POPULATION VIABILITY ANALYSIS:
DESERT-NESTING BALD EAGLE

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INTRODUCTION

In 1999, the U.S. Fish and Wildlife Service (FWS) proposed to delist the bald eagle *Haliaeetus leucocephalus* nationwide, citing growth of the population throughout the United States, and reduction of threats (64 FR 36454).

The bald eagle is the national symbol of the United States. It is a fish eating eagle that nests in streamside trees and, in Arizona, ledges on canyon walls. Destruction and dewatering of streams, persecution and poisoning at baits set by ranchers resulted in significant decline of bald eagles following European arrival particularly in the arid Western states.

In the 1960s, the widespread use of DDT resulted in further declines, even after a total ban on DDT in 1972. DDT is a persistent bio-accumulating pesticide whose breakdown products interfere with eggshell production in birds.

Originally listed under the *Endangered Species Preservation Act* in 1967, the bald eagle was transferred to the new endangered species list in 1973 when the *Endangered Species Act* 1973 (ESA) came into force.

FWS reported an increase in the numbers of occupied "breeding areas" (BAs) observed in the lower 48 states following the ban on DDT and the adoption of a recovery plans from 1982-1986. In 1963 National Audubon Society reported 417 active nests with 0.59 young per nest. In 1994, a collection of agencies reported 4,450 occupied BAs with 1.16 young per occupied BA. On the basis of this data, FWS downlisted the bald eagle to "threatened" in 1995 (60 FR 35999).

The "delisting goals" specify the following criteria for the population to be considered recovered in the southwestern region (64 FR 36458):

1. produce at least 10-12 young per year over 5 years and
2. have expanded to river systems other than the Verde and Salt,

In the same recovery rule, FWS noted the presence of 40 occupied BAs producing 25 young (0.63/occupied BA) in 1998 (36 in AZ, 4 in NM), and that breeding areas have been discovered outside the Verde and Salt in Gila, Bill Williams, San Carlos and Rio Grande river systems.

However they also note the risk that delisting could undermine the Nestwatch Program, which was responsible for "at least 15 percent of the bald eagle production" by guarding nests and rescuing 48 eagles or eggs from disturbance and entanglement in fishing tackle.

The FWS in its delisting proposal recognized only "one population of bald eagles in the lower 48 states" (64 FR 36458).

In this paper we examine the FWS claims that the Desert Nesting Bald Eagle (DNBE) population in the southwestern region (1) is just one part of a freely interbreeding continental population and (2) has recovered to the point that delisting is justified.

In considering delisting, we question that the original FWS delisting criteria are adequate. Instead we develop a stochastic model of population dynamics to determine extinction time distributions based on the available range of estimates of life table parameters. Such population viability analysis may be more informative than simple criteria to determine if recovery has been achieved.

We find that:

(1) the DNBE population qualifies for designation as a Distinct Population Segment under the Endangered Species Act, and

(2) that even with retention on the endangered species list, current life table data suggest that DNBE population is facing an appreciable risk of extinction in the near future.

This together with other empirical work suggests that far from removing the DNBE population from the endangered list, there is a clear need to retain and enhance protection for the DNBE population under the ESA.

DESERT NESTING BALD EAGLES REPRESENT A DISTINCT POPULATION SEGMENT

The assumption that all bald eagles in the lower 48 states form a single interbreeding population is not supported by available evidence.

Indeed, the principal agency responsible for data collection on the DNBE population, the Arizona Game and Fish Department (AGFD) treats the DNBE as a closed population: "Arizona supports a biologically isolated population of desert nesting Bald Eagles" (AGFD 1999).

DNBEs are smaller that bald eagles elsewhere. Average weight of males in AZ is 3.3kg compared with 4.1kg in CA and 4.7 kg in AK. AZ females average 4.5kg compared with 5.1kg in CA and 5.8kg in AK (Hunt et al. 1992). Arizona bald eagles are much smaller than California eagles of equivalent latitude, which does not support the hypothesis of a latitudinal gradient in size.

Desert Nesting Bald Eagles also show two adaptations to their desert habitat: early breeding and cliff nesting.

In order to adapt to high summer temperatures and to schedule breeding cycles appropriately for the spawning of native fish, particularly suckers, DNBEs breed in autumn, nest in winter and fledge in the late spring. Nest initiation occurs from November to February. Up to three eggs are laid and incubated from December to March. The eggs hatch after about 35 days, from February through April. Nestlings are in the nest for 12 weeks until May or June (AGFD 1999, Gerrard and Bortoletti 1988, Hunt et al. 1992, Stalmaster 1987).

Unlike Bald Eagles elsewhere in the lower 48 states, Desert Nesting Bald Eagles utilize cliff nest sites (AGFD 1994). Of 111 known nests, 53 (48%) were found on cliffs by Hunt et al. (1992).

Gene flow between DNBE and neighboring populations is probably less than one individual per generation. From 1983 to 2006 (23 years) 83 recognized individuals engaged in breeding activity and participated in 448 nesting attempts. (AGFD 2006) Only one of these individuals came from outside Arizona. From 1977 through 1999 (22 years), 256 nestlings have been banded but only one individual emigrated to California (AGFD 1999). This represents an extremely low rate of gene flow with neighboring populations, significantly less than one migrant per 8 years and thus sufficient to result in considerable genetic divergence and allele fixation by drift (Wright 1962).

BAs at the margins of the range, such as the isolated *Luna* BA on the New Mexico border, occupied by the only known immigrant to the DNBE population, from Texas, show low breeding success and offspring have minimally interbred with others in the population.

Patrophily is general for Bald eagles (Mabie et al. 1994). Hunt et al. (1992) surveyed band IDs for nine populations and found only two known outbreeding events, breeding at 331km and 418 km respectively from natal site.

FWS based the delisting decision in part on a claim that the DNBE population is not a "distinct population segment" citing as evidence two genetic studies in Hunt et al. (1992). However, one of these was statistically inadequate to detect differentiation and the second actually reported significant differentiation.

One study used only five allozyme loci with low sample sizes, and was unable to resolve AZ from other populations (MD, FL, WA, CA, TX, MN).

DNA fingerprinting analysis isolated population specific DNA markers, and suggested that CA and FL samples were closer to each other than to AZ (Hunt et al. 1992).

Less than fifty nesting pairs of Southwestern Desert Nesting Bald Eagles survive today: roughly 40 in AZ, 4 in UT, 4 in NM and 3 in Sonora, Mexico. Considering this is an isolated population, it meets the IUCN criteria for "critically endangered" on the basis of small population size and vulnerability to stochastic extinction (IUCN 2004).

For purposes of population modeling, the DNBEs were treated as a closed population not demographically linked to other populations. This assumption is strongly supported by the evidence.

POPULATION VIABILITY ANALYSIS (PVA)

Are stochastic extinction time models appropriate and reliable?

Beissinger and Westphal (1998) and Ellner et al (2002) criticized the low precision of stochastic population viability models for forecasting extinction risk.

However these criticisms apply only to the extent that data are poor and models do not incorporate uncertainty. Brook et al. (2002) dismiss the "alternatives" advocated by critics of PVA, noting that correctly applied, PVAs must account for all sources of uncertainty.

It is common to cite λ (lambda) the deterministic intrinsic rate of population increase as calculated from available life table data. Lambda is equal to 1 for a stable population and below 1 for a declining population. The interpretation of lambda is difficult however, without some measures of precision and uncertainty. Even for lambda of one, high stochastic variance in vital rates can lead to appreciable risk of extinction.

Extinction time distributions from stochastic population models are the best available means to translate all the uncertainties and variabilities in vital rates into a range of population outcomes.

All available data on numbers of known BAs, numbers of occupied BAs and numbers of fledglings since 1970 as well as survival estimates were taken from records of the Arizona Game and Fish Department and other studies.

Life table (fecundity and survival) parameter estimates were entered into the Vortex version 9 model (www.vortex9.org) to produce corresponding ranges of extinction time and extinction probability estimates.

Adult numbers

AGFD nest survey reports (1991- 2005) describe survey areas. However it remains unclear what proportion of all potential habitat was searched intensively. It is unclear how intensively the same areas were surveyed in the past and thus we have no reliable estimate of the probability that a breeding or occupied nest was overlooked in the past due to differences in survey effort or observer experience.

Different groups and agencies were involved in the surveys, with consequent differences in observer experience. Observer experience is also expected to improve with time, leading to increasing detections with time.

The searching protocol was not random nor unbiased since searchers naturally tend to search more in areas that bald eagles have been known to occupy in the past. The inevitably leads to a better search coverage with each passing year as new BAs are discovered.

Past undercounting of BAs

It is probable that some BAs first "discovered" in a particular year could have been present and even occupied in previous years. Canaca et al (2004) underscored the ephemeral nature of the evidence for a BAs existence by reporting that 18 nests in known BAs had disappeared by 2003.

Additional evidence that earlier BA counts may not be accurate come from the fact that between 1987-2003 only 83% of fledglings were banded, whereas in the same period, only 59.6% of breeding adults were banded (AGFD unpubl. data). There are three possible explanations for this discrepancy.

First, unbanded nestlings may suffer less mortality. Banding effects on bird mortalities have been recorded before, however most differences are minor and so this is an unlikely explanation.

Second, immigration could account for the discrepancy. This is also an unlikely explanation as bald eagles in adjacent areas are also banded at high frequencies and yet the only recorded immigration event has been from Texas to the Luna BA which is on the edge of DNBE range.

Finally, a large pool of undiscovered and thus unbanded nestlings could have been present in earlier surveys. This latter explanation is the most likely of the three and suggests that BAs may have been undercounted in earlier years.

The first widespread survey in 1975 estimated that 90% of potential habitat in Arizona, New Mexico and Colorado River had been surveyed, but again without estimation of probabilities of missed breeding areas or BAs (Rubink and Podborny 1976). This survey found 21 BAs, 18 adults, and 5 fledglings.

By 2001 the number of known BAs had arrived at the current level of 47.

In the 2005 survey, 39 of 47 known BAs were occupied or active. There were 78 or more adults and 38 fledglings (Jacobsen, K.V., J.S. Canaca, J.T. Driscoll, 2005.).

For some "occupied" but non-breeding BAs in some years, only one adult was observed. In others no adults were observed since it is sufficient to observe nest rebuilding to score a nest as "occupied." In all such cases the lower estimate of adult number was set to 1. Otherwise for all BAs occupied or breeding the upper estimate of adult number was 2.

Fig.1 shows the high and low estimates of adult numbers at BAs accounting for this source of uncertainty. The high estimate is simply twice the number of occupied or active BAs.

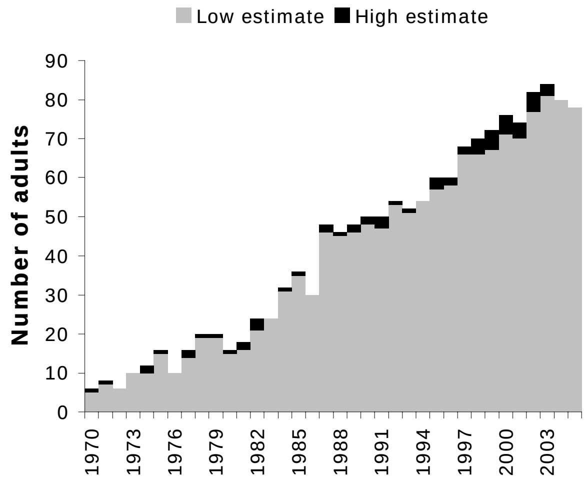

Figure 1. Numbers of bald eagle adults at breeding areas range of upper and lower estimates 1970- 2005.

There is little doubt that the rise shown in Fig 1 represents real upward growth of the DNBE population since 1975, however the full extent of real growth remains uncertain as earlier surveys may have missed occupied BAs.

Undercounting of adults

The "high" estimates shown in Fig 1 are only based on counting two adults at each occupied or active breeding area. Even assuming that surveys for BAs were exhaustive, additional uncertainty in estimating adult numbers comes from the possible presence of "floaters", non breeding adults undetected by surveys of BAs.

Such under-estimation of adult numbers results in over-estimation of fecundity, which is estimated as the number of nestlings per adult female.

However, overestimation of fecundity through undercounting of adults may be compensated for by underestimation of adult survival. If banded "floaters" were presumed dead when never resighted as adults, survival to adult stage is underestimated.

Adults move between BAs. Of 1510 total observations of occupied or breeding BAs, 39 involved a confirmed replacement of a male at a BA, and 37 a confirmed replacement of a female at a BA. As eagles age they are likely to be replaced by younger breeding adults at a BA. However not all replacements clearly relate to aging of incumbents. On three occasions, an older male actually replaced a younger male at a BA. Such movements between BAs in different years do not affect the annual adult count. If adults move between BAs in the same year however, there is potential for double counting. There is no known instance of a positively identified individual appearing at more than one BA in the same year, and so double counting was considered to be a negligible source of uncertainty.

Adult female pool

Specific IDs of sexes were lacking in most cases. The total adult female population was simply estimated as the number of occupied or active BAs, and a 50% adult sex ratio assumed. As discussed above, possible undercounting of BAs in earlier years and the existence of an unobserved adult "floater" population means that this underestimates actual adult female population, and so overestimates fecundity.

Fecundity

For the purposes of population modeling, we assumed that "birth" was represented by number of nestlings rather than eggs laid, as counts of numbers of eggs are less accurate than those of nestlings.

Nestling counts are also more useful than using fledgling counts. Most BAs except in core areas around the Salt-Verde confluence, were monitored by overflights. Nestlings are scored as having fledged if they reach 8 weeks of age (AGFD unpubl. data). This may overestimate actual fledging, as nestlings scored as having fledged may have actually died in the nest after the observation.

However, nestling counts also carry uncertainty. This uncertainty was captured by defining a range between upper and lower limits. If the nestling number was reported as "unknown" the lower limit was set to the known number of fledglings while the upper limit was set to the high estimate of egg number. (eg if eggs were scored 2+, upper limit was set to 3 nestlings).

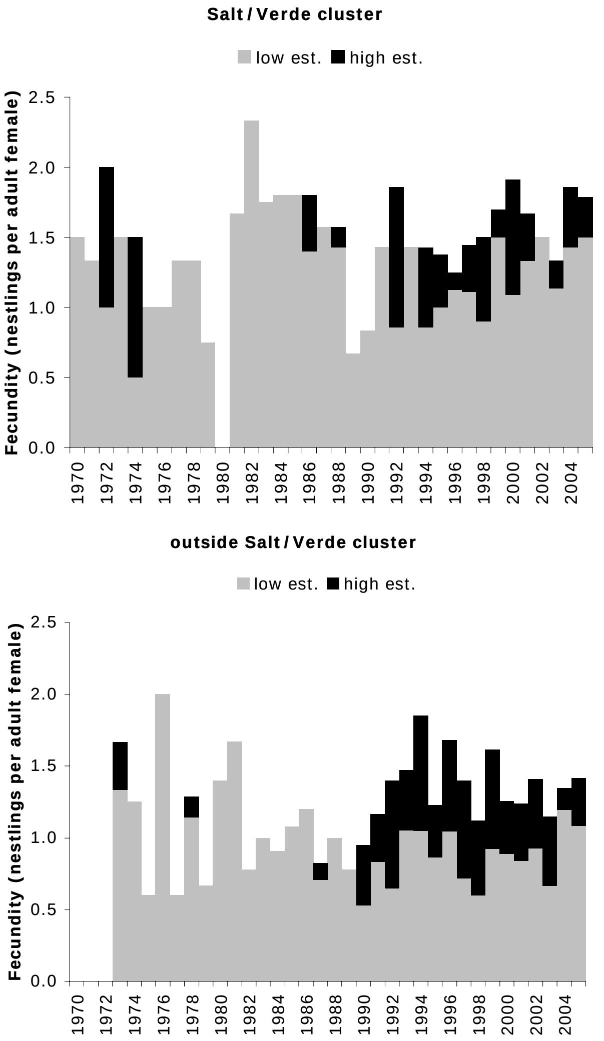

Figure 2. Number of nestlings per adult female, upper and lower estimates, inside and outside Salt/Verde cluster.

If nestling number was unknown, the lower limit was set to fledgling number and upper limit to the high egg estimate.

For nestling scores of 1+ or 2+, the upper limits were set to 2 and 3 respectively, and lower limits to 1 or 2 or fledgling number if greater.

Effect of prey supplementation

We hypothesized that the lower Verde and Salt BAs would have artificially higher productivity as a result of stocking with exotic rainbow trout and release of native fish captured from irrigation canals into this area by the Salt River Project (Canaca et al 2004).

To test this "prey supplementation" hypothesis, we divided BAs into 2 groups, those on the lower Salt River or lower Verde River up to Horseshoe Dam, and those outside this "Salt/Verde cluster."

There were significant differences in fecundity and nestling survival between these two groups of BAs.

There was considerable fluctuation but no evident time trend in fecundity estimates. Fecundity in the Salt Verde cluster may have increased slightly in recent years (Fig 2). However both low and high estimates were significantly different between the Salt/Verde BA cluster and outside this cluster (paired t-tests, P=0.001, P=0.004 respectively). The mean fecundity (low estimate) for Salt/Verde cluster BAs was 1.24 (SD 0.43) and for BAs outside the cluster 39% lower at 0.89 (0.41) nestlings per adult female. The mean fecundity (high estimate) for Salt/Verde cluster was 1.46 (SD 0.43) and outside the cluster 1.12 (0.48) nestlings per adult female.

For population modeling, fecundity estimates are expressed as a distribution of proportions of females producing 0,1,2 or 3 nestlings a season. The low estimate of fecundity outside the Salt Verde cluster was used as the lower limit of the fecundity range. The upper limit of the range was the high estimate of nestlings/female for the entire population. The median fecundity estimate was taken to be the average of these range limits (Table 1).

Nestling to fledgling survival

We derived low and high estimates of survival from nestling to fledgling (*Snest*) using high and low estimates of nestling numbers respectively. Under the supplementation hypothesis, we expected survival inside the Salt/Verde cluster to be higher than outside. Both low and high estimates were significantly different between Salt/Verde cluster and non-cluster BAs (paired t-tests, P=0.005, P=0.015 respectively).

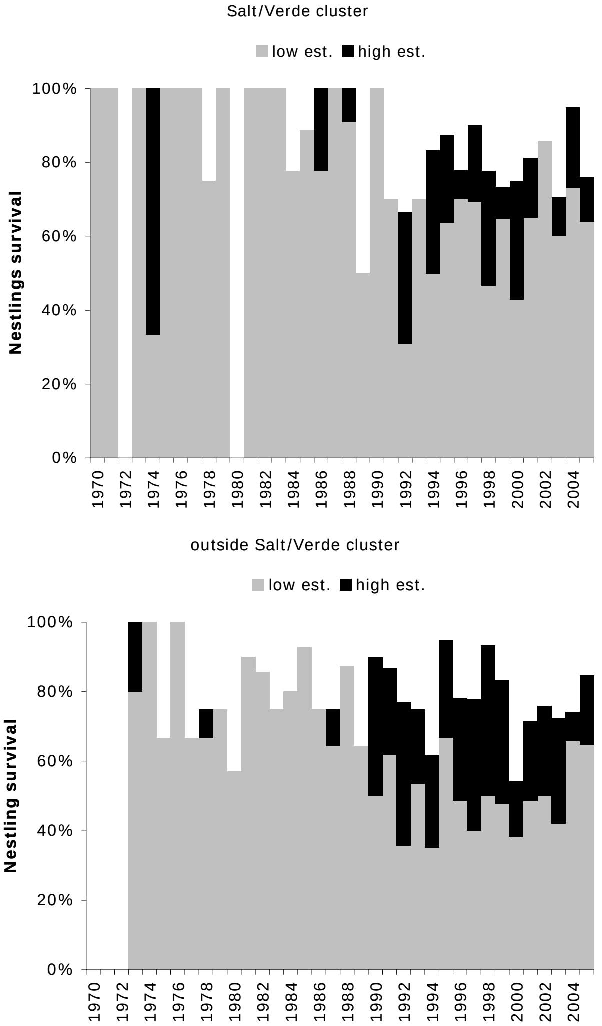

Figure 3. Nestling survival to fledging (*Snest*), high and low estimates, inside and outside Salt/Verde cluster.

Neither high nor low estimates of *Snest* for BAs in the Salt/Verde cluster declined significantly in linear regressions on year ($P>0.05$).

For the non-cluster BAs however, the linear regression for the low survival estimate on year was highly significant at $P<0.001$ with a declining trend. The regression for the high estimate on year was not significant (Fig 3).

Accordingly the ten years 1996-2005 for the non-cluster BAs were used to derive a lower limit of *Snest* for modeling purposes of 49.5% (ESD 3.9%). Environmental standard deviations (ESD) were calculated by the method of Akçakaya (2002).

The upper limit was taken to be the high estimate *Snest* for the entire period, for all BAs of 80.9% (ESD 15.3%).

Post-fledging juvenile and adult survival

We did not attempt to derive independent estimates for post-fledging survival because we did not have the complete record of bandings and resightings.

Juvenile mortality was unusually high. From 1987 to 1999, there were 214 fledglings. However, 97 or 41% of this number of fledglings were subsequently found dead (AGFD 1999). Hence fledgling to adult survival was no more than 59%.

Arizona Game and Fish Department estimated stage specific survival from resightings of banded nestlings using the program MARK (AGFD unpubl. data).

The AGFD best fitting model estimated survival from fledging to age 4 (maturity) at 0.28 (0.147-0.466, 95% CI).

For adults, annual survival was estimated at 0.877 (0.785-0.936, 95% CI) (AGFD unpubl.data).

A phenomenon peculiar to DNBEs that corroborates the high adult mortality estimates obtained by AGFD is the unusually high proportion of sub-adults attempting to breed.

From 1987 to 1990, Hunt et al. (1992) counted 39 individuals recruited into the breeding pool, of which 61.5% (n=24) were in subadult plumage. From 1991 to 1998, of 66 such recruits, 29% (n=19) were in subadult plumage (AGFD unpubl. data). No subadult breeding has produced fledglings. Outside Arizona, the known incidence of subadults attempting to breed is rare (0.02% according to Hunt et al. 1992). AGFD suggests that this phenomenon results from "an insufficiency of adults in the floating segment” of the population (AGFD 1994), most likely due to high adult mortality.

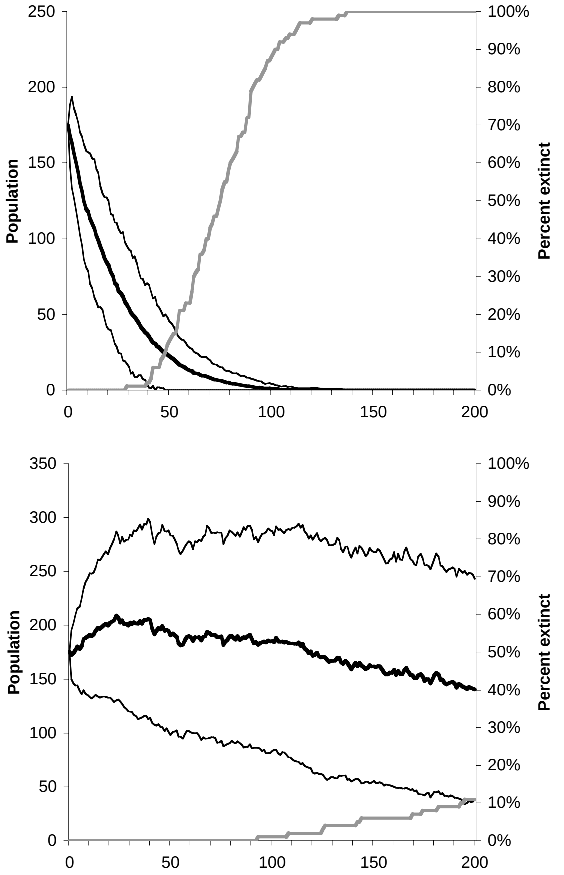

Figure 4. Means (+/- S.D.) of population sizes and percent of simulations extinct (gray line) for top: median scenario; bottom: scenario using upper 95% CI of adult survival.

Although male survival is lower than female survival, the difference is not statistically significant (AGFD unpubl. data). Observed nestling sex ratio determined during banding averaged 65% males (AGFD unpubl. data). Thus male mortality would have to be higher than females to result in a 50:50 adult sex ratio at breeding areas. To simplify modeling, a 50:50 sex ratio at birth and equal male and female age specific mortalities were assumed. Departure from this assumption does not greatly affect model outcomes.

Initial population size, K

Initial population size was set to 175. The high estimate of adults and young was 137 in 2005. The unknown number of juveniles, sub adults and "floaters" was guessed to be about 38.

Simulations were all started from simulated stable age/sex distribution, because actual distribution was unknown.

Carrying capacity was set arbitrarily to double the presumed initial population size. In general if fecundity and survival are sufficient to get the population to grow toward carrying capacity, risk of extinction is low, except for small carrying capacities, when stochastic extinction risk may be considerable.

Simulations

Ten simulations of the Vortex (www.vortex9.org) using parameter combinations that bracketed the range of uncertainty in the available data and life table estimates (Table 1).

Survival from nestling to age 1 was calculated as the product of two survival estimates, the survival from nestling to fledgling calculated in this paper, and the annual survival from fledgling to age 1 as estimated by AGFD. Environmental Standard Deviations of juvenile and adult mortalities were arbitrarily set to 5%, as ESDs were not estimated by AGFD.

No catastrophes, declines in carrying capacity or inbreeding depression were included in the simulations. These are all expected to aggravate extinction risk.

Each scenario was simulated 100 times for 200 years.

The scenarios and results are shown in Table 1 and Fig 4:

1. The median scenario used the average of upper and lower limits of fecundity and nestling survival as calculated above, and the AGFD median estimates of juvenile and adult survival. Median time to extinction was 75 years (Fig. 4, Table 1).
2. The early maturity scenario shortened age at maturity to 4 years, but was otherwise the same as median scenario. Median extinction time increased by 12 years.

3. The "Low fec." scenario used the lower limit of fecundity as calculated above, but otherwise was the same as Median scenario. Median extinction time decreased slightly relative to the Median scenario.
4. The "Low Snest" scenario used the lower limit of nestling survival *Snest* as calculated above, but otherwise was the same as Median scenario. Median extinction time decreased substantially relative to the Median scenario.
5. The "Low Sjuv" scenario used the lower 95% confidence limit of juvenile survival *Sjuv* as calculated by AGFD, but otherwise was the same as Median scenario. Median extinction time decreased by 97% relative to the Median scenario.
6. The "Low Sad" scenario used the lower 95% confidence limit of adult survival *Sad* as calculated by AGFD, but otherwise was the same as Median scenario. Median extinction time was more than halved relative to the Median scenario.
7. The "High fec." scenario used the upper limit of fecundity as calculated above, but otherwise was the same as Median scenario. Median extinction time increased slightly relative to the Median scenario. However all simulated populations still went extinct within 200 years.
8. The "High Snest" scenario used the upper limit of nestling survival as calculated above, but otherwise was the same as Median scenario. Median extinction time increased by 24% relative to the Median scenario.
9. The "High Sjuv" scenario used the upper 95% confidence limit of juvenile survival as calculated by AGFD, but otherwise was the same as Median scenario. Extinction risk within 200 years declined significantly relative to Median scenario from 100% to 23%.
10. The "High Sad" scenario used the upper 95% confidence limit of adult survival as calculated by AGFD, but otherwise was the same as Median scenario. Extinction risk within 200 years declined significantly relative to Median scenario from 100% to 11% (Fig 4).

Results for scenarios with all low or all high estimates are not shown. It should be clear that setting all parameters to their low limits resulted in very rapid extinction, while setting all parameters to their upper limits resulted in growth to carrying capacity with little risk of extinction.

In summary, simulated populations declined to extinction within 100 years on the basis of the median values of known life table parameters estimated in this paper for fecundity (*fec*) and nestling survival (*Snest*) or by AGFD for post-fledging juvenile (*Sjuv*) and adult survival (*Sad*). However, parameter space was quite broad. Populations could persist indefinitely at the upper 95% confidence limit of the parameter space for juvenile and adult survival. Juvenile and adult survival were the most critical parameters for the population model having the greatest effect on extinction risk, confirming qualitative arguments by Stalmaster (1987) among others. However, these parameters are expected to be more important simply because their influence extends across so many year classes. Other modeling approaches such as Bayesian estimation may be better able to reconcile all data and incorporate parameter distributions explicitly. Vortex models however are more readily understood and serve at least to bracket the range of variability in extinction outcomes. Clearly, more precise unbiased estimates of juvenile and adult survival would be desirable.

TABLE 1. Vortex simulations, parameters and results. (All simulations were run 100 times for 200 model years. Blank cells indicate parameters same as median scenario. * indicates average of time to extinction for simulated populations going extinct.)

Parameters	Median	Early maturity	Low fec.	Low Snest	Low Sjuv	Low Sad	High fec.	High Snest	High Sjuv	High Sad
Population initial	175									
K	350									
Age females mature	5	4								
Age males mature	5	4								
Max. breeding age	25									
% females success.	62.5%		53.5%				71.5%			
EV in % success.	20.0%		19.0%				8.0%			
% w 1 nestlings	34.5%		39.4%				29.6%			
% w 2 nestlings	58.6%		54.6%				62.5%			
% w 3 nestlings	7.0%		6.0%				8.0%			
Surv. nestling	*65.2%*			*49.5%*	*65.2%*			*80.9%*	*65.2%*	
Surv. fledge->age4	*28.0%*			*28.0%*	*14.7%*			*28.0%*	*46.6%*	
Mortality Nestling->1	52.6%			64.0%	59.6%			41.2%	46.1%	
EV in Mort N->1	15.0%			4.0%	15.0%			15.0%	15.0%	
Mortality 1->2	27.3%				38.1%				17.4%	
EV in Mort 1->2	5.0%				5.0%				5.0%	
Mortality 2->3	27.3%				38.1%				17.4%	
EV in Mort 2->3	5.0%				5.0%				5.0%	
Mortality 3->4	27.3%				38.1%				17.4%	
EV in Mort 3->4	5.0%				5.0%				5.0%	
Mortality 4->5+	12.3%					21.5%				6.4%
EV in Mort 4->5+	5.0%					5.0%				5.0%
RESULTS										
lambda	0.962	0.973	0.947	0.94	0.914	0.897	0.976	0.98	1.007	1.006
Median years to extinction	75	87	61	48	38	31	87	93	129*	150*
% extinct 200 yrs	100	100	100	100	100	100	100	99	23	11

ASSESSMENT OF THREATS

The foregoing analysis was based on the assumption of indefinite continuation of the same environmental conditions that have prevailed in recent years. Available evidence brings this assumption into question. In particular, the lower estimate of nestling survival outside of the supplemented Salt/Verde cluster BAs was found to decline significantly with time for reasons yet to be determined.

Although some threats may be attenuating slowly with time such as DDT residues, others are escalating as a result of urban development and growing human population in the greater Phoenix area in the heart of DNBE historical habitat.

We find that the assessment of threats made by FWS in their proposal to delist bald eagles needs reconsideration for the DNBEs. Some issues of importance were not considered in depth by the FWS when making their proposal (Table 3).

Decline in habitat extent and quality

Habitat conditions have declined and are expected to decline further in the foreseeable future. Critical habitat has been shown to be of significant benefit for listed species by Taylor et al (2005). Bald eagles were never given critical habitat by the FWS.

The southwest has already lost more than 90% of historic riparian habitat (Lofgren et al. 1990). The loss of riparian habitat is certain to worsen owing to increasing urban development, dewatering of streams via groundwater pumping, dams and diversions, livestock grazing, and lack of regular flooding needed to rejuvenate vegetation and native fish habitat.

Private property

An additional problem is that some of the key riparian habitat for DNBEs is on private hands and therefore subject to destruction for urban development or agriculture.

> "…Property has recently been sold or is planning to be sold in Camp Verde and Perkinsville BAs. Current owners of the Perkinsville have refused ground access to monitor the BA. The Winkelman BA is surrounded by housing, recreation, and industry." (AGFD 1999)

Decline of native fish

Native fish species in the river systems have declined precipitously and have been supplanted by non-natives. Hunt et al. (1992) cited fish diversity as a crucial feature of a suitable breeding location and native suckers as an important prey item for bald eagles. Surveys have shown that native fish have declined on the upper Salt River (AGFD 1999).

From 1967 to 1991, 17 species of southwestern fish were listed as threatened or endangered by FWS. Only four were reported to have improving population trends in 2000 by the FWS (USFWS 2003).

DNBE productivity at the Verde/Salt confluence appears to have been artificially boosted by the releases of native fish found in Salt River Project canals and AGFD releases of exotic rainbow trout for recreational fishers (Canaca et al 2004, p.8).

Conversely, this demonstrates that natural prey productivity elsewhere is insufficient to sustain the DNBE population.

Lack of nest tree recruitment

Half of all DNBE nests ever known in Arizona have been in riparian trees and snags (Driscoll 1999). The nests of the most productive BAs are found in large riparian trees. The cohort of large cottonwoods and willows along Arizona rivers is aging and dying without replacement due to a greater than 100 year gap in recruitment. This gap was caused by dams and diversions that ended the periodic flooding necessary for seedling development, as well as pervasive livestock grazing along Arizona waterways which has suppressed riparian forest recruitment for over 100 years. Bald eagles at 11 BAs (*Box Bar, Coolidge, Doka, Fort McDowell, Perkinsville, Pinto, 76, Sheep, Sycamore*, *Tonto*, and *Winkelman*) rely solely on riparian trees to nest. The large old cottonwood trees in these BAs are not being replaced (AGFD 1999).

Additionally, the increased storage capacity of Roosevelt Lake threatens the few nest trees remaining at the *Pinto* and *Tonto* BAs. Nest trees at both BAs will die due to inundation and dead trees will fall over time. Few or no alternate nest trees exist for the *Pinto* pair and most of the alternate trees available to the *Tonto* pair are located near housing communities or recreation areas (AGFD 1999).

Urban sprawl

The FWS recognizes that growth along the upper and middle Verde River will increase about 150% by 2040, leading to "increased contamination, increased wildfires, and increased alteration of the watershed and hydrologic regime". Increased recreational visitation in the Verde River riparian habitat was predicted to result in:

> "[b]ank compaction and erosion, channel morphology changes, riparian vegetation suppression and loss, increased pollution and trash, construction of picnicking and other recreational facilities with the riparian corridor, and many other adverse impacts will destroy or adversely alter razorback sucker habitat and habitat for bald eagle prey species. Bald eagle will be subjected to increasing disturbance effects and may have increased problems with entanglement in monofilament fishing line…" (USFWS 1998).

Along the lower Verde and Salt Rivers lies the huge metropolitan sprawl of Phoenix and satellite cities. Maricopa County's human population is expected to double to more than six million by 2030 (AZ Republic 3/25/98).

Proposed and ongoing developments are affecting the *Blue Point, Box Bar, Pleasant, Sheep,* and *Tonto* BAs:

- A turnaround for river-tubers (recreation involving floating downstream in an inflated tire inner tube) below Bulldog Cliffs near the *Blue Point* BA.
- A 360-unit housing development and 18-hole golf course 1.0 miles from the *Box Bar* BA.
- The City of Peoria annexed the north shore of Lake Pleasant to develop lakeside resorts.
- Continued housing, road, and business developments along lower Tonto Creek, near the *Sheep* and *Tonto* BAs (AGFD 1999).
- Campground developments at Roosevelt Lake by the US Forest Service, predicted to result in the loss of 12 nests and eight nestlings or eggs in next 50 years and nest productivity drops from 50-80% to 35% (USFWS 1993).
- Agricultural expansion near the *Fort McDowell* BA was followed by a 45% fall in nest productivity after 1987 (USFWS 1992a).

Stream dewatering

Dewatering of the middle portion of the Verde River is worsening due to agriculture and the growing population of Cottonwood and Camp Verde. Base flows, or stream flow during the driest times of the year, are now reduced to that of a small irrigation ditch.

The FWS recognizes groundwater drawdown as a significant impact on Verde River flows:

> "…The Verde River base flow is provided by groundwater discharge from the alluvium and Verde Formation (ADWR, 1994[*]).

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[*] References cited by USFWS: Arizona Department of Water Resources. 1994. *Arizona Riparian Protection Program: A report to the Governor, President of the Senate and Speaker of the House.* Phoenix, Arizona. 507 pp.; Miller, R.R. 1961. Man and the changing fish fauna of the American southwest. *Papers of the Michigan Academy of Science, Arts, and Letters* XLVI:365-404; Hendrickson, D.A. and W.L. Minckley. 1984. Cienegas – vanishing climax communities of the American southwest. *Desert Plants* 6:131-175; Stromberg, J.C. 1993. Fremont cottonwood-Gooding willow riparian forests: a review of their ecology, threats, and recovery potential. *Journal of the Arizona-Nevada Academy of Science* 26:97-110; Glennon, R.J. and T. Maddock, III. 1994. In search of subflow: Arizona's futile effort to separate groundwater from surface water. *Arizona Law Review* 36:567-610; Tellman, B., R. Yarde, and M.G. Wallace. 1997. *Arizona's changing rivers: how people have affected the rivers*. University of

> Thus, any withdrawal from either of those portions of the aquifer is expected to eventually deplete Verde River base flows….Groundwater pumping in Arizona has been repeatedly demonstrated to result in depletion of surface flows, degradation and loss of riparian habitats, and adverse impacts and local extirpation of aquatic and riparian flora and fauna (Miller, 1961; Hendrickson and Minckley, 1984; Stromberg, 1993; Glennon and Maddock, 1994; Tellman et al., 1997). …various studies predict that the accelerating amount of groundwater removal will begin to deplete Verde River flows in the near future (Owen-Joyce and Bell, 1983; ADWR, 1994; Ewing et al., 1994; McGavock, 1996)…"
>
> "…Another important and far-reaching result of increased urban/suburban development will be increased channelization of Verde River and its tributaries. Channelization within developed or developing areas is already increasing. This is illustrated by the five formal consultations that have been completed since 1993 on various flood and erosion repair and protection projects…Channelization has many adverse effects to razorback sucker, including direct habitat reduction by shortening of the river channel, loss of backwater larval and juvenile habitats, increased velocities, disruption of food base, and many others…" (USFWS 1998).

Global warming

The winter nesting phenology of DNBE is an adaptation to desert conditions. Nestlings are therefore vulnerable to early arrival of high temperatures. Heat stress is a significant mortality risk for nestlings. Of 51 nestling deaths, at least 4 have been attributed to heat stress. Nestlings may also attempt to fledge early in response to heat stress (AGFD 1999).

As global warming progresses, average temperatures will increase and, drought cycles may become more intense. Global warming is also likely to aggravate the loss of habitat and particularly large nest trees through heat stress, violent storms and erosion (SWRAG 2000).

Toxic contaminants

The FWS asserted that toxic contaminants in prey and in eggs, specifically DDT/DDE have declined since bans on production concurrent with the rise in US bald eagle populations.

However FWS ignore evidence that these and other toxicants remain a threat to the DNBE in Arizona. While organochlorine pesticide pollutant levels have declined nationwide, mercury has not declined since 1974 (64 FR 36461).

Organochlorines

DDT is still found at high levels in farming areas around Phoenix. The Salt and Gila and Salt rivers below the Salt River Project diversion dam remain impaired by toxic levels of DDT metabolites, toxaphene and chlordane in fish (ADEQ 2002). The AGFD found toxic levels of DDE in an egg from *Sycamore* BA in 1997 (AGFD 1999).

Eggshell thinning seems to have increased for DNBE although causes are not clear. Since 1977, four different studies have collected and analyzed Arizona bald eagle eggshells. Grubb et al. (1990) reported 8.8% thinning (1977-1985). Hunt et al. (1992) reported 4.9 percent thinning from 1987 to 1990, followed by 6.6% thinning 1991-1992. The most recent study from 27 BAs between 1993 and 1997 however, reported 9.7% thinning, the highest recorded since the late 1970s (AGFD 1999).

Arizona, Tucson, AZ. 198 pp; Owen-Joyce, S.J. 1984. Hydrology of a stream aquifer system in the Camp Verde area, Yavapai County, Arizona. *Arizona Department of Water Resources Bulletin 2*, Phoenix, Arizona. 219 pp; Ewing, D.B., J.C. Osterberg, and W.R. Talbot. 1994. *Groundwater study of the Big Chino Valley*, Technical Report. U.S. Bureau of Reclamation, Denver, Colorado; McGavock, E. 1996. *Overview of groundwater conditions in the Verde Valley, Arizona*. 9th Annual Symposium of the Arizona Hydrological Society. Prescott, AZ. Sept. 12-14, 1996.

Mercury

Mercury was found at levels "sufficiently high to cause failure in eggs along the Verde, Salt, and Gila rivers" according to AGFD (1999). USFWS found excessive mercury levels in fish from Alamo Lake, Lake Pleasant, the lower Verde River, the Salt River, and Tonto Creek in 1988. Seven of 13 eggs collected from 1994 to 1997 from the *Tower*, *76*, *Pinal*, and *Winkelman* BAs had toxic levels of mercury ranging from 2.11 to 8.02 ppm above the levels found to impair hatching in other birds (AGFD 1999)

Chronic lack of agency resolve

Despite assurances by FWS in the delisting proposal such as: "We will not issue these permits if the status of the bald eagle will be adversely effected" (64 FR 36458), the FWS has repeatedly issued permits for federal actions responsible for the deaths of at least 29 southwestern Desert Nesting Bald Eagles in the 1990s, and which were expected to result in 491 more deaths over the following five decades, even with the protection of listing under the Endangered Species Act in place (USFWS 1992b, USFWS 1993a, USFWS 1994, USFWS 1996, USFWS 1997).

AGFD found that "30 percent of all occupied territories (n=27) in 1994…may be adversely affected by currently planned projects…" (AGFD 1994).

The major threatening actions that continue to be permitted by FWS regardless of Bald Eagle listing are:

- livestock are still permitted by the US Forest Service and the BLM to graze riparian areas, halting recruitment of riparian deciduous nest tree species, muddying streams and destroying fish habitat.
- dams continue to release water at times that do not assist in recovery of downstream riparian habitat
- habitat continues to be inundated by reservoirs
- flying pilots continue to ignore AGFD flight advisories
- dewatering of remnant, free-flowing rivers continues
- exotic fish continue to be introduced into native fish habitat

Federal agencies currently have the legal obligation to adequately address each of these problems. To date, they have neglected to do so.

The FWS has repeatedly recognized in ESA section 7 consultations that federally permitted actions pose significant threats to DNBE but has simply allowed such actions to go forward:

> "Improper livestock grazing has resulted in widespread degradation and loss of riparian habitats in the western United States. These effects include changes in vegetation structure, composition and quantity, and widespread changes in watershed hydrology. Livestock grazing in riparian habitats typically results in reduction of riparian vegetation (especially palatable broadleaf plants lie willows and cottonwood saplings) and is often the most serious cause of riparian degradation" (USFWS 1993a)

The November 16, 1994, Biological Opinion of the FWS on a US military proposal to widen and/or realign segments of four of the nine military training routes in Arizona admits that:

> "nest watchers for ABENWP have documented numerous instances where low-level jet aircraft using MTRs [military training routes] have startled nesting bald eagles and chicks, and passed within close proximity (both above and below) to eagles flying around nesting and foraging areas. The elevation and lateral distance at which low-level flights occur near bald eagle nesting areas is of particular concern because eagles regularly fly to 610 m (2,000 ft) above the surrounding landscape. This puts eagle at risk of collision with low-flying aircraft traveling at speeds that do not enable pilots to avoid bird strikes. The Draft EA [Environmental Assessment] documents 62 bird strikes on six MTRs for the period 1990-1993, but gives no data on the species affected." (USFWS 1994)

The December 29, 1997, Biological Opinion for modifications of Horse Mesa Dam located on the Salt River admits that:

> "…The series of dams and reservoirs along this portion of the Salt River has greatly altered the rivers hydrologic regime and greatly affected aquatic and riparian habitats associated with the river. In the bald eagle breeding areas associated with Roosevelt Lake in the broad valley of the Tonto Basin, eagles generally place their nests in large cottonwood trees. The narrow, steep canyons where Apache, Canyon, and Saguaro lakes have been created, limit the potential for establishing stands of large cottonwood and willow trees…" (USFWS 1997b)

The March 30, 1998, Biological Opinion for assignment to the City of Scottsdale of CAP (Central Arizona Project0 water allocations belonging to Cottonwood Water Works, Inc. (CWW) and the Camp Verde Water System, Inc. (CVWS), admits that :

> "[g]roundwater pumping in Arizona has been repeatedly demonstrated to result in depletion of surface flows, degradation and loss of riparian habitats, and adverse impacts and local extirpation of aquatic and riparian flora and fauna" (USFWS 1998).

The FWS assertion in the delisting proposal of 1999 that recovery goals had been met or exceeded for the DNBE population, failed to cite earlier concerns expressed by FWS biologists that the recovery goals may have been inadequate or ill-informed. In 1993 the Bald Eagle Status Review Team pointed out that:

> "Since 1988, extensive research and surveys have refined our knowledge of distribution, demographics, and general ecology…" and

> "because of small population size and increasing or static threats, delisting is very unlikely" (USFWS 1993b).

The original Recovery Plan for the Bald Eagle acknowledged gaps in knowledge, and called for subsequent revision of recovery goals and objectives as new information emerged. However "[n]o revisions were written and no delisting goals were established..." (AGFD 1999)

Table 3. Comparison of FWS assessment of threats and assessment of threats based on Arizona specific data.

Threat	**FWS (1999) assessment of threat**	**Assessment of threat status in DNBE range (this paper)**
The Present or Threatened Destruction, Modification, or Curtailment of Its Habitat or Range	"no indications that availability of these habitats will limit the bald eagle population in the near future." (64 FR 36458)	Development continues to destroy DNBE habitat. Native fish species endangered and in decline. Nest tree recruitment faces >100 year gap. (see text for more details)
Over-Utilization for Commercial, Recreational, Scientific, or Educational Purposes	"no legal commercial or recreational use of bald eagles" (64 FR 36458)	International trade in Bald Eagle products has been permitted once again by the successful US bid to downlist bald eagles to Appendix II of the Convention on International Trade in Endangered Species or CITES at the 2004 Conference of Parties. Excessive incidental death due to low level flights, ORVs, human presence, toxicants, electrocution, roadkills, fishing tackle entanglement, continues.
Disease and Predation	" not considered to be a significant threat" (64 FR 36458)	Mortalities are aberrantly high particularly for nestlings. No information is available to determine the role of disease in these elevated mortalities.
The Inadequacy of Existing Regulatory Mechanisms	Bald and Golden Eagle Protection Act prohibits take. Migratory Bird Treat Act also prohibits take. Lacey Act bans commerce.	Bald and Golden Eagle Protection Act, Migratory Bird Act, Lacey Act have no provisions for habitat protection.
	Clean Water Act prevents pollution of waterways	Clean Water Act does not prevent physical destruction of habitat or dewatering of streams.
	Federal Insecticide Act regulates pesticides	Federal Insecticide Act does not require cleanup of existing contamination.
	National Environmental Policy Act (NEPA) requires agencies to document environmental impacts of federal projects.	NEPA requires disclosure of impacts, not the avoidance of environmental harm.
	CITES prohibits international trade (64 FR 36459)	Downlisting to CITES App II now reopens potential for commercial trade.
	FWS proposes a Conservation Agreement to substitute for ESA protection	Draft Conservation Agreement is legally non-binding "Nothing in this MOA shall obligate the cooperators to expend appropriations or to enter into any contract or other obligations" (AGFD 1999).

Table 3 (cont'd).

Threat	**FWS (1999) assessment of threat**	**Assessment of threat status in DNBE range (this paper)**
Other Natural or Manmade Factors Affecting Its Continued Existence: Disturbance	"Human disturbance of bald eagles is a continuing threat which may increase as numbers of bald eagles increase and human development continues to expand into the rural areas." (64 FR 36461)	Intensified developments around BAs include: -river-tubing (*Blue Point* BA). -360-unit housing subdivision and golf course (*Box Bar* BA). -lakeside resort development (*L. Pleasant* BA) Disturbance from shooting and recreation such as ORVs close to nests and non-compliance with BA closures is increasing (from 5 to 12% in 1997 at *L. Pleasant* BA) (AGFD 1999). AGFD has an overflight advisory for the Verde and Salt drainages but "most pilots disregard the advisory" (AGFD 1999). Air Force expansion of training routes in Arizona was predicted to result cumulatively, over a 50 year period in the loss of 450 eagles or eggs and 900 disturbances. (USFWS 1994).
	FWS recognizes risk of loss Netwatch program with delisting but proposes continuation of support under Conservation Agreement.	The Nestwatch program has rescued 48 or 16% of nestlings (AGFD 1999). Delisting will end mandatory federal funding for Nestwatch.
Other Natural or Manmade Factors Affecting Its Continued Existence: Harmful chemicals	Since ban, DDT in fish has declined. Lead in birdshot banned in 1991 (64 FR 36460)	DDE and Mercury still found in DNBE eggs in toxic levels. Eggshell thinning has increased in recent decades (see text for details).
Other Natural or Manmade Factors Affecting Its Continued Existence: Entanglement in fishing tackle	Since 1980s, 52 instances of threat by tackle (FWS 1999).	From 1986 to 1999, 62 instances at 19 BAs of fishing line and/or tackle in nests or entangling individuals. Two nestlings deaths caused by fishing entanglement. This threat is bound to increase with increased population and urban sprawl (AGFD 1999)

CONCLUSIONS

The US Fish and Wildlife Service ignores the unique situation of the Desert Nesting Bald Eagle population in Arizona in proposing delisting of the Bald Eagle nationwide. This population is closed and isolated demographically from other US populations. The DNBE population in Arizona meets the criteria for listing as a Distinct Population Segment under the Endangered Species Act.

Although the Desert Nesting Bald Eagle population has grown since the beginning of surveys in the 1970s, after DDT was banned, the true scale of population growth remains uncertain due to possible undercounting of breeding areas in previous surveys.

Despite population increases since 1970, available fecundity and survival estimates indicate that the population is likely to decline toward extinction in the near future.

Population simulations indicate a critical need for more accurate assessment of adult and juvenile survival, as populations could decline to extinction rapidly for median estimates of life table parameters, or persist indefinitely within the 95% confidence intervals of available survival estimates.

The lower estimate of nestling survival appears to have declined significantly through the study period outside of the Salt/Verde cluster. The causes of this decline warrant urgent investigation.

The DNBE population remains very small and vulnerable to extinction risk from stochastic environmental fluctuations alone or in combination with directional environmental changes from habitat degradation and global warming.

Prey supplementation by fish releases in the lower Salt and Verde rivers is clearly linked to increased fecundity and nestling survival for BAs in that "cluster." The population may appear to be recovering under "natural" conditions, when in fact any observed recovery may result at least in part from an artificial abundance of prey, coupled with constant human intervention in the form of the Nestwatch Program. Simulations using the significantly lower fecundity and nestling survival estimates of unsupplemented BAs show rapid declines to extinctions.

Prevailing habitat conditions and threats do not appear to be conducive to population persistence in the absence of such interventions.

A review of threats suggests that the FWS delisting justification was premature and that Desert Nesting Bald Eagles remain critically endangered by fishing, low level flights and other forms of human disturbance, decline of native fish prey base, decline of suitable nesting areas as mature riparian forests die without replacement, dewatering of streams, global warming and habitat loss.

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