

Desert Nesting Bald Eagle

post-fledging survival analysis 1977-2003

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Introduction

Population viability analysis (PVA) for the “Desert Nesting Bald Eagle” (DNBE) population in Arizona was based on estimates of adult and juvenile mortalities derived by Arizona Game and Fish Department (AGFD) from banding data over 16 years (Taylor and Silver 2006, AGFD unpubl.).

The AGFD analysis did not consider new factors arising out of the analysis of Taylor and Silver (2006).

Banding records are now available for 30 years. A reanalysis of post-fledging survival with available data and additional years of resightings will show if the assumptions of the earlier PVA remain valid.

Methods

418 DNBE nestlings were marked by Arizona Game and Fish Department from 1977-2006.

Of these 45 did not survive to fledge. Nestling to fledgling survival was estimated earlier (Taylor and Silver 2006). Hence, these individuals were removed from analysis, leaving 383 marked fledglings.

Since resightings were only done at breeding areas (BAs), at least first two years after fledging had zero probability of resighting. Only two individuals were resighted in the third year after fledging. Accordingly, all individuals marked two years before the right-censoring horizon of 2006 ago or later (2004+) were uninformative for survival or resight probability estimation and were removed from analysis. This left 330 individuals with usable encounter histories. 8 individuals were marked as adults at breeding areas and so were not included in model fitting for estimation of juvenile survival.

Encounter histories had 30 occasions (years from 1977 to 2006 inclusive).

Independent variables were entered as individual covariates:

- Sex (-1=male, 0=unknown, 1= female);
- Natal BA (-1 if not in Salt/Verde cluster, 0 if unknown, 1 if in Salt/Verde cluster¹);
- Breeding BA (as for Natal BA) the BA at which individual breeds or attempts to breed;
- Year of fledging (1977-2003, rescaled from 0-1).

The recapture only subroutine of Program MARK was used for model construction and fitting with a logit link function. Parameter matrices followed an age-cohort design.

For models of juvenile survival, only the 322 individuals marked as fledglings were used. Sex could not be used as an independent variable in models of juvenile survival since sex was not known until the individual reappeared as a young adult at a BA. Thus sex was only known for resighted individuals, not for all fledglings. Taylor and Silver (2006) found nestling survival declined over time for BAs outside the cluster, but remained constant inside the cluster. Hence an interaction between time and natal BA was tested in models of juvenile survival.

For estimation of adult survival, we used only the 77 individuals eventually resighted at BAs, including the 8

¹The Salt Verde cluster includes the following BAs: Bartlett, Blue Point, Box Bar, Bulldog, Doka, Fort McDowell, Granite Reef, Horse Mesa, Needle Rock, Orme, Rodeo, Sycamore, Yellow Cliffs

individuals marked as breeding adults. Because models were age structured, years of fledging had to be interpolated for these 8 adults by random resampling of ages at first resightings from observed distributions and back calculation of resampled year at fledging.

We hypothesized that survival of both young adult and adult groups would be linear functions (on the logit scale) of sex, year of fledging, natal BA and breeding BA.

The effects hypothesized were:

- Survival declines with increasing year of fledging;
- Survival lower for individuals fledging from BAs outside Salt-Verde (SV) cluster;
- Juvenile survival declines with time faster outside SV cluster (interaction term as found for nestling survival);
- Adult female survival higher than male;
- Adult survival lower on breeding BAs outside than inside SV cluster.
- Adult and young adult survival share same effects from independent variables, but different intercepts.

Hypotheses for survival were expressed as the following linear models:

logit Survival of age group*	Intercept	Sex	Year	Natal BA	Natal BA x Year	Breeding BA
Juvenile	A+		B*year+	C*nba+	D*(nba X year)	
Young adult	F+	H*sex+	I*year+	J*nba+		K*bba
Adult	G+	H*sex+	I*year+	J*nba+		K+bba

- * Juveniles ages 1-3, (fledging = year 0). Young adults ages 4-5, adults ages 6+

Hypotheses for resight probabilities (denoted P) were expected to be affected in similar ways, using the following set of models. No interactions were expected so none were modeled:

logit P of age group*	Intercept	Sex	Year	Natal BA	Breeding BA
Juvenile	L+	M*sex+	N*year+	O*nba+	P*bba
Young adult	Q+	R*sex+	S*year+	T*nba+	U*bba
Adult	V+	R*sex+	S*year+	T*nba+	U+bba

- Female P no different from male;
- P increases with time;
- P lower for individuals with natal BAs or breeding BAs outside SV cluster where monitoring effort was assumed to be less intense.

Age class definitions were also varied in stepwise fashion to test the hypothesized age class structure of juveniles age 0-3, young adults 4-5 and adults 6+.

Results

Graphical analysis

Proportions resighted declined, proportions of females increased and ages at first and last resighting went down with increasing year of fledging (data not shown). However, such trends in raw data are misleading without appropriate corrections. Proportion resighted and ages at first and last resighting are expected to decline solely due to differential “right-censoring”. More recently marked fledglings have less time in which to be resighted. Thus more recent cohorts inevitably must have lower resighting rates, and shorter times to first and last resightings.

To eliminate this effect, data were reduced to 119 individuals that fledged no later than 1993 (excluding 8 individuals marked as adults). Their encounter histories were then uniformly right-censored after 13 years of age. This age was chosen since it was the longest observed age at first resighting. These individuals could not differ in resighting

statistics due to different times between marking and right-censoring. Rather they should differ only due to external factors.

Proportions of marked fledglings resighted within 13 years after marking (that is, appearing at a BA) declined in the years 1984-1993 (Fig 1A). Ages at first resighting and last resighting showed a slight downward trend with year of fledging (Fig 1B).

Progressively more BAs have been discovered over the period of study and more have been discovered further from the geographical “core” of the Arizona population around the Salt-Verde confluence. Hence we expected proportionally more fledglings marked in later years to have come from BAs outside the cluster. This is confirmed by the increasing time trend of proportion of marked fledglings not in the SV cluster, a trend which nevertheless leveled off by 1989 (Fig 1A).

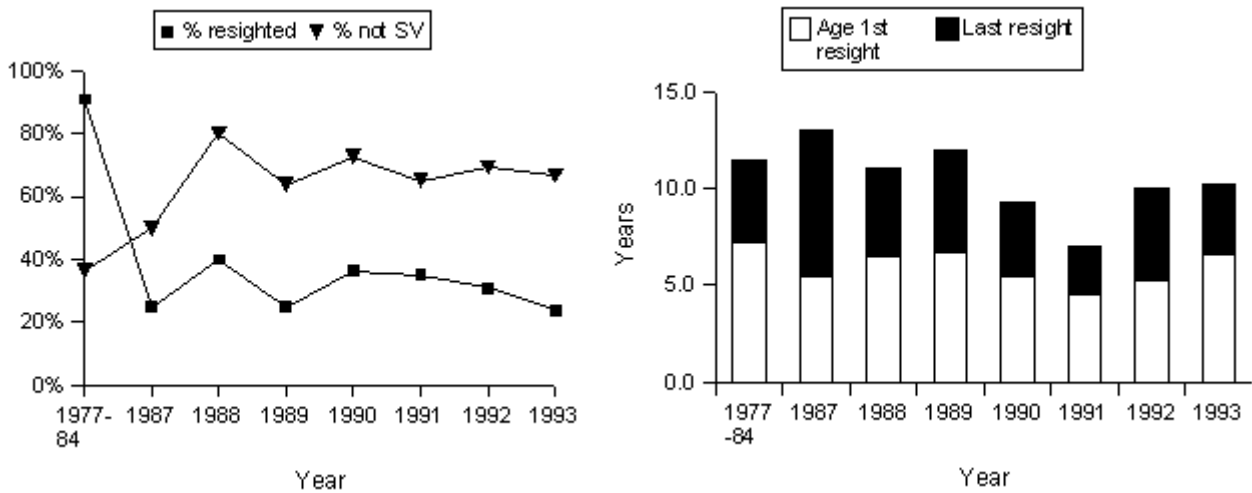


FIG 1 (A, left) Proportions of fledglings resighted and proportions of fledging marked that were in BAs outside of the Salt Verde cluster by year of fledging 1977-1993 (years 1977-1984 grouped due to low sample sizes). (B, right) Mean age at first resighting, and age at last resighting for resighted individuals fledged 1977-1993. Std Deviations not shown (Ages last resighting right censored at age 13.)

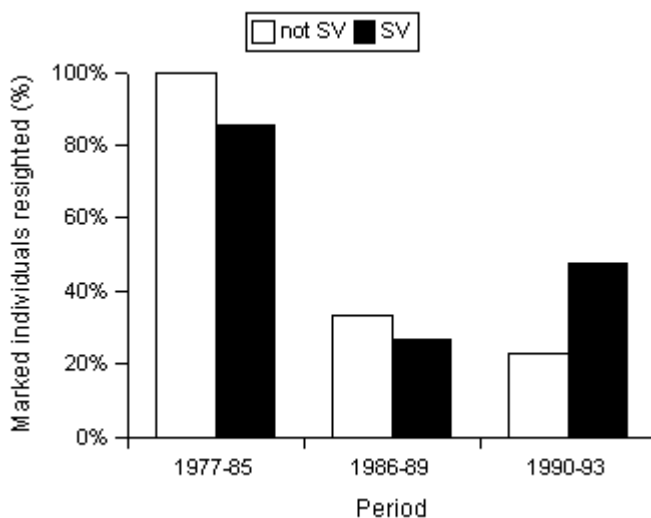


FIG2 Proportion of fledglings resighted that were marked as fledglings in three successive periods at BAs in the Salt-Verde cluster or not in the cluster.

It could be that the apparent decline in proportion resighted was due in part to a tendency for less resighting effort at BAs outside the SV cluster. Individuals marked outside the cluster may have been less likely to be resighted due to lower effort. However, proportions resighted declined from earlier to later periods for fledglings of both non SV BAs and SV BAs, although less consistently in the SV natal BA group (Fig. 2). Thus the decline in resighting probabilities appears not to be due to any hypothesized lower resighting effort for individuals marked at BAs outside the SV cluster but to other factors.

It must be recalled that raw proportions resighted do not reflect resighting effort or sightability alone but also probability of survival. To separately estimate these two component probabilities, it is necessary to fit appropriate mark recapture models.

Mark-recapture modeling

Hypothesized models as detailed above, were developed stepwise from the basic two parameter model (constant survival or resight probabilities).

Best-fitting models were selected not solely on minimal Akaike Information Criterion (AIC). Minimal AIC models sometimes had marginal parameters that contained zero within the 95% confidence interval around the fitted estimate. In such cases models were selected with statistically non-zero parameters, unless difference in AIC from previous steps exceeded 7.

The best fitting age structure for both adult and juvenile models had uniform survival for ages 1-4, survival to age 5 fixed and uniform survival for ages 6 and up (Table 1).

Juvenile survival (ages 1-4) was significantly correlated with year fledged, but not with Natal BA or the interaction of Natal BA and year.

Table 1. Age specific survival probabilities of best fitting juvenile and adult models (AIC=1144.9; AIC for 2 parameter constant model = 1970.3).

Annual survival prob. (%) to	Fitted estimates (95% C.I.)
ages 1-4 fledged 1977-1984	98.4 (80.6,99.9)*
ages 1-4 fledged 1985-1993	74.8 (69.2,80.0)*
ages 1-4 fledged 1994-2003	65.3 (59.5,71.1)*
age 5	100 (fixed)**
ages 6+	92.3 (89.6,94.4)**

* fitted by juvenile models

** fitted by adult models

The best fitting model was a categorical period model rather than linear trend model, with three periods of approx. equal length. Fitted juvenile survival declined significantly from early to more recent periods (Table 1) as suggested by graphical analysis (Figs 1A, 2).

Adult survival was not significantly correlated with any of the hypothesized factors, although sex was marginally significant (Table 1).

Fitted resighting probabilities (an index of effort) varied much as hypothesized (Table 2). Best fitting age structure was not a simple juvenile, young adult, adult structure for resighting probabilities. Rather, ages 3-7 had age-specific fitted estimates increasing by age, and ages 7+ a uniform single estimate.

Juvenile resighting probabilities were correlated with Natal BA. Fledglings from BAs in the Salt-Verde cluster were more likely to be resighted than those outside the cluster (Table 2).

Adult resighting probabilities were correlated with Sex, Natal BA and Breeding BA. Adults fledging from or breeding at BAs in the Salt-Verde cluster were more likely to be resighted than those outside the cluster. Females were less likely than males to be resighted explaining in part the male biased sex ratios of resighted adults (data not shown). Adult resighting probabilities were also weakly positively correlated with year fledged. However year fledged was also confounded with both natal BA and breeding BA.

Table 2. Age specific resighting probabilities of best fitting juvenile and adult models.

Resighting prob. (%) at	Fitted estimates (95% C.I.)	Male/Female adjustments	Natal BA SV/notSV adjustments	Breeding BA SV/notSV adjustments
ages 1-2	0 (fixed)*			
age 3	0.6 (0.1, 2.3)*		+0.3/-0.2	
age 4	21.7 (13.8,32.5)*		+7.4/-6.2	
age 5	52.8 (41.0,64.4)**	+/-5.4	+7.7/-7.8	+6.3/-6.4
age 6	61.3 (48.9,72.4)**	+/-5.3	+7.1/-7.6	+5.9/-6.3
age 7+	83.5 (78.4,87.6)**	+/-3.2	+3.9/-4.8	+3.3/-3.9

* fitted by juvenile models

** fitted by adult models

Discussion

Taylor and Silver (2006) hypothesized that fecundity and nestling survival would be lower outside the Salt-Verde cluster than inside, due to artificially higher fish abundances from dumping of fish removed from the Salt River Project canals. This hypothesis was supported with significantly lower numbers of nestlings per adult female outside than inside the cluster, and nestling survival declining with year outside the cluster, but remaining constant inside the cluster.

A similar effect was not found for juvenile survival however. Juvenile survival declined with year of fledging regardless of location of the natal BA.

Individuals fledging (or breeding) outside the Salt Verde cluster were however, less likely to be resighted and females less likely to be resighted than males.

Comparison with AGFD model estimates

AGFD (unpubl.) analyzed post-fledging survival for bald eagles banded or marked between 1987 and 2003 (Table 3). It is uncertain to what extent the data used by AGFD overlap with this study, as AGFD did not provide a list of individuals included in their analysis.

AGFD did report marginally significant sex and time correlations, but did not consider hypotheses to do with the Salt-Verde cluster.

The AGFD selected model had 3 age groups for survival probabilities: Ages 1-3 (fixed at 1, with zero resighting probability), Age 4, Ages 5+, with more age groups for resighted probabilities, similar to those found in this analysis.

When this model structure was fitted to the juvenile model data set used in this study, the AIC was significantly greater (2986.2) than for the best fitting model of this study (1271.4). Indeed it was greater than that found for the basic 2 parameter model (no age differences, AIC=1970.3). Fitted parameters were however, close to those reported by AGFD with survival estimates slightly higher for adults (Table 3).

Table 3. Comparison of fitted parameters derived by fitting same model used by AGFD(unpubl) to data used in this study, and as reported by AGFD (unpubl) for “level 2” adjusted data.

Parameter	This study			AGFD (unpubl.)		
	Estimate	Lower 95%CI	Upper 95%CI	Estimate	Lower 95%CI	Upper 95%CI
Prob. survival to ages 1-3 (S)	1	fixed		1	fixed	
S4 (actually survival from 0 to 4)	0.28	0.22	0.34	0.28	0.15	0.47
S to ages 1,2,3,4	0.73	0.68	0.76	0.73	0.62	0.83
S5+	0.92	0.89	0.95	0.88	0.79	0.94
Prob. resight at ages 1-3 (P)	0	fixed		0	fixed	
P4	0.21	0.14	0.32	0.22	0.07	0.53
P5	0.46	0.35	0.58	0.44	0.20	0.71
P6	0.56	0.44	0.89	0.70	0.51	0.84
P7	0.78	0.65	0.88	0.88	0.75	0.94
p8+	0.78	0.73	0.83	0.95	0.85	0.99

Table 4. Comparison of survival estimates with other studies (as cited by AGFD unpubl.).

Study	Population	Annual juvenile Surv.	Fledging-Age 4 Surv.	Adult Surv.
Brown and Amadon (1968)	US	22-76%	3%	-
Gerrard et al (1978)	Canada	37-83%		
<i>This study (1994-2003 estimate)</i>	AZ	65.3%	18.2%	92.3%
Hunt et al (1992)	AZ	65.1%	18%	-
AGFD (unpubl.)	AZ	73%	28%	88%
McCullough (1986)	ME	54-91%	31%	91%
Harmata et al (1999)	Yellowstone NP	64-87%	34%	-
Driscoll et al (1999)	AZ	84%	50%	84%
Jenkins et al (1999)	northern CA	77-95%		95%
Beuhler et al (1991)	Chesapeake Bay	75-100%	57%	83%
Bowman et al (1995)	AK	71-95%	61%	
McClelland et al (1996)	Glacier NP	91%		

Comparison with other studies

The juvenile survival estimates reported here are very close to those reported by Hunt et al (1992) for the Arizona population, which in turn are close to the bottom of the range of values so far reported for Bald Eagles (Table 4). Adult survival estimates are however toward the top of the reported range, second only to that reported by Jenkins et al (1999) for northern California.

Is the downward trend in juvenile survival real?

There is no obvious explanation for the observed and fitted downward trend in juvenile survival over the period of study apart from a real decline in mortality. There are several possibilities to explain the “missing” birds in later years of resighting effort:

- Birds emigrated. Juvenile birds are known to migrate north to Canada and return to Arizona. If this is the case we might expect band recoveries or resightings outside of Arizona. However, no such reports are evident to date that might confirm this explanation. Even if birds did emigrate permanently however, they are effectively “dead” to the Arizona population.
- Birds are not dead, but have joined a non-breeding “floater population.” If this is the case we would expect progressive delay in average time to first resighting at a BA, since birds would be spending more time in the floater population before attempting to breed. However, age at first resighting actually declined slightly with time rather than increased (Fig 1B).
- Resighting effort has fallen off, so birds are surviving at same rate but simply less likely to be resighted. In fact, models show if anything a slight increase in fitted resighting probabilities with increasing year fledged.
- Birds are dying at higher rate. Increased mortality seems to be the only conclusion that can be drawn from the data.

The discovery of new BAs has flattened off since about 2000, so one possibility is that increased juvenile mortality (and nestling mortality found by Taylor and Silver 2006) may indicate arrival of the population at carrying capacity with heavy competition for limited food and suitable breeding areas.

The other possibility is that environment and habitat have deteriorated, with a resulting increase in juvenile mortalities.

Significance for Population Viability Analysis

Taylor and Silver (2006) reported PVA results ranging from rapid extinction to population persistence based on their analysis of fecundities and AGFD estimates of survival and accounting for a range of uncertainty (Table 4).

Based on this reanalysis, current juvenile survival is significantly less than that estimated by AGFD, due to a highly significant downward time trend. AGFD alluded to a marginally significant time trend in survival in their analysis but did not present details.

Mean estimate of juvenile survival of 65% per annum is 8% less than that reported by AGFD and close to the lower 95% CI limit of that estimate. However, adult survival estimated in this study is about 4% higher than that found by AGFD. Hence, we expect a PVA based on this data in general to produce less optimistic predictions of extinction risk than found by Taylor and Silver (2006).

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