DEMOGRAPHIC ANALYSIS OF THE ARIZONA BALD EAGLE POPULATION

DRAFT

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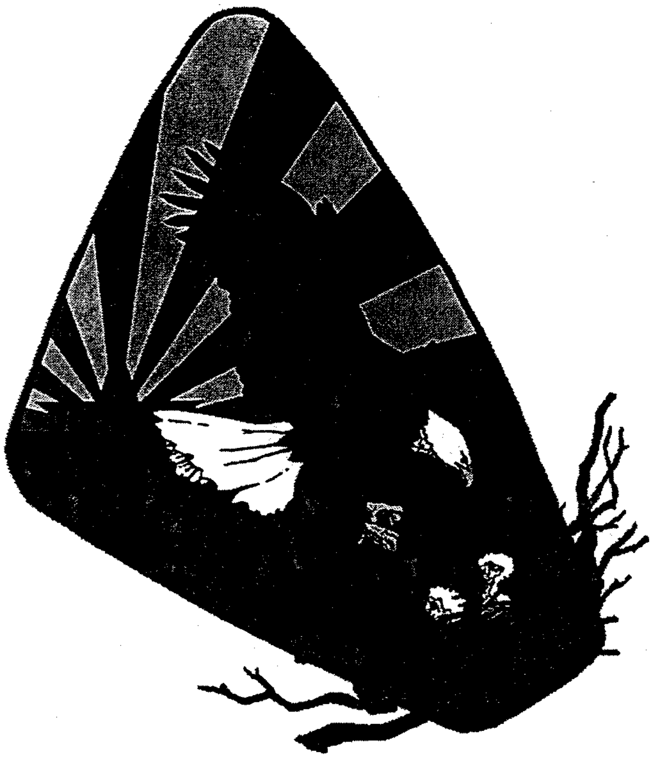

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EXECUTIVE SUMMARY

The Arizona bald eagle population has been extensively surveyed and monitored since 1983; the Arizona Game and Fish Department has carried out this effort since 1991. Little information is available for comparison from the period before the mid-1970's, and no information is available on causes of the initial decline in Arizona bald eagles. In light of this situation, status of the current population is evaluated by recent trends, not by comparison to an earlier baseline or by reduction of risks.

Here, we present the first use of demographic analysis techniques to bring together our multi-year data on productivity and mark-resight data from the same monitored population. Survivorship and productivity data allow us to test whether the Arizona population has all the elements of an increasing population. After several years of intensive management to enhance reproductive output, this analysis also serves as an evaluation of this management and the related survey and monitoring practices.

We used Program MARK to analyze information on 314 banded fledglings, and 37 banded adults. We estimated age-specific survivorship as well as the size of the non-breeding portion of the adult population. This unmonitored portion of the population consisted of pre-reproductive juveniles and non-breeding adult bald eagles; however, our resulting population dynamics model also estimated the size of these population segments. These data were used in demographic analyses to estimate the replacement rate of the population (λ). We used a Leslie matrix to create a deterministic demographic model, followed by examination of elasticities in the matrix model. Modified versions of the primary model were used to gauge the relative importance of delayed reproduction in females and an apparent sex ratio bias in nestlings.

The Leslie matrix model indicated that when we saw 70 breeding birds in adult plumage (a typical value) the total population size (including fledglings, juveniles, and floaters) is 162. As a group, the demographic models projected future declines ranging from 3.6-5.5% annually. In contrast, the trend in number of Arizona breeding bald eagles each year indicated that this segment of the population – and by extension the unmonitored remainder of the population – has been increasing at the rate of about 4.0% per year. We offer 3 alternative explanations for the apparent increase in the number of breeding adults in the face of a declining overall population: 1) The breeding adult population segment has not been growing; apparent recruits to the population represent discoveries of breeding areas that have been in existence, but undocumented. 2) The adult segment is recruiting internally from the floater segment. 3) The adult segment is recruiting externally from immigrants to Arizona. Following Alternative 1, we find an average annual decrease of 1.3% when we exclude counts of adults at newly discovered breeding areas. This is consistent with our demographic models. Although there has been no direct evidence of significant immigration into the Arizona population, uncertainty about the source of the increasing number of adults detected each year suggests that future studies should be initiated to better understand current population dynamics. This includes possible shifts in age structure of breeding bald eagles under the current management program (Alternative 2), and the possible immigration of breeders to our population (Alternative 3).

This analysis also highlights other gaps in our understanding of the biology of Arizona bald eagles. Compared to other bald eagle populations, we observed lower *apparent* survivorship for juveniles before the age of 4. However, some of these losses may reflect emigration, not mortality. Use of radiotelemetry to track juveniles would enable us understand the relative importance of emigration and mortality that reduce the number of Arizona-born juveniles returning to breed in Arizona. Understanding the exact causes of loss of juveniles (emigration, specific types of mortality) is one step in evaluating our best options for continuing management. Elasticities indicate increasing adult survivorship would theoretically have a larger impact on population growth than would reducing juvenile mortality or increasing productivity. However, without a better understanding of specific factors that limit population expansion, we cannot evaluate whether or not a management focus on adult survivorship would be effective.

The Arizona population is one of the most studied bald eagle populations ever; nonetheless, this analysis points to parameters that must be more clearly understood. Although causes of sex ratio bias in raptors have been the focus of considerable research, this is the first study we are aware of that reports a strong male-biased sex ratio for bald eagles, and incorporates this sex ratio into a demographic analysis. This is also the first study to estimate the size of the floater segment for Arizona bald eagles, although we are not the first to call for more careful understanding of the role of the non-breeding adult population segment in buffering populations from stochastic decreases. Our analysis was unable to estimate survivorship for this crucial element of the population, and it is unlikely that survivorship estimates for breeders are equal to those for non-breeders in the same age class. The small size of the Arizona breeding population makes this segment of the adult population particularly important for describing population stability. The apparent increase in number of breeders and breeding areas leads to further questions: Is the increase in breeding areas due to an increase in the number of adult bald eagles and/or to an increase in suitable habitat? If the latter, what environmental factors were previously limiting the number of breeding areas in Arizona? These questions cannot be answered at the scale of the breeding area, but will require consideration of factors at the landscape and watershed scales. Because non-breeding bald eagles spend much of their time in migration across North America, and their ecology within Arizona is not well understood, questions about factors impacting survivorship will also have to be pursued at larger scales.

DEMOGRAPHIC ANALYSIS OF THE ARIZONA BALD EAGLE POPULATION

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INTRODUCTION

The bald eagle (*Haliaeetus leucocephalus*) is the common North American representative of sea eagles, a genus of fish predators occurring on all but two continents (Brown and Amadon 1989). However, bald eagles do not prey upon fish exclusively, and supplement their diet with waterfowl, shorebirds, small mammals, and carrion. Historically widespread across North America, populations began a significant decline in the late 1800s due to the combined effects of shooting for feather collection, habitat modifications following European settlement, loss of large bison herds that supplied carrion, and extensive predator control measures (U.S. Fish and Wildlife Service 1999). The Bald Eagle Protection Act of 1940 (16 U.S.C. 668-668d) reduced purposeful killing of bald eagles, but subsequent widespread use of the insecticide dichloro-diphenyl-trichloroethane (DDT) nearly brought the population to extinction before it was banned as a pesticide in the United States in 1973 (U.S. Fish and Wildlife Service 1999).

This description is not based on information from Arizona, but reflects those affecting the species across their range, with the relative importance of each factor varying regionally. In Arizona before the 1970's, there was no focused effort to describe the breeding population, and only 1 breeding pair was described before the era of dam construction (Mearns 1890). This inability to reconstruct the historical range and densities of Arizona bald eagles affects our ability to quantify declines or identify their causes. Some factors affecting the national population may have negatively impacted the Arizona population, as they still exist today. It is likely that riparian nesting and foraging habitat of bald eagles in Arizona were affected to a greater extent, than those in northern and eastern parts of the continent by water development projects (Rubink and Podborny 1976; Hunt and others 1992). Introduction of non-native fish that utilized the water column differently from native species affected the quality and quantity of available prey (Rubink and Podborny 1976). Another possible source of decline was widespread use of DDT, as residues of dichloro-diphenyl-dichloroethylene (DDE, a toxic break-down product of DDT) persist at harmful levels in waterfowl and some fish in cotton-growing regions of Arizona (King and others 1997). We do not know the extent to which waterfowl over hunting, or ingestion of lead shot and other contaminants in waterfowl and fish might have contributed to population declines. Although many activities around nesting bald eagles are now strictly regulated, and killing of bald eagles has been illegal since the 1940's, current harassment and killing of Arizona bald eagles continue to decrease nest success (Rubink and Podborny 1976; Grubb and King 1991; Hunt and others 1992) and survivorship (Hunt and others 1992).

To evaluate the status of Arizona bald eagles, the focus of this demographic analysis is therefore not on whether there has been complete removal of original impacts affecting their decline, but on whether the current population has the ability to sustain or increase itself. Attempts have been made since the 1970's to estimate the size and status of the population. A non-breeding adult segment of the population exists, but has been difficult to characterize (Hunt and others 1992). In Arizona, breeding areas (BAs) are located along the Salt, Verde, and Gila rivers (Fig. 1). These more densely populated drainages have also recruited to and from BAs along the Bill Williams and Agua Fria rivers. Single breeding areas in the eastern part of the state along the San Francisco and Little Colorado rivers have not recruited from these primary drainages. However, the only known immigrant to the population was recruited into one of these BAs (Luna) in the White Mountains. This single occurrence of immigration does not conflict with treating the Arizona bald eagle population as closed, consisting of 48 known BAs and possibly 8 more BAs in New Mexico. Because this apparently isolated population occupies a limited number of BAs, a more complete description would consider how small-population effects (e.g., loss of genetic variability, ability to recover from stochastic population decreases) might affect population stability, in addition to traditional considerations (e.g. population size and various demographic parameters).

HISTORY OF EFFORTS TO DESCRIBE STATUS

The first in a series of studies of bald eagle breeding biology was initiated just before passage of the Endangered Species Act of 1973 (16 U.S.C. 1531-1544). The U.S. Fish and Wildlife Service (USFWS) instituted surveys nationwide in 1972 to assess the distribution of the species, estimate population size, and collect productivity information. The status report for the southwestern region estimated that 90% of potential habitat in Arizona, New Mexico, and along the Colorado River had been surveyed by helicopter or on foot in 1975, and the number of breeding adults (all in Arizona) was estimated at 18 birds, with 5 fledglings annually (Rubink and Podborny 1976). Twenty-one breeding areas were known to be available at that time.

This report led to studies by Robert Ohmart and colleagues at Arizona State University. Their work from 1977 through 1982 included the first in a series of mark-resight efforts to understand movements within the breeding population, estimate survivorship of adults, and to describe age at first reproduction, pair-bond duration, and tenure of individual birds in the breeding population (Hildebrandt and Ohmart 1978; Ohmart and Sell 1980; Haywood and Ohmart 1980, 1981, 1982, 1983; Hildebrandt 1981). During this same period, a report on Arizona bald eagles was written by Stumph and Creighton (1977) of the U.S. Bureau of Reclamation.

The Arizona Bald Eagle Nestwatch Program (ABENWP) was initiated and coordinated by the U.S. Forest Service (USFS) from 1978-1985, by USFWS from 1986-1990, and by the Arizona Game and Fish Department (AGFD) since 1991. Contractors for the program monitor 10-15 BAs near high recreational areas to educate the public about the breeding bald eagles, monitor the breeding attempt, collect behavioral data, and alert wildlife biologists when intervention can rescue a failing reproductive effort. In addition, seasonal closures are enacted at some BAs in high-use recreational areas to reduce any affects recreation can have on the breeding cycle. Our analysis of current population dynamics includes effects of ongoing efforts to prevent disturbance of adults and nestlings during the breeding season.

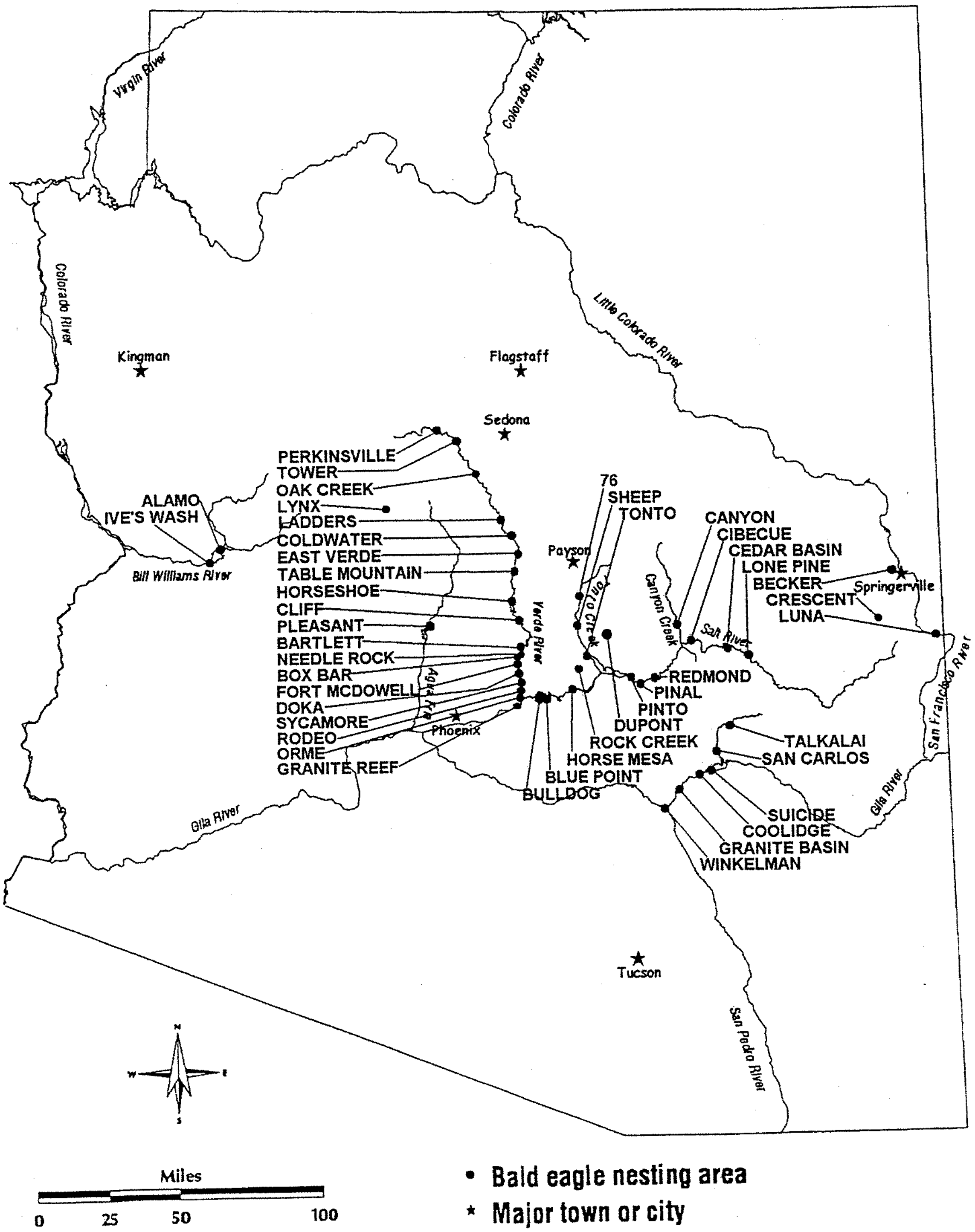

Figure 1. Known Arizona bald eagle BAs.

The intensive survey and monitoring efforts begun in the 1970's resulted in USFWS classification of the bald eagle as endangered in 43 states, including Arizona, and as threatened in 5 others (USFWS 1982). The Southwestern Bald Eagle Recovery Plan (USFWS 1982) was formulated, and a research project was initiated by Teryl Grubb (USFS) from 1983-1985 (Grubb 1986). During this project, intensive monitoring of active BAs began in order to describe productivity of Arizona bald eagles, and to accurately time trips to the nest to band nestlings. This study created the basic protocol for the current, longer-term AGFD effort, laying out goals, timing, and locations for surveys and in-depth monitoring. In 1987, BioSystems Analysis, Inc. began a 4-year contract to describe impact of water development projects on bald eagles in Arizona (Hunt and others 1992).

The bald eagle was subsequently downlisted to threatened status (USFWS 1995), and later proposed for delisting (USFWS 1999). Delisting criteria were established in 4 separate regional recovery plans, with the Southwestern Region Recovery Team recommending delisting criteria following the 1995 downlisting (USFWS 1999). The project at AGFD was initiated to guide management efforts to bring about the delisting of bald eagles, and has generated a comprehensive data set that we used to describe the population dynamics of Arizona bald eagles. Thus, we created models to explore the relative importance of different stages of bald eagle life history in maintaining or increasing this population. Recovery and delisting criteria were all couched in terms of demonstrating that population numbers, productivity levels, and/or number of subpopulations reflect ability of the bald eagle to avoid complications of small-population effects. Our description of the status of bald eagles in Arizona addresses the first 2 of these demographic concerns. We also discuss aspects of bald eagle biology that are most sensitive to threats and/or management.

DEMOGRAPHIC ANALYSIS

As a simple assessment of how well a species is maintaining itself, we can estimate the turnover rate of the most easily observed stages of the life cycle. For nesting birds, the breeding adult stage is a typical focus. If the number of breeding adults is steady or increasing each year, we can make an initial assessment that the population is not in crisis. To test this assessment, and to examine the limiting parameters of a species' biology, we need to examine the species' life history in more detail.

These detailed analyses are called demographic analyses. Reconstructing elements of a species' life history can test our understanding of species' biology, allow us to evaluate resilience of the species in the face of random or catastrophic environmental perturbations, estimate rates of population decline or growth, and describe the relative merits of different management options (Fig. 2). Development of demographic models can also reveal population parameters that limit population numbers, and provide direction for studies to improve understanding of the species' biology. In recent years, there has been increased demand for demographic analyses to support the effectiveness of management activities. Following their application to endangered species, another focus has become prediction of extinction risk (Step 5 in Fig. 2).

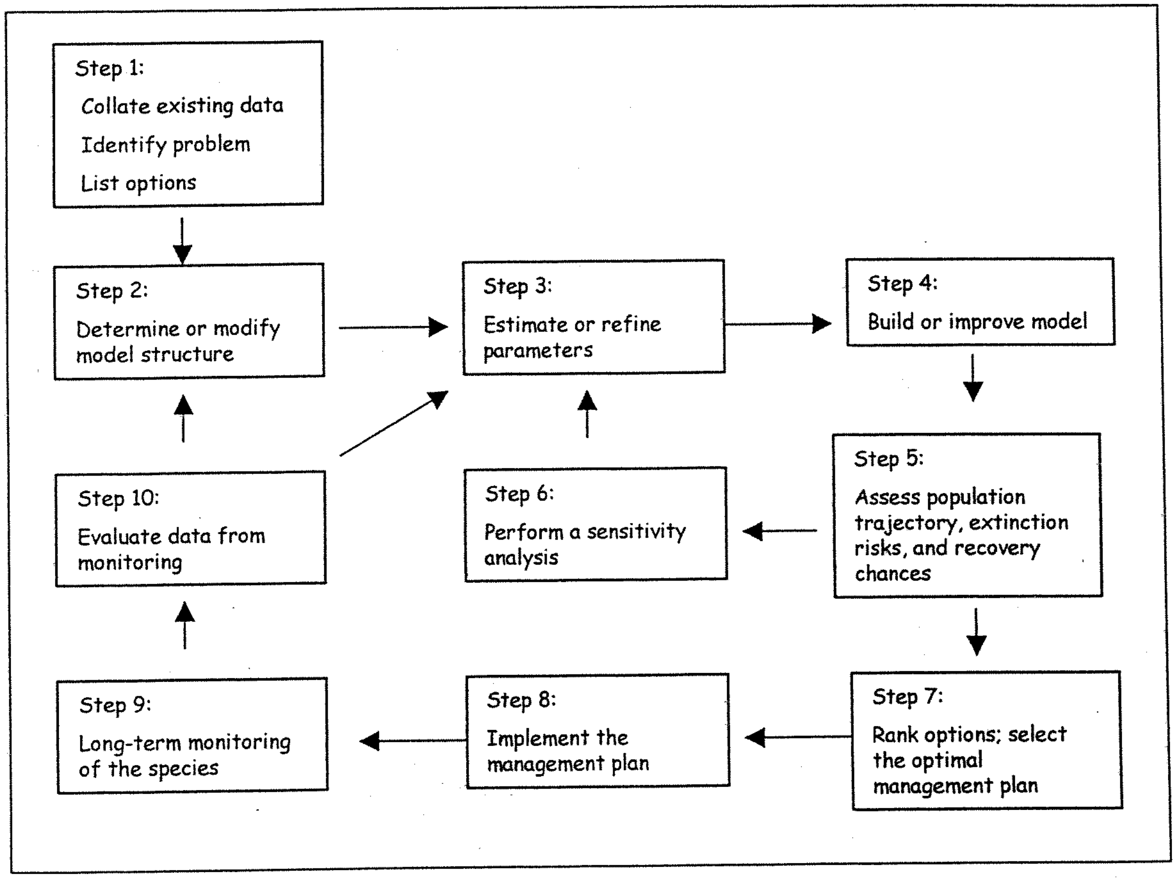

Figure 2. Components of a typical population viability analysis used to describe current status and guide recovery management (modified from Akçakaya and others 1997).

Analyses that attempt to project extinction risk into the future usually consider the relationship between threats and population dynamics. This connection differentiates population viability analysis (PVA) from other types of demographic analysis. However, Beissinger and Westphal (1998) identified major problems with this use of PVA models. Complex, biologically realistic models may not capture reality because demographic data, the main inputs of the models, are often inaccurate, imprecise, or variable due to environmental stochasticity and catastrophes. Most PVA models cannot be validated, and projections usually do not incorporate future changes in habitat quality or quantity. Use of these models to forecast extinction has also come under criticism (Beissinger and Westphal 1998). Even when the data are accurate and threats well known, stochasticity inherent to all biological processes can generate large errors in forecasting extinction risk (Taylor 1995). Furthermore, demographic models can give the false impression that they completely capture the status of a population, when in fact they do not encompass risks arising from genetic factors. Although genetic models have made important contributions for managing endangered species in the wild (Hedrick and Miller 1992; Haig and others 1993), their application has been limited because the currencies of genetics (e.g., loss of heterozygosity and expression of deleterious recessive alleles) are not easily translated into extinction rates.

Despite these limitations, wildlife biologists must make management decisions about threatened populations, so it is preferable that these decisions use the best data available, and that assumptions for using these data are easy to recognize and critique. Demographic models provide the most transparent vehicle to use the best information available to describe the status of populations. Noting the caveats and recommendations of Beissinger and Westphal (1998), we used a simple, single population model for Arizona bald eagles, built in a deterministic (matrix) form, to describe current population growth rates. We performed an elasticity analysis to evaluate the vital rates (e.g., age-specific fecundity and survivorship) that govern this model.

Longer datasets, especially for a long-lived species like bald eagles, can provide more accurate estimates of parameters like birth and death rates. AGFD has collected data on Arizona bald eagles since 1991, and for this report we estimated survivorship using cohorts back to 1987 (Hunt and others 1992). For consistency, we use productivity data from the same period, although we also report rates from an earlier study (Grubb 1986) that formed the basis for the current study. We interpret vital rates with the highest elasticities as those parameters that are most sensitive to accurate estimation, and that have more impact on population growth rate if they experience a small increase or decrease (Beissinger and Westphal 1998). Our goal in this report is not to predict the future fate of bald eagles, but to discuss the current status of the population, and to consider management options for improving this status. We avoid discussion of extinction probabilities and focus instead on how this analysis improves understanding of population dynamics in Arizona bald eagles (i.e. the first 6 steps of Fig. 2). At this time, we are using this analysis to guide future information gathering, but postpone consideration of management changes (i.e. the 7th step in Fig. 2) until we develop better understanding of factors that limit expansion of Arizona's bald eagle population.

METHODS

STUDY AREA

We collected data at bald eagle BAs along lakes, rivers, and reservoirs throughout central Arizona (Fig. 1). These BAs extended from Winkelman in the south, to near Clarkdale in the north. BAs ranged from 329 m (1080 ft) elevation at Alamo Lake, to 2438 m (8000 ft) at Luna. Most BAs were at elevations below 975 m (3200 ft) and within the Upper and Lower Sonoran Life Zones and transition areas described in Brown (1982). Representative riparian vegetation includes Fremont cottonwood (*Populus fremontii*), Goodding willow (*Salix gooddingii*), Arizona sycamore (*Platanus wrightii*), and introduced salt cedar (*Tamarix* spp.), while the surrounding uplands are vegetated with blue paloverde (*Cercidium floridium*), mesquite (*Prosopsis* spp.), ironwood (*Olyneya tesota*), saguaro (*Carnegia gigantea*), teddy bear cholla (*Opuntia bigelovii*), juniper (*Juniperus* spp.), and pinyon pine (Pinus edulis.).

The Becker BA is within a Plains and Great Basin Grassland biotic community (Brown 1982). An isolated patch of Fremont cottonwoods along the eastern shore of the reservoir created local nesting habitat similar to riparian areas of the Upper and Lower Sonoran Life Zones.

Dupont, Lynx, Rock Creek, and Luna BAs are in Montane-Conifer Forest (Brown 1982), where riparian vegetation includes narrowleaf cottonwood (*Populus angustifolia*), thinleaf alder (*Alnus tenuifolia*), Bebb's willow (*Salix bebbiana*) and coyote willow (*S. exigua*). The first 3 BAs are located in isolated patches of Montane-Conifer Forest surrounded by Interior Chaparral, which consists mainly of pinyon – juniper woodland, shrub live oak (*Quercus turbinalla*), and pointed and pringle manzanita (*Arctostaphylos pungens and A. pringlei*).

DATA COLLECTION

Breeding Area Status and Productivity

We used intensive surveys and monitoring to estimate the number of breeding adults and to describe productivity as a function of the number of breeding attempts. Monthly occupancy and reproductive assessment (ORA) and nest survey flights were conducted at most known BAs to describe BA breeding status, monitor productivity, estimate age of nestlings, and to detect new BAs and occupied nests. When ORA flights were not adequate to interpret breeding or occupancy status, a follow-up ground nest survey of the BA was scheduled.

We used helicopter flights throughout the breeding season to classify BAs as unoccupied, occupied, or active based on operational definitions (Appendix A) derived from Postupalsky (1974, 1983) and Steenhof and Kochert (1982). Since 1982, Arizona has also participated in nationwide surveys for wintering bald eagles (e.g., Driscoll and others 2002). Flight paths for the annual winter counts included all known major waterways including those with Arizona breeding areas. Winter count flights were scheduled each year for the first full week in January to coincide with early breeding activity of our resident breeders, so these flights were also used as our first ORA flight. Each month of ORA flights lasted a consistent number of flying days, with a predetermined set of river systems on each day. January flights included 4 days to allow for counts of wintering birds. Flights during the first week in February, and during the third week of both March and April covered 2 days. One day covered BAs on the Verde, Bill Williams, and Aqua Fria rivers; the other day covered the Salt and Gila rivers. These 2-day flights were for ORA and nest surveys, with no bird counts. Flights during these months were used to determine the status and stage of any breeding attempts, and to search for new BAs and alternate nests. Biologists used reported sightings of bald eagle pairs and spacing between known BAs to prioritize areas for surveys. They used knowledge of suitable nesting areas to target searches within the BAs.

By May, the occurrence of late and second breeding attempts is minimal. Therefore, flights during the third week in May and June involved only 1 flight day to follow the status of nests active in April.

Some known BAs were not monitored using ORA flights. For instance, BAs in the White Mountains were monitored by ABENWP contractors (Luna BA), or local AGFD or USFS personnel (Becker BA). Because there were 10 teams of ABENWP contractors each year, and some subsequently move to new BAs after a failure, different sets of BAs were monitored by flights each year. However, each known BA was monitored each year either using flights or more intensive ground survey effort.

ORA flights were spaced to monitor each phase of the breeding attempt: nest building, incubation, hatching (up to 2 weeks of age), nestling (2-8 weeks), pre-fledging (8-12 weeks), and post-fledging (after 12 weeks). We used observed incubation and hatching dates, in conjunction with a development guide (Carpenter 1989), to estimate the age of nestlings. If fledglings were not observed during the last ORA flight or by ABENWP contractors, we nonetheless classified a breeding attempt as successful if nestlings were known to have lived to at least 8 weeks of age and we found no evidence of later death. We occasionally reversed our determination if, in a subsequent year, a visit revealed the nestling had died in or near the nest, or if a banded nestling presumed dead was later identified alive. The standard procedure, classifying nestlings as successful fledges once they reached 8 weeks of age, maximized the estimate of fledging success; however, daily monitoring by the ABENWP at many nests tempered these estimates by enhancing documentation of nestling deaths. We used survey data to calculate occupancy rate, BA success rate, productivity, and fledging rate per hatchling from 1991 through 2002. Data for the 4 preceding years were taken from Hunt and others (1992).

Banding and Resighting

To estimate survivorship of bald eagles, we banded nestlings and identified them upon return as breeding adults (Appendix B). Plumage of resighted breeders was also classified as adult ('Definitive and Basic IV'), near-adult (NAD, 'Basic III'), or subadult (SAD, 'Basic II'), following McCollough (1989). From 1977 to 1985, biologists used USFWS aluminum bands engraved with 8-digit numeric codes to band nestlings (Hildebrandt and Ohmart 1978; Hildebrandt 1981; Grubb 1986; Haywood and Ohmart 1980, 1981, 1982, 1983;). However, due to difficulty reading the engraved bands, this allowed for the identification of individuals only through band recoveries, or through the time-consuming process of capturing birds. In this report, we refer to these birds as 'single-banded.'

Various attempts were made to increase the visibility and readability of the USFWS bands (Hildebrandt 1981; Grubb 1986). These attempts had limited success. Beginning in 1987, bald eagles were banded with a USFWS band as well as a color-anodized aluminum visual identification (VID) band engraved with a unique symbol to aid in identification from a distance (Hunt and others 1992; Mesta and others 1992). Most banding was done on nestlings in the pre-fledging phase, but to derive age-specific survivorship estimates, it was also necessary to have some birds that were first banded as adults. From 1987 to 1990, 8 breeding adults were captured and banded (Hunt and others 1992). Due to the lack of visual markers, we were unable to identify most single banded breeders. We could therefore not use these adults to calculate the proportion of a cohort that survived to age 4, but once they occupied a BA we could give them an artificial identity and used various criteria to decide whether the same bird returned the next year (see below). We could therefore use these birds to estimate survivorship of older adults. We attempted to band every nestling at accessible BAs, and succeeded in banding 84% of known fledglings from 1991 through 2003 (Appendix C). Nestlings were not banded if the process would harm the nest, nestlings, or the climbers. During banding of nestlings, we measured the tarsus laterally, classifying those with measurements greater than 12.5 mm as females (Hunt and others 1992). This measurement correctly classified all but 1 of 50 nestlings that were later autopsied or sexed when they returned to breed (Appendix D). The misclassified nestling was a male with a 13 cm tarsus lateral, which was originally classified as a female. Misclassification of additional nestlings, combined with reported female-biased dispersal (Harmata and others 2000) could result in incorrect estimates of the sex ratio; however this error would be more serious if true females were classified as male nestlings.

We collected resighting data during the breeding season, and were most successful at active nests, which were visited regularly by adults. Identification of adults at BAs that were occupied was less likely as adult presence was less predictable. Most resighting was accomplished with Questar® spotting scopes (15x – 210x) from a distance sufficient to read the symbol, but far enough to avoid disrupting normal behaviors. Exact distance depended on topography, weather, temperature, legibility of the band, and tolerance of individual birds to human activity. Breeding adults tend to remain within the BA year-round, so if a VID band could not be read with a spotting scope, trapping attempts were made during the non-breeding season.

The inability to identify every banded breeding adult in each BA annually (Appendix B) created gaps in our understanding of survivorship and breeding tenure. We used the following guidelines to associate identities with adults:

1. For the mark-resight analysis, the following assumptions were related to the premises that banded birds had fledged in Arizona, and the identity of those with unread bands is best derived from identified banded birds of the same sex that occurred in the same BA in adjacent years. Because we never extrapolated these identities past the last year a band was actually read, this procedure did not affect survivorship estimates, but increased estimated resighting rates.

    a. Same-color-banded, same-sex birds from contiguous years were considered the same bird. For example, the male seen in 1993 at the Tower BA had a purple band, but its symbol could not be read. We assumed that this male was the same as the purple-banded male present at the BA in 1994, when the band was read. Of 168 instances between 1987 and 2002 in Arizona when we were able to read same-color bands in consecutive years, replacements only occurred 4 times.

    b. If a band's symbol could not be read, but the cohort could be identified, the bird was included in the age-specific mark-resight analysis. The purple band of a female breeder at Horse Mesa BA went unread, but purple bands were only used for the 1989 cohort.

c. Once a single-banded bird was trapped and identified, we equated these birds with the [unidentified] single-banded ones that had occupied the same BA in previous years. Single-banded males trapped, identified, and then VID-banded in 1988 (Cliff and Blue Point BAs) were considered identical with those that had occupied the BAs since 1984 (Cliff) and 1983 (Blue Point). At Blue Point, the BA was apparently unoccupied in 1987, but the trapped bird in 1988 was from the 1979 cohort, consistent with the NAD single-banded male that first arrived in 1983.

d. The same single-banded male was observed at the Pinal BA from 1987 through 2003. The band was first read in 2002. Although there were intervening years during which banding status could not be ascertained, and 1 year when the BA was apparently unoccupied, it was most parsimonious to assume the identity of the bird had not changed over this period. Regarding the assumption that ownership of the BA did not change after the BA was unoccupied in 2001, we think it unlikely that a nestling banded in Arizona in 1981 first arrived at a BA here in 2002, coincidentally at the same BA where another single-banded male had been in residence.

e. The single-banded SAD plumage male that arrived at Sheep BA in 1994 was an Arizona male fledgling single-banded in 1991. Because VID-banding had been in use in Arizona since 1987, this bird's banding and plumage is consistent with only 1 single-banded Arizona fledgling in 1991, when too few VID bands were taken to a nest.

2. To describe adult tenures (length of reproductive period and duration of pair bonds) in the breeding population, we did not need to identify birds sufficiently to assign their cohort. The following rules were used for determining which unbanded or unread banded birds at a BA were the same across years:

   a. If the plumage of an unbanded resident bird changed from adult to NAD or SAD, or from NAD to SAD, it was assumed to be a different bird. Similarly, if USFWS bands were on different legs, we identified these as separate birds. At the Pinto BA, we identified a replacement between unread single-banded birds because the 1992 male was banded on the right leg, while the 1993 male was banded on the left.

   b. Unbanded birds were identified as those from previous years if the first time we observed the bird was unequivocally the first year it occupied the territory, and the last time was the latest date it could have occupied the BA. Thus, we excluded birds if they were present when a BA was discovered unless it was a pioneering effort. We also excluded birds from analysis if the BA had been occupied in previous or following years, but no ground survey had determined the occupant's banding status. We identified a bird's last year of tenure if the BA was unoccupied the following year, or if we documented replacement by a banded bird or by an unbanded one of a different plumage.

We used resighting information to describe time-to-identify for VID and single-banded birds, to determine if bald eagles occupied an alternate BA once replaced at the first BA, and to describe age at first reproduction. Interpolated identifications enabled us to describe the typical reproductive period of a bald eagle's life. We used survival analysis (Fox 1993) to describe duration of the breeding stage and length of pair bonds, treating years as intervals during which the pair bond survived or was severed. We calculated median length of pair bond and tenure; since some birds occupying BAs in 2002 will certainly return, means would provide estimates that were biased low.

DEMOGRAPHIC MODELING

We described the regional population dynamics of a species that is elsewhere increasing after dramatic population declines (USFWS 1995, 1999). Models assumed the Arizona bald eagle population was subject to the same dynamics around the state, and that factors affecting vital rates over the period of this study were stable. These assumptions carried through to survivorship and population growth estimates; we estimated survivorship and productivity over the entire period as if there were no upward or downward trends in these rates. We estimated population parameters to create deterministic demographic models to project population growth rate (λ; number of individuals in year(t+1)/number in year(t)). Deterministic models, while reflecting less biological intricacy than stochastic ones, should nonetheless compute similar λ, and have the advantage of leading easily to sensitivity analysis. This allowed us to focus on major parameters influencing bald eagle population dynamics.

Survivorship and Resighting Estimation

Depending on their age and banding status, we used different individuals in the analyses to describe productivity, survivorship, and reproductive life history. We classified juvenile bald eagles from cohorts since 1987 as either banded or unbanded. Both groups were used to estimate nestling mortality and fledging success. Banded juveniles were also used to estimate average age at first reproduction, senescence for males and females, sex ratios of nestlings and adults, and to calculate age-specific survivorship. Although single-banded birds provided information about reproductive life history and lifespan, we only identified 12 of 23 single-banded breeders, and therefore could not estimate the proportion of any cohort surviving to breeding age. Our analysis instead focused on survivorship of cohorts beginning in 1987 (first year of VID banding), but included single-banded birds and the banded immigrant with older VID-banded birds for estimates of survivorship after 7 years of age.

We used Program MARK (White and Burnham 1999) to estimate survivorship assuming a closed population with resighting of live birds. The program permits development of a series of models to describe survivorship and resighting rates. We compared models to choose the most appropriate one. If bald eagle survivorship varies with age or sex, but a particular model does not include these variables, our estimate will be biased. Conversely, the more predictors we use to fit the model, the less bias. However, using the same data to estimate more parameters means that the variance of our estimates increases. To choose the model that minimized both variance and bias, we used Akaike's criterion to compare the information content of different models (Anderson and Burnham 1999a, b).

Because resighting only occurred at BAs, we could not directly estimate resighting or survivorship rates before age 4. Instead, for all models, we set the estimate of survivorship to 1 and resighting rate to 0 for the first 3 years of each cohort. Consequently, in all models, the survivorship estimate at age 4 is the survivorship estimate from fledging to age 4. Thus, we assumed that juvenile survivorship differs from that of adults, even when we were not modeling differences between adult age classes. For demographic models that required age-specific survivorship, we assumed that survivorship was equal across these ages and estimated it as the fourth-root of the survivorship (Φ) estimate from fledging to age 4:

$$\Phi_{\text{fledgling-to-4}} = (\Phi_{\text{fledgling-to-1}}) * (\Phi_{\text{1-to-2}}) * (\Phi_{\text{2-to-3}}) * (\Phi_{\text{3-to-4}})$$

$$\text{Where: } \Phi_{\text{fledgling-to-1}} = \Phi_{\text{1-to-2}} = \Phi_{\text{2-to-3}} = \Phi_{\text{3-to-4}} = \Phi_j$$

$$\text{So, } \Phi_{\text{fledgling-to-4}} = \Phi_j^4$$

Models were developed to test whether estimates were improved by considering differences by adult age, sex, and over different time periods. Resighting rates might vary, for instance, depending on year-to-year differences in project funding or on experience level of project biologists. *A priori*, we created 5 intervals to test time effects on resighting: the study period for Hunt and others (1992; 1987-1990), new effort by a single researcher at AGFD (1991-1992), a period of 2 researchers from AGFD with 1 of them in training each year (1993-1995, 2002), a period of intensive resighting work from the same group of 3 trained personnel (1996-1998, 2003), and a final period during which only a single trained person conducted surveys and monitoring (1999-2001). We used annual intervals to test for possible year-to-year differences in survivorship, since food availability might vary on this scale, and there was no *a priori* reason to create longer time intervals. We also tested for a gradual (linear) increase in survivorship to mirror ongoing long-term management. A similar trend was possible in resighting rates because bald eagles and BAs became more familiar over the study period, which might have led to more efficient identification. We tested for effects of all combinations of these factors on survivorship, and for effects of all combinations of age and time on resighting rate. Because we identified birds in breeding pairs, we did not test for sex-specific differences in resighting rates. We did, however, model sex-and-age-specific differences in resighting rate, to test for later age-at-first reproduction in females.

These models correspond with various hypotheses about breeding biology of Arizona bald eagles. For instance, to test the hypothesis that more young adults act as floaters, we compared the efficiency of models with and without age-specific resighting rates. Further, if females began breeding at a later age, younger females should have a lower resighting rate than same-aged males. Due to observed male sex-ratio bias in nestlings and breeding adults, we predicted that males in this monogamous species (= equal sex ratio of breeders in any year) would suffer higher mortality and/or have lower resighting rates (i.e., be more likely to be floaters) in at least one adult age class. We tested this idea with models for sex-specific and sex-by-age-specific survivorship as well as sex-by-age-specific resighting rates. For both survivorship and resighting rate estimates, we considered the possibility that females might have consistently higher survivorship than males (additive model) or that female survivorship might only be higher for some age classes.

Bald eagles that defer reproduction for up to several years, result in variability in age-at-first-reproduction. To test for differing age at first reproduction and differing survivorship between sexes, we had to estimate survivorship and resighting rates for each year (age) separately, at least among younger birds, when the differences were predicted to occur. We estimated annual survivorship and resighting rates for adults aged 5 through 7. Because we had no reason to predict age-specific survivorship differences in older birds, we assumed survivorship rates were similar for all adults over age 8, and created a single age class for this group plus single- and adult-banded birds that could not be aged. Similarly, because bald eagles are believed to remain on their BAs until death, we assumed that resighting rates for older birds were uniform; therefore we created 1 age class to estimate resighting rates for unaged birds on BAs, plus all birds age 8 and older.

Mark-resight data can be analyzed under the following assumptions (White and Burnham 1999): 1) Every marked animal present in the population at time (i) has the same probability of recapture (p_i). 2) Every marked animal in the population immediately after time (i) has the same probability of surviving to time (i +1). 3) Marks are not lost or missed. 4) All samples are instantaneous, relative to the interval between occasion (i) and (i +1), and each release is made immediately after the sample.

Regarding bald eagles in this study: 1) Resighting rate (p_i) was a function of our ability to identify all breeding birds, but also depended on whether the bird was breeding that year or not. Some birds in each age class were non-breeders, so $p_i = 0$. Breeding birds had a finite probability of resighting. These situations require multistrata models (Hestbeck and others 1991), which estimate transitions between strata (floating/breeding) for each age class in addition to survivorship and resighting rate for each stratum. Our dataset is not amenable to estimating survivorship or resighting rate for non-breeders since this stage was never resighted. For this reason and to use our relatively small dataset to test models with parameters of most interest, we used Jolly-Seber models for capture-recapture (Jolly 1965; Seber 1965). Carothers (1979) demonstrated that errors in survivorship estimates due to violation of the assumption of equal catchability are usually quite small compared to variance estimates (i.e., bias is usually quite small). We assumed we identified adults at all occupied BAs each year; however, due to logistical and time constraints, this was not the case. Adults were more likely to be identified if ORA flights indicated breeding activity at the BA. Some BAs consistently had more breeding activity than others, so these BAs (and birds that occupied them in consecutive years) would be ground surveyed more often. This could have reduced survivorship estimates. 2) Survivorship estimates were based only on breeding birds, and may not accurately estimate age-specific survivorship for floaters. Because we understand little about the biology of floaters, we cannot predict whether their survivorship might be lower or higher than that of breeders. 3) It is unlikely that marks are lost (see Methods, Data Collection, Banding and Resighting). However, some bands were not read the first year they were seen, so some of the recently sighted birds had bands but were not identified. This had the effect of underestimating survivorship; however, because few birds were involved (see below), the effect was probably small. 4) Although we monitored during the entire breeding season and banded during the pre-fledging period, we assumed that all subsequent nestling mortalities were documented, and all adults alive during that time survived to the post-fledging period. In situations where adults died during the breeding season (non-instantaneous observation), we treated the bird as being alive through the post-fledging interval because it had potentially contributed to production of that year's cohort.

Based on the relative geographic isolation of Arizona BAs from those in nearby states and Sonora, Arizona bald eagles have been treated as a closed population. Since 1977, there has been only 1 known (banded) male immigrant (from Texas) and 1 female emigrant (to California). The ability to detect movements between populations depends on banding and survey intensity in other states and/or countries. To be conservative and in the absence of contrary information, we proceeded to model the Arizona bald eagle population as a closed population, but also present a brief analysis of the level of banding and resight activities in other states. If there was significant immigration and/or emigration, population growth rates (λ) based on a closed population could be used to interpret the Arizona population as a "sink" or "source," respectively.

Estimating Number of Floaters

Although biologists have been aware of the existence of floaters due to the rapid replacement of breeders during the breeding season, there has been no attempt to quantify their contribution to the population in Arizona. Mark-resight analysis allowed us to estimate the proportion of non-breeders in each age class. Once banded, juveniles were not observed in subsequent years, due to the method of resighting birds at breeding areas. However, we also did not resight adults every year, and many apparently did not occupy a BA as soon as they were physiologically able to breed. All of these elements contributed to adult resighting rates less than 1. Thus, resighting rates were lower due to floaters, but also due to incomplete identification of breeders. Although ORA flights were carried out at all BAs each year, we usually only followed up with ground surveys at BAs that were nesting successfully as a time-cost measure. We attempted to estimate decreases in resighting rates due to floaters by assuming all banded birds were sighted each year between the first and last year they were seen (see Banding and Resighting section).

Using this assumption in Program MARK did not appreciatively affect survivorship estimates, but increased the resighting estimates so they did not account for failure to resight due to survey effort. Thus, resighting rates provided an estimate of the proportion of each age class that attempted to breed by at least defending (occupying) a BA. We report resighting rates for adult age classes, and in the population size and structure estimate, subdivide age-classes into breeder and floater components.

A Deterministic Matrix Population Model

The matrix population model was age-structured, with seven year-classes and an adult stage. The model assumed post-hatching censusing and calculated the number of birds as a simple function of age-specific fertility and survivorship schedules (Caswell 1989; Donovan and Welden 2002). The model generated a stable age population (the proportion of each age class remains stable over time), and a summary estimate of λ. However, these models do not account for variability in life history parameters, so they reflect average effects of consistently operating factors, and each individual suffers the same average fate. We calculated fertilities as the proportion of females breeding from each age class, times the average number of hatchlings for occupied BAs. Therefore, fertilities take into account failure of a certain proportion of birds in an age class to defend a BA, failure of some territorial pairs to nest, and failure of some eggs to hatch. Our estimate of nestling survivorship to age 1 includes fledging success, which has been influenced by management practices to increase this parameter (e.g. ABENWP monitoring, and life-saving interventions by biologists). Two modifications were made to compare our original model with one assuming males comprise 65% of nestlings, and another assuming females delay reproduction according to the schedule characterized by our data. These models reflect best estimates from our empirical data but are not the focus of our analysis, since we only have limited data to assess the technique for sexing nestlings, and our capture-recapture analysis did not support different ages at first reproduction for males and females.

To explore our demographic model, we used sensitivity analysis (Caswell 1989; Donovan and Welden 2002) to calculate the sensitivity of λ to changes in age-specific vital rates. As our measure of sensitivity, we used elasticity, the proportional change in λ for a 1% change in the vital rate.

POPULATION GROWTH RATE (λ) CALCULATED FROM NUMBER OF ADULTS OCCUPYING BAS

Assuming a stable age structure, one estimate of λ could be calculated using a simple ratio of any stage or age class from one year to the next. We used counts of breeders (bald eagles occupying known breeding areas) since 1991 to describe one such stage class (Appendix A). We assumed each occupied BA held only 1 adult unless the BA was active or we observed 2 adults at the same time. We took into account exceptions, such as when 1 male was involved in nesting attempts with 2 females at 2 different BAs.

From 1991 to 2002, the number of known BAs increased from 28 to 47, with a corresponding increase in the number of adults at occupied BAs. This increase in number of BAs might reflect 1) pioneer efforts by pairs to create new or to reoccupy historical BAs, or 2) discovery of existing BAs which were occupied in the past but remained undetected in the intervening time. Because bald eagles have been known to modify large nests of golden eagles, great blue herons, osprey, etc. (Hunt and others 1992; Beatty and others1995b), we monitored several large nest sites along Arizona's riparian areas during the ORA flights. We used evidence from these surveys to document both pioneering behavior and the reoccupation of historical BAs. Since 1991, we have described 19 BAs as either pioneer efforts or reoccupied historical BAs, while three BAs were in existence before their discovery (Table 1). We documented territorial adult bald eagles in some areas for many years before nesting activity was initiated. For analysis purposes, we did not consider these birds as breeders. However, once we recorded nesting activity, we considered the pioneer effort a BA, and considered any subsequent occupying birds to be breeders.

We report count-based estimates of λ only for 1991 through 2003, years within our analysis framework when AGFD was monitoring BAs to count adults. The geometric mean of annual λs is the unbiased estimator for λ (Morris and Doak 2002). If newly discovered BAs were unoccupied the previous year, the estimate of λ would be accurate. However, if those BAs were occupied before 1991 but unobserved, the estimate of λ would reflect survey effort, not a true increase in population numbers. For this reason, we calculated λ using 3 methods: 1) Reflecting the first scenario, we used all adults seen in a given year compared to all adults seen in the previous year. 2) Reflecting the second scenario, we used only adults at previously identified BAs, excluding those at new BAs to compare to the previous year's count of adults. 3) The third method assumed that we were able to identify pioneer efforts. Thus, only adults in recently discovered existing BAs (Talkalai, Rock Creek, and Oak Creek BAs) were excluded from counts of adults, and only in the first year after the BA was discovered.

Table 1. For the years contiguous with the current study, earliest recorded breeding activity for bald eagle BAs in Arizona. Some BAs may have existed much earlier. The 'historical' designation indicates that despite intensive survey effort, breeding activity has not been documented for at least 10 years. Abbreviations described below.

Breeding Area	First year	First status	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03
Alamo	88	Pioneer					O	S1	S1	S2	S2	S2	S1	S1	S2	F	F	F	F	S1	F	S1	O
Ash	84	Existing		S1	S2	U	U	U	U	U	U	U	U	U	U	U	---	---	---	---	---	---	---
Bartlett	64	Existing	F	F	S1	S1	F	S2	S2	F	F	S1	S1	S1	S2	S2	F	S2	S1	F	F	F	S1
Becker	99	Pioneer															O	O	F	O	O	O1	U
Blue Point	71	Existing	S3	S2	S1	U	S3	S2	F	O	S2	S2	S2	S2	S2	S2	S3	F	S1	F	S1	S2	F
Box Bar	96	Reoccupied													O	F	F	S2	F	S2	S2	S1	S1
Bulldog	03	Pioneer																					S2
Camp Verde	92	Reoccupied										F	O1	U	U	U	U	U	U	U	U	U	U
Canyon	86	Existing				S1	S1	S1	S1	S2	F	S1	S1	F	O	O	O1	O	O	O	U	U	O1
Cedar Basin	78	Existing	F	F	F	F	F	F	F	F	O1	F	F	F	O1	F	F	F	O	O1	O1	O1	U
Chino	85	Existing			S2	F	F	U	U	U	U	U		U	U	U	U		---	---	---	---	---
Cibecue	73	Existing	F	S3	S1	S1	F	O	S1	F	S2	F	F	S1	S1	O	O	O1	S1	O1	O	F	F
Cliff	84	Pioneer		F	S2	F	O	S2	F	O	O	F	O	F	O	O1	O1	O	O	O1	O	O	O
Coldwater	98	Reoccupied																F	F	F	F	S2	S1
Coolidge	85	Existing			F	S1	S2	S2	O	O	S1	S1	S2	F	S2	F	S2	F	F	F	F	S2	S1
Crescent	03	Pioneer																					F
Doka	98	Pioneer																S1	S2	S2	S2	S2	S1
Dupont	97	Existing															F	S1	O1	F	O	U	F
East Verde	73	Existing	F	S1	S2	S2	S1	S2	S2	F	F	S1	S1	F	S1	S1	F	F	S2	O	F	F	O
Fort McDowell	68	Existing	S3	S3	S3	S2	S1	F	S2	F	S1	F	S2	F	F	O	S2	F	S1	S2	S2	S2	F
Granite Basin	99	Pioneer																	F	O	F	O1	O1
Granite Reef	02	Pioneer																				S2	F
Horse Mesa	82	Existing	F	F	F	S2	S2	S1	F	S2	S3	F	S1	F	S1	S2	S1	F	S1	S1	S1	S1	S2
Horseshoe	75	Existing	S1	S2	S2	F	S3	S1	F	S2	F	F	O	F	F	S1	S2	F	S2	S2	S2	S2	S1
Ive's Wash	87	Pioneer					S1	S1	S1	F	S2	S2	S1	S1	S1	F	F	O	O	O1	O1	O1	O
Ladders	72	Existing	S2	F	S2	S2	F	S2	S2	F	S2	S2	F	S2	O	S1	F	S3	S2	O	S1	S2	S2
Lone Pine	84	Existing		F	F	S1	F	S2	O	F	S1	F	F	F	O	F	F	O1	S2	F	S1	F	O
Luna	94	Pioneer												S1	S1	S2	S3	S1	S1	S1	F	S2	S1
Lynx	02	Pioneer																				F	F
Mule Hoof	74	Existing	U	U	U	U	U	U	U	O	O1	O1	U	U	U	U	U	U	U	U	U	U	---
Oak Creek	02	Existing																				S2	S1
Orme	87	Existing				S1	S2	S1	O	S1	S1	S1	S1	S2	F	F	S2	S1	S1	F	O	S2	S1
Needle Rock	02	Reoccupied																				S1	S1
Perkinsville	00	Reoccupied							O	O	O	O	U	U	U	U	O	O1	U	S1	S1	F	S2

Table 1. Continued.

Breeding Area	First year	First status	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03
Pinal	78	Existing	S1	S1	S1	U	S2	F	S1	S2	S1	F	S1	S1	F	F	F	O1	O	F	U	S1	F
Pinto	89	Pioneer						O	F	O2	F	F	S1	F	S2	S3	F	O	S2	O	S2	F	O
Pleasant	84	Existing	U	F	F	U	O	U	O	O	O	F	S1	S2	S2	F	S2	S1	S1	S2	S2	S1	S1
Redmond	74	Existing	S2	F	S2	S1	S2	S1	F	S1	F	O	O	F	S1	F	F	S1	F	S1	S1	F	O1
Rock Creek	02	Reoccupied																			O	S1	F
Rodeo	00	Pioneer																		F	F	S1	F
San Carlos	95	Pioneer													S2	S1	F	S2	O1	F	O1	F	O1
76	81	Existing	S1	S2	S1	S1	F	S2	O	S1	S1	S1	F	S2	F	S1	S2	S2	S1	S2	S2	O1	O
Sheep	82	Pioneer	F	O	O	F	F	F	O	O	U	O	O	F	O	S2	O	O	S1	F	F	S2	F
Suicide	99	Pioneer																	S2	S3	S2	F	S3
Sycamore	97	Pioneer															F	S1	S2	F	S2	S1	S2
Table Mountain	88	Existing					O	F	F	S1	S1	F	S2	S1	S2	S1	S1	F	S1	F	F	O	F
Talkalai	94	Existing												F	F	F	O	O	F	F	S1	S2	O
Tonto	92	Pioneer										F	S2	S1	S1	S2	S2	S1	S2	F	S1	S2	F
Tower	93	Reoccupied											S1	F	F	S2	S1	S2	S2	S2	S1	S2	S1
Winkelman	96	Pioneer													O	F	F	O	U	U	U	U	U

S(number) = successful(number fledged), F = Failed, O = occupied, O1 = occupied with only one bald eagle confirmed, U = unoccupied

RESULTS

From 1987 to 2003, 503 nestlings were documented in Arizona (Table 2). Of these, 126 (25%) died before fledging. Two hundred thirty-nine banded and 63 unbanded nestlings fledged, after which we have no further information on their fate. Some of the unbanded nestlings probably returned as unbanded breeders. Seventy-five banded fledglings subsequently returned to breed in Arizona (*n*=49) or California (*n*=1), or were known to have died before breeding (*n*=25). We have records for at least 151 breeders in the population: 59 juvenile-banded from the study period, 11 identified juvenile-banded from before 1987, at least 61 unbanded adults (only some replacements can be detected), and 19 unidentified single-banded (from before 1987) or adult-banded birds (most from 1987 and 1988).

Table 2. Status of nestling and breeding adult bald eagles in Arizona, 1987 to 2003.

Status	Count			
Fate of nestlings	503			
Dead before fledging		126		
Unbanded fledglings		63		
Banded fledglings		314		
Unknown			239	
Known dead before breeding			25	
Bred in Arizona			49	
Bred in California			1	
Identity of breeders	151			
Unbanded (minimum estimate)		61		
Banded		90		
Fledged in Arizona between 1987-2003			59	
Unidentified				10
Cohort identified				49
Fledged before 1987 (single- or adult-banded)			30	
Unidentified				19
Cohort identified				11
Fledged in Texas			1	

Four breeders (2.5%) were in SAD plumage and 35 (21.9%) in NAD plumage. Fledgling-banded breeders were used to describe age-specific plumage for the first sighting of each bird (Fig. 3.). Both banded SAD birds were 3 years old, and all but 1 NAD bird was 4 years old. However, other NAD birds were as young as 3 and as old as 6, so this plumage is not a reliable predictor of age.

Identification of banded adults reflected the successful use of colored VID bands for distance resighting. Some birds were not identified before they were replaced at territories, so we used a life table approach to survival analysis to describe median time to identify individuals based on whether they were single-banded or also carried a VID band. VID banding significantly reduced the time needed to identify birds (Wilcoxon statistic=27.1, *df*=1, $P < 0.0005$; Fig. 4). Median time to identify single-banded birds was 8.0 yrs; for VID-banded birds it was less than one full breeding season at only 0.6 years. During the first breeding season a VID-banded bird was seen, there was a 78% chance it would be identified, but only 13% of single-banded birds were identified their first year on a BA (Fig. 4). By the end of their fourth year on a BA, all VID-banded birds were identified.

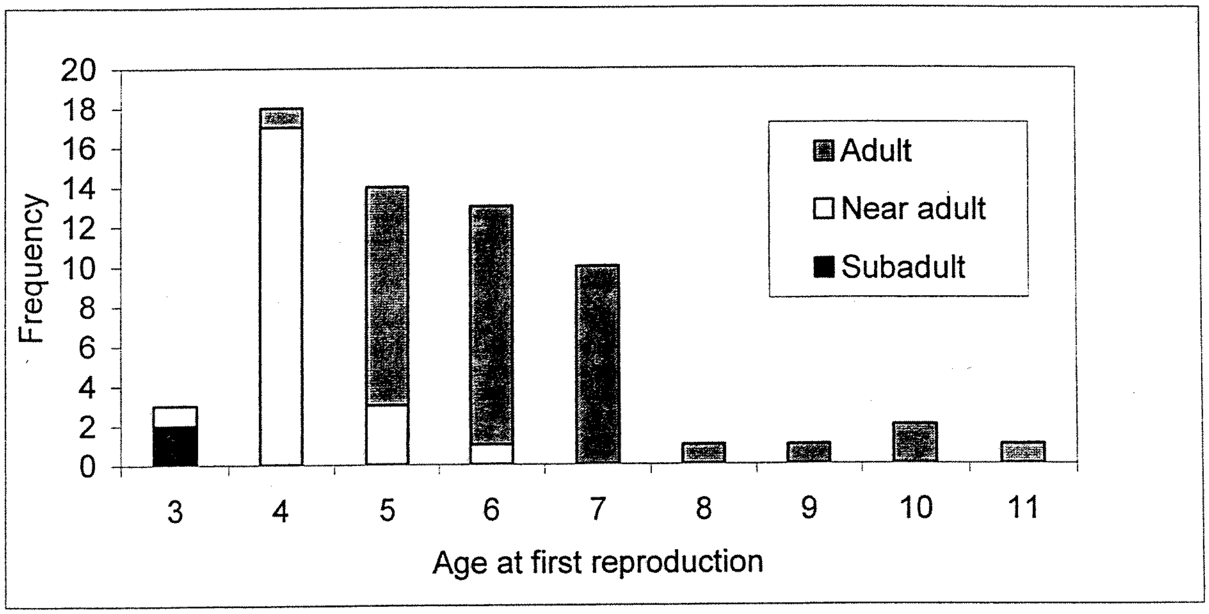

Figure 3. Age-specific plumage for first resighting of banded birds.

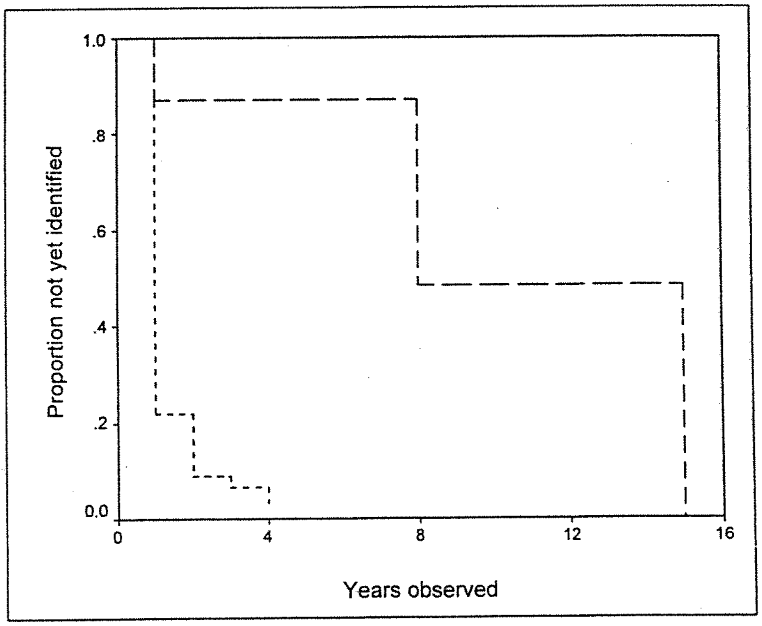

Figure 4. Proportion of unidentified banded birds after the indicated years of residence in a BA. Separate curves for birds banded only with a USFWS band (dashed line; N_{single}=17) or with a VID band (solid line; N_{VID}=65). Censored cases, for which the band was not read before the bird left the BA, are included in the above totals (N_{single}=12, N_{VID}=9).

INPUTS FOR SIMULATION MODELS

Estimates of Reproductive Parameters

Forty-nine identified juvenile-banded birds returned to Arizona to breed during the study period (Fig. 5). Females returned 0.91 years later than males on average (*t*=2.117, *df*=49, *P*=0.040). The female age at first reproduction was consistent with an average age of 6 (*t*=-0.145, *P*=0.886), but not with an average age of 5 (*t*=2.613, *P*=0.018), whereas the sample for males is consistent with an average age of 5 (*t*=0.130, *P*=0.897), but not 6 (*t*=-3.778, *P*=0.001). P-values were not corrected for multiple tests on a single set of data. In fact, these data are a subset of those used in the capture-recapture analysis (here, only resighted birds were analyzed and no resighting probability estimates were generated), and in the larger analysis, the most parsimonious models did not include estimate sex-specific differences in age-at-first-reproduction.

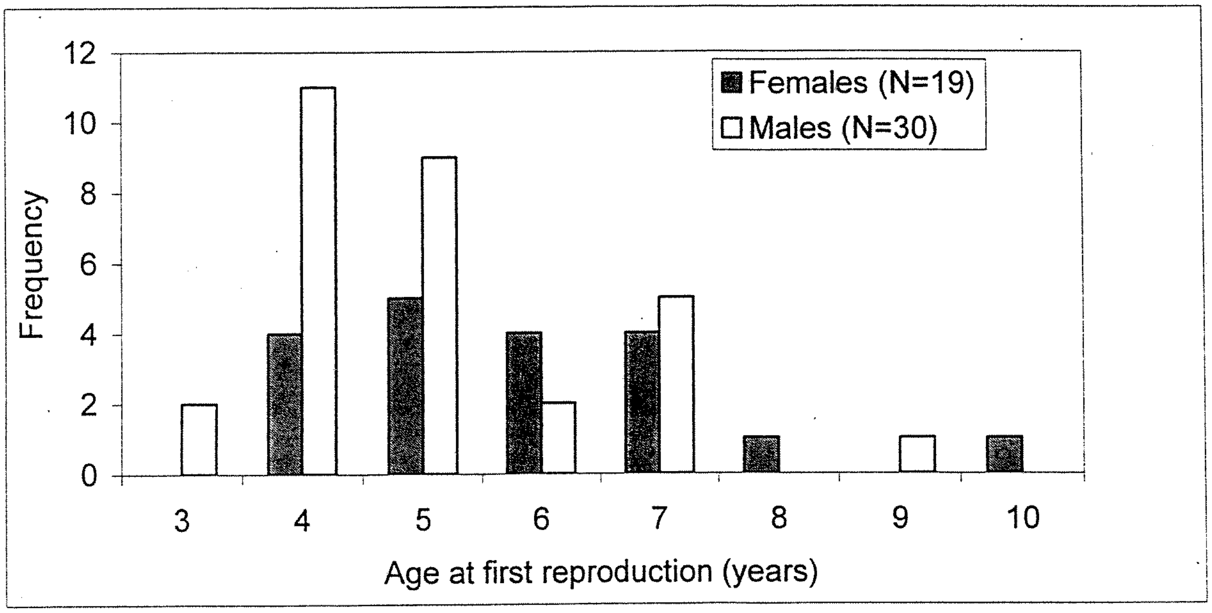

Figure 5. Age at first reproduction for juvenile-banded birds in Arizona, 1987-2003. Bar heights between the sexes should not be compared, since sample size differs.

Monitoring breeding status allowed us to estimate parameters describing breeding behavior, reproductive success of adults, and nestling and fledgling survivorship (Tables 3 and 4). Following breeding status criteria (Appendix A), the number of occupied BAs since 1987 has increased steadily with the number of known BAs. In contrast, the number of successful BAs has increased at a more gradual overall rate (only 49% of occupied BAs are successful), and matches the higher variability seen in the number of active BAs (Fig. 6).

Males represented 65% of banded nestlings since 1987; this percentage has varied from 41% to 76% over this period, based on tarsus width measurements of an average of 17.2 nestlings sexed each year (Table 4). Female nestlings outnumbered males only in 2002.

Table 3. Status summary for breeding areas in Arizona, 1983-2002.

Year	Known	Occupied	Active	Successful	Occupancy Rate	Activity Rate	Success Rate
1983	14	13	13	7	0.93	1.00	0.54
1984	17	17	16	8	1.00	0.94	0.47
1985	19	19	18	13	1.00	0.95	0.68
1986	21	17	17	12	0.81	1.00	0.71
1987	23	21	19	11	0.91	0.90	0.52
1988	25	21	20	15	0.84	0.95	0.71
1989	26	23	17	9	0.88	0.74	0.39
1990	26	24	17	9	0.92	0.71	0.38
1991	26	23	19	13	0.88	0.83	0.57
1992	28	26	23	10	0.93	0.88	0.38
1993	29	26	21	16	0.90	0.81	0.62
1994	31	28	27	13	0.90	0.96	0.46
1995	32	29	22	15	0.91	0.76	0.52
1996	34	30	26	14	0.88	0.87	0.47
1997	35	32	27	12	0.91	0.84	0.38
1998	36	34	24	14	0.94	0.71	0.41
1999	39	36	29	21	0.92	0.81	0.58
2000	41	38	27	13	0.93	0.71	0.34
2001	41	36	29	19	0.88	0.81	0.53
2002	46	41	34	23	0.89	0.83	0.56
2003	47	41	30	18	0.87	0.73	0.44
Mean 1987-2003	33.2	29.9	24.2	14.4	0.901	0.816	0.487

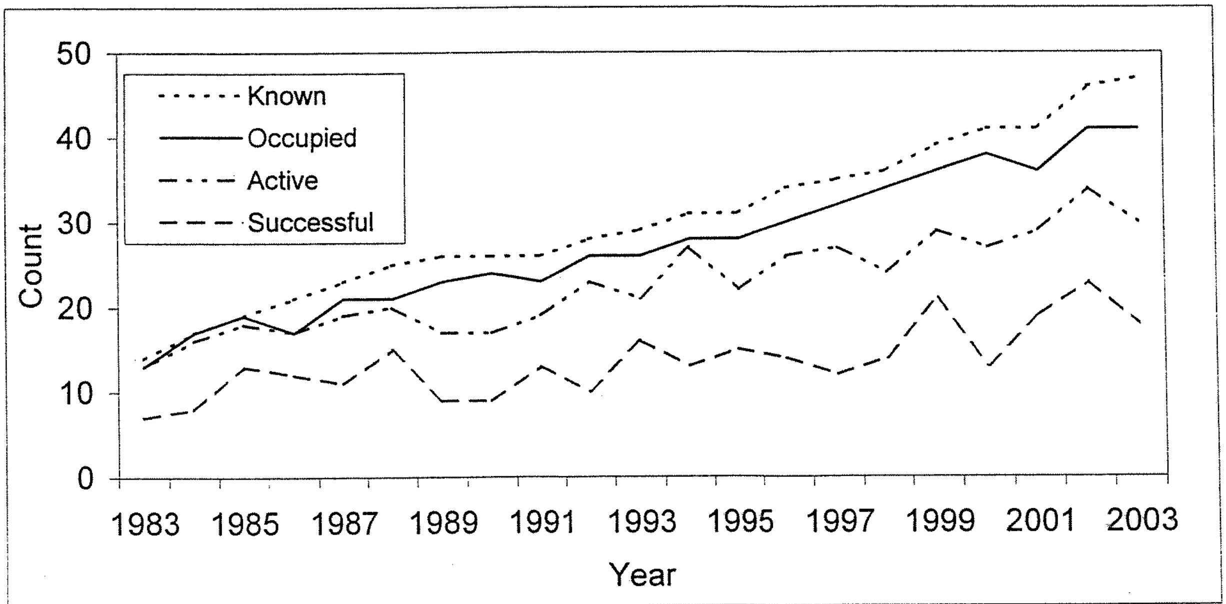

Figure 6. Changes in the number of known, occupied, active, and successful BAs in central Arizona from 1983 through 2003.

Table 4. Productivity and nestling sex ratio summaries for bald eagles in Arizona, 1983-2002.

Year	Breeding areas			Nestlings per occupied BA	Nestlings at 6-8 weeks				Fledglings		
	Occupied	Active	Successful		Banded males	Banded females	Proportion Males	Total banded and unbanded	Total	Per nestling	Per occupied BA (productivity)
1983	12	12	7	--	--	--	--	--	13	--	1.08
1984	17	16	8	--	--	--	--	--	15	--	0.94
1985	18	18	13	--	--	--	--	--	22	--	1.22
1986	19	18	12	--	--	--	--	--	17	--	0.89
1987	21	19	11	1.10	12	6	0.67	23	20	0.87	0.95
1988	21	20	15	1.24	12	7	0.63	26	23	0.88	1.10
1989	23	17	9	1.00	8	4	0.67	23	13	0.57	0.57
1990	24	17	9	0.63	6	5	0.55	15	14	0.93	0.58
1991	23	19	13	1.09	12	9	0.57	25	20	0.80	0.87
1992	26	23	10	0.77	7	7	0.50	20	14	0.70	0.54
1993	26	21	16	1.15	14	8	0.64	30	21	0.70	0.81
1994	28	27	13	1.07	14	6	0.70	30	18	0.60	0.64
1995	29	22	15	1.04	14	6	0.70	29	23	0.79	0.82
1996	30	26	14	1.10	18	8	0.69	33	23	0.70	0.77
1997	32	27	12	0.94	19	5	0.79	30	23	0.77	0.72
1998	34	24	14	0.79	13	5	0.72	27	21	0.78	0.62
1999	36	29	21	1.11	16	10	0.62	40	31	0.78	0.86
2000	38	27	13	0.97	17	7	0.71	37	22	0.59	0.58
2001	36	29	19	1.03	16	5	0.76	37	28	0.76	0.78
2002	41	34	23	1.10	12	17	0.41	47	37	0.79	0.90
2003	41	30	18	0.80	13	5	0.72	33	26	0.79	0.63
Mean (1987-2003)	29.9	24.2	14.4	0.995	13.1	7.1	0.650	29.6	22.2	0.754	0.749

Survivorship Estimates from Program MARK and Literature

The data fit the global model poorly (χ^2=344.3, df=1, P<0.0005). This was attributable to juvenile-banded birds since 1999 that have not entered the breeding population to be resighted. Adult-banded birds showed no lack-of-fit. We adjusted for this idiosyncrasy of the dataset in 2 steps. 1) For the first 3 years after fledging we fixed parameter estimates for resighting and survivorship rates at 0 and 1, respectively. 2) To compensate for remaining variance inflation in the dataset, for computations and model choice we adjusted the Akaike criterion statistic by VIF=4.95.

Of the 48 models developed (Table 5), the best model used age to estimate resighting rates but estimated all annual survivorship rates after age 4 as equal ($[\Phi_{.}\ p_{\mathrm{age}}]$). Model weights ($w_i$) are the relative likelihoods for each model given the data (Burnham and Anderson 2001). The w_i were normalized so that all models for the same dataset sum to 1, so the w_i indicate the relative support for each model. This first model $\{\Phi_{.e}\ p_{\mathrm{age}}\}$ fit Level 1 data 1.44 (=0.174/0.121) times better than the $\{\Phi_{\mathrm{age}}\ p_{\mathrm{age}}\}$ model, which estimated survivorship and resighting rates as a function of adult age. The best 12 models for Level 1 include the best set for Level 2 data, although their rank by weight differs. Considering Level 1 data only, and summing w_i for the appropriate models, those models that included age as a predictor of survivorship, with or without other factors, were supported 48% of the time (Table 6). Models that included sex as a predictor were only supported 18% of the time, which indicated a larger dataset might distinguish survivorship rates for males and females of the same age. Survivorship models that included time received stronger support (31% of the relative support), so the capture-recapture analysis may indicate an important linear trend as the study continues.

The intended effect of using Level 2 assumptions was to reduce the impact of survey effort on estimates of resighting rate. By decreasing the contribution of survey effort, resighting rate estimates should have more strongly reflected recruitment of different age classes as breeders. As expected, comparison of model weights (Table 6) indicated that resighting rates for Level 2 models were less influenced by time (survey familiarity) than were Level 1 models, and models that incorporated adult age structure were even more predictive.

The relative importance of adult age structure was slightly less for Level 2 survivorship models than for Level 1, whereas the relative importance of including a trend over time in these models was increased. Because survivorship estimates for the same models differ very little between the Level 1 and 2 data, we proceeded with Level 2 estimates. Juvenile survivorship was estimated as slightly higher and adult survivorship slightly lower than for Level 1 models, but the difference was less than 1% for each age class. We favored Level 2 models because they allowed us to provide an initial estimate of the proportion of the population acting as floaters in any age class.

Table 5. Summary of model testing for banded Arizona bald eagles. Models were completed using the original data (Level 1) and by assuming additional 'resightings' for all years between positive identifications of the same bird at the same BA (Level 2). Models are described by parameters used to predict survivorship (Φ) and resighting rate (*p*), and the best 12 are ordered by the corrected quasi Akaike criterion value (QAIC) for Level 1 analysis; the favored model has the lowest QAIC and the highest weight. For reference, the constant and global models are reported at the bottom in italics. All models, including the constant model, set survivorship to ages 1 to 3 at 1 and resighting rates for these ages at 0; all models also estimate survivorship and resighting rate separately for 4-year-olds (see text).

Model[a]	Parameters estimated	Original data (Level 1)			Interpolate residency to years between positive identifications of same banded bird (Level 2)		
		QAIC	ΔQAIC[b]	Model weight	QAIC	ΔQAIC[b]	Model weight
Φ(.) p(ageL)	5	685.0	0.0	0.174	545.6	0.0	0.248
Φ(ageL) p(ageL)	7	685.7	0.7	0.122	548.7	3.1	0.054
Φ(T) p(ageL)	6	685.7	0.7	0.121	546.6	1.0	0.149
Φ(T) p(ageL+T)	6	686.3	1.4	0.088	546.8	1.2	0.135
Φ(ageL+T) p(ageL)	7	686.6	1.6	0.076	548.8	3.2	0.049
Φ(ageL+T) p(ageL+T)	7	687.0	2.0	0.064	547.8	2.2	0.083
Φ(sex+ageL) p(ageL+T)	8	687.4	2.5	0.051	549.8	4.2	0.031
Φ(sex+ageL) p(ageL)	8	687.5	2.5	0.049	550.5	4.9	0.021
Φ(sex) p(ageL+T)	7	687.5	2.5	0.049	548.5	2.9	0.058
Φ(sex) p(ageL)	8	688.6	3.7	0.028	551.5	5.9	0.013
Φ(sex+ageL+T) p(ageL)	7	688.8	3.8	0.026	549.5	3.9	0.036
Φ(sex+ageL+T) p(ageL+T)	8	688.8	3.8	0.026	549.7	4.1	0.032
Φ(.) p(.)	*4*	*689.4*	*4.5*	*0.019*	*557.4*	*11.8*	*0.001*
*Φ(sex*age*time)p(sex*age*time)*	*248*	*831.5*	*146.5*	*0.000*	*699.0*	*153.4*	*0.000*

[a] Parentheses indicate factors allowed to vary in each model: age=year classes for eagles over 4 years old; ageL=linear change with age over 4 years old; time=separate groups each year for survivorship, intervals of similar survey effort (see text) for resighting rate; T=linear change in either rate with time. For example, the third model estimated survivorship as a linear function of survey year but not as a function of age or sex. Resighting rates for that model were calculated as a linear function of age.

[b] Difference between QAIC for the model and the minimum AIC for the set of models.

Table 6. Favored models with original data (Level 1) and by assigning further 'resightings' for years between positive identifications of the same bird at the same BA (Level 2).

	Sum of model weights	
	Level 1	Level 2
Models that estimate survivorship using ...		
Adult age structure only	0.243	0.202
Adult age structure and any other factors	0.482	0.427
Sex only	0.054	0.049
Sex and any other factors	0.178	0.160
Time only	0.165	0.185
Time and any other factors	0.306	0.330
Models that estimate resighting rates using ...		
Adult age structure only	0.549	0.741
Adult age structure and any other factors	0.875	0.908
Time only	0.000	0.000
Time and any other factors	0.326	0.167
Sex and any other factors	0.000	0.000

Model weights indicated that adult age and a decreasing time trend might influence survivorship estimates, while age contributes most to estimates of resighting rates (Table 6). Because sex was not supported as a predictor of survivorship in the best model, model averaging (White and Burnham 1999) was used to generate sex-specific survivorship estimates (Table 7). The model-averaged parameter estimates show only a slightly higher survivorship rate for females compared to males, not contrary to our predictions, but the pattern is probably too small to be biologically relevant.

Table 7. Sex- and age-specific survivorship and resighting rate estimates (95% CI) using model averaging on Level 2 data in Program MARK.

To age	Survivorship estimates		Resighting rate estimates
	Females	Males	
1-3	1[a]	1[a]	0[a]
4	0.29 (0.131,0.535)[b]	0.28 (0.130,0.514)[b]	0.23 (0.065,0.576)
5	0.94 (0.642,0.992)	0.93 (0.638,0.992)	0.45 (0.190,0.736)
6	0.93 (0.668,0.987)	0.92 (0.666,0.986)	0.70 (0.484,0.852)
7	0.91 (0.729,0.978)	0.90 (0.730,0.971)	0.87 (0.729,0.948)
8 and older	0.88 (0.764,0.973)	0.87 (0.759,0.936)	0.95 (0.850,0.988)

[a] These parameters were fixed in each model, not estimated.

[b] Because survivorship for ages 1 through 3 was fixed at 1, the survivorship estimate at age 4 is survivorship from fledging to age 4.

For demographic modeling, we used survivorship estimates from the best, age-specific capture-recapture model (Table 8). Demographic models required annual survivorship estimates for each of the earliest age classes, but we could only create a direct estimate of survivorship from fledging to age 4. For simplicity, we assumed equal survivorship for each of the first 4 age classes. In this case, 72.7% annual survivorship for 4 years results in 27.9% survivorship from fledging to age 4, which was the resighting rate from Program MARK (Table 8). Estimates from previous studies (Table 9) indicated considerable variability in survivorship estimates and in the shape of the mortality schedule. We experimented with the effect of partitioning juvenile survivorship to reflect patterns seen in other studies (Table 9), and noticed no effect on population growth estimates, therefore we assumed equal survivorship over the first 4 years (Table 10).

Table 8. Age-specific resighting and survivorship estimates (95% CI) from Program MARK using Level 2 data.

Age	Survivorship to age	Resighting rate at age
1-3	1[a]	0[a]
4	0.28 (0.147,0.466)[b]	0.22 (0.066,0.534)[b]
5	0.88 (0.785,0.936)	0.44 (0.201,0.714)
6		0.70 (0.513,0.841)
7		0.88 (0.745,0.944)
8 and older		0.95 (0.852,0.987)

[a] These parameters were fixed in each model, not estimated.

[b] Because survivorship for ages 1 through 3 was fixed at 1, the survivorship estimate at age 4 is survivorship from fledging to age 4.

Final Inputs To Each Simulation Model

Where possible, we used data from this study to provide parameter estimates for the simulations. The final parameter estimates for the simulations are in Table 10. Table 11 is the resulting Leslie matrix for our primary model, assuming equal sex ratios and similar age at first reproduction for males and females. One other model was built assuming later age at first reproduction for females. Our sex ratio estimates based on tarsus width indicate a male-biased sex ratio in nestlings. No other analysis to date has assumed male-biased sex ratios, so for comparison as third model simulated a population producing 65% male nestlings. For all models, we used an initial population size of 200 eagles.

Table 9. Age-specific survivorship estimates for bald eagles across their range The estimate from Stalmaster (1987) is a summary of work by the early 1980's; the Grier (1980) study gives hypothetical but often-cited values from an earlier demographic analysis.

Study	Population status	Annual survivorship to age …									Adult class limits
		Nestling to fledging	1	2	3	4	5	6	Adult	Fledging to 4*	
This study		0.75	0.73	0.73	0.73	0.73	0.88	0.88	0.88	0.28	7+
Driscoll and others (1999)		0.84	0.84						0.84	0.50	1+
Hunt and others (1992)		0.84								0.18	
Stalmaster (1987)		0.85									
Grier (1980; low)	Declining		0.30	0.70					0.70	0.10	2+
Grier (1980; moderate)	Declining		0.60	0.80					0.80	0.31	2+
Grier (1980; stationary)	Stationary		0.60	0.85					0.85	0.37	2+
Grier (1980; high)	Expanding		0.70	0.90					0.90	0.51	2+
Brown and Amadon (1968)			0.22	0.44	0.39	0.76	0.68			0.03	
McCollough (1986; pre-feeding)			0.54	0.79	0.91				0.91	0.31	3+
Harmata and others (1999)			0.87	0.85	0.64	0.71	0.60	0.67		0.34	
Buehler and others (1991)	Expanding		1.00	0.92	0.75	0.83	0.83	0.83	0.83	0.57	4 to 6
Bowman and others (1995)	Expanding		0.71	0.95	0.95	0.95			0.88	0.61	5+
Gerrard and others (1978; wing marks)			0.37	0.62	0.83						
Gerrard and others (1978; bands)			0.53	0.51	0.74						
Wood (1992)			0.63	0.84	0.94						
Jenkins and others (1999)	Expanding		0.77	0.95					0.95		2+
McClelland and others (1996)			0.91								

* This is the product of annual survivorship for each of the 4 annual age classes from fledging to age 4.

Table 10. Parameters for input in the matrix demographic analyses.

	Proportion of females that breed	
Parameter	Same as males at each age	Defer reproduction relative to males
Proportion age 3 females that breed (occupy a BA)	0.00	0.0
Proportion age 4 females that breed	0.22	0.21
Proportion age 5 females that breed	0.44	0.42
Proportion age 6 females that breed	0.70	0.63
Proportion age 7 females that breed	0.88	0.90
Proportion females age 8 and older that breed	0.95	0.95
Nestling sex ratio (% males)	0.50 or 0.65	
Nestlings per occupied BA	0.995	
Survivorship of hatchlings through fledging	0.750	
Survivorship of fledglings through age 1	0.73	
Survivorship age 1 to age 2	0.73	
Survivorship age 2 to age 3	0.73	
Survivorship age 3 to age 4	0.73	
Survivorship age 4 to age 5	0.88	
Survivorship age 5 to age 6	0.88	
Survivorship age 6 to age 7	0.88	
Annual survivorship after age 7	0.88	
Initial population size	200	

Table 11. Leslie matrix for deterministic model assuming 50% of nestlings are female. Program MARK estimates used for survivorship and estimating age-specific breeding probability.

	F(h)	F(1)	F(2)	F(3)	F(4)	F(5)	F(6)	F(7)	F(8+)
Nestlings	0	0	0	0.000	0.080	0.193	0.306	0.382	0.416
1	0.546	0	0	0	0	0	0	0	0
2	0	0.728	0	0	0	0	0	0	0
3	0	0	0.728	0	0	0	0	0	0
4	0	0	0	0.728	0	0	0	0	0
5	0	0	0	0	0.877	0	0	0	0
6	0	0	0	0	0	0.877	0	0	0
7	0	0	0	0	0	0	0.877	0	0
8+	0	0	0	0	0	0	0	0.877	0.877

ESTIMATES OF λ AND ELASTICITY ANALYSIS

Based on simulations, the population is projected to be declining at a rate of 3.6 to 5.5% per year (Table 12). Elasticity analysis (Table 13) indicated how short-term changes in individual parameters could change a population decline from 3% per year to 0% per year. Nestling survival to age 1 would have to increase 49.7% (to 81.7% survival from the current 54.6%). Alternatively, fertilities would need to increase by the same proportion. Juvenile survivorship of each age class from 1 to 4 could change 12.5% and have the same effect, or adult annual survivorship could change only 4.7%, from 87.7% to 91.8%. A smaller change in adult survivorship would have a more dramatic impact on population persistence than would a larger change in nestling survivorship, but this analysis does not address the tractability of managing to change any of these vital rates. For instance, management to improve survivorship of nestlings may be more feasible than management to improve adult survivorship. Existing long-term management to increase productivity may have exploited much of the potential to change productivity, however, and sources of adult mortality in Arizona bald eagles are not yet well understood. Elasticity analysis describes potential for population increases (or declines), but does not weigh the costs of achieving these changes.

Table 12. Estimates of λ from different models.

Estimate type	Model	λ
Breeding Adult Segment	Ratio of all eagles at BAs current year to previous year (counts taken from Table 1 and reported in Table 14)	1.040
	Ratio of eagles at BAs current year to previous year; newly identified BAs not included	0.984
	Ratio of eagles at BAs current year to previous year; Newly identified BAs with Existing status not included	1.043
Deterministic	Nestling sex ratio 50% males; MARK-estimated age-specific survivorship	0.964
	Nestling ratio 50% males; females defer reproduction 1 year later than males	0.963
	Nestling sex ratio 65% males; MARK-estimated age-specific survivorship	0.945

Table 13. Elasticities for comparing possible management impacts on persistence of the Arizona bald eagle population. A 1% increase in the estimate for each parameter would have the effect of bringing the replacement rate, λ, closer to even (1.0) by the percentage indicated in the table.

Parameter	Estimated % change in (1-λ)	Associated priority management options
Survival of nestlings to 1 year	6.0	Decrease mortality including: adverse affects of development/projects, falling from nests, human disturbances, Mexican chicken bugs, and monofilament entanglement. Increase quality of prey base and riparian habitats to support successful fledging.
Survival of juveniles (1 to 4 years old)	23.9	Describe habitat use by juveniles and decrease mortality from electrocution, lead poisoning, shooting, and starvation.
Survival of adults (5 years and older)	64.0	Understand habitat use by floaters and decrease mortality from shooting, lead poisoning, and monofilament entanglement.
Fertilities	6.0	Decrease egg failure from heavy metals, organochlorines, and human disturbance. Increase quality of prey base and riparian habitats, and number of suitable BAs.

Elasticities indicated that increased age at first reproduction for females would have a small impact on survivorship; this is also observed by comparing λ for models that differ only in age at first reproduction for females (Table 12). These comparisons predicted a decrease in λ of about

0.1% if females begin breeding at age 6 on average instead of age 5. Similar comparisons of λ for models that differ only in sex ratio indicate that when the sex ratio is biased in favor of males, λ would be almost 2% lower than if the sex ratio were equal.

Stable Age Structure

We used the primary deterministic model to illustrate the expected age structure in the current population (Fig. 7). We used the resighting rate estimates to divide each age class into breeding adults (birds occupying BAs), juveniles, and floaters (if at least 4 years old). The proportion of birds in adult plumage (for simplicity, assume these are all birds older than 5) in any year is estimated to be 48.7%. Some of these birds will be floaters, and not occupying BAs. This means that if we identify 70 adult-plumage birds occupying BAs in any given year, we predict we will also find 2 near-adult plumage birds occupying BAs, there will be 33 nestlings (20.1% of the population), and 58 individuals will not be seen at all, since these birds are juveniles (26.4%) or reproductive-aged floaters (9.7%).

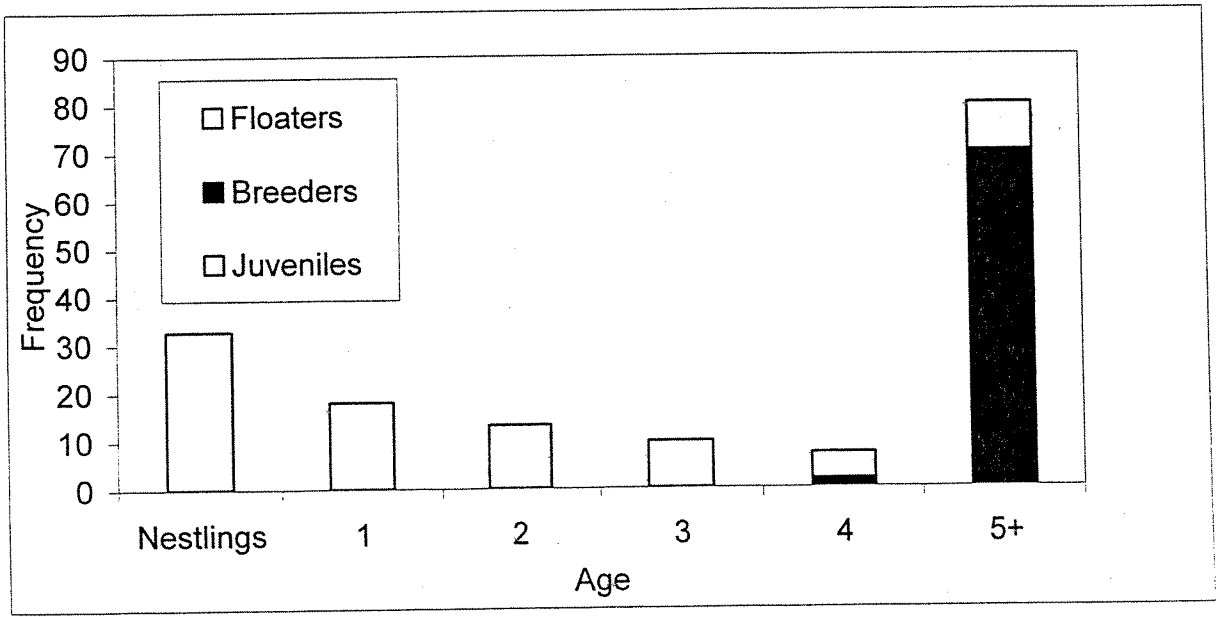

Figure 7. Age distribution using survivorship estimates from mark-resight data and assuming a stable age distribution with 70 adult plumage birds (5 years of age or older) occupying BAs.

POPULATION GROWTH RATE (λ) CALCULATED FROM NUMBER OF ADULTS OCCUPYING BAS

Simple ratios comparing numbers of breeding adults in 1 year to the number in the previous year indicate an expanding Arizona bald eagle population (Tables 12 and 14). These trends assumed we were able to census all breeding birds each year. In some cases we counted adults occupying newly discovered, but previously existing BAs (Table 3; evidence that BAs were previously existing might include presence of more than 1 nest in the breeding area). If we treated these adults as new recruits to the population, we confounded search effort with population growth and overestimate the population replacement rate. When we based the estimate of λ on adults at previously existing territories, the replacement rate was slightly less than 1.

Table 14. Estimate of λ based on number of birds occupying BAs in central Arizona. Note that in 7 different years, 1 male occupied BAs with 2 different females, so the count of adults is an odd number.

Year	Counts of breeding adults			Males at 2 BAs	Occupied BAs Where 2 Adults Not Confirmed	Replacement rate (λ)		
	Total	Previously Existing BAs	Previously Existing or Pioneered BAs			All Adults	Previously Existing BAs	Previously Existing or Pioneered BAs
1987	41	37	39	0	1	1.024	0.927	1.026
1988	42	38	40	0	0	1.048	1.024	1.100
1989	44	43	44	1	1	1.068	1.068	1.068
1990	47	47	47	1	0	0.915	0.915	0.915
1991	43	43	43	1	2	1.163	1.070	1.163
1992	50	46	50	1	1	1.020	0.980	1.020
1993	51	49	51	0	1	1.098	1.020	1.059
1994	56	52	54	0	0	0.982	0.946	1.019
1995	55	53	55	0	1	1.073	1.000	1.073
1996	59	55	59	0	1	1.051	0.983	1.017
1997	62	58	60	0	2	1.048	0.984	1.083
1998	65	61	65	0	3	1.062	0.969	1.062
1999	69	63	69	0	3	1.029	0.986	1.029
2000	71	68	71	0	5	0.958	0.958	0.958
2001	68	68	68	1	3	1.118	0.971	1.059
2002	76	66	72	1	5	1.013	0.961	1.069
2003	77	73	77	1	4			
MEAN	62.0	54.4	56.9	0.4	1.8	1.040*	0.984*	1.043*

*Geometric means.

OTHER ELEMENTS DESCRIBING REPRODUCTIVE BIOLOGY

Breeding Stage, Pair Bonds, And BA Switching

Since 1987, we have identified at least 82 unique breeding pairs for which we can identify the first year of mating. This is a minimum estimate of the total number of breeding pairs, since many pairs included an unbanded bird. Replacement of unbanded birds was only documented when the BA was unoccupied the following year, when the bird was known to die, or when it was replaced by a banded bird or one with a different plumage. Also, survival analysis of pair bond duration could not be applied to pairs that were not identified during the first year together (left-censored data). Median pair duration was 4.9 years. Due to incomplete documentation of replacement of unbanded birds, this is a maximum estimate.

In contrast, individual breeders remained at a BA a median of 9.2 years (35.1% cases were right censored, with unknown total length of tenure because they are still in residence); there was no statistically significant difference in tenure of males and females (Behan statistic, *df*=1, *P*=0.434). Again, these are maximum tenure estimates since replacement of 1 unbanded individual by another could often not be detected. Because the typical bald eagle's tenure lasted longer than the pair bond, a bald eagle was likely to have more than 1 mate in its lifetime.

Dispersal Distances from Natal to Breeding BA

Dispersal distances for 18 females and 35 males from their natal to their first breeding area are plotted in Figure 8. Females have been reported to disperse farther than male bald eagles in 1 other population (Harmata and others 1999). In our study, females traveled 76.9 km farther than males to breeding areas (t-test assuming unequal variances on square-root transformed distances, *t*=3.656, *df*=24.0, *P*=0.001), with females traveling an average of 121.3 km and males traveling 44.4 km. With the possible exception of a female that dispersed 428 km, these distances do not indicate that migration from the region is a simple extension of this type of sex-specific, within-region dispersal.

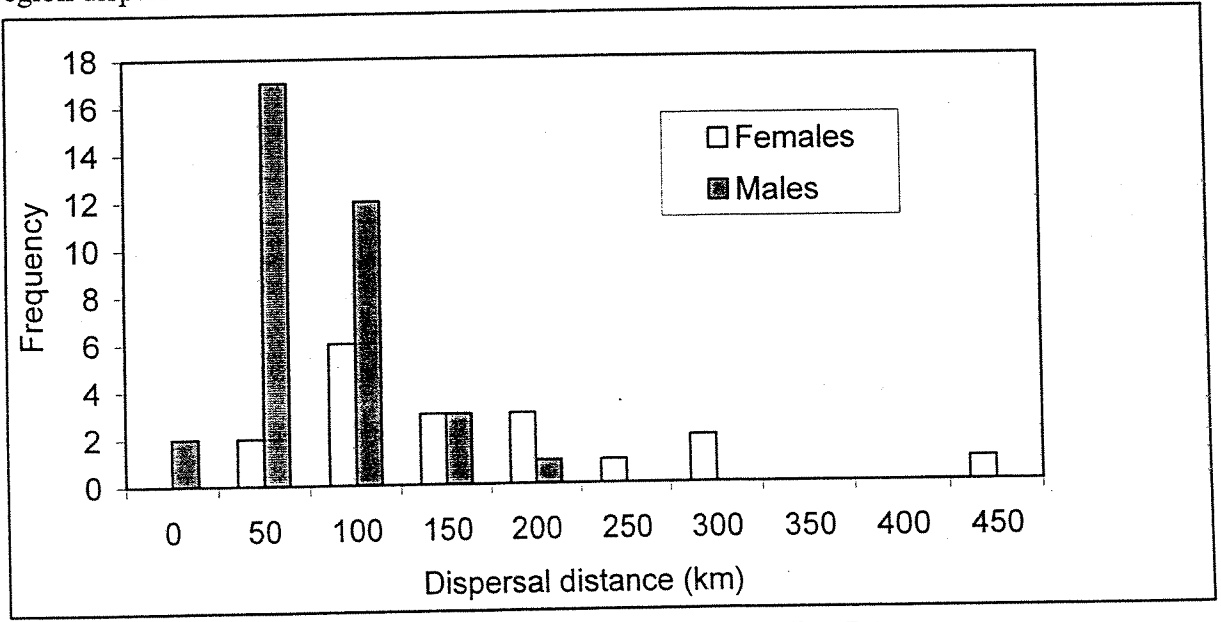

Figure 8. Dispersal distance from natal BA to first known breeding BA.

DISCUSSION

Our dataset and analysis are extensive and touch on diverse topics. Life history theory provides one context for interpreting the suite of vital rates we have estimated. If the Arizona population had been isolated during its evolution, we may not expect vital rates in this environment to be optimal at the same level as in other parts of the range. Current birth and death schedules, however, are difficult to associate with historical environments due to extreme habitat modification in recent times. In fact, some vital rates measured today reflect direct intervention to manage population dynamics. In Arizona, for instance, most management focuses on enhancing survival of nestlings and adults at BAs, and our productivity estimates reflect these efforts.

The suite of life history traits can also be considered for the role they play in population dynamics. Our analyses did not provide a definitive answer to the question of whether the Arizona bald eagle population is stable, but did identify gaps in our data collection. Is there better evidence of immigration to the Arizona population serving to enhance the breeding segment of the population? Is the population age and stage structure still stabilizing but not yet at equilibrium? Finally, how is the small size of the Arizona bald eagle population mirrored in its genetic pool and contributing to stochastic factors that affect population growth? In the sections below, we discuss individual vital rates, the sensitivity of population dynamics to each of these rates, and resulting focus for further study and management.

COMPARISON OF LIFE HISTORY PARAMETERS TO OTHER STUDIES

Reproductive Rates

Table 15 reports data for studies to date in Arizona, plus information from Stalmaster (1987), who summarized rangewide data collected by the early 1980's, and later studies from across the range. In general, Arizona had a lower nest success rate than elsewhere, but this has not resulted in depressed productivity compared to other regions. The occupancy rate of known BAs in Arizona was about 90% (Table 4). This is higher than typical rates of 70% reported by Stalmaster (1987). He speculated that high occupancy rates indicate populations are large enough to saturate available BAs, and further population growth will be limited by lack of additional habitat.

Variable methods were used to measure productivity, so exact comparisons between studies were difficult. Studies outside Arizona typically computed productivity based on 2 or 3 flights per breeding season to count the number of *nestlings* that attained 8 weeks of age (Postupalsky 1973; Fraser and others 1983). However, our study and Driscoll and others (1999) used 6 ORA flights to describe breeding activity, usually continuing past the 8-week stage. Consequently, we were more likely to document mortality of nestlings and fledglings after 8 weeks of age, leading to lower productivity and nest success estimates than under the conventional protocol. On average, 1.4 8-week-olds (6%) later died each year before fledging. Including these birds, we would estimate productivity at 0.80. Conversely, intensive management to increase Arizona's bald eagle productivity was introduced in 1978 with the establishment of the first BA closure. This management has increased in intensity over time with such practices as daily monitoring and education by the ABENWP, the establishment of 17 BA closures, and efforts of biologists to intervene in bald eagle life-threatening situations. These practices have helped directly save 30 (or 11.1% of 270) banded fledglings from 1987-2001, and indirectly an undetermined number through closures, ABENWP daily monitoring, and education of recreationist before productivity is affected. Without these efforts, we can assume that natural Arizona productivity since 1978 would be considerably lower than what we have documented.

Table 15. Bald eagle productivity estimates across North America. Stalmaster (1987) summarized most studies that were completed by the early 1980's; his summary statistics are included here plus information from studies begun by the early 1980's, and from all reported periods of study in Arizona.

Study area	Average # BAs Monitored per year	Productivity (Fledglings per occupied BA)	Success per Occupancy	Years	Study
Arizona	8.8	0.80	0.52	1975-1980	Grubb and others 1983
Arizona	15.0	1.18	0.65	1981-1985	Grubb and others 1986
Arizona	25.4	0.69	0.45	1987-1993	Driscoll and others 1999
Arizona	22.3	1.00	0.50	1987-1990	Hunt and others 1992
Arizona	33.2	0.75	0.49	1991-2002	This study
Wisconsin	254	1.28	0.76	1983-1988	Kozie and Anderson 1991
Aleutian Islands, AK	23/island	0.67-1.24[1]	0.48-0.86[1]	1993-1994	Anthony and others 1999
Colorado/Wyoming	9.4	1.21	0.63	1981-1989	Kralovec and others 1992
Florida	40	1.21		1985-1988	Wood and Collopy 1993
Chesapeake	145	1.18	0.69	1981-1990	Buehler and others 1991
Nationwide		0.92	0.58	Pre-1986	Stalmaster 1987
Washington	173	0.85	0.66	1981-1985	McAllister 1986
Interior Alaska	231	0.77	0.52	1989-1994	Steidl and others 1997
British Columbia	26.0	0.70	0.48	1992-1996	Elliot and others 1998
Minnesota	22.3	0.68	0.51	1973-1993	Grim and Kallemeyn 1995

[1] per active breeding area

Compared to earlier studies in Arizona, we estimated a similar rate of nest success, but lower productivity than Grubb and others (1983, 1986), and higher productivity than Driscoll and others (1999), a report that included data from early years of our study. The discrepancy was not due to changes over time, with our data reflecting higher productivity in later years. Rather, the difference in reported productivity between our study and that of Grubb and others (1983, 1986) could be attributed to an increase in monitoring efforts and management within the BAs (as described above). Discrepancies with Driscoll and others (1999) arose because under our more conservative operational definition of occupied BAs, we reported fewer breeding pairs each year. Because ORA flights are not generally suited to identifying territorial (occupancy) behavior unless the BA is active, surveyors often use other sources of information for assessing BA occupancy. For instance, if the area was used historically for breeding and if bald eagles were present during the breeding season, the area might be considered an occupied BA. However, in addition to breeders, Arizona hosts non-breeding adults from this population as well as wintering bald eagles from other states that occasionally remain late into the breeding season. Therefore, we only defined a BA once recent breeding activity was confirmed, (Appendix A). Until the BA was defined, it would not be considered occupied. Applying our standards to observations from 1987 through 1993, we recognize 2-4 fewer BAs per year than reported in Driscoll and others (1999), and calculated a productivity rate of 0.77 fledglings/occupied BA for the years 1987 through 1993, closer to the rate for the whole period through 2001.

Survivorship

Although Grier (1980) and Stalmaster (1987) identified adult survivorship as a key element in maintaining bald eagles – more influential than productivity rates, for instance – at that time there were few estimates of adult survivorship. Table 9 summarizes results from rangewide studies of survivorship to date. Although the growth rate of Arizona's population is a function of interrelationships between many vital rates, the relative importance of survivorship led us to compare rates in Arizona to those in other populations that have been characterized as expanding, declining, or stable. Note that parameters taken from Grier (1980) are not empirical, but were theoretical values based on experience and considered in a separate demographic analysis. Our rates of nestling and juvenile survivorship are generally lower than those reported elsewhere, but juvenile survivorship should be considered *apparent* survivorship. That is, our estimate includes losses to the population due to emigration as well as mortality. There is currently a single report of emigration (to a BA in California), so it would be conservative to continue treating Arizona bald eagles as a closed population until and unless more direct evidence is acquired.

Compared to other studies, we report relatively high survivorship in young breeders and low survivorship in older breeders. As in other studies, we lack information on relative survivorship of breeding and non-breeding same-aged adults.

Our rate of nestling deaths (25%) is similar to that reported by Driscoll and others (1999) for Arizona during the period 1987-1993, and higher than the 15% level in rangewide studies examined by Stalmaster (1987). However, as Driscoll and others (1999) noted, additional monitoring flights and daily observation by ABENWP probably documented more mortalities than if the typical protocol had been followed. Conversely, Arizona bald eagle management practices to increase productivity have been in place since the late 1970s. Thus our rate of nestling deaths probably reports lower (but more accurate) survivorship than a less intensive monitoring protocol would capture, but also reflects increased survivorship due to very active management at the nest to enhance survivorship.

Driscoll and others (1999) reported demographic values for Arizona birds, including 14 fledgling-banded breeders, based on studies from 1987 through 1993. Since then, we have detected 30 more fledglings that have returned as breeders. Due to the low number of resightings, Driscoll and others (1999) estimated breeder survivorship by counting all known replacements of banded and unbanded adults as deaths. Because some replacements of unbanded birds go undetected, their 84% annual survivorship estimate was biased high, but is similar to our estimate of 87.7%.

ASSUMPTIONS USED TO DEVELOP THE MODELS

Sex Ratios and Age at First Reproduction

Sex ratio of available breeders may vary year to year, especially in a small population. Any shift in number of potential breeding pairs can impact other parameters, such as productivity, which can affect the viability of the population (Brook and others 2000, Lacy 2000). No other study has reported skewed sex ratios in nestling bald eagles. Bortolotti (1984) reported 53 males in a sample of 103 nestlings (51.5% males), and Harmata and others (1999) reported 50.9% males in 218 nestlings. However, skewed sex ratios have been noted in other raptors (Krackow 1993) including golden eagles (Edwards and others 1988). Skewed sex ratios in raptors are usually investigated for insight into evolution of sex ratios, but in Arizona we are more concerned with the effect this bias may have on population dynamics, from the reduced ability to form monogamous pairs.

In a monogamous species, sex ratios consistently different from 1, will depress the replacement rate (Lacy 2000). If the biased sex ratio has an adaptive basis in monogamous bald eagles of the Southwest, we predicted males would suffer greater mortality than females, or would occur at higher frequency in the floating population. However, we did not detect an important difference in survivorship, resighting rates, or tenure between males and females. In Northern California, males and females also had similar tenures (Jenkins and Jackman 1993). In our analysis, even if the sex ratio was assumed equal, λ estimates for our models were still less than 1.

Furthermore, our direct estimates of age-at-first reproduction indicate that males return to breed (occupy a BA) at approximately age 5, while the female typically does not enter the population until almost 6. The mark-resight analysis does not indicate that we have sufficient information to accept this difference. Bowman and others (1995) assumed that Alaska bald eagles defer reproduction until age 8, and Harmata and others (1999) estimated reproduction begins at age 6. Later first reproduction in females has not been reported in other eagle populations.

UNDERSTANDING DIFFERENT POPULATION GROWTH RATE ESTIMATES

Our best estimate of the number of breeding adults supports the interpretation of an increasing population, but the demographic models indicate the population is not replacing itself (Table 12). Although the percentage differences appear small, population growth rate reflects multiplicative effects. A 3% decline sustained over 23 years results in a 50% reduction of the initial population size; a 3% increase sustained over the same number of years results in the opposite effect. The discrepancy between the demographic λ and count-based estimates might reflect incorrect assumptions about newly discovered BAs (and resulting inaccuracy in adult counts), idiosyncrasies of our data, survivorship estimates that are low, or the possibility that the breeding segment of the population is recruiting from unmarked populations (Fig. 9). Some of these possibilities have been discussed elsewhere in this report. Here, we consider the possibility that the breeding segment of the population is recruiting at greater rates than the rest of the population.

Is the Arizona Population Closed?

Because most recent work has theorized that Arizona bald eagles form a closed population (e.g., Hunt and others 1992), our models described population dynamics as if there was no immigration from or emigration to other populations. Because the breeding segment of the Arizona population appeared to be growing, while our overall population projections showed a decline, one source of adults might have been immigrants. We are aware of only 1 immigrant, from Texas (Mabie and others 1994). This male pioneered the Luna BA, which is considerably distant from the body of breeding areas on the Salt, Verde, and Gila Rivers. One female Arizona-banded fledgling is known to have attempted to breed outside of Arizona, in California (Ron Jurek, California Fish and Game, pers. comm.).

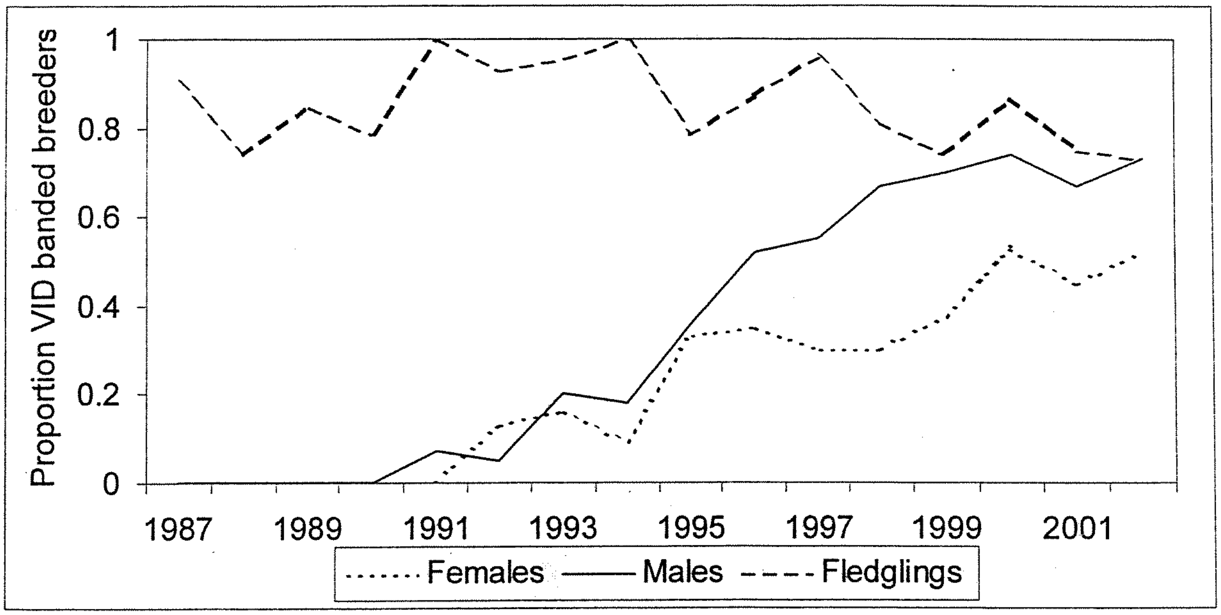

Figure 9. Proportion fledglings banded each year and proportion breeding adults that were banded. Note that banded fledglings are not expected to return as breeders until they are at least 4 years old.

Despite the low numbers in this anecdotal evidence, it is possible that immigrants were present but not detected because of low banding efforts in states that provide breeders for the Arizona population. Similarly, failure to sight Arizona fledglings breeding elsewhere may have been due to low levels of monitoring in other states. Banding information from other western states indicates that California and Texas were the only states able to contribute significant numbers of unbanded immigrants during this study (Table 16). Colorado, which had a large number of BAs also had a very intensive banding effort, so immigrant adults were more likely to have been detected and identified.

Sonora, Mexico, was also a possible source of recruits, and is considered part of the geographic range of this population. In 2001, a 14-year-old banded bald eagle from Arizona was seen during the breeding season at El Novillo Reservoir in Sonora, where there was, however, no known BA. Banded nestlings from Mexico have been reported in Arizona and other states along their northern migration, but there are no reports of them breeding north of Sonora (R. Mesta, USFWS, pers. comm.). The possibility of exchange of breeders between Arizona and Sonora should lead to closer attention to Sonoran bald eagles in the future. Nonetheless, the small number of BAs, combined with high nestling and juvenile mortality rate make it unlikely that fledglings from Sonora have been a significant source of breeders in Arizona (R. Mesta, USFWS, pers. comm.).

Table 16. Bald eagle banding and resighting information in states and countries surrounding Arizona.

States/regions	Banding years	Number of birds banded per year	Number of occupied breeding areas
Baja California	-	0	< 6
California	1958-2000	0-26	>151
Colorado	1976-2001	0-31	42
Nevada	1983, 1988,1989, 1993	1	3-4
New Mexico	1975-1988	1	3-4
Sonora	1988-present	1-2	3-6
Texas	1957-1991	0-25	17-35 (currently ~110)
Utah	1964-1994	0-9	2-4

While confirming immigration into Arizona will be difficult due to the lack of banding effort in surrounding populations, we cannot ignore the possibility that fledglings from undetected BAs within Arizona have recruited into this population. At least 4 existing BAs were discovered during our study. While production in these 4BAs cannot account for all of the recruitment of unbanded adults to the Arizona population, the same phenomenon operating at a larger scale might be adequate.

Because the banding effort in Arizona has been relatively constant since before 1987, if the Arizona population is closed, we expect the proportion of banded breeders to level off eventually. Figure 8 contrasts the proportion of known fledglings banded each year with the proportion of observed adults that were VID banded. These values are apparently still converging and therefore not conclusive.

However, the rate of return for females is slower than that for males. This difference is consistent with the hypothesis that bald eagles, especially or primarily females, are immigrating in the Arizona breeding population. Female dispersal from natal to breeding areas has been shown elsewhere to be longer than that of males (Harmata and others 2000). In Arizona, females tend to travel further from their natal sites than males to establish a breeding area (Fig. 8). However, on average females only travel 72.4 km further, which is consistent with local dispersal, for instance to avoid incest, and is not necessarily the same as migration out of the area altogether. This topic requires a better understanding of the migration process than our data can support.

Invisible Population Segments Described in the Analysis

Another possible source of breeding adults could come from the pool of Arizona adults that are floaters. When we compared counts of breeders from one year to the next, we were not actually comparing counts of all adult birds. Resighting rates indicated that in addition to the 70 or so adult breeders each year, there was a group of about one-fifth as many floaters (Fig. 7). In any given year, some will move into the breeding population to replace breeding adults, fill any vacancies, establish new BAs or reoccupy historical BAs, while others will continue to defer breeding for up to several years (we have documented birds first breeding at 13 years). If there has been a recent increase in the recruitment rate of breeders from the floating segment, this could explain the discrepancy between population growth calculated from breeder counts (improving status) or from vital rates across all segments of the population (declining status). If this hypothesis is correct, then the proportion of adults that were floaters has been changing, with a higher numbers in the past and a lower number more recently.

Our estimate of the number of floaters is indirect and based on assumptions about reproductive behavior of bald eagles. Other studies have used similar techniques for translating observations on breeders into estimates of the number of floaters (Brown 1969; Hunt 1998; Kenward and others 1999; Newton and Rothery 2001; Arnold and others 2002). Of the 59 identified banded breeders in our study, three moved from one BA to another. Consequently, we assumed bald eagles do not change BAs, so tenure at the BA they are first associated with captures the beginning and end of their phase as a breeder. Also, our estimate of the number of floaters relies on our ability to accurately describe the age at first reproduction for each resighted, known-age banded bird. Of 49 such birds, 43 were seen their first year on the BA, 2 may have been there for 1 year before they were seen, 3 for 2 years, and 1 may have been present for as many as 6 years. Our assumptions seem reasonable, but the estimate of the size of this population segment may nonetheless be inaccurate due to sample size and the possibility that floaters have been recruited into the breeding segment at variable rates, with greater recruitment in recent years. Nonetheless, our analysis puts a shape on an otherwise invisible segment of the population, and allows us to begin considering its importance.

Hunt and others (1992) and Driscoll and others (1999) emphasized the relatively high proportion of breeders in NAD or SAD plumage as evidence that even inexperienced breeders could successfully defend BAs. Driscoll and others (1999) speculated that occurrence of SAD breeders indicated a small or non-existent adult floater segment in the population, enabling occupancy by young birds that otherwise would not successfully defend a BA. Elsewhere in their range, bald eagles have rarely bred in SAD or NAD plumages. However in Arizona, there have been both SAD (N=4) and NAD (N=35) breeders. Three of the SAD birds had active nests, but all failed. This is consistent with observations from other studies where no records of successful breeding by birds in SAD plumage have occurred. However, we also estimated that about one-fifth of birds over 4 years of age were floaters. The NAD breeders in our study had a success rate of 0.49, which was comparable to the overall success rate for the population (Table 3). Driscoll and others (1999) proposed that Arizona birds in NAD plumage should be considered adults, and the nest success rate we report supports the idea that these birds are effective breeders. Also, our information on known-aged birds indicates that NAD plumage does not accurately predict age, since some were in this plumage into their seventh year (Fig. 3). In contrast, both known-age SAD breeders were 3 years old.

Our estimated age structure predicted that 22.5% of the population was juveniles, another segment of the population that has not been directly examined. We estimated that 24.4% of fledglings survived to age 4 and returned to Arizona. Assuming there is negligible emigration, which would otherwise lower the apparent survivorship estimate, this rate is relatively low compared to juvenile survivorship in other studies. Sensitivity analysis indicated that a moderate change in juvenile survivorship could have a significant impact on population growth rate (Table 13). Alternatively, increasing juvenile survivorship may have little impact on recruitment in Arizona, if there is considerable emigration of juveniles to other regions. These considerations illustrate the benefits of a study monitoring or describing the behavior of juveniles.

GAPS IN OUR UNDERSTANDING OF ARIZONA BALD EAGLES

In theory, once identified sources of mortality are eliminated and threats to reproduction minimized, only the intrinsic growth rate of a species would limit the rate of population growth. However, there is a possibility that, in recent years, habitat suitability has limited the recruitment of breeders, and slowed the growth of the population to the point where individuals are not a direct reflection of overall population size. This is supported in our analysis by: 1) the relatively high BA occupancy rates, 2) NAD breeders have been considered subadults that go unchallenged by experienced adults for abundant breeding habitat, but are actually competent breeders, and 3) the discrepancy between breeder replacement rates and population replacement rates estimated from vital rates across all age classes.

For territorial birds with a non-trivial proportion of adults acting as floaters, simple description of breeder replacement rates is inadequate to describe population status (Hunt 1998). In a population at equilibrium, the proportion of adults acting as floaters can be a measure of the population's ability to buffer year-to-year environmental and demographic stochasticity. Floaters can act to provide a minimum number of breeding adults, even in years with low juvenile recruitment. However, in a declining population, the buffering capacity of the floating segment may serve to temporarily mask this decline. Understanding the connection between the breeder and floater pools and their mutual link to habitat availability is necessary to characterize current population dynamics.

Assessing availability of breeding habitat is not the intent of this report, but to identify demographic rates that warrant more attention so better estimates can be provided, and to characterize factors that limit these rates. Although we compared specific vital rates for Arizona bald eagles to those reported elsewhere, not all differences necessarily resulted from recent effects on bald eagle life history. It would not be surprising if the bald eagle population in the arid Southwest has been subject to unique recent limits on vital rates (such as productivity), but some differences may reflect a life history that has evolved to prosper in the Southwest.

We used demographic models to consider the ability of the population to increase in size. The accuracy of our models is contingent on reproductive and survivorship rates that remained constant over the period of study. We have made no attempt to quantify the extent to which mortality factors, and those factors limiting reproduction, have declined, remained constant, or increased in intensity. However, we considered the possibility that reproductive success may be increasingly limited by habitat availability. Also, although the fate of a small population is sensitive to environmental stochasticity and/or catastrophic events, we did not address these unpredictable elements in this study.

Our focus at this point is on key information gaps and important parameters. For instance, our analysis is especially sensitive to adult and juvenile survivorship rates, therefore our estimates would be more accurate if they were based on resighting more birds. Likewise, because survivorship estimates for juveniles and older adults were low, identifying and measuring the specific contributors to mortality should be given priority. Juveniles and perhaps non-breeding adults migrate annually across large regions, but we have no information on migration- or region-specific sources of mortality and how these can impact eagles that breed in the Southwest. This lack of information leads us to question how are these annual migrations related to migration of breeders out of their natal populations? Which corridors were most important for exchange of adults historically, and which are most likely to be established now, connecting to populations that are projected to increase?

Elasticities indicate which vital rates most affect model outcomes, so they point to estimates that require more study or better parameter estimation. Theoretically, vital rates with the highest elasticity also provide the quickest route to population recovery, but this does not mean that it is logistically and biologically feasible to increase these vital rates; these are separate considerations. Elasticities do not necessarily point to the vital rates involved in causing or perpetuating the decline, and it should be realized that recovery will require more time in populations declining due to limiting factors operating on vital rates with low elasticities than with high elasticities.

One of the final benefits of performing a demographic analysis is that we can compare relative outcomes of investing in different types of management in the short- or long-term (Fig. 2). Recovery actions in Arizona to date have focused on increasing productivity by protecting breeding bald eagles from human interference. We anticipate exploring the influence of these management options in the near future. At this stage, closing the gap in our understanding will be the focus of the most immediate changes in our work.

RECOMMENDATIONS

This analysis assumed that within age classes, survivorship for breeding and non-breeding adults was the same. An additional protocol will have to be developed to have direct observations and resighting of non-breeding adults.

We used patterns in published studies of survivorship of juvenile bald eagles to partition our estimate of survivorship from fledging to age 4. While not affecting the outcome of our demographic analysis, this approach highlights our lack of information on survivorship of juveniles in our unique desert nesting population. This gap could be addressed by developing a monitoring protocol with elements of increased effort to identify banded birds in wintering concentrations, and with use of telemetry technology to determine the age and cause of mortality.

The annual effort to identify breeding adults contributes to estimates of adult survivorship, tenure at a BA, duration of pair bonds, and age of senescence. Currently, efforts are being made to identify successful breeders, but to reduce possible bias; effort should be made to get to BAs earlier to identify unsuccessful breeders as well. Non-breeding adult bald eagles are more difficult to locate and identify once a breeding effort fails.

The sensitivity of our demographic analysis to estimates of adult survivorship supports the need to accurately estimate survivorship. The size of the current sample was sufficient to develop age-specific but not sex-and-age-specific survivorship rates. Therefore, we need to continue our marking and resighting efforts.

We have been able to band most fledglings in each cohort, but not all BAs are currently accessible to biologists. As currently accessible nests are abandoned or fall, it becomes increasingly important to gain access to other, currently unavailable nest locations.

Although current management practices increase fledging success, we realize that this does not have the same potential effect to increase the population as changing adult mortality. However, until further work can illuminate factors limiting the Arizona population, we argue that limitations on productivity must continue to be a focus of management. Additionally, these localized efforts are logistically easier, while our ability to manage adult mortality from diffuse sources is less certain.

To investigate the dynamic relationship of Arizona's bald eagle population with those of surrounding states and countries, we should start with a better understanding of current banding efforts across the suspected historic range of this population. These efforts might enable us to identify and later quantify migration into and out of this population. After determining out-of-state breeding areas of most interest for such an effort, we should investigate the possibility of interstate cooperation to perform these studies.

Our first suggestion for focusing effort within Arizona would be to concentrate on identifying any banded adults, and on banding all possible fledglings on the Bill Williams River, and at the Luna and Becker BAs. The BAs along the Bill Williams River seem to recruit strongly from that same drainage and are closest to California. The origin of adults in this drainage could inform us both about possible immigration and about difficulties of colonizing new drainages within Arizona. Since the only known immigrant to the Arizona population was breeding at the other White Mountain BA at Luna, it is important to identify these bald eagles each year to document immigration or connection to other Arizona BAs as a source or recipient of Arizona fledglings as breeders.

In light of this analysis, questions will surface as to the implications delisting will have on the Arizona bald eagle. Within the next 2 years, we recommend the Southwestern Bald Eagle Management Committee draft a plan to incorporate this analysis into the Conservation Agreement for the Bald Eagle in Arizona. This document, when finalized and signed by the cooperating agencies, will establish goals to achieve certain population parameters. Through continued management of the Arizona population after removal from the Endangered Species List, we can progress towards achieving those goals, until the population has recovered.

Future analyses will need to develop a logistic regression model to describe relative effects on nest success (odds of fledging at least 1 eaglet) from: nest substrate (tree, snag, cliff), nest orientation, number of low-flying planes, hikers, boaters, nest height, and type of foraging territory (reservoir, regulated river, unregulated river). A similar but inconclusive analysis was performed by Hunt and others (1992) using discriminant analysis. These analyses can serve 2 functions: 1) To identify factors which have relatively predictable impacts on nest success, and 2) To identify management impacts to specific BAs. The later function allows us to quantify the probable impact of closure areas around specific nests, so the benefits of such closures can be weighed.

Increasing public education to prevent mortality from incidental shooting, entanglement in monofilament, lead poisoning, etc., is needed to reduce the human induced causes of mortality. Heightened awareness to the cause of bald eagle mortality will bring consideration, understanding, and respect for the species' plight in Arizona. These losses are preventable, and this recommendation can be implemented, but it requires public support .

We recognize that our best information addresses the demographic status of the population, not the genetic status. For instance, we have little information about heterozygosity and any developmental effects of homozygosity in Arizona bald bagles. Hunt and others (1992) examined the level of genetic variability and heterozygosity in Arizona's population and found them comparable to other bald eagle populations. However, they cautioned against interpreting the results due to the low number of individuals and the few loci examined. The current study did not examine the 'genetic status' of Arizona bald eagles. However, we documented 3 cases of incest between parents and offspring (89F01 and 92J02) or siblings (89J11 and 94J12, 94J06 and 94J07). Speculation exists that inbreeding may reduce the fitness of the individual by a reduction in productivity (Newton 1979; Hunt and others 1992). Incestuous relationships are reported in other species of raptors, but minimal information exists on its effects to reproductive success (Carlson and others 1998). It is possible that productivity in Arizona is not increasing at the same rate as occupancy due in part to the occurrence of inbreeding activity. Only future genetic study will enable us to assess this link.

Continuation of Mark-Resight Work.

We began the analysis with models for testing whether females begin breeding after males, whether males have lower survivorship at any age, and whether survivorship has important connections to year-to-year variation in environmental effects. Although age structure differentiated resighting (breeding likelihood) rates, the differences due to sex-specific age differences were judged not important for describing either survivorship or resighting rate. Larger sample sizes will make it easier to detect meaningful effects that are perhaps smaller in magnitude than the age-specific effect on resighting rates.

LITERATURE CITED

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APPENDIX A: RAPTOR REPRODUCTIVE STATUS CRITERIA

Breeding Area (BA): An area containing one or more nests within the range of one mated pair of birds. Operationally, once a BA is established, we consider it a BA whether it is occupied by bald eagles in a given year or not, until/unless it is designated historical.

Occupied BA/Nest: An occupied BA must have an occupied nest, which is any nest, where at least one of the following activity patterns was observed during the breeding season:

a. Young were raised.
b. Eggs were laid.
c. One adult sitting low in the nest, presumably incubating.
d. Two adults present on or near the nest.
e. One adult and one bird in immature plumage at or near a nest, if mating behavior was observed (display flight, nest repair, coition).
f. A recently repaired nest with fresh sticks, or fresh boughs on top, and/or droppings and/or molted feathers on its rim or underneath.

Active Nest: One in which eggs have been laid. Activity patterns (a), (b), and (c) above are diagnostic of an active nest.

Unoccupied BA/Nest: A nest or group of alternate nests at which none of the activity patterns diagnostic of an occupied nest were observed in a given breeding season. BAs must be existing as occupied before they can be recognized and classified as unoccupied.

Successful BA/Nest: An occupied nest from which at least 1 young fledged during the breeding season under consideration. We classified nests as successful if at least 1 young was raised past 8 weeks of development.

Failed BA/Nest: An occupied nest from which no young fledged due to any cause.

Historical BA: A BA that has remained unoccupied for 10 consecutive years. Given that some records of breeding occupancy are sparse in the literature before 1973, this term also applies to any BA recorded not showing signs of occupancy since that time.

Reoccupied BA: A Historical BA, which shows signs diagnostic of being active.

Pioneer Effort: The occupancy of a new nest, in previously undocumented breeding habitat, where there is no evidence of prior activity. These occur in areas monitored by the ORA flights before discovery due to 1) the presence of a large nest built by another or unknown species, or 2) the observed suitability of the habitat.

APPENDIX B: ADULT IDENTIFICATION CHRONOLOGY

Identification of breeding bald eagles in Arizona 1987 to 2003.

Breeding Area	Number	Sex	1987[1]	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Alamo	01	F	X	X	X	X	X	X	X	X	X	89F01	X	89F01	X	89F01	X	89F01	X
		M	X	X	X	X	X	X	X	X	X	92J02	92J02	92J02	92J02	92J02		92J02	X
Bartlett	03	F	X	CF01	CF01	X	X	X	X	X	X	NAD	X	X	X	93J05	X	X	X
		M	X2	88M03	88M03	88M03	88M03	X	X	X	X	X	X	X	X	X	X	95J07	95J07
Blue Point	04	F	X	DF02	X	SAD	X	X	X	X	X	X	X	97F04	97F04	97F04		97F04	97F04
		M	83M04	83M04	83M04	83M04	83M04	83M04	83M04	83M04	83M04	83M04	83M04	83M04	X	X	X	95J04	95J04
Box Bar	05	F									91J06	91J06	91J06	94J07	94J07	94J07	94J07	94J07	94J07
		M									90J03	90J03	94J06	91J09	91J09	X	91J09	94J06	94J06
Camp Verde	06	F						X	X1	U	U	U	U	U	U	U	U	U	U
		M						X	X1	U	U	U	U	U	U	U	U	U	U
Cibecue	10	F	X	X1	X	NAD	X	X	X	X	X	X	X	X1	X	X1	X	X	X
		M	X	88M10	X	X	X	X	X	X	X	X	X	X1	X	X1	X	X	X
Cliff	11	F	X	X	X	X	X	X	SAD	X	X	X1	X1	X	X	X1	X	X	X
		M	X	84M11	84M11	84M11	84M11	84M11	84M11	84M11		X1	X1	X	X	X1	X	X	X
Coolidge	12	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		M	X	X	X	X	X	X	X	X	X	91J13	X	93J04		93J04	93J04	X	X
East Verde	14	F	LF01	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		M	87M14	87M14	87M14		X	X	X	X	X	X	X	X	88J03	X	X	88J03	X
Fort McDowell	15	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		M	X	X	X	X	X	X	X	X	X	X	93J10	93J10	93J10	X		93J10	93J10
Horse Mesa	16	F	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X
		M	X	X1	X	X	X	X	X	X	X	X	X	NAD	X	X	X	X	X
Horseshoe	17	F	87F17	87F17	87F17	87F17	87F17	X	X	X	X	X	X	X	X	X	X	X	X
		M	X	88M17	88M17	88M17	X	X	88J03	X	X	X	X	X	X	X	X	X	X
Ive's Wash	18	F	X	X	X	X	X	X	X	X	91J12	91J12	X	91J12	X	X1	X1	X1	X
		M	X	NAD	X	X	X	X	X	X	88J05	88J05	X	88J05	X	X1	X1	X1	X
Ladders	19	F	X	88F19	88F19	88F19	88F19	88F19	88F19	X	X	X	X	X	X	X	X	X	X
		M	X	X	89M19	90M19	X	X	X	X	X	X	X	X	X	X	X	X	98J17

[1] 1987-1990 information from Hunt and others 1992.

Appendix A. Continued.

Breeding Area	Number	Sex	1987[1]	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Lone Pine	20	F	X	X	X	X	X	X	X	X	X	X	X	X1	X	X	X	X	X
		M	X	X	X	X	X	X	X	X	X	X	X	X1	X	X	X	X	X
Luna	21	F								94F21	94F21	94F21	X	94F21	94F21	X	X	94F21	94F21
		M								94M21	94M21	94M21	94M21	94M21	X	94M21	X	94M21	94M21
Orme	23	F	X	X	NAD	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		M	X	NAD	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Perkinsville	24	F			NAD	X	X	X	U	U	U	U	X	X1	U	94J13	94J13	94J13	94J13
		M			NAD	X	X	X1	U	U	U	U	X	X1	U	96J15	96J15	96J15	96J15
Pinal	25	F	87F25	87F25	87F25	87F25	87F25	87F25	87F25	87F25	X	90J05	90J05	X1	X	X	U	90J05	90J05
		M	X	X	X	X	X	X	X	X	X	X	X	X1	X	X	U	87M25	87M25
Pinto	26	F		87F26	87F26	87F26	87F26	87F26	87F26	87F26	87F26	87F26	87F26	X	91J08	X	X	X	X
		M	X	X	X	X	X	X	X	X	88J04	88J04	88J04	X	94J04	X	X	X	X
Pleasant	27	F	X1	U	X1	X	X	NAD	X	X	X	X	X	X	X	X	X	X	X
		M	X1	U	X1	NAD	87J04	87J04	87J04	87J04	87J04	87J04	87J04	87J04	87J04	87J04	87J04	87J04	87J04
Redmond	28	F	X	X	X	X	X	X	X	X	X	X	X	X	X	89J02	X	89J02	X1
		M	X	88M28	88M28	88M28	88M28	X	X	87J05	87J05	87J05	87J05	87J05	87J05	87J05	87J05	87J05	X1
San Carlos	29	F									89J12	89J12	X	89J12	89J12	X	X1	X	X1
		M									90J04	90J04	90J04	90J04	X1	X	X1	X	X1
76	30	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X1	X
		M	X	X	X	X	X	X	X	X	X	88M30	88M30	88M30	88M30	88M30	88M30	X1	X
Sheep	31	F	X	X	X	X	U	88J11	88J11	88J11	88J11	88J11	X	X	88J11	88J11	88J11	88J11	88J11
		M	X	NAD	X	X	U	X	X	NAD	X	91J14	X	X	94J12	94J12	94J12	94J12	94J12
Table Mountain	32	F	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		M	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Talkalai	33	F								X	88J10	88J10	X	X	X	X	88J10	88J10	X
		M								X	X	X	X	X	X	X	X	X	X
Tonto	34	F						87J15	87J15	87J15	87J15	87J15	87J15	87J15	87J15	87J15	87J15	87J15	87J15
		M						X	87J18	87J18	87J18	87J18	87J18	87J18	87J18	87J18	87J18	87J18	87J18
Tower	35	F							X	X	X	X	X	X	X	X	X	X	X
		M							X	89J08	89J08	89J08	89J08	89J08	89J08	89J08	89J08	89J08	89J08
Winkelman	36	F									X	91J08	X	X	U	U	U	U	U
		M									X	92J07	X	X	U	U	U	U	U

[1] 1987-1990 information from Hunt and others 1992.

Appendix A. Continued.

Breeding Area	Number	Sex	1987[1]	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Dupont	37	F											X	X	X1	X	X	U	X
		M											88J07	88J07	X1	X	X	U	X
Becker	38	F											X	X	X	X	X	X1	U
		M											X	X	X	X	X	X1	U
Sycamore	39	F											90J02	90J02	90J02	X	X	X	X
		M											92J06	92J06	92J06	X	X	92J06	92J06
Doka	40	F												X	X	X	X	X	X
		M												94J05	94J05	94J05	94J05	94J05	94J05
Coldwater	41	F												X	X	X	X	X	X
		M												92J07	92J07	X	X	X	X
Granite Basin	42	F													X	X	X	X1	X1
		M													X	X	X	X1	X1
Suicide	43	F													X	92J13	92J13	92J13	92J13
		M													X	93J09	93J09	93J09	93J09
Rodeo	44	F														95J??	95J??	95J??	97J14
		M														X	X	X	X
Lynx	46	F																95J09	95J09
		M																X	98J??
Granite Reef	47	F																X	X
		M																X	X
Needle Rock	48	F																X	X
		M																98J06	98J06
Oak Creek	49	F																X	96J14
		M																X	X
Bulldog	58	F																	X
		M																	
Crescent	59	F																	X
		M																	X

[1] 1987-1990 information from Hunt and others 1992.

U = BA was visited and found unoccupied, X = Two birds occupied the BA but not identified, X1 = Only one bird could be confirmed in the BA, because only nest reconstruction was seen or only one bird was seen at any one time. Blank or stippled cells indicate the BA was not visited.
Band color and identification: White cells = ORA information only; banded or unbanded status of birds could not be confirmed. Yellow cells = Confirmed unbanded birds, Gray cells = USFWS but no VID band All other cell shading = corresponds to Visual Identification (VID) band color (blue, black, red, purple, green). If the VID or USFWS band was read, the bird's identity is indicated in the cell. Birds identified by band year, followed by age/sex at banding (J=banded nestling, F=banded adult female, M=banded adult male), then BA number at the time of banding. Information on subadult (SAD) or near-adult plumage (NAD) reflects a change in plumage and therefore replacement.

APPENDIX C: BANDING TABLES

Bald eagle nestlings banded from 1977 to 1982 in Arizona by Robert Ohmart as reported by Hunt and others1992.

Natal Area	Bird Number[1]	Sex	USFWS Band	Breeding Area	First Year Breeding	Age of Death	Comments
1977							
Fort McDowell	---	---	629-04451				
	---	---	629-04452			0	
Bartlett	---	M	629-04453	Cibecue	?	12	
	---	---	629-04454			3	
East Verde	---	---	629-04455				
	---	---	629-04456				
1978							
Fort McDowell	---	---	629-04457				
	---	---	629-04458				
Cibecue	---	---	629-04459[2]				
	---	---	629-04461[2]				
Bartlett	---	---	629-04460			0	
1979							
Bartlett	85F01	F	629-04462	Alamo	1987	8	Replaced.
Fort McDowell	83M04	M	629-04463	Blue Point	1983	19	
	89F01	F	629-04464	Alamo	1989		
Pinal	---	---	629-04465				
	---	---	629-04466				
Redmond	84M11	M	629-04467	Cliff	1984		
1980							
East Verde	---	---	629-04468				
	---	---	629-04469				
Bartlett	---	---	629-04470				
1981							
Bartlett	---	---	629-04471			0	
	87F26	F	629-04472	Pinto	1988	16	Replaced.
Redmond	87M25	M	629-04473	Pinal	1987		
	---	---	629-04477				
Pinal	---	---	629-04474				
Fort McDowell	---	---	629-04475				
	---	---	629-04476				
1982							
Redmond	---	---	629-04478				
	---	---	629-04480				

[1] AGFD bird number.
[2] USFWS band placed on left leg.

Bald eagle nestlings banded from 1983 to 1985 in Arizona by Teryl Grubb as reported by Hunt and others 1992.

Natal Area	Bird Number[1]	Sex	USFWS Band	Breeding Area	First Year Breeding	Age of Death	Comments
1983							
Pinal	---	---	629-14551				
Fort McDowell	---	---	629-14552				
	88M30	M	629-14553[2]	76	1988	19	Replaced.
Horseshoe	---	---	629-14554				
Redmond	---	---	629-14556				
	---	---	629-14557[2]				

[1] AGFD bird number.
[2] USFWS band placed on left leg.

Appendix C. Continued.

Natal Area	Bird Number[1]	Sex	USFWS Band	Breeding Area	First Year Breeding	Age of Death	Comments
1984							
Blue Point	---	---	629-14558				
	88M03	M	629-14559	Bartlett	1988	7	
East Verde	97F04	F	629-14560	Blue Point	1997		
Horseshoe	---	---	629-14561				
	90M19	M	629-14562	Ladders	1990	6	
Cibecue	---	---	629-14563				
	---	---	629-14564				
	---	---	629-14565				
1985							
Ladders	---	---	629-14566				
Bartlett	---	---	629-14567				
Ash	---	---	629-14568				

[1] AGFD bird number.

Bald eagle nestlings banded from 1987 to 1990 in Arizona by Hunt and others 1992.

Natal Area	Bird Number[1]	Sex	USFWS Band	VID Symbol[2]	Breeding Area	First Year Breeding	Age of Death	Comments
1987								
Orme	87J01	M	629-15184	Z				
	87J02	F	629-15185	Y				Sighted 1989.
Fort McDowell	87J03	M	629-15186	X				Sighted 1988.
Horse Mesa	87J04	M	629-15187	W	Pleasant	1991		
	87J05	M	629-15188	V	Redmond	1994		
Coolidge	87J06	M	629-15189	U				
	87J07	M	629-15190	S				
Ladders	87J08	M	629-15191	R			0	
	87J09	M	629-15192	P			0	
Blue Point	87J10	M	629-15193	O			0	
	87J11	M	629-15194	N				
	87J12	F	629-15195	M				
Horseshoe	87J13	F	629-15196	K	California			Breeding Temecula, Ca.
	87J14	M	629-15197	H			3	
	87J15	F	629-15198	G	Tonto	1992		
Redmond	87J16	F	629-15199	→				
	87J17	M	629-15200	Backwards 2				
Pinal	87J18	M	629-26451	Backwards 3	Tonto	1993		
	87J19	?	629-26452	Backwards 4				
East Verde	87J20	F	629-26453	Backwards 5				Sighted 1987.
1988								
Alamo	88J01	F	629-26457	①				
Ladders	88J02	M	629-26462	②			0	
	88J03	M	629-26468	③	Horseshoe/East Verde	1993		
Orme	88J04	M	629-26469	④	Pinto	1995	9	Replaced.
Ive's Wash	88J05	M	629-26464	⑤	Ive's Wash	1995		
Cliff	88J06	F	629-26465	⑥				Sighted 2002.
	88J07	M	629-26466	⑦	Dupont	1997		
Coolidge	88J08	M	629-26467	⑧				
	88J09	M	629-26473	Circle A				
76	88J10	F	629-26471	Circle B	Talkalai	1995		
	88J11	F	629-26472	Circle C	Sheep	1992		

[1] AGFD bird number.
[2] VID color bands: 1987=blue, 1988=green, 1989=purple, 1990=blue

Appendix C. Continued.

Natal Area	Bird Number[1]	Sex	USFWS Band	VID Symbol[2]	Breeding Area	First Year Breeding	Age of Death	Comments
1988 continued								
Blue Point	88J12	M	629-26473	Circle D			0	
	88J13	M	629-26474	Circle E			0	
	88J14	F	629-26475	Circle G			0	
Horseshoe	88J15	M	629-26476	Circle H				
Lone Pine	88J16	M	629-26477	Circle K				
	88J17	M	629-26478	Circle M				
Redmond	88J18	F	629-26479	Circle N			0	
	88J19	F	629-26480	Circle P			0	
1989								
Alamo	89J01	M	629-32602	Diamond 1				
Ive's Wash	89J02	F	629-32603	Diamond 2	Redmond	1999		
	89J03	M	629-32604	Diamond 3			0	
Fort McDowell	89J04	F	629-32605	Diamond 4				
	89J05	F	629-32624	Diamond 5				
East Verde	89J06	M	629-32625	Diamond 6				
	89J07	F	629-32626	Diamond 7				
Ladders	89J08	M	629-32627	Diamond 8	Tower	1993		
	89J09	M	629-32628	Diamond A				
Pinal	89J10	M	629-32629	Diamond B				
Bartlett	89J11	M	629-32630	Diamond C				
	89J12	F	629-32631	Diamond D	San Carlos	1995		
1990								
Alamo	90J01	F	629-32653	1/A				
	90J02	F	629-32654	1/B	Sycamore	1997	10	Replaced
Horse Mesa	90J03	M	629-32655	1/C	Box Bar	1995	6	Replaced.
	90J04	M	629-32656	1/E	San Carlos	1995		
Horseshoe	90J05	F	629-32657	1/G	Pinal	1995		
	90J06	M	629-32658	1/H				
Pinal	90J07	F	629-32659	1/K				
	90J08	M	629-32660	1/M				
76	90J09	M	629-32661	1/N				
Orme	90J10	F	629-32662	1/P				
Redmond	90J11	M	629-32663	1/R				

[1] AGFD bird number.

[2] VID color bands: 1987=blue, 1988=green, 1989=purple, 1990=blue.

Bald eagle nestlings banded from 1991 to 1992 in Arizona by Mesta and others 1992.

Natal Area	Bird Number[1]	Sex	USFWS Band	VID Symbol (Blue Color)	Breeding Area	First Year Breeding	Age of Death	Comments
1991								
Horse Mesa	91J01	F	629-32751	2/A				
	91J02	F	629-32752	2/B				
	91J03	M[2]	629-32753	--	Sheep	1994	3	Replaced.
Ive's Wash	91J04	M	629-32754	2/C			0	
	91J05	F	629-32755	2/D			0	
Fort McDowell	91J06	F	629-32756	2/E	Box Bar	1995	6	Replaced.
Alamo	91J07	F	629-36004	2/G				
	91J08	F	629-36005	2/H	Winkelman/Pinto	1996		
Pinal	91J09	M[2]	629-36006	2/K	Box Bar	1998		
Coolidge	91J10	F	629-36007	2/M				
76	91J11	M	629-36008	2/N				

[1] AGFD bird number.

[2] Single banded three year old male breeding at the Sheep BA in 1994, assumed to be this Horse Mesa nestling.

Appendix C. Continued.

Natal Area	Bird Number[1]	Sex	USFWS Band	VID Symbol (Blue Color)	Breeding Area	First Year Breeding	Age of Death	Comments
1991 continued								
Blue Point	91J12	F	629-36009	2/P	Ive's Wash	1995		
	91J13	M	629-36010	2/R	Coolidge	1996	5	
Ladders	91J14	M	629-36011	2/S	Sheep	1995	7	Replaced.
Redmond	91J15	F	629-36012	2/T				
	91J16	M	629-36013	2/U			0	
Cibecue	91J17	M	629-36014	2/V				
	91J18	M	629-36015	2/W				
Table Mountain	91J19	M	629-36016	2/X				
Lone Pine	91J20	M	629-36017	2/Y				
Orme	91J21	M	629-36018	2/Z				
1992								
Alamo	92J01	F	629-36019	3/A				
	92J02	M	629-36020	3/B	Alamo	1996		
Ive's Wash	92J03	M	629-36021	3/C				
	92J04	M	629-36022	3/D				
Orme	92J05	F	629-36025	3/E			0	
	92J06	M	629-36026	3/G	Sycamore	1997	8	Replaced.
Coolidge	92J07	M	629-36027	3/H	Winkelman/Coldwater	1996		
Blue Point	92J08	F	629-36028	3/K				
	92J09	M	629-36029	3/M				
Ladders	92J10	M	629-36030	3/N				
	92J11	F	629-36033	3/P				
76	92J12	F	629-36031	3/R				
East Verde	92J13	F	629-36032	3/S	Suicide	1999		
Bartlett	92J14	F	629-36034	3/T				

[1] AGFD bird number.

[2] Reported as female when banded. Breeding as a male in the Box Bar pair.

Bald eagle nestlings banded from 1993 to 2002 in Arizona.

Natal Area	Bird Number	Sex	USFWS Band	VID Symbol (Blue Color)	Breeding Area	First Year Breeding	Age of Death	Comments
1993								
Alamo	93J01	F	629-36037	4/A				Fostered to Ive's Wash.
Ive's Wash	93J02	F	629-36038	4/B				
Pleasant	93J03	M	629-36039	4/C				Died 1993?
Bartlett	93J04	M	629-36040	4/D	Coolidge	1998		
East Verde	93J05	F	629-36041	4/E	Bartlett	2000	7	Replaced.
Pinal	93J06	M	629-36042	4/G				
Fort McDowell	93J07	M	629-36043	4/H			0	
	93J08	M	629-36044	4/K				
Blue Point	93J09	M	629-36045	4/M	Suicide	1999		
	93J10	M	629-36046	4/N	Fort McDowell	1997		
Tonto	93J11	M	629-36047	4/P				
	93J12	M	629-36048	4/R				
Pinto	93J13	M	629-36049	4/S				
Orme	93J14	F	629-36050	4/T			0	
	93J15	F	629-36051	4/U				
Horse Mesa	93J16	F	629-36052	4/V				
Coolidge	93J17	M	629-36053	4/W				
	93J18	F	629-36054	4/X				
Tower	93J19	M	629-36055	4/Y				
Alamo	93J20	M	629-36056	4/Z				
Table Mountain	93J21	F	629-36057	1/Z				
	93J22	M	629-36058	1/Y				

Appendix C. Continued.

Natal Area	Bird Number	Sex	USFWS Band	VID Symbol (Blue Color)	Breeding Area	First Year Breeding	Age of Death	Comments
1994								
Ive's Wash	94J01	M	629-36071	5/A			0	
Tonto	94J02	M	629-36072	5/B			0	
	94J03	M	629-36073	5/C				
Blue Point	94J04	M	629-36074	5/D	Pinto	1998		
	94J05	M	629-36075	5/E	Doka	1998		
Pleasant	94J06	M	629-36076	5/G	Box Bar/Box Bar	1997		Replaced and reentered.
	94J07	F	629-36077	5/H	Box Bar	1998		
Alamo	94J08	F	629-36078	5/K				
Bartlett	94J09	F	629-36079	5/M				
Orme	94J10	M	629-36080	5/N			0	
	94J11	M	629-36081	5/P				
76	94J12	M	629-36082	5/R	Sheep	1999		
	94J13	F	629-36083	5/S	Perkinsville	2000		
Table Mountain	94J14	M	629-36084	5/T				
Ladders	94J15	M	629-36085	5/U				
	94J16	F	629-36086	5/V				
Cibecue	94J17	M	629-36087	5/W				
Luna	94J18	F	629-36088	5/X				
Pinal	94J19	M	629-36089	5/Y				
1995								
Alamo	95J01	M	629-15768	6/A				
	95J02	M	629-15769	6/B				
Pleasant	95J03	F	629-15766	6/C				
	95J04	M	629-15767	6/D	Blue Point	1999		
Blue Point	95J05	F	629-15770	6/E				
	95J06	F	629-15771	6/G				
Tonto	95J07	M	629-15772	6/H	Bartlett	2001		Sighted 1995.
Pinto	95J08	F	629-15773	6/K				
	95J09	F	629-15774	6/M	Lynx	2002		
East Verde	95J10	M	629-15775	6/N				
Redmond	95J11	M	629-15776	6/P				Sighted 1998.
Orme	95J12	F	629-15777	6/R			0	
	95J13	F	629-15778	6/S			0	
Horse Mesa	95J14	M	629-15779	6/T				
Table Mountain	95J15	M	629-15780	6/U				
	95J16	M	629-15781	6/V				
Ive's Wash	95J17	M	629-15782	6/W				
Coolidge	95J18	M	629-15783	6/X				
	95J19	F	629-15784	6/Y				
Luna	95J20	M	629-15785	6/Z				
1996								
Blue Point	96J01	M	629-23541	7/A			0	
	96J02	M	629-23542	7/B				
Pinto	96J03	M	629-23543	7/C				
	96J04	M	629-23544	7/D				
	96J05	F	629-23545	7/E				
Pleasant	96J06	F	629-23546	7/G			0	
	96J07	M	629-23547	7/H			0	
East Verde	96J08	M	629-23548	7/K				
Sheep	96J09	F	629-23549	7/M				
	96J10	M	629-23550	7/N				
Tonto	96J11	M	629-23551	7/P				
	96J12	M	629-23552	7/R				

Appendix C. Continued.

Natal Area	Bird Number	Sex	USFWS Band	VID Symbol (Blue Color)	Breeding Area	First Year Breeding	Age of Death	Comments
1996 continued								
Ladders	96J13	F	629-23553	7/S				
Tower	96J14	F	629-23554	7/T	Oak Creek	2003		
	96J15	M	629-23555	7/U	Perkinsville	2000		
Table Mountain	96J16	M	629-23556	7/V			0	
	96J17	M	629-23557	7/W				
Ive's Wash	96J18	M	629-23558	7/X				
Horseshoe	96J19	M	629-23559	7/Y				
76	96J20	F	629-23560	7/Z			0	
	96J21	F	629-23561	1/X				
Luna	96J22	F	629-23562	1/V			0	
	96J23	F	629-23563	1/U			0	
Box Bar	96J24	F	629-23564	1/T			0	
Bartlett	96J25	M	629-23565	3/Y				
	96J26	M	629-23566	3/W				
1997								
Tonto	97J01	F	629-23567	8/A				
	97J02	F	629-23568	8/B				
Fort McDowell	97J03	M	629-23569	8/C				Sighted 2002.
	97J04	M	629-23570	8/D				
Pleasant	97J05	M	629-23571	8/E				
	97J06	M	629-23572	8/G			3	
Blue Point	97J07	F	629-23573	8/H			0	
	97J08	M	629-23574	8/K				
	97J09	F	629-23575	8/M				
Orme	97J10	M	629-23576	8/N				
	97J11	F	629-23577	8/P				
Luna	97J12	M	629-23578	8/R				
	97J13	F	629-23579	8/S			0	
Coolidge	97J14	F	629-23580	8/T	Rodeo	2003		
	97J15	M	629-23581	8/U				
Towers	97J16	M	629-23582	8/V				
Horseshoe	97J17	M	629-23583	8/W				
	97J18	M	629-23584	8/X				
Box Bar	97J19	M	629-23585	8/Y				Fostered to San Carlos.
76	97J20	M	629-23586	8/Z				
	97J21	M	629-23587	3/U				
Table Mountain	97J22	F	629-23588	3/V				
San Carlos	97J23	M	629-23589	5/Z			0	
Luna	97J24	M	629-23590	0/Z				
1998								
Fort McDowell	98J01	M	629-42651	9/A			0	
Sycamore	98J02	F	629-42652	9/B				
Pleasant	98J03	M	629-42653	9/C				
Box Bar	98J04	M	629-42654	9/D				
	98J05	F	629-42655	9/E			1	
Tonto	98J06	M	629-42656	9/G	Needle Rock	2002	5	
San Carlos	98J07	M	629-42657	9/H				
	98J08	F	629-42658	9/K				
Towers	98J09	M	629-42659	9/M				
	98J10	M	629-42660	9/N				
Ladders	98J11	M	629-42661	9/P				
	98J12	M	629-42662	9/R				
	98J13	M	629-42663	9/S			5	

Appendix C. Continued.

Natal Area	Bird Number	Sex	USFWS Band	VID Symbol (Blue Color)	Breeding Area	First Year Breeding	Age of Death	Comments
1998 continued.								
Orme	98J14	F	629-42664	9/T				
Luna	98J15	M	629-42665	9/U				
76	98J16	F	629-42666	9/V				
	98J17	M	629-42667	9/W	Ladders	2003		
Redmond	98J18	M	629-42668	9/X				
1999								
Fort McDowell	99J01	M	629-42669	0/A			0	
	99J02	F	629-42670	0/B				
Tonto	99J03	M	629-42671	0/C				
	99J04	F	629-42672	0/D				
Sycamore	99J05	M	629-42673	0/E				
	99J06	F	629-42674	0/G				
Horseshoe	99J07	M	629-42675	0/H				
	99J08	F	629-42676	0/K				
Tower	99J09	M	629-42677	0/M				
	99J10	F	629-42678	0/N				
Pleasant	99J11	M	629-42680	0/R				
Blue Point	99J12	F	629-42679	0/P				
Pinto	99J13	F	629-42681	0/S				
	99J14	M	629-42682	0/T				
East Verde	99J15	M	629-42683	0/U				
	99J16	M	629-42684	0/V				
76	99J17	F	629-42685	0/W				
Sheep	99J18	F	629-42686	0/X				
Luna	99J19	M	629-42687	0/Y				
	99J20	M	629-42688	9/Y			0	
Ladders	99J21	M	629-42689	9/Z				
	99J22	F	629-42690	11/Z				
Orme	99J23	F	629-42691	11/Y				
Bartlett	99J24	M	629-42692	11/X				
Redmond	99J25	M	629-42693	11/W				
Cibecue	99J26	M	629-42694	11/V				
2000								
Fort McDowell	00J01	F	629-42695	11/A				
	00J02	M	629-42696	11/B				
Box Bar	00J03	F	629-42697	11/C				
	00J04	M	629-42698	11/D				
Doka	00J05	M	629-42699	11/E				
Pleasant	00J06	M	629-42700	11/G				
	00J07	M	629-23591	11/H				
76	00J08	F	629-23592	11/K				
	00J09	F	629-23593	11/M				
Suicide	00J10	M	629-23594	11/N				
	00J11	M	629-23595	11/P				
	00J12	F	629-23596	11/R				
Horseshoe	00J13	F	629-23597	11/S				
	00J14	F	629-23598	11/T				
Redmond	00J15	F	629-23599	11/U				
Luna	00J16	F	629-23600	12/Z			0	
	00J17	M	629-29451	12/Y			0	
	00J18	M	629-29452	12/X				
Tower	00J19	M	629-29453	12/W				
	00J20	M	629-29454	12/V				

Appendix C. Continued.

Natal Area	Bird Number	Sex	USFWS Band	VID Symbol (Blue Color)	Breeding Area	First Year Breeding	Age of Death	Comments
2000 continued.								
Sheep	00J21	M	629-29455	12/U			0	
Alamo	00J22	F	629-29456	12/T			0	
Pinal	00J23	M	629-29457	12/S				
	00J24	M	629-29458	12/R				
2001								
Fort McDowell	01J01	M	629-29459	12/A				
	01J02	M	629-69460	12/B				
Box Bar	01J03	F	629-29136	12/C				
	01J04	F	629-29137	12/D				
Tonto	01J05	M	629-29138	12/E				
Pinto	01J06	M	629-29139	12/G				
	01J07	F	629-29140	12/H				
Pleasant	01J08	M	629-29141	12/K				
	01J09	M	629-29142	12/M				
Talkalai	01J10	F	629-29143	12/N				
Tower	01J11	M	629-29144	12/P			0	
Horseshoe	01J12	M	629-29145	13/A				
	01J13	F	629-29146	13/B				
Suicide	01J14	F	629-29147	13/C				
	01J15	M	629-29148	13/D				
Orme	01J16	M	629-29149	13/E				
76	01J17	M	629-29150	13/H				
	01J18	M	629-44001	13/K				
Ladders	01J19	M	629-44002	13/M				
	01J20	M	629-44003	13/N				
Redmond	01J21	M	629-44004	13/P				
Lone Pine	01J22	M	629-44005	13/R				
2002								
Sycamore	02J01	F	629-44006	13/S			0	
Fort McDowell	02J03	M	629-44007	13/U				
	02J04	M	629-44008	13/V				
Box Bar	02J05	F	629-44009	13/W				
Tonto	02J07	M	629-44010	13/X				
	02J08	M	629-45351	13/Y				
Alamo	02J09	F	629-45352	13/Z				
Pleasant	02J10	F	629-45353	14/A				
Orme	02J11	F	629-45354	14/B				
	02J12	F	629-45355	14/C			0	
Rodeo	02J13	F	629-45356	14/D				
Talkalai	02J14	M	629-45357	14/E				
	02J15	M	629-45358	14/H				
Sheep	02J16	M	629-45359	14/K				
	02J17	F	629-45360	14/M				
Tower	02J18	F	629-45361	14/N				
	02J19	M	629-45362	14/P				
Needle Rock	02J20	F	629-45363	14/R			0	
Luna	02J21	F	629-45364	14/S				
	02J22	F	629-45365	14/U				
Ladders	02J23	M	629-45366	14/V				
	02J24	M	629-45365	14/W				
Granite Reef	02J25	F	629-45368	14/X				
	02J26	F	629-45369	14/Y				

Appendix C. Continued.

Natal Area	Bird Number	Sex	USFWS Band	VID Symbol (Blue Color)	Breeding Area	First Year Breeding	Age of Death	Comments
2002 continued								
Horseshoe	02J27	F	629-45370	14/Z			0	
	02J28	F	629-45371	15/A				
Pinal	02J29	M	629-45301	15/B				
Coolidge	02J30	M	629-45302	15/C			0	
	02J31	F	629-45303	15/D			0	
2003								
Sycamore	03J01	M	629-45305	15/E				
Sycamore	03J02	F	629-45306	15/H				
Needle Rock	03J03	F	629-45307	15/K				
Box Bar	03J04	F	629-45308	15/M				
Suicide	03J05	M	629-45309	15/N				
Suicide	03J06	M	629-45310	15/P				
Suicide	03J07	M	629-45311	15/R				
Luna	03J08	M	629-45312	15/S				
Pleasant	03J09	F	629-45313	15/U				
Tower	03J10	M	629-45314	15/V				
Tower	03J11	F	629-45315	15/W			0	
Orme	03J12	M	629-45316	15/X				
Bartlett	03J13	M	629-45317	15/Y				
Horseshoe	03J14	F	629-45318	15/Z				
Ladders	03J15	M	629-45319	17/A				
Ladders	03J16	M	629-45321	17/B				
Coolidge	03J17	M	629-45320	16/A			0	
Coolidge	03J18	M	629-45322	16/B				

APPENDIX D: TARSUS MEASUREMENTS USED TO SEX NESTLINGS

Nestlings were sexed by measuring the tarsus laterally (Hunt et al. 1992). Fledglings (third column) are classified to tarsus width (post-1993) or reported sex. Two additional nestlings from the period pre-1994 were not sexed. Adults that returned to breed (N=38 plus one that was not sexed as a nestling) or floaters that were recovered dead (N=1) could also be sexed behaviorally or by autopsy (Columns 3 and 4). The last two columns were used to estimate error rates for sexing nestlings, and the entire dataset was used to estimate sex ratios of nestlings.

Tarsus measurement (mm) or sex based on that measurement*	Count of birds seen only as fledglings, or that were identified and sexed as adults		
	Fledglings	M	F
F	30		13
M	47	19	
10	8	1	
10.5	26	1	
11	41	3	
11.5	19	3	
12	12	2	
12.5	19		
13	35	1	2
13.5	1		1
14	16		1
14.5	7		1
15	2		1
Total	263	30	19

*Measurements of nestlings before 1994 not available, but nestling sex following the protocol described here was listed in Hunt and others 1992 (1987-1990 data), Mesta and others 1992 (1991-1992 data), and Driscoll and others 1993 (1993 data).