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SURVIVAL OF NORTHERN GOSHAWKS IN THE SOUTHERN CASCADES OF CALIFORNIA

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Abstract. From 1983 to 1992, 95 Northern Goshawks (*Accipiter gentilis*) were marked with numbered, colored leg bands in northern California. We used capture-recapture techniques to estimate survival and resighting (or recapture) rates. Low sample size of marked birds and low resighting rates contributed to lack of fit of these data to the capture-recapture model. Survival estimates were generated, but variance was high. There were indications, however, that survival in goshawks varied among years, and survival of females was higher than males. We suggest that researchers interested in estimating survivorship of raptors strive for large numbers of marked birds, high resighting rates, and at least 5 years of data. These recommendations necessitate large study areas, large field crews, and careful consideration of model assumptions and raptor biology.

Key Words: *Accipiter gentilis*; California; capture-recapture; Northern Goshawk; survival.

In many wildlife studies, the presence of animals in certain habitats is often thought to be an indication of the quality of those habitats. Presence of individuals and estimates of relative densities among different habitats, however, may not be adequate to assess habitat quality (Van Horne 1983, Vickery et al. 1992). Other demographic parameters, such as reproductive success and survival, perhaps in conjunction with density, may be important indicators of habitat quality or "habitat fitness" (i.e., the capacity of a habitat to support optimum fecundity and high survival).

Much of the research conducted on Northern Goshawks (*Accipiter gentilis*) has focused on habitat use during the breeding season, often with some associated measure of reproductive success (Reynolds and Wight 1978, Crocker-Bedford 1990). Estimates of survival, however, are difficult to obtain for most species and involve some degree of uncertainty because absence of a marked individual does not necessarily indicate mortality. This is particularly true for studies of marked goshawks because of their low densities, large home ranges, high mobility, and secretive behavior.

Capture-recapture methodology (Cormack 1964, Jolly 1965, Seber 1965) conducted over long periods of time with an adequate sample of marked individuals, each of which has a high probability of being resighted ("visually recaptured"), can overcome these challenges. Capture-recapture models have been developed to account for the uncertainty inherent in survival estimation.

We used capture-recapture techniques to (1) explore the feasibility of calculating survival estimates for goshawks, (2) calculate point estimations and variances of survival, and (3) examine the yearly variation in survivorship and sex-related differences in goshawks. We then make recommendations for studies designed to estimate survival and suggest a cautious approach to interpretation of the results.

STUDY AREA AND METHODS

Northern Goshawks were captured on the Goosenest Ranger District of the Klamath National Forest and adjacent lands on the Shasta–Trinity and Modoc National Forests in the southern Cascades of northern California. The area was dominated by Sierra montane and upper montane forests. The former was comprised of Douglas-fir (*Pseudotsuga menziesii*), incense-cedar (*Calocedrus decurrens*), red fir (*Abies magnifica*), white fir (*A. concolor*), and ponderosa pine (*Pinus ponderosa*), and was interspersed with permanent streams and wet meadows with stands of lodgepole pine (*P. contorta*) and trembling aspen (*Populus tremuloides*). Upper montane forests consisted of pure stands of red fir, white fir, and lodgepole pine with some ponderosa pine. Stream drainages were few and typically dry. Forest seral stages were characterized by small patches of unmanaged mature forest interspersed among varying degrees of managed forest. Dominant silvicultural systems included thinning, shelterwood cuts, and small clearcuts.

Surveys for nests were conducted on 10,440 and 10,230 ha blocks in Sierra montane and upper montane forest types, respectively. We used conspecific alarm and begging tapes to elicit responses from adult and fledgling goshawks and visual clues (feathers, prey remains, nest structures, whitewash) to locate nests (Kimmel and Yahner 1990, Kennedy and Stahlecker 1993). In addition, about 20 nests outside of the study blocks were monitored. Adult goshawks were captured at nests with dho-gaza sets with a live Great Horned Owl (*Bubo virginianus*) as a decoy (Bloom et al. 1992). Adults were marked with uniquely numbered plastic colored leg bands and U.S. Fish and Wildlife Service aluminum leg bands. We used camouflaged blinds and spotting scopes to observe marked adults at nests in subsequent years; some bands were read when adults were re-trapped in subsequent years.

We input capture-resighting data as a capture history matrix, and used program RELEASE for data summarization and goodness-of-fit tests (Burnham et al.

TABLE 1. NUMBER OF FEMALE AND MALE NORTHERN GOSHAWKS BANDED IN THE SOUTHERN CASCADE RANGE, CALIFORNIA, 1983–1992

Year	Female	Male
1983	0	3
1984	2	2
1985	2	6
1986	2	6
1987	8	7
1988	6	6
1989	4	4
1990	2	6
1991	4	2
1992	10	13
Totals	40	55

1987). Goodness-of-fit tests examine the data with a series of χ^2 contingency tables to determine if the data fit the capture-recapture model. In RELEASE, goodness-of-fit has two components that look for differences in survival and recapture rates among cohorts (groups rereleased on different occasions; TEST 2) and subcohorts (individuals with different capture histories; TEST 3). Differences, shown by low P-values, among cohorts or subcohorts indicate lack of fit. We used program SURGE (Lebreton et al. 1992) to derive point estimates and variances of survival. Models used for estimation of survival were based on the Cormack-Jolly-Seber (Cormack 1964, Jolly 1965, Seber 1965) model $\{\phi, p\}$, where ϕ = survival and p = probability of resighting.

We examined eight models, where ϕ and p were assumed to vary among years (subscript t) and between sexes (subscripts F for female and M for male). Twelve models were used to evaluate the interaction between time and sex. We used Akaike's Information Criteria (AIC), which is a numerical measure based on the deviance and the number of parameters in a model, and the principle of parsimony to select the model that best fit the data with the fewest number of parameters, and was still biologically reasonable (i.e., the "best" model) (Burnham et al. 1987, Lebreton et al. 1992).

RESULTS

We marked 95 adult goshawks with color bands and collected resightings of these marked birds from 1983 to 1992 (Tables 1, 2). For all goshawks (i.e., females and males combined) goodness-of-fit tests indicated that there was a definite lack of fit of the data to the capture-recapture model at the cohort and subcohort levels (χ^2 = 12.9, df = 7, P = 0.07 and χ^2 = 16.6, df = 12, P = 0.16 for TESTS 2 and 3, respectively), and overall fit of the data to the model was inadequate (χ^2 = 29.6, df = 19, P = 0.06 for TEST 2 + TEST 3; Burnham et al. 1987:71–77).

We first examined two sets of nested models to estimate survival (Table 3). Time-specific models revealed that there may be yearly differences in survival of goshawks, as model $\{\phi_t, p\}$ had the lowest AIC value, with $\{\phi_t, p_t\}$ as a competitive model (Likelihood ratio test, χ^2 = 4.67, df = 7, P = 0.70). The model with no time specificity ($\{\phi, p\}$) was not competitive (χ^2 = 30.6, df = 8, P = 0.0002). Survival rates were not estimable in some years because of low sample sizes (Table 4). According to our analysis, survival and resighting probabilities were higher for females than for males, but wide confidence intervals, due mainly to low sample sizes, precluded us from demonstrating a statistical difference (Table 4).

We then examined 12 models where the parameters ϕ and p were allowed to vary as an interaction between time (years) and sex (Table 3). The model $\{\phi_{Ft}, \phi_{Mt}, p\}$ had the lowest AIC value, which indicated that survival varied among years and between sexes (Table 4).

TABLE 2. MARK-RECAPTURE DATA ARRAY FOR NORTHERN GOSHAWKS IN THE SOUTHERN CASCADES, CALIFORNIA, 1983–1992. R_i IS THE NUMBER OF GOSHAWKS MARKED AND RELEASED ON THE iTH OCCASION (OR YEAR OF STUDY), m_{ij} THE NUMBER OF GOSHAWKS MARKED AND RELEASED ON OCCASION i THAT WERE RECAPTURED OR RESIGHTED ON OCCASION j, AND r_i THE TOTAL NUMBER OF GOSHAWKS MARKED AND RELEASED ON OCCASION i THAT WERE LATER RECAPTURED (= Σm_{ij})

		m_{ij} for j =									
i	R_i	2	3	4	5	6	7	8	9	10	r_i
1	3	1	1	0	0	0	0	0	1	0	3
2	5		1	1	1	1	0	0	0	0	4
3	10			6	3	1	0	0	0	0	10
4	15				9	0	0	0	0	0	9
5	28					13	1	0	0	0	14
6	27						7	1	0	0	8
7	16							5	0	0	5
8	14								4	2	6
9	11									3	3

TABLE 3. CAPTURE-RECAPTURE MODELS, WHERE ϕ IS SURVIVAL RATE AND p IS RECAPTURE RATE, USED TO ESTIMATE SURVIVAL IN NORTHERN GOSHAWKS IN THE SOUTHERN CASCADES OF CALIFORNIA, 1983–1992. ASSOCIATED AKAIKE'S INFORMATION CRITERIA (AIC = [2 × NO. OF PARAMETERS] + DEVIANCE) IS USED TO EVALUATE RELATED MODELS; LOWEST AIC VALUE INDICATES THE BEST MODEL (I.E., THE MODEL WITH THE FEWEST PARAMETERS AND FITS THE DATA AND IS BIOLOGICALLY REASONABLE). SUBSCRIPT t INDICATES TIME (I.E., SURVIVAL AND RECAPTURE RATES ESTIMATED FOR EACH YEAR, 1983–1990); SUBSCRIPTS F AND M INDICATE FEMALES AND MALES, RESPECTIVELY

Model	No. of parameters	Deviance	AIC
Time-specific models			
$\{\phi_t, p_t\}$	17	236.53	270.53
$\{\phi_t, p\}$	10	241.20	261.20
$\{\phi, p_t\}$	10	258.08	278.08
$\{\phi, p\}$	2	271.82	275.82
Sex-specific models			
$\{\phi_F, \phi_M, p_F, p_M\}$	4	268.77	276.77
$\{\phi_F, \phi_M, p_{F+M}\}$	3	269.51	275.51
$\{\phi_{F+M}, p_F, p_M\}$	3	269.43	275.43
$\{\phi_{F+M}, p_{F+M}\}$	2	271.82	275.82
Time- and sex-specific models			
$\{\phi_{Ft}, \phi_{Mt}, p_{Ft}, p_{Mt}\}$	34	223.21	291.21
$\{\phi_{Ft}, \phi_{Mt}, p_{Ft}, p_M\}$	27	231.69	285.69
$\{\phi_{Ft}, \phi_{Mt}, p_F, p_{Mt}\}$	27	227.40	281.40
$\{\phi_{Ft}, \phi_{Mt}, p_F, p_M\}$	20	235.88	275.88
$\{\phi_{Ft}, \phi_M, p_{Ft}, p_{Mt}\}$	27	234.86	288.86
$\{\phi_F, \phi_{Mt}, p_{Ft}, p_{Mt}\}$	27	236.70	290.70
$\{\phi_F, \phi_M, p_{Ft}, p_{Mt}\}$	20	248.31	288.31
$\{\phi_{Ft}, \phi_M, p_{Ft}, p_M\}$	19	243.81	281.81
$\{\phi_F, \phi_{Mt}, p_F, p_{Mt}\}$	19	248.21	286.21
$\{\phi_{Ft}, \phi_M, p_F, p_{Mt}\}$	20	239.05	279.05
$\{\phi_F, \phi_{Mt}, p_{Ft}, p_M\}$	20	245.14	285.14
$\{\phi_{Ft}, \phi_{Mt}, p\}$	19	236.50	274.50

TABLE 4. MAXIMUM LIKELIHOOD ESTIMATES OF SURVIVAL (ϕ) AND PROBABILITY OF RESIGHTING (P) FOR NORTHERN GOSHAWKS IN THE SOUTHERN CASCADE RANGE, CALIFORNIA, 1983–1992, BASED ON CAPTURE-RECAPTURE TECHNIQUES. NUMBERED SUBSCRIPTS INDICATE THE YEAR FOR WHICH SURVIVAL IS ESTIMATED; SUBSCRIPTS F INDICATE SURVIVAL ESTIMATES FOR FEMALES, M FOR MALES. ESTIMATES ARE SHOWN FOR MODELS WITH THE LOWEST AIC VALUES (SEE TEXT FOR FURTHER EXPLANATION)

Model	Parameter	ϕ	SE(ϕ)	P	SE (P)
$\{\phi_t, p\}$	ϕ_{83}	Inest.[1]	Inest.	0.54	0.06
	ϕ_{84}	0.91	0.15		
	ϕ_{85}	Inest.	Inest.		
	ϕ_{86}	0.94	0.12		
	ϕ_{87}	0.71	0.14		
	ϕ_{88}	0.39	0.11		
	ϕ_{89}	0.43	0.14		
	ϕ_{90}	0.58	0.19		
$\{\phi_{Ft}, \phi_{Mt}, p\}$	ϕ_{F83}	Inest.	Inest.	0.54	0.07
	ϕ_{F84}	0.85	0.19		
	ϕ_{F85}	Inest.	Inest.		
	ϕ_{F86}	0.93	0.15		
	ϕ_{F87}	0.80	0.18		
	ϕ_{F88}	0.44	0.15		
	ϕ_{F89}	0.35	0.17		
	ϕ_{F90}	0.81	0.27		
	ϕ_{M83}	Inest.	Inest.		
	ϕ_{M84}	Inest.	Inest.		
	ϕ_{M85}	Inest.	Inest.		
	ϕ_{M86}	0.94	0.30		
	ϕ_{M87}	0.57	0.22		
	ϕ_{M88}	0.31	0.16		
	ϕ_{M89}	0.60	0.31		
	ϕ_{M90}	0.20	0.19		

[1] Parameter inestimable.

DISCUSSION

Much interest has been generated by the estimates of survival and associated population rate of change (λ) generated for the federally listed Northern Spotted Owl (*Strix occidentalis caurina*) (Anderson and Burnham 1992). We were able to calculate survival estimates for goshawks using the same capture-recapture methodology, but these estimates were imprecise due to small samples of marked birds and low resighting rates. In addition, the estimates that were produced were likely biased low because some marked goshawks emigrated off of the study area, and only birds that were associated with successful nests were resighted. These problems contributed to the lack of fit of the data to the capture-recapture model, resulting in low resighting probabilities and biased parameter estimates. However, empirical estimates of survival for goshawks in Arizona by Leslie et al. (pers. comm.) showed that survival may indeed be higher than our estimates, but their data did support the conclusion that female survival is higher than male survival.

We recommend to researchers wishing to estimate ϕ and λ that they strive for large numbers of banded birds, the highest resighting rates possible, and >5 years of data collected over a broad geographic area. Opportunities to coordinate banding and resighting efforts with adjacently located studies should be considered and encouraged. In addition, we recommend that researchers become familiar with all the assumptions of capture-recapture models when planning their study (see Burnham et al. 1987:51–54). Capture and recapture episodes are assumed to be instantaneous, an obviously unrealistic requirement. Confining banding and resighting efforts to as short a time period as possible, however, would move toward fulfilling this assumption. A 1-month capture and resighting period may be realistic for field conditions. Another important assumption is that marks not be lost or misread. Color band loss over time and error in identifying bands needs to be assessed.

Studies such as these will require large field crews and will be expensive. We strongly suggest that the biology of Northern Goshawks, such as their wide-ranging habits and mobility, be considered carefully when designing a study and interpreting results of survival estimation. We believe that these recommendations will be helpful in survival studies of other raptor species as well.

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