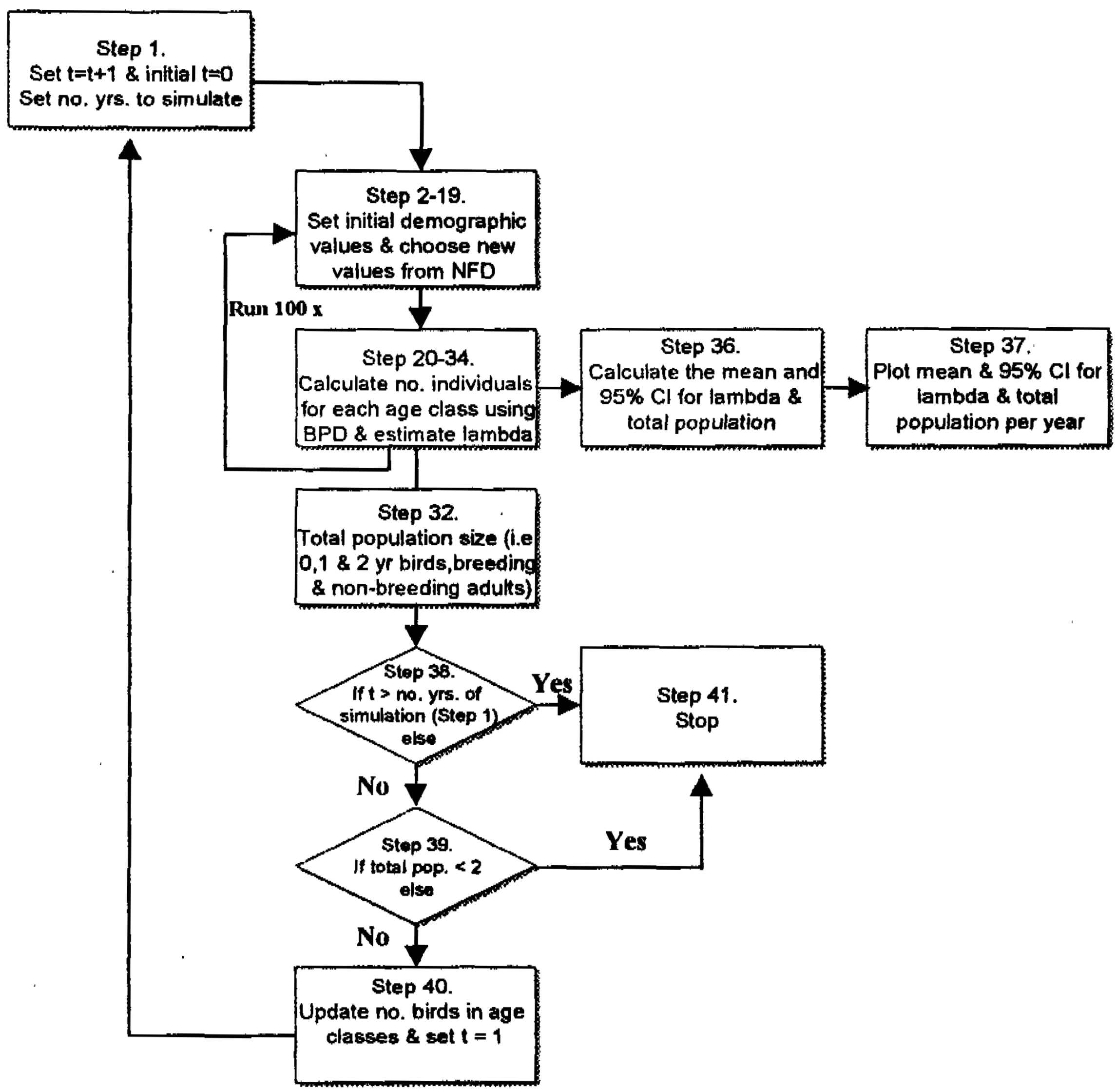
Appendix 1a. Population viability analysis model used to estimate population projection for northern goshawks on the Apache-Sitgreaves National Forest, Arizona.

STEP	TASKS
0	Set t = 1 + t and enter initial t = 0
1	Enter the number of years to simulate population growth.
2	Enter the maximum number of territories within the area of simulation.
3	Enter the initial number of 0-year-old birds.
4	Enter the initial number of 1-year-old birds.
5	Enter the initial number of 2-year-old birds.
6	Enter the initial number of breeding adults (3+) year old birds.
7	Enter the initial number of non-territorial ("Floaters") female adults.
8	Enter the calculated activity rate and SD.
9	Enter the calculated fecundity and SD.
10	Add **STEPS 3+4+5+6+7** = Initial total population.
11	Enter the calculated 0-year-old survivorship rate and SD.
12	Randomly choose a 0-year-old survivorship rate from a normal frequency distribution calculated using the survivorship statistics from **STEP 11** and truncate values > 0 and < 1.
13	Enter the calculated 1-year-old survivorship rate and SD.
14	Randomly choose a 1-year-old survivorship rate from a normal frequency distribution calculated using the survivorship statistics from **STEP 13** and truncate values > 0 and < 1.
15	Enter the calculated 2-year-old survivorship rate and SD.
16	Randomly choose a 2-year-old survivorship rate from a normal frequency distribution calculated using the survivorship statistics from **STEP 15** and truncate values > 0 and < 1.
17	Enter the calculated adult female survivorship rate and SD.
18	Randomly choose an adult survivorship rate from a normal frequency distribution calculated using the survivorship statistics from **STEP 17** and truncate values > 0 and < 1. (Breeders)
19	Randomly choose an adult survivorship rate from a normal frequency distribution calculated using the survivorship statistics from **STEP 17** and truncate values > 0 and < 1. (Floaters)

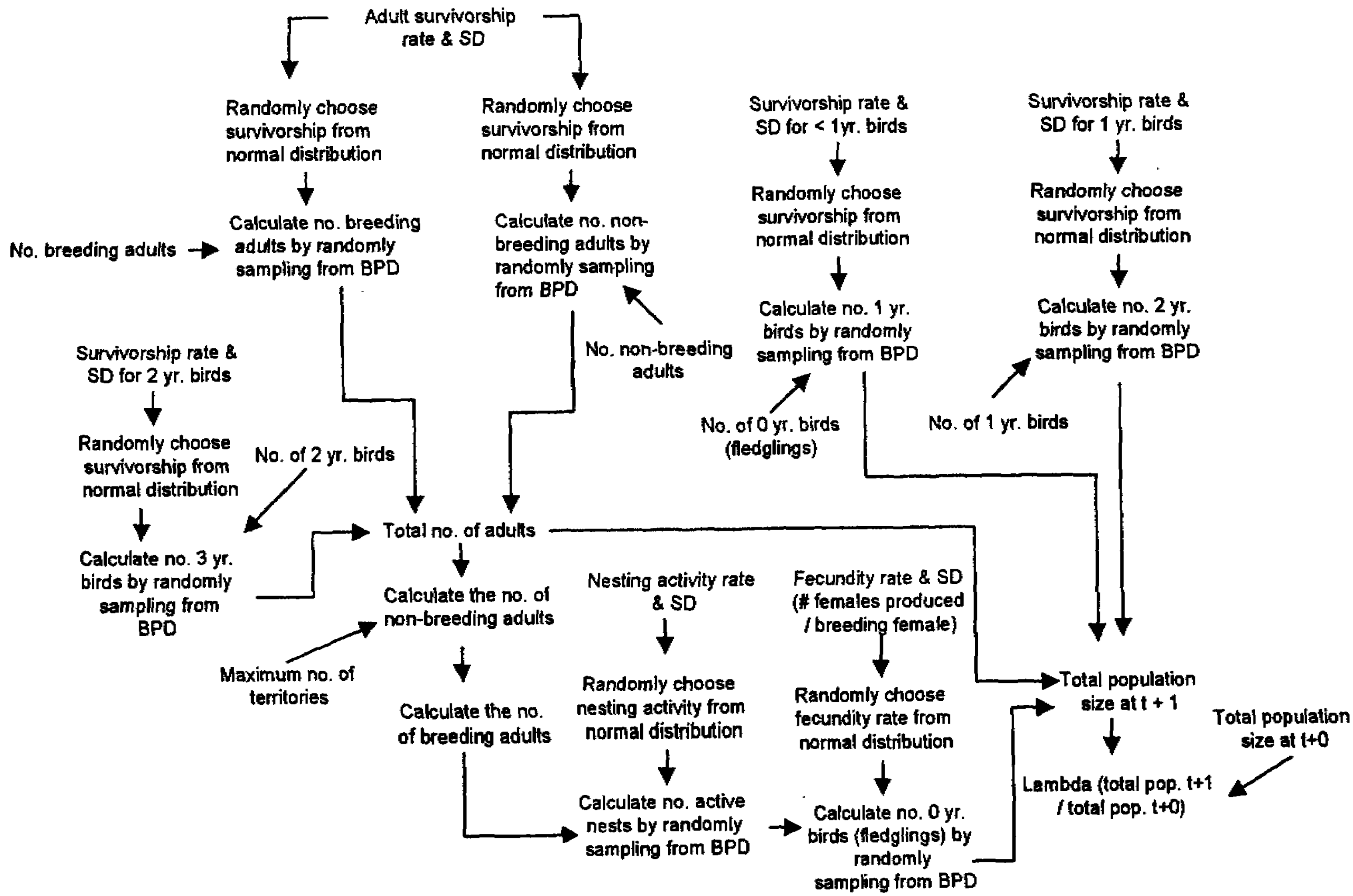
t + 1	
20	Calculate the number of 1-year-old birds by randomly sampling from a binomial probability distribution. The probability of success at each trial equals the value from **STEP 12** (i.e., the 0-year-old survivorship rate) and the number of trials equals the number of 0-year-olds from the previous year (**STEP 3**). (Calculates the number of 1-year-olds in t+1)
21	Calculate the number of 2-year-old birds by randomly sampling from a binomial probability distribution. The probability of success at each trial equals the value from **STEP 14** (i.e., the 1-year-old survivorship rate) and the number of trials equals the number of 1-year-olds from the previous year (**STEP 4**). (Calculates the number of 2-year-olds in t+1)
22	Calculate the number of 3-year-old birds (new adults) by randomly sampling from a binomial probability distribution. The probability of success at each trial equals the value from **STEP 16** (i.e., the 2-year-old survivorship rate) and the number of trials equals the number of 2-year-olds from the previous year (**STEP 5**). (Calculates the number of 3-year-olds in t+1)
23	Calculate the number of adult birds (i.e., that were previous breeders) by randomly sampling from a binomial probability distribution. The probability of success at each trial equals the value from **STEP 18** (i.e., the adult survivorship rate for breeders) and the number of trials equals the number of breeding adults from the previous year (**STEP 6**). (Calculates a portion of the number of breeding adults in t+1)
24	Calculate the number of "floating" adult birds (i.e., from previous floaters) by randomly sampling from a binomial probability distribution. The probability of success at each trial equals the value from **STEP 19** (i.e., the adult survivorship rate for floaters) and the number of trials equals the number of floating adults from the previous year (**STEP 7**). (Calculates the number of floating adults just prior to the breeding season in t+1)
25	Add the number of "new" adults, breeding adults and floating adults (**STEP 22 + STEP 23 + STEP 24**)
26	IF the total number of adults in **STEP 25** is # the maximum number of territories value in **STEP 2**, then the number of floaters at t+1 = 0. ELSE the total number of adults in **STEP 25** minus the maximum number of territories value in **STEP 2**, equals the number of floaters at t+1.
27	The total number of breeding adults equals **STEP 25 - STEP 26**.
28	Randomly choose an activity rate from a normal frequency distribution using the mean activity statistics from **STEP 8** and truncate values > 0 and < 1.

29	Calculate the number of active nests by randomly sampling from a binomial probability distribution. The probability of success at each trial equals the value from **STEP 28** and the number of trials equals the number of breeders **(STEP 27)**
30	Randomly choose a mean fecundity rate from a normal frequency distribution using the mean fecundity statistics from **STEP 9** and truncate values > 0 and <1.
31	Calculate the number of 0-year-olds by randomly sampling from a binomial probability distribution. The probability of success at each trial equals the value from **STEP 30** and the number of trials equals the number of active nests from **STEP 29.**
32	The total population size a t+1 = **STEP 20** + **STEP 21** + **STEP 25** + **STEP 31**
33	Lambda equals the total population size at t+1 **(STEP 32)** divided by the total population size at t+0 **(STEP 10)**.
34	Save values from **STEPS 20, 21, 22, 23, 24, 29, 31, 32 & 33**
35	Repeat **STEP 20** through **STEP 34** 100 times
36	Calculate a mean and 95% CI for **STEPS 20, 21, 22, 23, 24, 29, 31, 32 & 33** and write to file
37	Plot **STEP 32** (mean and CI) and Plot **STEP 33** (mean and CI) on separate line graphs (x-axis = time t and y-axis = either total population or lambda respectively).
38	If t ∃ **STEP 1** go to **STEP 41** end, ELSE go to **STEP 39**
39	If **STEP 32** # 1 then go to **STEP 41** else go to **STEP 40**
40	Update values for **STEPS 3, 4, 5, 6, & 7** and add t=1 to **STEP 0**
41	**STOP**

Appendix 1B. Population viability analysis model used to estimate population projection for northern goshawks on the Apache-Sitgreaves National Forest, Arizona. NFD = normal frequency distribution, BPD = binary probability distribution, CI = confidence interval.



Appendix 1C. Detail of the population viability analysis model steps 2 though 34 used to estimate lambda and population size. NFD = normal frequency distribution, BPD = binary probability distribution, CI = confidence interval, SD = standard deviation.



CHAPTER II

Habitat characteristics associated with high and low quality Northern Goshawk territories

INTRODUCTION

A top predator of the ponderosa pine (*Pinus ponderosa*) forest ecosystem, the northern goshawk (*Accipiter gentilis*) nests in mature and old-growth forest stands (Squires and Reynolds 1997). The goshawk is a state species of special concern in Arizona (Arizona Game and Fish Department *in prep)* and a U.S. Forest Service (USFS) sensitive species in the Southwestern Region (USDA Forest Service 1993*a*). The southwestern population of the northern goshawk was recently evaluated for potential listing under the federal Endangered Species Act (U.S. Fish and Wildlife Service 1998). Concern over the status of the goshawk prompted the U.S. Forest Service to develop management recommendations for southwestern forests occupied by breeding goshawks (Reynolds et al. 1992). Implementation of these recommendations may affect goshawks throughout ponderosa pine forests of Arizona and New Mexico. Although USFS goshawk management guidelines define desired stand and landscape-level forest conditions, benefits of these recommendations have not been empirically assessed. Similarly, long-term goshawk responses to forest restoration prescriptions are unknown and cannot be directly evaluated for at least a decade.

Goshawks use areas with high canopy closure and a high density of large trees for both nesting (many studies, summarized by Reynolds et al. 1992) and foraging (Beier and Drennan 1997, Drennan and Beier, unpublished data). Management actions that decrease canopy or tree density may decrease goshawk reproduction and survival. For example, reduction of canopy cover may favor red-tailed hawks (*Buteo jamaicensis*) and great horned owls (*Bubo virginanus*) that compete with (and prey on) goshawks (Cranell and DeStefano 1992, Rohner and Doyle 1992). Such concerns have been cited by some observers as evidence that forest restoration prescriptions may harm goshawks. However, the fact that goshawks prefer dense habitat structure does not necessarily mean that goshawk fitness will decline significantly, or at all, when forest conditions become less dense. To address this issue, this pilot study related one aspect of goshawk fitness (nest productivity) directly to stand structure for two goshawk nests on the Apache-Sitgreaves National Forest in Arizona. By using existing data from a long-term (8-year) study of goshawk demography, I examined the relationship between landscape-scale habitat characteristics and goshawk population performance. The objective of this pilot study was to measure and compare landscape-scale habitat characteristics within high and low reproductive northern goshawk nesting territories on the Apache-Sitgreaves National Forest.

STUDY AREA

The Sitgreaves portion of the Apache-Sitgreaves National Forest is located on the Mogollon Plateau in east-central Arizona, and encompasses approximately 330,300 ha. Elevation ranges from 1,768 to 2,417 m. A wide range of vegetation communities occured within the study area (Brown 1994). The southern portion of the study area was dominated by deep drainages with mixed-conifer communities of Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor),* and ponderosa pine (*Pinus ponderosa*), with pockets of aspen (*Populus tremuloides*), New Mexico locust (*Robinia neomexicana*) and Gambel oak (*Quercus gambelii*). Ridgetops generally were dominated by ponderosa pine forest. As elevation decreased to the north, a ponderosa pine/juniper-pinyon ecotone transitioned to juniper-pinyon woodland, dominated by alligator juniper (*Juniperus deppeana*), Utah juniper (*J. osteosperma*), and Rocky Mountain pinyon (*P. edulis*).

METHODS

I classified all northern goshawk territories within the ponderosa pine forest type that were monitored from 1993-2000 into high and low reproductive classes (Fig. 1). Territories that averaged 1 fledgling produced/active nest were considered high, and those averaging #1 fledgling/active nest were considered low. I randomly chose a northern goshawk territory from each reproductive class. Territories chosen were Willow Wash (high) and Timber Mesa (low) (Table 1).

A 1,215 ha (3000 ac) circle was centered on the geographic centroid of the nest location occupied during the monitoring period for each territory. This represented the core area of the northern goshawk's 2,430 ha nesting home range, including foraging area, nest area, and post-fledging family area (Reynolds et al. 1992). I overlaid 1,215 ha circles on USFS forest stand boundaries (provided by the USFS) using ArcView (ver. 3.01, Environmental Systems Research Institute 1996). A grid of uniformly spaced points was randomly superimposed on each stand, with 1 point per 4 ha (Fig. 2). The points were located in the field using a global positioning system.

I measured forest structure within each stand using the intensive survey option of the regular stand and reforestation stocking exam protocol outlined in the 1993 Standard Specification Stand Exam manual (USDA Forest Service 1993*b*). I used the forest measurement standards developed for the Rocky Mountain, Southwest, and Intermountain regions of the USFS. I used a variable radius plot design with 10 basal area factor fixed angle gauge (Stoddard and Stoddard 1987:142). Crews measured height and diameter at breast height (DBH), or the diameter at root crown (DRC) for non-mercantile timber (e.g., oaks, junipers and pinyon pine), of each tree in the plot.

I used the forest stand model RMSTAND (Rev. 1999.07.14) to generate the following forest stand characteristics: forest type (ponderosa pine, mixed-conifer, pinyon/juniper, oak Woodland), maximum stand density index (SDI), stand SDI, number of trees by vegetation structural stage (VSS) class, basal area (BA) by VSS class. SDI is a relative measure of forest stand density that provides a relationship between stand BA, trees/unit area, and mean stand diameter (McTague and Patton 1989). VSS classes are delimited into six successional stages of a forest ecosystem by DBH ranges of the dominate trees: VSS 1 = grass-forb/shrub (DBH:0-1 in), VSS 2 = seedling-sapling (DBH:1-5 in), VSS 3 = young forest (DBH:5-12 in), VSS 4 = mid-aged forest (DBH:12-18 in), VSS 5 = mature forest (DBH:18-24 in), and VSS 6 = old forest

(DBH: > 24 in) (Reynolds et al. 1992). The letters A, B and C that follow the VSS class depict a canopy closure of 0-39%, 40%-59%, and > 60%, respectively. An uneven VSS class is one where >50% of the BA is within >1 forest age class.

Summary statistics were generated for each stand variable, and all forest stand data are reported in English units (e.g., acres, feet, inches) to conform to USFS standards and guidelines. SDI, number of trees by VSS class, and BA by VSS class were summarized for ponderosa pine forest types only. For each territory, frequency histograms were generated for height, and DRC and number of stems of non-mercantile timber detected at sample points. I used Sturges' rule, which delineates number of classes used in frequency histograms by variable sample size (Sturges 1926).

RESULTS

The major forest cover type within both territories was ponderosa pine, followed by pinyon/juniper (Table 2). The high productive territory (Willow Wash) had more area in pinyon/juniper and open field cover types than did the low productive territory (Timber Mesa). Within the ponderosa pine forest type, Willow Wash had an average SDI of 147/acre (range 52-302) as opposed to Timber Mesa's average SDI of 191/acre (range 73-359). The maximum SDI for the ponderosa pine forest type is 450/acre.

Willow Wash had more VSS stand classes present within the ponderosa pine forest type than were found on Timber Mesa (Table 3). The amount of area within uneven forest structure of trees > 5 in DBH was higher in Willow Wash and the number of stands classified as VSS 3C was less than Timber Mesa. Forest stands classified as ponderosa pine had the greatest number of trees per area and highest BA within VSS Class 3 (Fig. 1A, B, C, and D). Number of trees within VSS 6 was relatively equal between the 2 territories, but BA of trees within this size class was greater and more variable in the Willow Wash territory.

For non-mercantile timber, there were more alligator junipers detected in all stands on Timber Mesa (n=344) compared to Willow Wash (n=185) (Fig. 7), however size and height of these trees showed no obvious differences. Willow Wash had more Rocky Mountain junipers (n=233) than Timber Mesa (n=6) (Fig. 8). Willow Wash had more pinyon pines (n=145), but they appeared smaller in size (DRC) and height than those found at Timber Mesa (n=83) (Fig 9). Willow Wash had fewer Gambel oaks (n=47) than did Timber Mesa (n=159), but more were in larger size classes (15-28 in DRC, Fig. 10). Too few Arizona white oaks were present to make comparisons between the territories.

DISCUSSION

SDI can be a useful stand descriptor in prescribing stand structure that promote favorable northern goshawk habitat. For example, use of SDI as a metric to describe favorable nesting areas has been demonstrated in Douglas fir forests (Lilieholm et al. 1993). The lower mean SDI value found within the higher reproductive Willow Wash territory may be an indication of greater prey abundance. Moore and Deiter (1992) demonstrated that higher SDI values within ponderosa pine forests are associated with lower production of understory grasses, forbs, and shrubs. These understory components are habitat elements of many of the prey items consumed by northern goshawks (Reynolds et al. 1992). It is possible that higher prey abundance accompanied by more open forest conditions within the Willow Wash territory may make prey more available to northern goshawks.

The Willow Wash territory may have possesed forest structural characteristics that contributed to its higher reproductive rate. For example, there were more area of pinyon/juniper forest type and more area of open fields, which may provide for a wider variety of prey species available. Subsequently, there were more Rocky mountain juniper and pinyon pine in Willow Wash, whose berries and nuts provide a rich source of food for many northern goshawk prey species (Reynolds et al. 1992).

The ponderosa pine forest types within Willow Wash had a greater number of stands classified in different VSS classes and more of these stands were classified as uneven. This diversity of structural characteristics may provide for a greater variety of prey species available due to the greater potential niche breadth of these forest stands. There were also fewer VSS 3C forest structural stage stands within the ponderosa pine forest stands of Willow Wash. These dense forest stands may inhibit foraging by northern goshawk, which are behaviorally and morphologically adapted for hunting in moderately dense mature forests (Squires and Reynolds 1997). Making comparisons of forest stand structure between only 2 territories is highly premature, but this study does provide the framework needed that would enable researchers to describe forest structural characteristics that are associated with highly productive northern goshawk territories.

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Table 1. Demographic characteristics of high and low reproductive northern goshawk territories monitored on the Apache-Sitgreaves National Forest, Arizona 1993-2000.

Territory	No. yrs. monitored	No. yrs of nest attempts	Total no. fledglings	Total no. female fledglings	Fledglings/nest attempt
Willow Wash (high)	7	4	7	2	1.8
Timber Mesa (low)	8	5	5	1	1

Table 2. Number of ha surveyed within 2 northern goshawk territories on the Apache-Sitgreaves National Forest classified by vegetation type (PIPO = ponderosa pine, PJ = pinyon/juniper, DF = Douglas fir).

Territory	Total area surveyed (ha)	Hectares PIPO (%)	Hectares PJ (%)	Hectares field (%)	Other hectares (%)[b]
Willow Wash	1045[a]	772 (74)	193 (18)	80 (8)	---
(high)	(2583 ac)	(1908 ac)	(477 ac)	(198 ac)	
Timber Mesa	1215	1028 (85)	95 (8)	25 (2)	67 (5)
(low)	(3002 ac)	(2541 ac)	(234 ac)	(61 ac)	(166 ac)

[a] 169 ha (417 ac) were private land, consisting largely of meadows, pinyon/juniper, and scattered residential development.

[b] 49 ha (120 ac) of oak woodland and 19 ha (46 ac) of Douglas fir.

Table 3. Mean number of trees per acre, ∃5 in. diameter, by Vegetation Structural Stage (VSS) for forest stands classified as ponderosa pine forest type within northern goshawk territories monitored on the Apache-Sitgreaves National Forest, Arizona 1993-2000.

	Willow Wash (high)		Timber Mesa (low)	
VSS class[a]	Acres (%)	Mean no. trees >5"/acre (range)	Acres (%)	Mean no. trees >5"/acre (range)
2B	96 (5)	73	---	---
3A	273 (14)	96 (46-139)	506 (20)	111 (74-141)
3B	641 (34)	228 (137-307)	686 (27)	177 (126-208)
3C	118 (6)	341 (223-501)	1016 (40)	281 (193-384)
4A	29 (2)	55 (52-57)	---	---
Uneven	742 (39)	138 (83-225)	331 (13)	250 (95-994)

[a] see text for VSS class descriptions

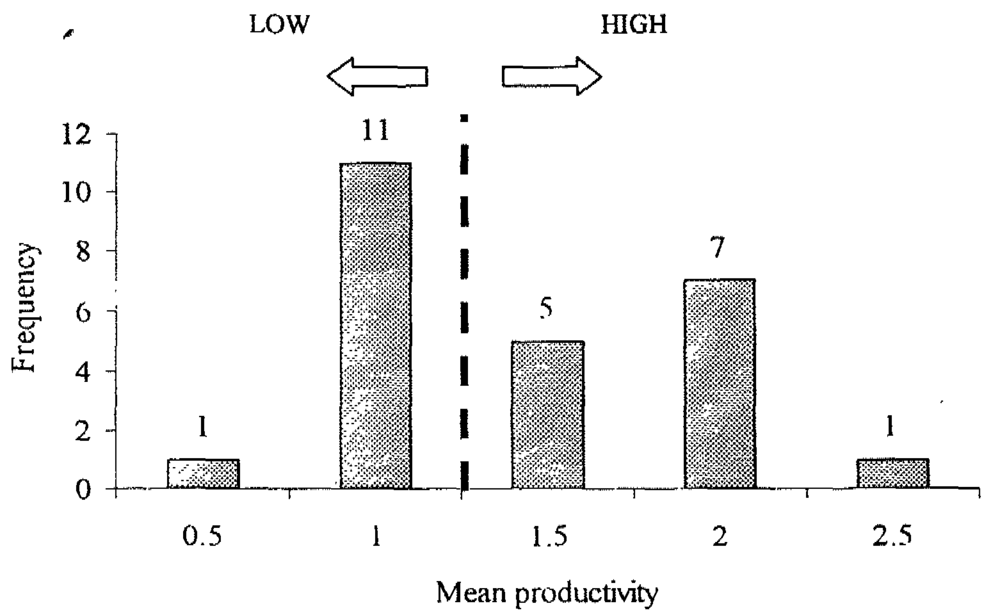


Figure 1. Productivity (mean number of young produced per nesting attempt) for northern goshawk territories (n=46) monitored 1993-2000 on the Apache-Sitgreaves National Forest, Arizona.

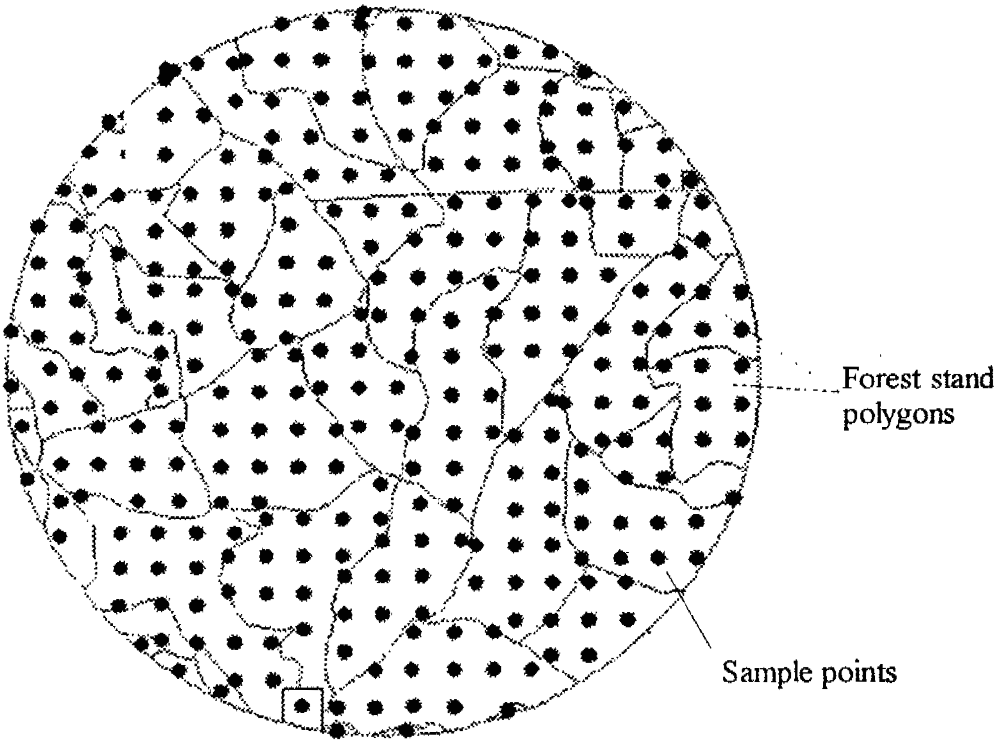


Figure 2. Core area (1,215 ha) of a northern goshawk territory, depicting forest stand boundaries and layout of sample points.

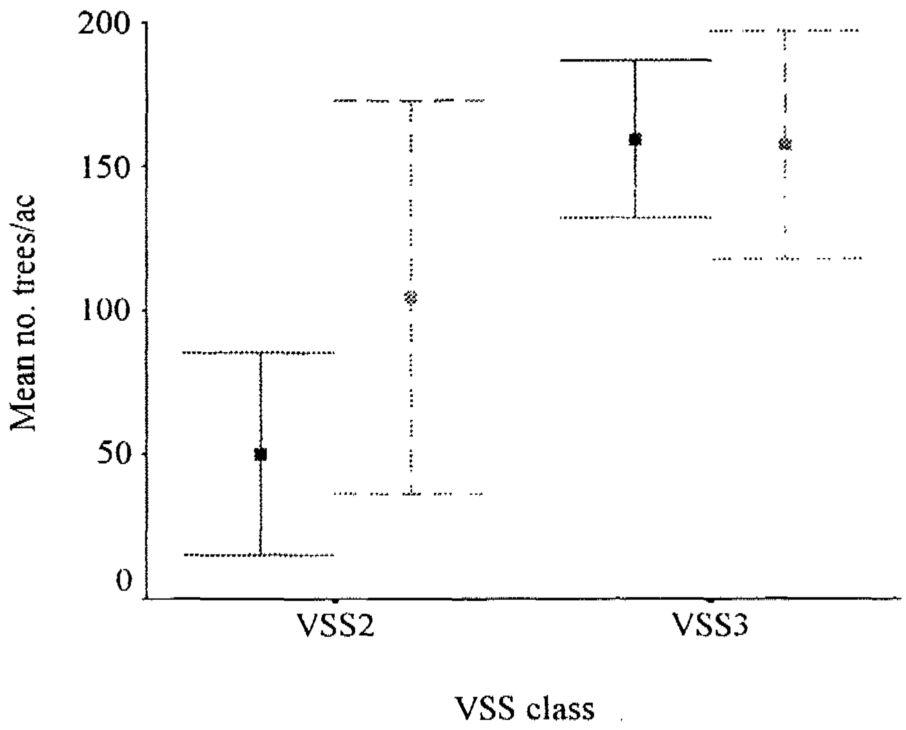


Figure 3. Density of ponderosa pine (mean, 95% CI) by Vegetation Structural Stage (VSS) 2 and 3 (see text) at high productive (Willow Wash - dashed lines) and low productive (Timber Mesa - solid lines) northern goshawk territories on the Apache-Sitgreaves National Forest, Arizona.

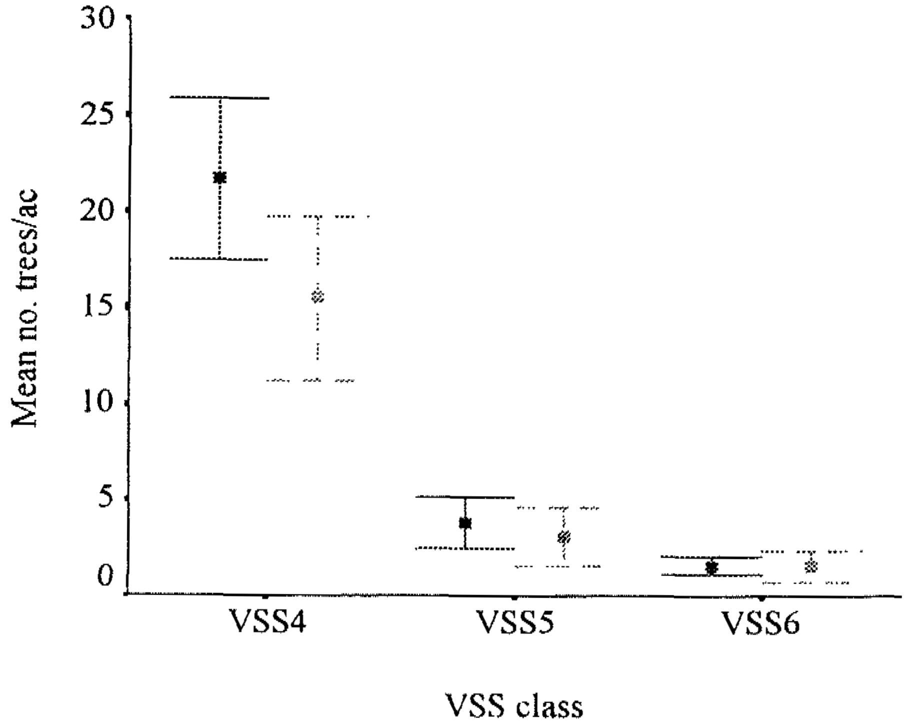


Figure 4. Density of ponderosa pine (mean, 95% CI) by Vegetation Structural Stage (VSS) 4, 5 and 6 (see text) at high productive (Willow Wash - dashed lines) and low productive (Timber Mesa - solid lines) northern goshawk territories on the Apache-Sitgreaves National Forest, Arizona.

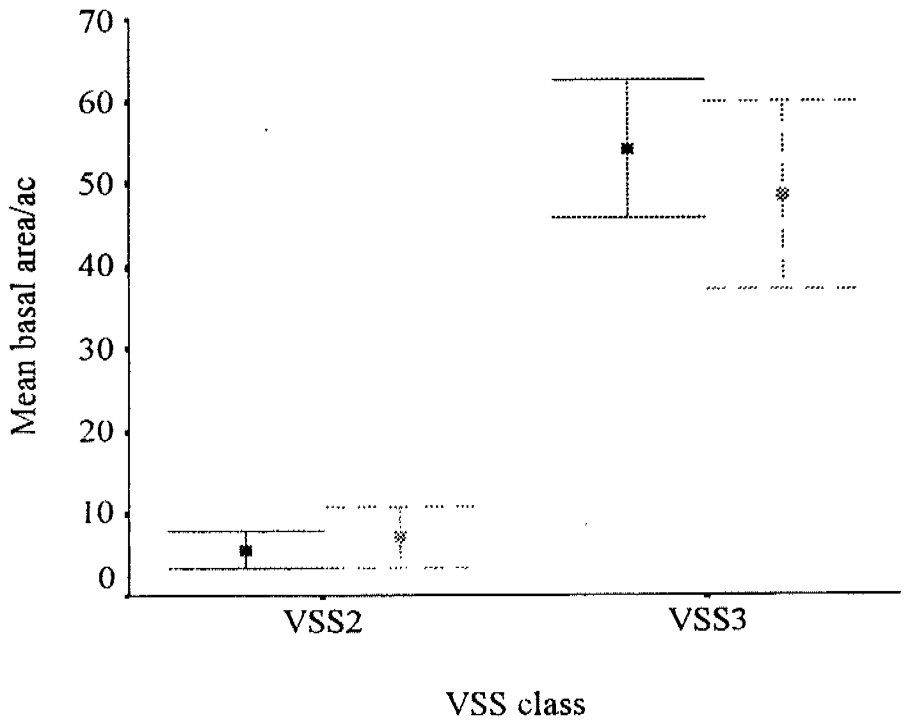


Figure 5. Basal area/acre of ponderosa pine (mean, 95% CI) by Vegetation Structural Stage (VSS) 2 and 3 (see text) at high productive (Willow Wash - dashed lines) and low productive (Timber Mesa - solid lines) northern goshawk territories on the Apache-Sitgreaves National Forest, Arizona.

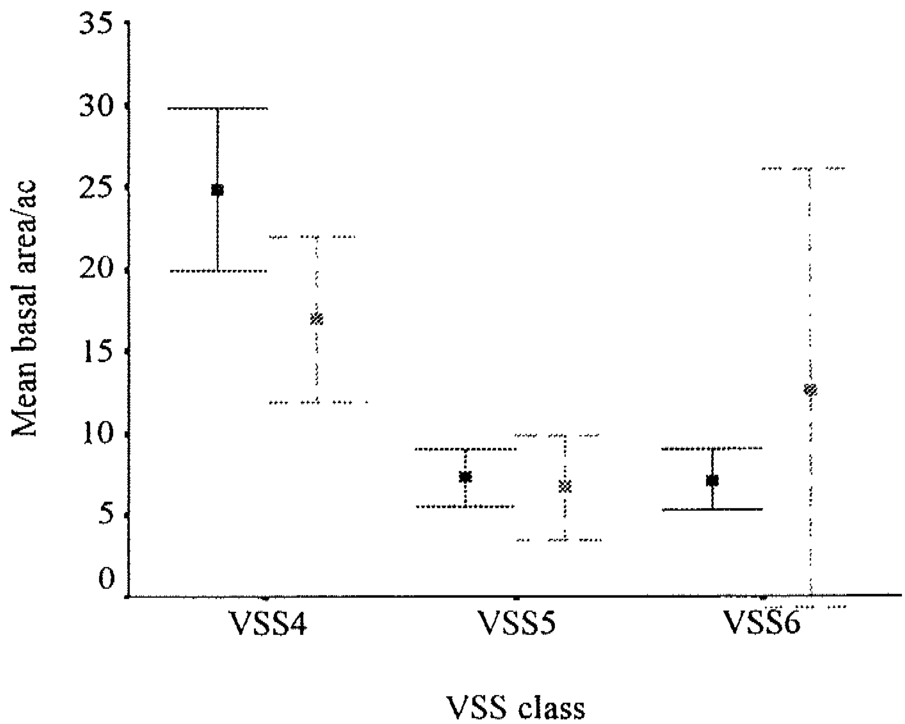


Figure 6. Basal area/acre of ponderosa pine (mean, 95% CI) by Vegetation Structural Stage (VSS) 4, 5 and 6 (see text) at high productive (Willow Wash - dashed lines) and low productive (Timber Mesa - solid lines) northern goshawk territories on the Apache-Sitgreaves National Forest, Arizona.

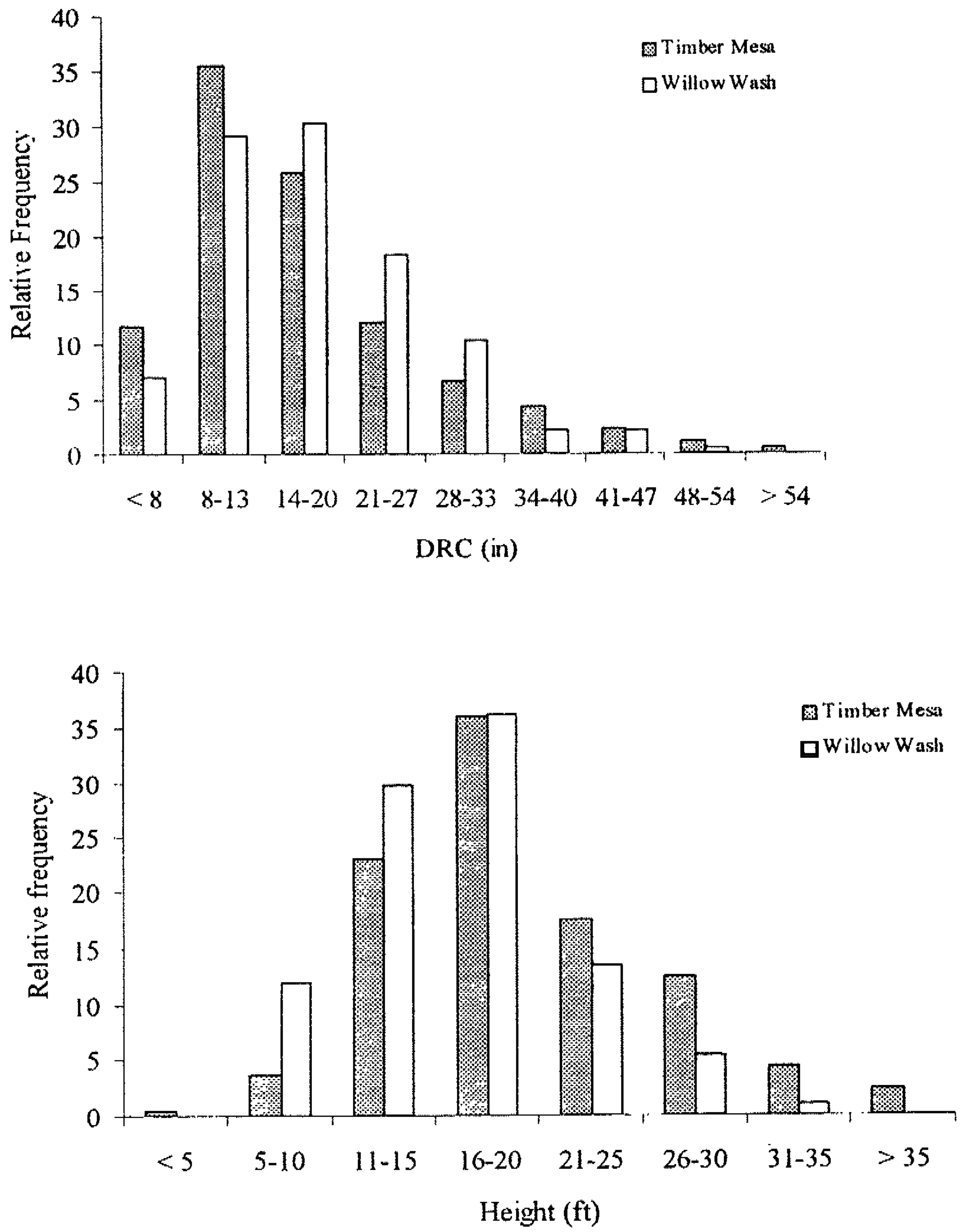


Figure 7. Size (height and dia. root crown; DRC) of alligator junipers in two northern goshawk territories on the Apache-Sitgreaves National Fores, Arizona.

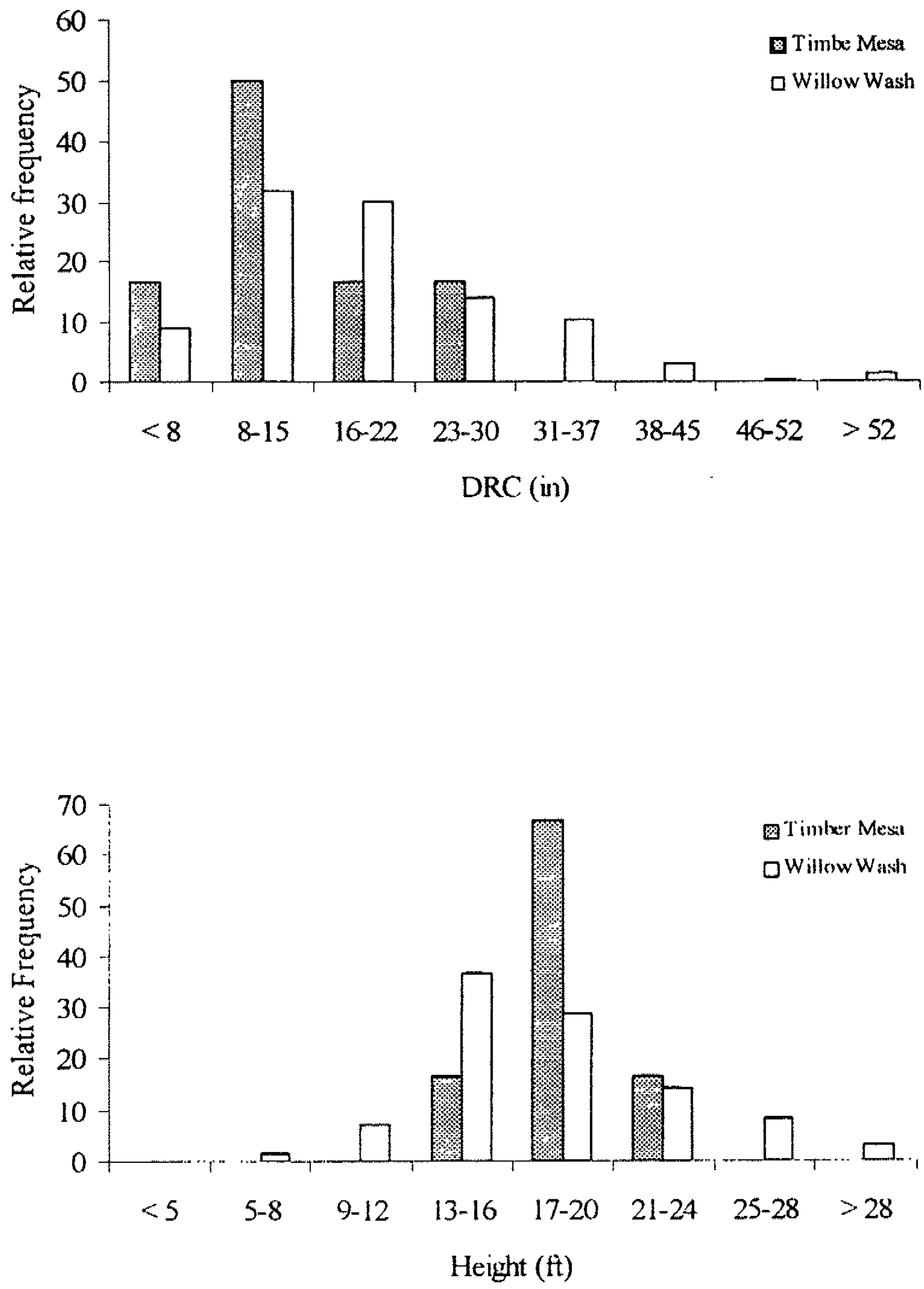
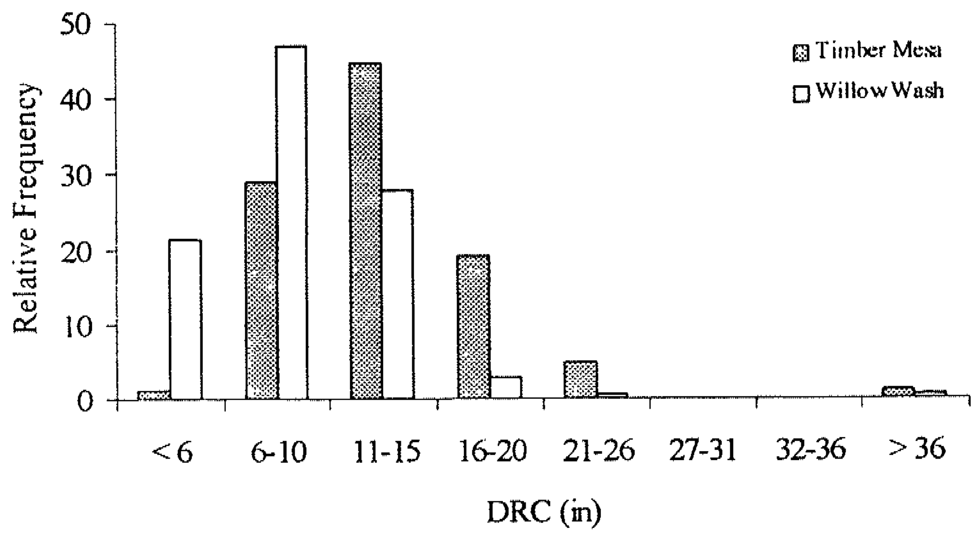


Figure 8. Size (height and dia. root crown; DRC) of Rocky mountain juniper in two northern goshawk territories on the Apache-Sitreaves National Forest, Arizona.



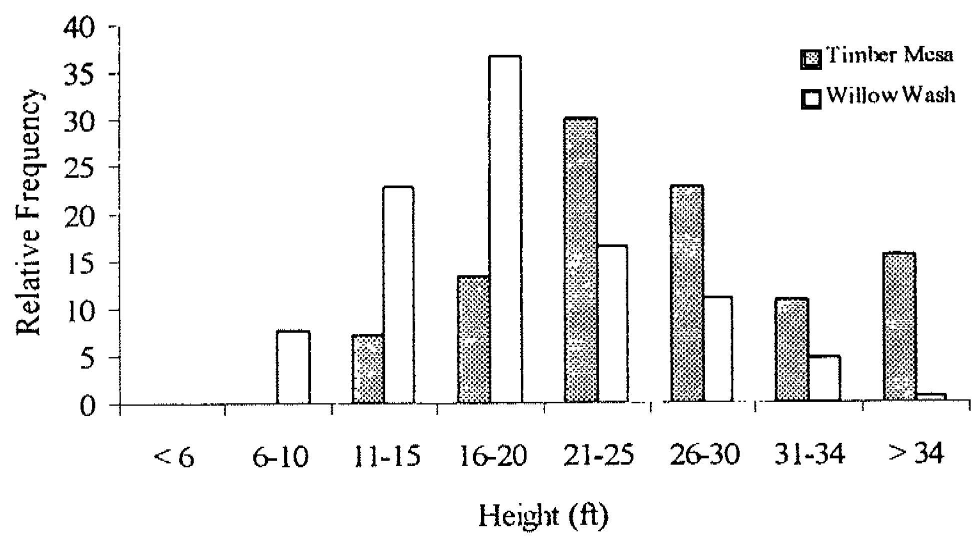
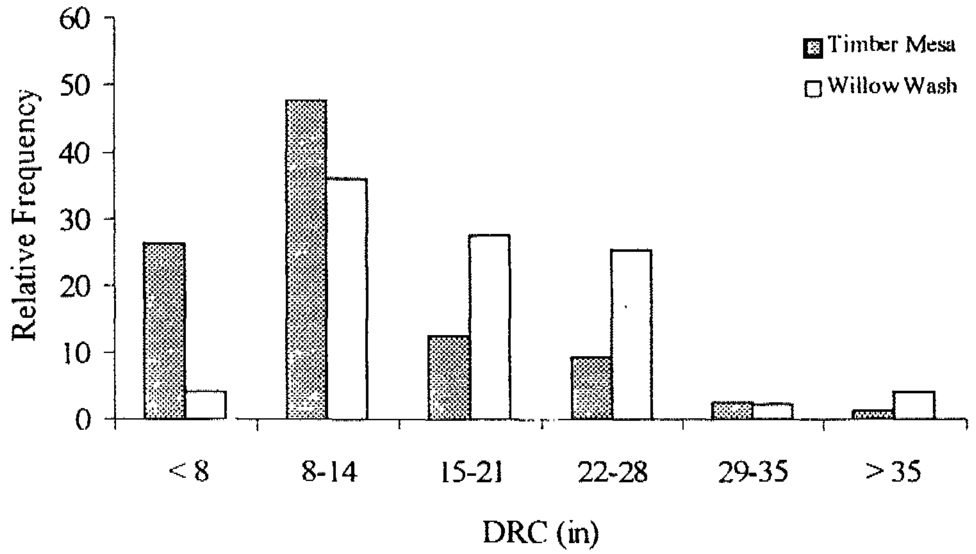


Figure 9. Size (height and dia. root crown; DRC) of pinyon pines in two northern goshawk territories on the Apache-Sitreaves National Forest, Arizona.



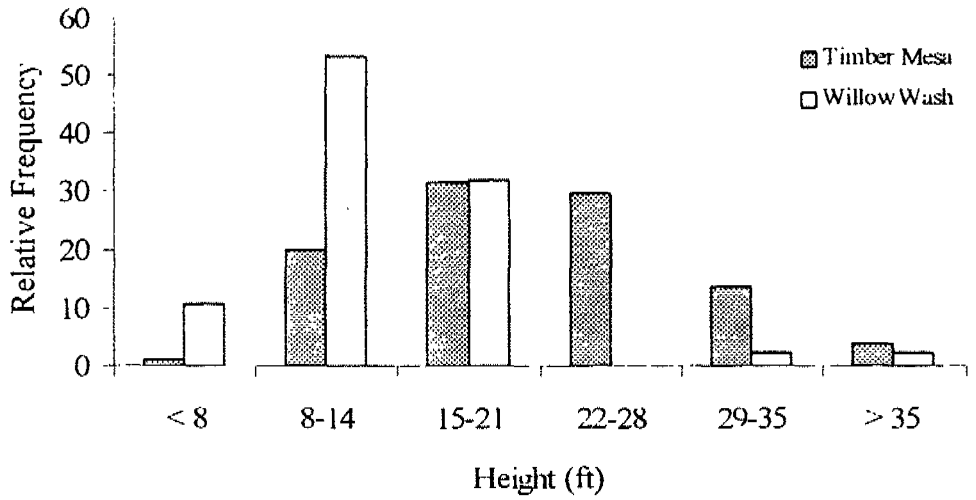


Figure 10. Size (height and dia. root crown; DRC) of Gambel oaks in two northern goshawk territories on the Apache-Sitreaves National Forest, Arizona.