

Ecology of Bald Eagles in Arizona

Volume I

Population
Overview

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For:
Bureau of Reclamation

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ECOLOGY OF BALD EAGLES IN ARIZONA

Part A

POPULATION OVERVIEW

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EXECUTIVE SUMMARY

From 1987-1990, BioSystems Analysis, Inc. investigated the ecology of Arizona's nesting population of bald eagles. The study was funded by the U.S. Bureau of Reclamation for the purpose of determining what factors limit the Arizona eagles, and particularly whether the reservoirs and regulated flows produced by the construction and operation of water projects have been harmful or beneficial. In directing the study, Reclamation consulted with the U.S. Fish and Wildlife Service and the Arizona Game and Fish Department.

The current known nesting population is small, but appears to be maintaining itself, and is possibly expanding. Known breeding areas increased from two in 1970 to 28 in 1990; 21 have produced young since 1980. Whether the increase in known sites has resulted from the founding of new territories or from increased nest search efforts is unknown. Three territories (11%) are believed to be new, 9 (32%) were not reported prior to discovery by agency personnel, and 16 (57%) were probably in existence prior to being documented. The latter assessment is based upon anecdotal reports and/or territories containing old or numerous nests (some with eggshell fragments).

The only report of bald eagles nesting in Arizona prior to the completion of the first large dam (Roosevelt in 1911) was by Edgar A. Mearns, who in 1890 referred to a long-established pair at Stoneman Lake. No other reference to breeding pairs appeared in the literature until 1937 when Bent reported breeding at two sites, one of which had occurred on the Salt River Bird Reservation before its inundation by Roosevelt Reservoir. It is unknown whether, in pristine times, bald eagles nested on the Salt and Verde drainages where most of the known breeding population now resides. We believe early fish communities there could have supported nesting eagles. Trees for nesting would have been plentiful before grazing and woodcutting destroyed the riparian forests.

It is also unknown whether bald eagles in Arizona declined during the DDT-era as they did elsewhere in North America. Very high levels of DDE have been detected in cotton-growing regions of Arizona, but bald eagle prey fishes may not have been strongly contaminated owing to their occurrence upstream of most agricultural areas. Waterfowl were probably a source of contamination to both breeding pairs and younger eagles.

Nesting bald eagles in Arizona demonstrated occupancy and reproductive performance during 1970-1990 at rates comparable to those reported for other populations considered healthy. During this period, a mean brood size of 1.6 young in Arizona equaled the mean reported for other populations. The mean number of young per occupied site was 0.90 eaglets, compared to 0.92 elsewhere. Nest success in Arizona has averaged about 57 percent compared to 58 percent for other populations. Both productivity and nest success rates have remained somewhat stable over the entire 20-year period. The 85 percent nest occupancy rate ($n=295$ known nest-years) was 14 percent higher than the average for other populations, suggesting greater stability in habitat or food supplies in Arizona than elsewhere.

Nestling mortality rates in Arizona are comparable to the 15 percent reported for other populations. Of the 276 known young hatched in Arizona, 232 (84%) survived to fledge, and 44 (16%) died before fledging. Our data contain 13 additional mortality records for post-fledging juveniles still in the nest area. Heat stress was apparently responsible for most known nestling and fledgling mortalities, followed by unknown factors, falling or disappearing from the nest, human disturbance near the nest, and nest

parasites (i.e., Mexican chicken bugs). This assessment is based on deductions concerning the principal cause of mortality, and may contain error; some deaths likely resulted from combinations of factors.

One nestling death resulted from entanglement with fishing line (monofilament), and we saved three others by removing fishing line, hooks, and lures from their legs, toes, tongues, and bodies. Fishing paraphernalia is apparently brought to the nest attached to fish which have escaped from anglers by breaking the line. We found fishing paraphernalia in 40 percent of the Arizona nests we entered that contained young.

Analysis of contaminants in unhatched bald eagle eggs from Arizona showed geometric means of 5.5 ppm DDE and 2.2 ppm PCBs (wet weight). DDE levels of this magnitude have elsewhere been associated with reduced productivity, but no DDE effect on productivity was apparent in the areas where the eggs were obtained. Seven eggs showed a mean percent thinning of 4.9 percent, well below the 10 percent level associated with reduced productivity. Examination of shell ultrastructure in these eggs showed far fewer irregularities and "holes" than contaminated shells from California. At the present time, organochlorines do not appear to pose a significant threat to the bald eagles in Arizona. However, periodic monitoring of pesticide levels in bald eagles and their prey would be prudent.

Of 111 known nests, 53 were on cliffs (or pinnacles), 46 were in trees, 11 in snags, and 1 was on an artificial nesting platform. In breeding areas where tree and cliff nests were both available, eagles non-randomly chose cliffs rather than trees; however, nest success did not differ significantly between the two substrates. Eagles are less susceptible to heat stress and parasites in trees, but are more vulnerable to disturbance. We found nest parasites in 39 percent of cliff nests, and none in tree nests.

The agencies directed BioSystems to employ radio-telemetry to study the ecology of eight breeding pairs. Six of the selected sites were reproductively successful during the year(s) of study and provided a basis for a comparison of habitats with and without water project influences. Two pairs occupied settings in which flows were completely regulated and where both river and reservoir habitats were present. Two others were on free-flowing rivers without reservoirs. The remaining two were intermediate in habitat setting, containing reservoirs fed by free-flowing rivers rather than regulated ones. Thus, our findings in each territory could be contrasted with results obtained from another in a similar setting, and with four others in different settings.

We radio-tagged at least one adult bald eagle in each selected territory and sampled its daily home range movements for at least one breeding season. From dawn through much of the day, we attempted to witness as many foraging events as possible. After each observed forage ($n=841$), we visited the exact location where prey was attacked and recorded macro- and microhabitat features. Observers positioned within view of the nest bowl identified prey as it was delivered and estimated its size and status. We collected prey remains not only at nests in the studied territories but throughout central Arizona. To assess prey availability, we observed fish behavior, conducted fish population surveys, and mapped river and reservoir habitats. We investigated the life-histories of prey fishes, with emphasis on factors promoting their vulnerability to eagles. We recorded human interactions with eagles.

An analysis of the remains of 2,601 prey items collected in nests, under perches, and just after foraging events at 23 breeding areas in Arizona yielded 71.4 percent fish biomass, 18.3 percent mammal, and 10.3 percent bird. The most important fish in prey remains were catfish spp. (mainly channel catfish), followed by carp, sucker spp. (desert and Sonora suckers), and perciforms (mainly black crappie, yellow

bass, and largemouth bass). Of these fish, only the suckers are native to Arizona. The most frequently used mammals were rabbits, and the most important prey birds were American coots and eared grebes. These and other waterbirds were taken mainly in winter and early spring. In all, 104 species of fish, birds, mammals, reptiles, amphibians and invertebrates have been thus far identified as the prey of Arizona bald eagles.

Observational data on prey deliveries at the intensively studied territories yielded somewhat different results than those of prey remains analyses at the same sites. Because of differences in durability, the remains of certain prey taxa tended to persist in the nest longer than those with more delicate body parts. In general, this resulted in over-representation of mammals, birds, and catfish in prey remains, and under-representation of suckers and perciforms (bass, crappie, sunfish). Results of the experimental feeding of fish to a captive bald eagle at the Phoenix Zoo gave similar results.

As another way of estimating the relative importance of the various fish taxa, we assessed the frequency with which each accounted for more than 15 percent of the estimated biomass in the 23 territories. We found these seven taxa to be represented (in descending order of importance): carp, suckers (Sonora and desert suckers), channel catfish, largemouth bass, flathead catfish, crappie (virtually all were black crappie), and yellow bass.

Higher frequencies of mammals in the diets of certain pairs suggested deficiencies in food (i.e., fish) availability, but this hypothesis was not supported by statistical comparisons of diet and productivity. Data on 21 mammal forages (at territories where we employed telemetry) suggested that they were taken mainly near rivers or reservoirs. Nesting eagles took mammals in significantly greater proportions during the early periods of the nesting cycle than in later periods.

Telemetry studies revealed that eagles foraged in both riverine and reservoir habitats. On rivers, eagles took mainly live fish, while on reservoirs, carrion predominated in the diet. Eagles took fish species largely in relation to their relative abundance in river reaches and reservoirs, but ecological and life history characteristics also accounted for variation in their degree of vulnerability and for seasonal differences in exploitation.

On rivers, suckers were especially vulnerable when they spawned in riffles (see Glossary for definitions of terms) in March and early April. The duration of their spawning was extended in river sections receiving cool, deep-water releases downstream of stratified reservoirs, a phenomenon that related to shifting zones of optimum spawning temperature. Eagles also took suckers, as well as carp, when these fish foraged in riffles and runs. Riffles attracted spawning and foraging fish because of high photosynthetic rates, oxygenation, clean substrate, and invertebrate populations.

At four territories where we compared eagle foraging habitat selection with the relative abundance of river habitat types, eagles attacked prey in riffles disproportionate to the occurrence of this habitat along the river. Some riffles, because of their morphology, maintained shallow-water conditions even at high flows, a configuration we termed "super-riffle" habitat. In several territories where super-riffles occurred, we found that eagles visited river kilometer segments with super-riffles significantly more frequently than those that did not contain them. At three breeding areas where nests overlooked super-riffles, the nest area was the primary focus of riverine foraging. At a fourth territory, where there were no super-riffles in the immediate nest vicinity, the main foci of eagle visitation were the nearest areas containing super-riffles. We failed to detect any preference by the eagles for runs, pools, or pocket

water. However, while most observed river forages for suckers ($n=98$) were in riffles, we saw carp taken mainly in runs and riffles ($n=21$), and catfish in runs and pocket water ($n=12$). The preponderance of riffles in our observational data may therefore relate partly to the relative frequency of species taken.

Eagles often perched and foraged at reservoirs. In four productive breeding areas where both riverine and lacustrine habitats were present, eagles visited reservoirs more frequently than river sections, even when the nest was on the river (data weighted for nest effect). At a reservoir nest very near a river section, 91-97 percent of prey biomass delivered to the nest was obtained on the reservoir. At another nest, located on a river 7 km from a reservoir, 67 percent of biomass delivered during late April and May came from the reservoir. At the two remaining sites, reservoir forages accounted for 28 percent and 48 percent of delivered biomass.

On reservoirs, most observed bald eagle forages for fish were in deep water, and most were taken either as carrion or as they floated moribund on the surface. Carp were occasionally taken alive in shallows, and possibly when they swam near the surface in deeper water. Eagles took catfish and perciforms mainly as carrion. Black crappie and yellow bass exhibited post-spawning die-offs, but the cause of mortality among 20-cm catfish was unknown. Largemouth bass mortality appeared to be mainly caused by anglers. Foraging eagles were especially attracted to areas where rivers entered reservoirs. We plotted the locations of these inflows together with those of super-riffles on the Salt and Verde rivers, and found a significant positive correlation with the distribution of bald eagle nests active during the past five years.

Overall, reservoirs, dams, or regulated river reaches do not appear to have a negative effect on bald eagle reproduction. In a sample of 21 bald eagle territories fledging at least one young since 1980, we compared reproductive performance between 12 sites in which habitats were artificially altered (reservoirs and/or regulated reaches) with 9 on unregulated streams. In habitats altered by dam construction, 134 young fledged from 12 sites in 122 occupied nest-years, for a mean of 1.1 young per year. In "natural" habitats, the eagles produced 93 young at 9 sites in 92 nest-years, for a mean of 1.0 young. The difference in productivity between altered and unaltered habitat was not significant.

We also found no significant relationship between an assortment of environmental variables and yearly success rates among 13 territories where there was sufficient duration of occupancy for statistical comparison ($n=186$ nest-years since 1970). The variables we compared included nest elevation (above sea level), normal and peak spring flows, reservoir elevations, maximum and minimum air temperatures, precipitation, and a human disturbance index. The latter was based on perceived ambient disturbance levels, rather than specific factors.

Human disturbance is most likely to cause nest failure when adults are prevented from returning to the nest during incubation and before the young can thermoregulate. Our data and those of previous studies contain records of nest failure that could be directly attributed to human disturbance during this sensitive period. Also consistent with previous findings was that humans on foot tended to be more disturbing to eagles than people in boats or road vehicles. In our opinion, a significant reason for the healthy overall rates of nest success in Arizona is the protection afforded by the Interagency Arizona Bald Eagle Nestwatch Program.

In considering carrying capacity and management strategies for other southwestern river systems, our work suggests that the features of bald eagle habitat that render it suitable for breeding include: (1) nesting substrate offering security from large predators and human disturbance; and, (2) two or more of the following fish taxa occurring in substantial numbers: carp, suckers (spp.), catfish (spp.), and perciforms (the latter in reservoirs). Factors which appear to strongly increase habitat quality include; (3) reservoirs supporting warm water fisheries; (4) reservoir inflow areas; and, (5) super-riffles.

Understanding the ecology of Arizona eagles also requires knowledge of nonbreeders. Because of long-delayed maturation, young individuals (ages 1-4) make up a sizeable segment of the total population. Another segment is formed by non-breeding adults (5+ years) that accumulate when all serviceable breeding locations are occupied by pairs. The resulting "floating" population of non-breeding adults serves an important function in quickly providing replacements when breeders die, buffering the reproductive segment against annual perturbations in natality and mortality.

To study the non-breeding population, we (1) observed the post-fledging behavior and migrations of 11 radio-tagged juveniles, (2) recorded their subsequent movements in Arizona in winter and spring, (3) monitored the movements of eight subadults and near-adults with radio-telemetry, and, (4) placed color (VID) bands on 62 nestlings and 18 older eagles. These bands enable visual recognition of individuals and will eventually provide the basis for a life table when banded birds enter the breeding population.

All the radio-tagged juveniles migrated northward from their natal areas at 16 to 21 weeks of age. Soaring was the predominant mode of travel, and the birds moved up to 650 km per day at still-air ground speeds of 20-25 mph, which were increased greatly on occasion by tail winds. The longest distance traveled was 1,955 km to Swan Lake, Manitoba. Another juvenile that was still migrating northward in coastal British Columbia when tracking was terminated might have gone further. Habitats varied among stopping places; several birds stopped in areas where there was abundant fish carrion, but one eagle stopped and remained in open ranchland near Dillon, Montana. Two birds went to Yellowstone Lake, and another reversed its course upon reaching the coast of northern Oregon and flew southward to the coast of northern California. One of the eagles that went to Yellowstone Lake returned there the following summer. Breeding adults did not migrate.

Of the 11 radio-tagged juvenile eagles that migrated from their natal territories, at least eight (73%) had returned to Arizona by fall or winter. Two were first detected in late September and may have returned earlier. We monitored their movements and those of the eight radio-tagged subadults and near-adults in airplane roll-call surveys throughout central Arizona. These nomadic eagles traveled extensively within central Arizona from September to May and exploited a variety of habitats. They frequented both streams and reservoirs (particularly inflow areas) and appeared more attracted to tributaries than mainstem riverine habitats. The non-breeding eagles apparently remain in the Southwest all winter, but none were found in central Arizona after late May.

Mortality rates of the non-breeding eagles were impossible to determine. Of five known cases of mortality among subadults and near-adults in Arizona, all were human caused. Assuming an Arizona origin of all banded breeders, of the 46 Arizona nestlings banded prior to 1986, a minimum of 18 (39%) survived to breeding age (4-5 years old) and a minimum of four (9%) survived through their twelfth year of life.

There have been 39 known cases of adult bald eagle mortality in Arizona: 11 based on direct knowledge and 28 known indirectly by evidence of disappearance or replacement. The latter was determined by the presence of a near-adult in a breeding pair, or the presence or absence of a banded individual within the pair. The causes of adult mortality were mainly unknown (77%). Of known causes, about half were shooting and half were apparently natural.

Of the 39 known adult mortalities, 21 (54%) were recorded during our study (1987-1990), resulting in a 16 percent annual adult mortality rate. These mortalities were discovered mainly at sites under closest study; therefore many more mortalities were likely to have occurred than were detected. At the four closest territories to Phoenix, there was a 22 percent ($n=7$) minimum adult mortality rate during the four years.

Although missing members of pairs are rapidly replaced in Arizona, most known replacements have been young (near-adult or subadult) eagles. Of 39 known vacancies at breeding areas, 15 (38.5%) were filled by adults, and 24 (61.5%) by near-adults or subadults. However, a bias existed in that replacements by full-adults may have gone unnoticed. Of the 15 full-adult replacements, 8 followed the known death of a previous adult, 5 were determined because the new adult was banded, and the remaining 2 were recorded because the previous adult was banded. Irrespective of the bias, the proportion of young eagles as members of pairs in Arizona is substantially higher than reported for any other bald eagle population.

In four cases, both members of breeding pairs lacked full-adult plumage: two of these pairs apparently did not lay eggs while the other two pairs hatched two young each. Of 28 incidents (24 nest-years) of near-adult or subadult eagles in Arizona breeding pairs, 11 (46%) successfully fledged young, 2 (8%) hatched young which died in the nest, 3 (13%) laid eggs which did not hatch, and the remaining 8 (33%) apparently did not lay eggs.

The appearance of breeding eagles lacking full-adult plumage suggests an insufficiency of adults in the floating segment. Perhaps adults, that would otherwise be floaters, are founding new territories, but it is also possible that excessive adult mortality drains the floating segment. In this case, the Arizona population would lack the buffering effect of a healthy floating segment and would be susceptible to decline. If the subadult replacements are a result of a growing population, than full-adult floaters will eventually increase as the nesting population approaches carrying capacity and a stable age-distribution. The high rate of change in adult tenure at some Arizona bald eagle breeding areas suggests that factors other than natural mortality are at work, such as shooting. However, some replacements may be due to increased altercations with other eagles seeking breeding status or with other species of nesting raptors in the area.

There is as yet no evidence for gene flow into Arizona from outside sources. We sighted 18 banded birds during our study, 17 of which were breeding. We verified the numbers on eight of these bands; all had been placed on nestlings in Arizona during previous studies by Robert Ohmart or Teryl Grubb.

Morphological comparisons of breeding bald eagles from Arizona, California, the Greater Yellowstone, and Alaska revealed that, for most measurements, the Arizona eagles were significantly smaller than those from the other populations sampled. Lack of high variance in mensural characters in the Arizona sample does not support the notion that the Arizona population was recently founded or augmented by a collection of migrants from other populations.

Neither enzyme electrophoresis nor DNA fingerprinting resolved any specific genetic markers from which Arizona eagles could be differentiated from those of other populations, although most individuals could be assigned to their respective populations with combinations of DNA banding. Similarity coefficients in the fingerprinting data suggested that Arizona bald eagles were more closely related to California birds than to those from Florida. This was surprising because Arizona eagles are apparently more similar in size to eagles from Florida than from California. Also surprising was that California samples were more similar to those from Florida than from Arizona.

Both techniques showed higher levels of genetic heterozygosity in the Arizona samples than the other populations tested. If the genes assayed truly represent the gene pool, then these healthy levels of variation imply that the Arizona eagles are not currently experiencing inbreeding problems and may be capable of adapting to future environmental change. This, together with the occupancy and reproductive data, suggests that the population may be viable over the long term.

We were unable to show a quality of uniqueness among the Arizona eagles that implies the existence of adaptations to the desert environment, even though the Arizona bald eagles are smaller than those from California and the Greater Yellowstone. However, were the population extirpated, there is no firm reason to believe that bald eagles released into Arizona from elsewhere would possess the adaptations required to increase their numbers. Furthermore, releases to augment a reduced population in Arizona might be deleterious because of genetic disruption of existing adaptations.

Because we cannot yet demonstrate that Arizona bald eagles are part of a larger population, it is prudent to assume isolation. If isolated, the 21 pairs productive in Arizona since 1980 conform to the definition of a small population which may be susceptible to the genetic, demographic, and environmental threats known to be associated with small numbers. There is evidence of high adult mortality at some sites and an indication of deficient age structure in the floating segment. These apparent problems may soon disappear, but until they do, it would be wise to regard the population in need of continued protection and management. The most encouraging sign would be a reduction in the frequency of near-adults as members of pairs at established sites. Appropriate to this end would be management efforts encouraging survivorship, especially that of breeding adults.

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A1 INTRODUCTION

Arizona supports a nesting population of bald eagles mainly along the Salt and Verde rivers in the central part of the state. The number of pairs is small, appears to be geographically isolated from other populations (at least currently), and occupies habitat drier, warmer, and less vegetated than is typical for the species (Figure A1.0-1). Large trees are in short supply along the desert rivers, and most pairs use open cliff nests. The population is classified as endangered by both federal and state governments.

Of particular interest to those concerned with the welfare of Arizona's native bald eagles are: (1) whether or not current reproduction and survivorship are sufficient to maintain the population, especially in view of the rapidly increasing numbers of people in Arizona; (2) how habitat, prey, and public-use factors are affecting bald eagles; and, (3) whether or not the population is large enough to avoid difficulties associated with small populations. To address these considerations, the United States Bureau of Reclamation (Reclamation), in consultation with the U.S. Fish and Wildlife Service (USFWS), and the Arizona Game and Fish Department (AGF), employed BioSystems Analysis, Inc. (BioSystems) to study the ecology of nesting bald eagles in Arizona. The premise for conducting the investigation was that a detailed knowledge of the bald eagle may be necessary if the species is to maintain itself in Arizona, and one day recover to a non-endangered status. This report, in partial fulfillment of Reclamation Contract No. 6-CS-30-04470, details the results of field studies by BioSystems performed through three bald eagle breeding seasons: 1987, 1988, and 1989.

The central question posed in Reclamation's original "Request for Proposal" (RFP) concerned the impacts of water development projects on bald eagles. At the time we began our study, there was little consensus among scientists, agency personnel, or conservation groups as to whether the regulated flows and reservoirs produced by these projects harmed or benefitted bald eagles in the southwest. This question not only involved the existence and operation of water projects already underway, but also concerned the building of Cliff Dam (since rejected) and other proposals outlined in Plan 6 of the Central Arizona Project (CAP), including water diversions in the Verde River drainage. Because of the endangered status of Bald Eagles in Arizona, in order to pursue the CAP plan, Reclamation was required by Section 7 of the Endangered Species Act to consult with the Fish and Wildlife Service. The result of that consultation was a commitment by Reclamation to provide for this study.

In preparing BioSystems' inquiry into the ecology of the Arizona eagles, we attempted to maintain this issue of the consequences of water projects as the focus of our research. In doing so, we faced the problem (mainly budgetary) of whether to concentrate on specific project effects on specific pairs of eagles, or whether to seek a broader understanding of the ecology of the population as a whole and its more general relationships to water projects. This dilemma, familiar in impact studies over a variety of disciplines, was recognized by the agencies who opted for obtaining a population perspective. They knew, however, that such knowledge would nevertheless require in-depth investigations of the activities of specific eagles, the habitats they occupy, and the prey populations they depend upon.

Studies of Breeding Bald Eagles

In choosing for intensive study among a score of bald eagle breeding areas the agencies selected eight as representative of various river and reservoir habitats, including those where flows were artificially regulated and those on free-flowing rivers. The agencies' plan was to radio-tag adult eagles at each of the eight sites, and, by intensively tracking them during the nesting season, to discover their relationship to food supplies and habitat.

The agencies had recognized the importance of studying the foraging ecology of the nesting pairs long before BioSystems began its work in Arizona. During the late 1970s and early 1980s, Reclamation and USFWS had supported investigations of foraging ecology by Robert Ohmart, Dennis Haywood, Ronald Sell, and Thomas Hildebrandt (Arizona State University) and by Teryl Grubb and Larry Forbis of the U.S. Forest Service. These studies, which provided important baseline information on the population, relied on visual observation alone. Although much valuable information was obtained on foraging, especially in the nest vicinity where watchers were posted, when the eagles typically departed on hunting forays to other areas, their whereabouts and activities were largely unknown. Among the resulting errors, apparent to us only in hindsight, were: (1) overemphasis on areas visible from nest observation points; (2) insufficient area samples to rank the relative importance of river foraging habitat (e.g., runs, riffles, and pools); (3) the assumption that flying eagles were foraging rather than commuting; (4) the supposition that foraging range could be described on the basis of soaring range; and (5) the underestimation of the importance of reservoir habitats.

To illustrate the difference in sensitivity with and without the aid of telemetry, we recall our studies at the "Blue Point" bald eagle breeding area in 1988 where only the adult male carried a radio transmitter. We recorded 147 forage attempts by this bird, of which 79 were actually seen by radio trackers; the remaining attempts were inferred from prey delivered to the nest. During this period, we observed only one forage by his mate (who had no radio), although she delivered 53 prey items to the nest.

The agencies requested that BioSystems attach radio transmitters to the adult male eagle of each pair among the eight selected breeding areas, and at two of the sites, radio-tag the female as well. However, as we had learned in previous studies, it was not always possible to catch a specific eagle, and certain pairs, chosen for study in a particular year, did not nest successfully. In the latter case, the foraging activities of eagles without young to feed were apt to be much diminished and not nearly as revealing of habitat and prey selection as those with broods.

In the end, we were able to track the foraging activities of five adult males and four adult females at eight breeding areas (Table A1.0-1), one of which contained a lone female (Pinto) involved in a polygynous relationship with a nearby pair (Pinal). This female attempted to nest, but failed to hatch eggs. At one other of the eight sites (Cliff in 1989), one young hatched, but died soon afterward. The remaining six territories were successful in producing young during our study.

The six successful breeding areas where we monitored the adults' activities with telemetry proved ideal for a comparison of bald eagle ecology between regulated and unregulated environments. Two of the pairs (Bartlett and Blue Point) occupied settings in which flows were completely regulated, and where both river and reservoir habitats were present. During the nesting season, the water released from the dams was cooler than in unregulated reaches because it derived from the cool depths of the stratified reservoirs, and the reservoirs themselves were fed by yet other reservoirs upstream. Two other breeding areas (Ladders and East Verde) were on free-flowing rivers without reservoirs. These river sections differed from the regulated river reaches in temperature, sediment load, and the relative proportions of prey fish species. Finally, two more breeding areas (Horseshoe and Pinal/Pinto) were intermediate in habitat type, containing reservoirs fed by free-flowing rivers rather than regulated ones.

Thus, there were two territories in each of three settings. Findings and generalizations regarding foraging ecology in each territory could be contrasted with results obtained from: (1) a different territory with a *similar* habitat setting, and (2) territories with *different* settings.

Table A1.0-1. Eight breeding areas in Arizona where BioSystems used radio telemetry to study the ecology of bald eagles. The Pinto female was involved in a polygynous triangle with the Pinal pair, and her territory is included with that of Pinal throughout most of this report (= Pinal/Pinto).

| Breeding Area | Radio-tagged Adults | Successful? | Location | Habitat Setting | |
|---------------|---------------------|-------------|-------------|--|---------------------------|
| | | | | River | Reservoir |
| Bartlett | Male | Yes | Verde River | Regulated (cool water release) | Fed by regulated reach |
| Blue Point | Male | Yes | Salt River | Regulated (cool water release) | Fed by regulated reach |
| Ladders | Female | Yes | Verde River | Free flowing | None |
| East Verde | Male | Yes | Verde River | Free flowing | None |
| Horseshoe | Both | Yes | Verde River | Free flowing | Fed by free flowing river |
| Pinal | Female | Yes | Salt River | Free flowing | Fed by free flowing river |
| Cliff | Male | No | Verde River | Regulated (warm water release) | Fed by regulated reach |
| Pinto | Female | No | Salt River | Territory within Pinal breeding area (see caption) | Fed by free-flowing river |

Our comparison of bald eagle ecology in habitats with and without water projects does not equate to contrasting modern environments with those of pristine times. The free-flowing reaches present in four of the six territories are substantially different today than they would have been, say, 500 years ago. The most significant changes have been: (1) reductions of large trees in the riparian zone; (2) less constant flow regimes owing to the general loss of soil throughout the landscape; and (3) the replacement of most native fishes with exotic species. Rather, as we have said, our study of the differences among bald eagles nesting in regulated versus unregulated environments is directed toward: (1) evaluating the net effects of water projects on bald eagles, the central question of this investigation, and (2) providing land and water managers with further knowledge on how to balance the needs of humans and eagles.

At each of the six territories, we obtained data on home range and foraging by tracking the radio-tagged adult eagles throughout much of the breeding season, with most intense concentration during periods when there were young in the nest. We studied prey selection by closely observing prey deliveries by the adult eagles to the young, and by collecting prey remains in the nests and at foraging sites. We recorded data on habitat use by foraging eagles by assessing and measuring macro- and microhabitat features at the points at which prey were attacked. We assessed prey availability in both river and reservoir environments by performing fish population surveys in actual and potential foraging areas. Our findings led us to investigate life-histories of the prey fishes, particularly spawning, feeding, and mortality. We measured the distribution of stream habitat in four breeding areas and compared the distributions with the home range movements of the radio-tagged eagles. We recorded human interactions with eagles on an incidental basis to obtain a view of the most harmful modes of interaction. The results of all these investigations are given in Part B of this report.

Studies of Nonbreeders

The investigations outlined above primarily address the ecology of adult bald eagles during the breeding season, and thus the factors affecting the population's ability to increase its numbers. There is also a sizable nonbreeding segment of the population whose survival is essential to the maintenance of the breeding segment and about which virtually nothing was known before this study began. During the four or five years bald eagles require to mature, they range over a wide variety of habitats and geographic settings, many of which bear the benefits and risks of human influence. These birds are generally scattered in the landscape, rather than attached to specific locations, and they are visually indistinguishable from birds from northern populations also wintering in Arizona.

To shed light on this virtually unknown population segment, we investigated the post-fledging dispersal of juvenile eagles and their movements through at least the first year of life. During our study, we radio-tagged ten juvenile bald eagles prior to fledging and recorded their departures and migration, as well as return of some of them to Arizona. We also telemetered five subadults (1-3 years old) and three near-adults (ca. 4 years old), some of which had been banded as nestlings in Arizona. In airplane surveys conducted mainly in the central part of the state and elsewhere on occasion, we searched for all these birds and recorded their habitat use.

Population Ecology

For obvious reasons, the agencies were interested in learning as much as possible of the demography of native Arizona bald eagles. Because of the small number of pairs and the rapid increase of Arizona's human population, the prospect of a sudden decline of eagles to extirpation or inbreeding depression was

not beyond visualizing. The agencies, being aware of the fact that natality is but one-half of the demographic equation, also desired an investigation of mortality rates and causes.

BioSystems approached this matter from a number of directions. We assembled the historical data on occupancy and nesting success (Part D) to ascertain temporal and locational trends in these factors. We examined the findings of previous field workers concerning the many factors that might affect eagles on a population basis. We accumulated information on eagle mortalities and mate replacements in unpublished reports and agency records, and investigated deaths and replacements that occurred during our study (Part C). We also drew upon our telemetry-based work at the priority territories (Part B) where we studied prey and habitat features used by successful pairs of eagles as a way of approaching the natural and human-related factors that influence occupancy and reproduction. Lastly, we set in motion a visual identification (VID) banding program (colored aluminum tarsal bands with engraved symbols) which allows individual eagles to be identified from a distance. It will now be possible to record turnovers in breeding adult tenure and to eventually construct a life table. Over the years of our study, we VID-banded nearly all the young produced at known nests, in addition to the adults and subadults we captured for radio-tagging.

Another of the agencies' concerns was whether or not there is a qualitative distinction between the southwestern bald eagles and those from other areas of North America. If the genome of desert-dwelling eagles contain DNA sequences controlling specific adaptations to life in a desert environment, then an eventual loss of the population would be far more significant than if possible recruits from northern environs were the evolutionary equivalents of native Arizona eagles.

BioSystems attempted to resolve this question in several ways. We collected blood samples for DNA and enzyme comparisons between Arizona bald eagles and those from several other populations. Results of these studies, which include genetic heterozygosity estimates, are given in Section E6 and E7. These latter estimations help resolve the question of whether or not the current population might be experiencing inbreeding difficulties. We also compared morphological measurements of Arizona eagles with those from other populations, looking mainly for size differences. We sought to compare eggshell morphology with those from other areas, and although we obtained baseline micrographs, the apparent variable effects of organochlorines currently affecting shell morphology probably obscured any genetically controlled differences, if any.

Population-wide Prey Studies

Another research goal was to examine the diets of all the nesting eagles in Arizona and relate the differences found to the types of habitat occupied by the pairs. To do this, we collected and analyzed prey remains from the nests of almost all the reproductively active pairs in Arizona. By measuring the bones of fishes and other prey, we were able to estimate their original lengths and biomass and thus their relative contributions to the eagles' diets. This approach strengthened our understanding of the trophic factors which likely limit the distribution of the breeding population. In developing a concept of bald eagle foraging ecology during our telemetry studies at the selected territories, the wider perspective of prey selection over the entire region was elucidating. By comparing observational data on prey deliveries at the priority nests with prey remains collected from the same nests, we were able to estimate the degree to which certain biases, inherent in prey remains data, affected our estimates of dietary contribution of prey species in the larger sample.

Guide to this Report

Our study is based on observations and records of specific events occurring both locally, and over large areas. Since our perception of the ecology of the Arizona eagles is based on these observations, we must make them available to the reader who is faced with accepting or rejecting our overall views, conclusions, and recommendations. The presentation of details is also useful to those involved in protecting eagles and managing their habitats. Some of our data (*e.g.*, those on natural history events) are ancillary to the main topics of our work, and yet seem relevant to an overall understanding and probably to questions not yet posed.

In writing and organizing the report, we wished to avoid confusing or discouraging the reader with an initial presentation of these specific details, but rather to begin with a section in which conclusions relating to the scope of work would be presented mainly without reference to local conditions or events. Part A contains this population overview which is partly a summary of our findings and partly an analysis of populational and study area data sets. However, in some cases (*e.g.* home range studies) we were unable to explain our points without going into specifics. To adequately evaluate our conclusions, some of which are tentative, we urge the reader to examine the material throughout this report. To facilitate access to the particulars in each part and section, we offer this outline of its organization:

Part B contains the results of our telemetry-based field studies at the priority breeding areas. It begins by describing the habitat setting for each site and the reason it was selected. The next section (B2) outlines our research approach and provides an overview of our field methods (specifics appear in Section E8—Methods). Because these methods are central to our studies of foraging ecology, we recommend that the reader review Sections B1 and B2 before proceeding with the current part (A). Section B3 briefly describes the geography of the Salt and Verde rivers (a more extensive treatment is given in Section D2). Section B4 gives the results of BioSystems' field work at the eight territories, and includes descriptions of home range, prey selection, foraging habitat, prey populations, and human effects. In reading these sections, the reader will need to refer to BioSystems' River Map Atlas for an orientation to geographical features and to the glossary given at the end of this volume. Section B5 begins with an analysis of prey data for 23 bald eagle breeding areas in Arizona where remains were collected, and concludes by comparing the results with prey delivery and experimental data.

Part C details what is known of the demography of Arizona bald eagles and also describes our studies of the nonbreeding segment of the population. Section C2 details available knowledge of occupancy and productivity of the Arizona population, including both historical and new information. Section C3 similarly recounts all available knowledge on bald eagle deaths—from losses in the egg stage to those of territory-holding adults—and discusses the factors responsible. Because of the many accounts of events occurring in specific places, the reader will find it necessary to consult Part D which describes the history and setting of all known breeding areas in Arizona and the River Map Atlas. Section C4 reviews available information of public disturbance effects on bald eagles. In Section C5, we chronicle our telemetry studies of the post-fledging behavior, departure, and migration of juvenile bald eagles, and present data on their subsequent return to Arizona. We also report data on the use of habitat by a sample of radio-tagged subadult and near-adult bald eagles. In Section C6, we present survivorship data for bald eagles banded in Arizona, including those banded in previous studies.

Part D is offered as a reference to existing knowledge on the history of the Arizona nesting population; it reviews published and unpublished reports, notes and interviews. Section D2 characterizes the habitats

occupied by the nesting eagles, both directly and in the larger context of drainages. Also described is the history of environmental effects by Spanish- and English-speaking cultures. Section D3 summarizes the known history of bald eagle occurrence in Arizona, while Section D4 presents all known information on each of the 28 breeding areas. Section D5 describes an additional 22 historical nest sites that have, or may have, been active in the past. Section D6 catalogs potential nest sites for future search efforts, based on eagle sightings and reports from the public. Section D7 gives information on wildlife sightings and interactions recorded in the eagle territories.

Part E contains a number of special reports and appendices, beginning with a review (Section E1) of the historical changes that have occurred in prey fish populations and aquatic habitats in Arizona. Section E2 describes the fish communities currently existing within Central Arizona, and Section E3 details the life history of each species of prey fish. Section E4 reports the occurrence and possible effects of chlorinated hydrocarbons in bald eagle eggs from Arizona, followed by a study of eggshell morphology as revealed by electron microscopy (Section E5). Genetic variation among Arizona eagles is compared with those from other regions in Sections E6 and E7, using both DNA fingerprinting and enzyme electrophoresis. Section E8 details BioSystems' methods, including copies of field forms and codes that may be useful to those continuing to obtain data on the population. Section E9 gives a list of scientific names of species mentioned in the report.

BioSystems' River Map Atlas is referenced throughout the report. The Atlas shows topographical features and the 0.1 kilometer indices along river centerlines used to specify the locations of perching and foraging events and the many other details of this study; readers will frequently be referred to these maps (see Glossary for distinction between Km, km, and Skm).

Part F includes a series of maps showing the locations of all active and historic bald eagle nests in Arizona, and provides productivity data and nest descriptions for each site. Distribution of this part of the report will be limited to appropriate management agencies.

The six parts of this report render obsolete the two interim reports submitted to Reclamation in 1987 and 1988.

A2 OVERVIEW OF THE NESTING POPULATION

The genus *Haliaeetus*, extant for at least 25 million years, is nearly cosmopolitan, occurring on all continents except South America and Antarctica (Figure A2.0-1). Most widely distributed among the eight living species is the white-tailed sea eagle (*H. albicilla*), the bald eagle's closest relative, which occurs in both maritime and continental Eurasia (Brown and Amadon 1968, Murphy 1979, Amadon 1983). The bald eagle (*H. leucocephalus*) was once thought to be the only sea eagle inhabiting North America; however, a pair of white-tailed sea eagles recently (1982) attempted to breed on Attu Island in the Alaskan archipelago (Amadon 1983, Tobish and Balsh 1987). Stellar's sea eagles (*H. pelagicus*) also occasionally travel to the Alaskan coast from Asia; likewise, bald eagles sometimes wander into northeast Asia (Stalmaster 1987).

According to Gerrard and Bortolotti (1988), when Europeans first arrived in North America, the bald eagle was believed to have "nested on both coasts and along every major river and large lake in the interior from Florida to Baja California in the south and from Labrador to Alaska in the north." The species bred in what is now every state and province in the United States and Canada (except Hawaii). On 20 June 1782, the bald eagle was officially adopted as the symbol of the United States of America.

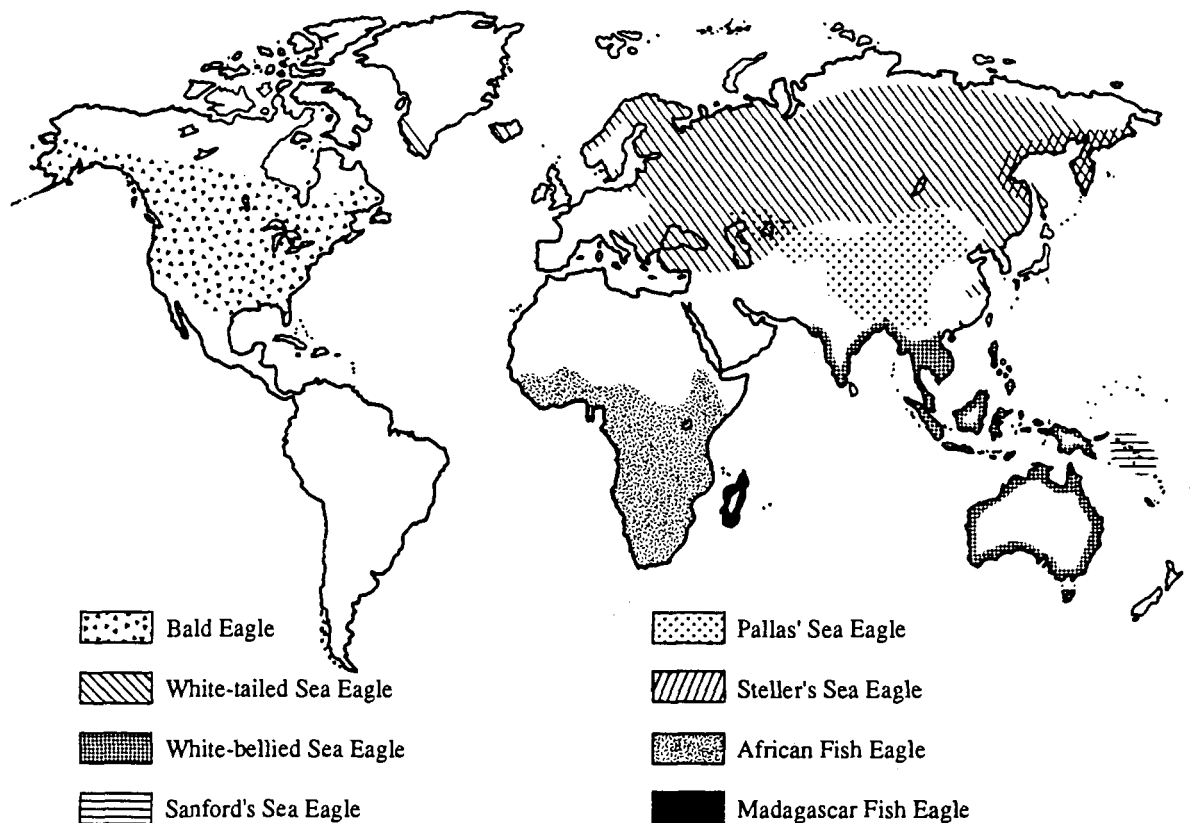


Figure A2.0-1. Worldwide distribution of the eight sea eagles, genus *Haliaeetus* (redrawn from Stalmaster 1987).

Seventy years later, bald eagle numbers had radically declined throughout most of the United States as a result of human persecution. Widespread shooting for feathers and trophies led to the extirpation of eagles from some areas (Gerrard and Bortolotti 1988). Not only were eagles shot, but their prey base was also greatly reduced. Populations of big game animals (*e.g.*, bison), which may have been seasonally important to eagles as carrion, were decimated, as were waterfowl. Large-scale control of predatory animals (shooting and poisoning for bounties paid by the U.S. Government) in the early 1900s decreased eagle numbers even further. While eagles were not necessarily targeted, they ate strychnine-laced carrion intended to kill wolves, coyotes, and other predators. The government even placed bounties on bald eagles in the unfounded belief that they threatened salmon fisheries. A bounty program in Alaska from 1902 to 1952 resulted in the death of about 150,000 bald eagles (Stalmaster 1987). The Bald Eagle Protection Act (U.S. Congress 1940), passed in 1940, reduced some of the eagle killing, but livestock raisers and others continued to kill eagles over much of North America.

Even more serious difficulties began for bald eagles in 1946 when the highly persistent pesticide DDT, developed during World War II to control mosquitoes, was introduced to agriculture. Widespread declines of bald eagles, peregrine falcons, ospreys, and brown pelicans were attributed primarily to DDE, a stable metabolite of DDT, which reached eagles in magnified proportions via the food chains. DDE collected in the fatty tissues of adult bald eagles, inhibiting the metabolism of calcium during egg formation. The resulting thin-shelled eggs tended to break under the weight of the incubating adults.

The abrupt impact of DDT on bald eagle productivity was well documented by Charles Broley, who had been monitoring reproduction in the Florida population since 1941. Nest success was about 85 percent in 1946, but declined steadily to 14 percent by 1952. By 1958, Broley could find only three successful nests compared to 125 nests in pre-DDT years (Broley 1947, 1950, 1958).

The decline in bald eagle numbers across North America prompted the USFWS to list southern populations of the bald eagle as endangered in 1967, under the Endangered Species Preservation Act of 1966. Bald eagles nesting above 40°N Latitude were not listed until after the Endangered Species Act was passed in 1973, when surveys revealed that populations there were also declining. By 1978, the bald eagle had been listed as endangered in all of the lower 48 contiguous states except Washington, Oregon, Minnesota, Wisconsin, and Michigan, where they were listed as threatened (U.S. Fish and Wildlife Service 1990b).

The great reductions of raptor and brown pelican populations led to expanded research into pesticide contamination, an effort with its roots in the now celebrated conference on peregrine falcon declines held in Madison, Wisconsin in 1965 (Hickey 1969). These and other studies led to a virtual ban on DDT in Canada in 1969, and seriously restricted use in the United States by 1973. As a direct result of these rulings, bald eagle populations slowly began to recover. The number of known occupied territories doubled between 1982 and 1990 when they were reported nesting in all but five of the 50 United States (Figure A2.0-2). Recently, the USFWS has initiated procedures to delist the bald eagle or downlist it to "threatened" over much of its range (U.S. Fish and Wildlife Service 1990b).



Figure A2.0-2. Numbers of known occupied bald eagle territories in each of the lower 48 United States in 1982 (1,482) compared to 1990 (3,014). 1982 data from Stalmaster 1987. 1990 data from Chuck Kjos, USFWS bald eagle coordinator, Minneapolis, MN (pers. comm.). In some states the observed increase has resulted from the release of captive stocks.

A2.1 BALD EAGLES IN ARIZONA

Observations of bald eagles in Arizona are mentioned in the literature from as early as 1866 by Coues in the vicinity of Fort Whipple (now Prescott), and in 1875 by Henshaw south of Fort Apache. Bald eagle bones dated from 700 to 1300 A.D. were found in the Wupatki Pueblo (Wupatki National Monument) along the Little Colorado River near Grand Falls (Hargrave 1939). These remains suggest bald eagles may have been present in Arizona for centuries, although it is possible that the bones resulted from trading with other regions.

The first bald eagle breeding information was recorded by Edgar A. Mearns (1890): "A pair of these birds has bred for many years past in a pine tree near Stoneman Lake." Bent (1937) reported breeding at Fort Whipple in 1866 and on the Salt River Bird Reservation, which was inundated by Roosevelt Reservoir in 1911 (Salt River Project Archives). Bent also mentioned the possibility of bald eagles occurring as far south as Central Mexico. Jenks and Stevenson (1937) reported nests along rivers in the

White Mountains, and Phillips *et al.* (1964) reported nesting in currently occupied breeding areas along the Salt and Verde rivers as early as 1930. We provide further information and discussion of the historical record in Sections D3, D4, and D5.

Although historical data are now available on many breeding areas prior to 1970 (see sections C2, D3, and D4), the agencies knew of only two nest sites in that year, both on the lower Verde River near Phoenix. Duane Rubink's (USFWS) nest surveys began in 1972, and by 1974 eight breeding areas had been discovered (Rubink and Podborny 1976). As nest search flights explored more inaccessible reaches of the Salt and Verde rivers and their tributaries, the number of known breeding areas in Arizona grew to 12 by 1979, 18 by 1984, and 28 by 1989, these occurring on five drainages (Figure A2.1-1). The chronology of events in the breeding cycle of Arizona bald eagles is shown in Figure A2.1-2.

The development of current knowledge on breeding and productivity of bald eagle pairs in Arizona has resulted from the efforts of a great many people. Sections C2 and D3 provide details of the contributions of these researchers and the Arizona Bald Eagle Nestwatch Program.

The rapid increase in the number of known bald eagle breeding areas in Arizona (Figure A2.1-3) was partly the result of increased nest search effort, and, in some cases because of the founding of new territories (see Section A5). Some sites were reported occupied by adults prior to their discovery by management agencies (see Section D4), and many contained multiple nests, some very old, bleached by the sun, and dilapidated. We entered some of these nests for measurement and collection of prey remains, and found old eggshell fragments, suggesting that the sites had been active prior to our knowledge of their existence (see Section A5). Although tree nests often fall (or are blown out), with few exceptions, cliff nests in Arizona have remained in place since their original discovery; several nests present in the 1930s are still being used in the 1990s.

Since 1970, productivity of the Arizona population, expressed as the number of young per occupied nest (Postupalsky 1974), has fluctuated from zero in 1972 to 1.60 in 1981. However, by comparing productivity over five year periods a more stable picture appears, with values ranging from 0.85 to 1.11 (Table A2.1-1). Over the 21 year period, 1970–1990, 226 known eaglets fledged, an average of 10.8 young per year.

Table A2.1-1. Trends in bald eagle reproductive success in Arizona during 1970–1989.

| Period | Breeding Areas ¹ | % Nest Success | Mean Brood Size | Productivity |
|-----------|-----------------------------|----------------|-----------------|--------------|
| 1970–1974 | 8 | 72.2 | 1.54 | 1.11 |
| 1975–1979 | 12 | 53.8 | 1.57 | 0.85 |
| 1980–1984 | 18 | 54.8 | 1.85 | 1.01 |
| 1985–1989 | 28 | 56.1 | 1.60 | 0.90 |

¹ Number of known breeding areas at end of five-year period.

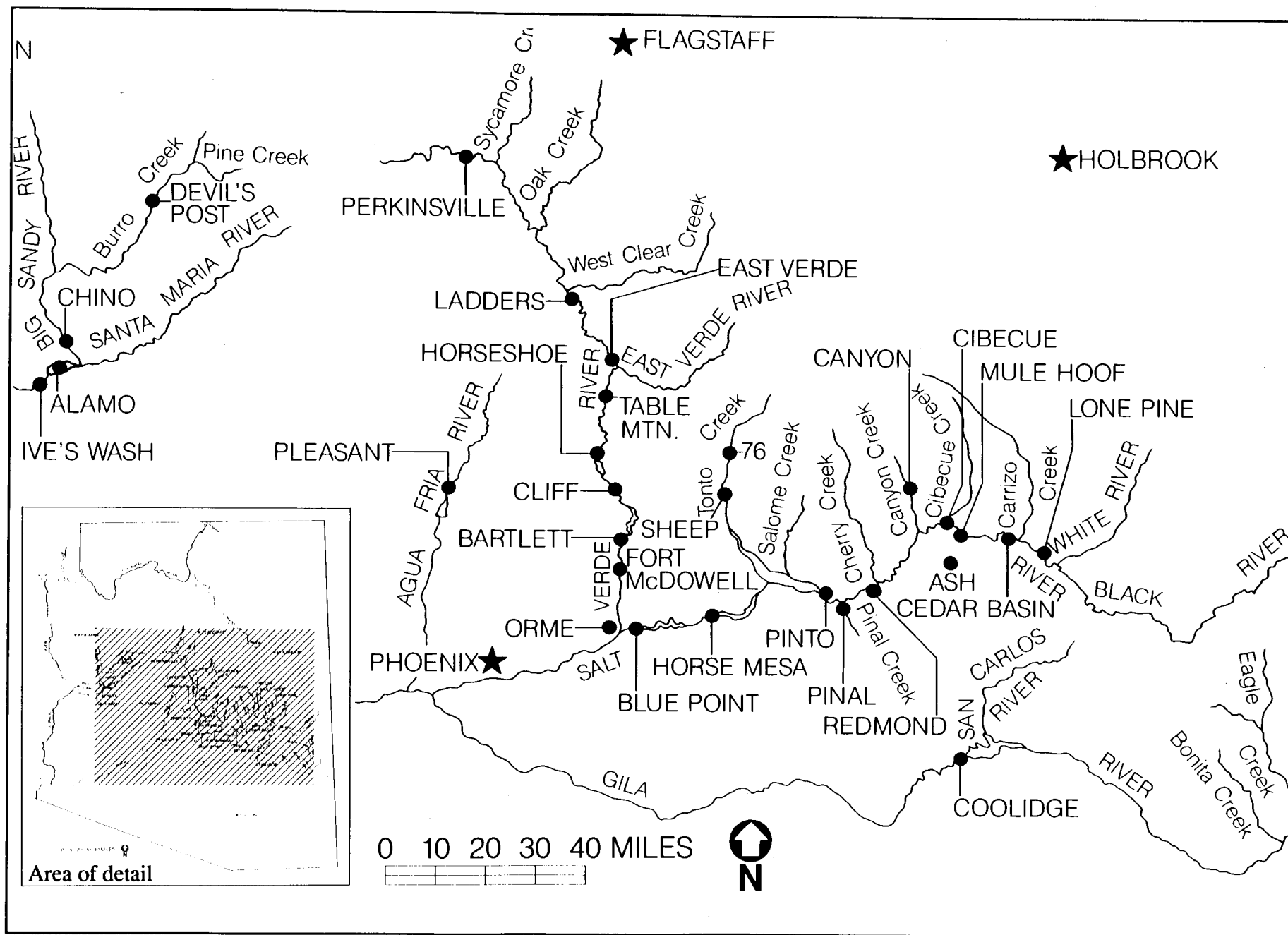


Figure A2.1-1. Known bald eagle breeding areas in Arizona.

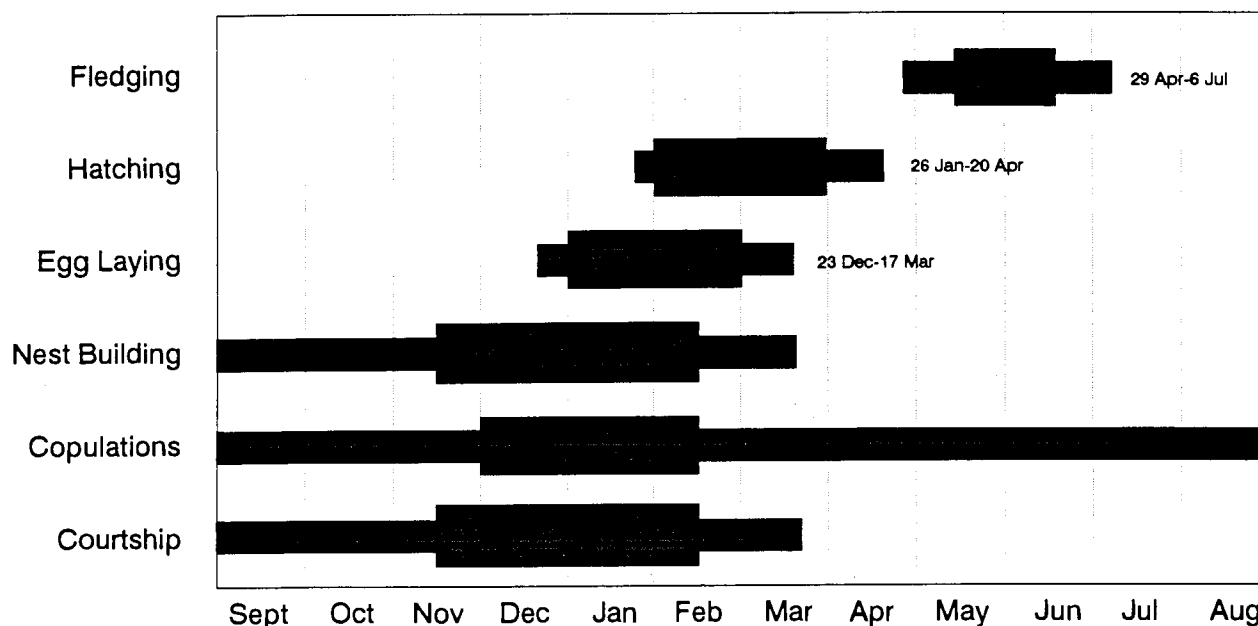


Figure A2.1-2. Nesting chronology of bald eagles in Arizona. Wide bars indicate peak activity periods.

Stalmaster (1987) reported that successful bald eagle nests contain an average of 1.6 young. The mean brood size (number of young per successful nest) for the Arizona population from 1970-1990 was 1.65, equal to the average of other populations. During this same period, mean productivity in Arizona per occupied site was 0.90 eaglets. This value, too, is equal to the average productivity for other populations throughout North America (0.92 young, Stalmaster 1987).

Throughout North America, 50 percent of broods contained one eaglet, 46 percent two eaglets, and 4 percent three eaglets (Stalmaster 1987). Of 162 broods produced in Arizona, 38 percent consisted of one eaglet, 53 percent 2 eaglets, and 9 percent 3 eaglets. Thus, Arizona eagles produced 12 percent fewer one-eaglet broods, 7 percent more broods with two young, and 5 percent more broods with three young than other populations.

Yearly nest success, expressed as the percentage of occupied nests producing young (Postupalsky 1974), has fluctuated from 0-100 percent from 1970 to 1990. Again, by comparing data over five year periods, nest success appears more constant, ranging from 53.8 to 72.2 percent (see Table A2.1-1). The relatively high nest success from 1970-1974 (72%) may be due to sampling error arising from the low number (2-5) of known nests during this period. Nest success for the remaining three periods (1975-1979, 1980-1984, 1985-1989) was more stable (53-56%). Mean nest success over the twenty year period (1970-1989) was 56.6 percent, roughly equal to the mean for populations throughout North America (58 percent - reported by Stalmaster 1987).

The rate of nest occupancy is yet another means by which to compare the performance of Arizona eagles with other populations. Occupancy rates may be a measure of habitat stability (Newton 1979); for example, rough-legged hawks do not breed in years (or areas) of food shortage, while peregrines, with far more varied and stable diets, tend to occupy eyries year after year. Of 295 known nest-years for

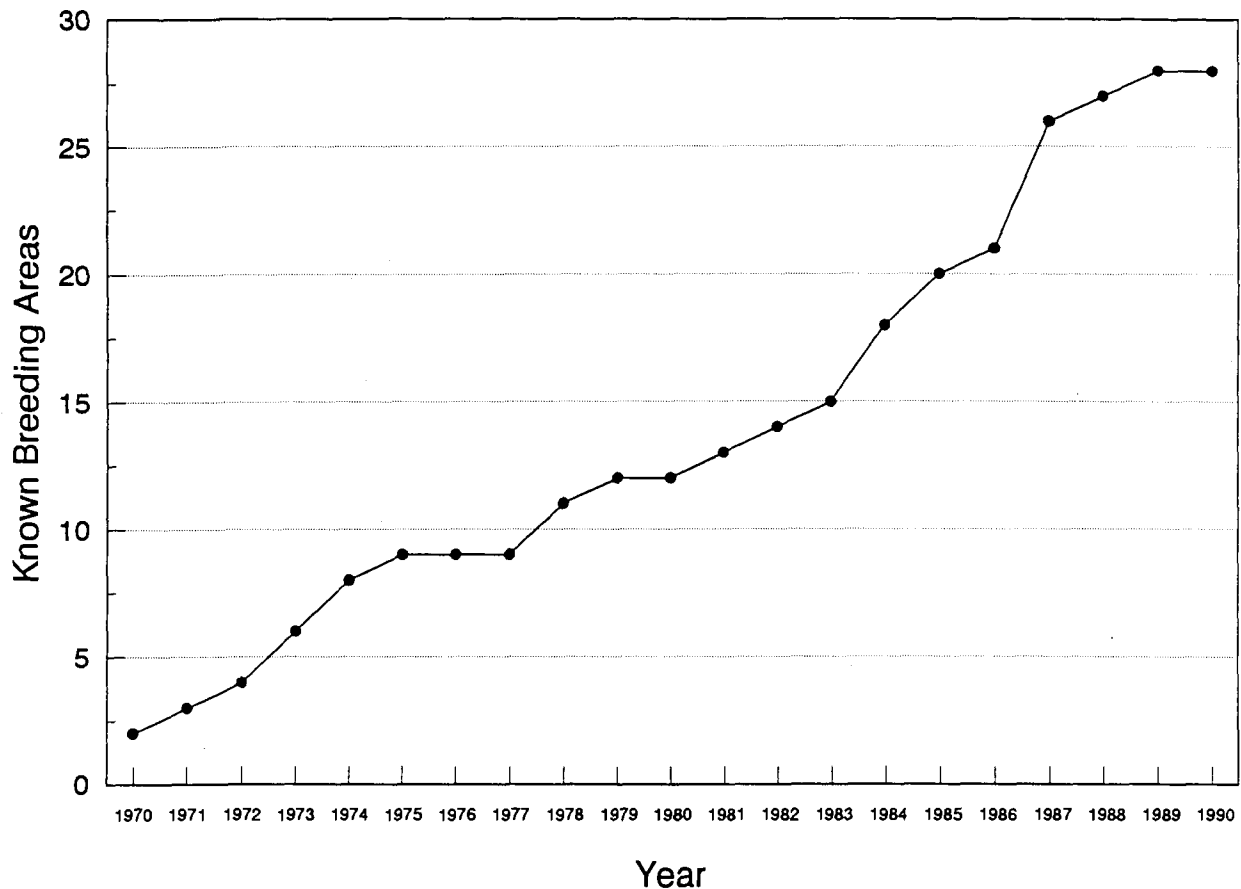


Figure A2.1-3. Number of known bald eagle breeding areas in Arizona, 1970-1990.

Arizona bald eagles from 1970-1990 (number of known breeding areas times number of years), only 15 percent were unoccupied; 85 percent were occupied, 73 percent were active (laid eggs), and 46 percent successfully fledged young. This *occupancy* rate was 14 percent higher than the 71 percent noted by Stalmaster (1987) for North America. Similarly, Arizona nests were *active* 5 percent more than the average for other populations (68%), and were *successful* 3 percent more often (43%, Stalmaster 1987).

Whether or not the population of bald eagles in Arizona followed the continental pattern of decline during the DDT era will probably never be known because consistent records of occupancy and reproduction in the state were not kept until 1972 (see Part D). However, DDT was applied extensively to cotton and vegetable crops prior to the ban in 1973, and Hunt *et al.* (1986) pointed out that the highest DDE levels recorded during the 1967-1979 National Starling Monitoring Program were from Maricopa, Arizona and Chaves, New Mexico. Moreover, DDT was (and is still) used in Mexico, creating a source of contamination for waterfowl passing through Arizona, as well as for juvenile and subadult eagles venturing into Mexico following their return from northward migrations (see Section A4).

However, it is also possible that DDT use on agricultural crops did not have as serious and direct an impact on breeding bald eagles in Arizona as in other regions. Many nests are located on free-flowing streams in very rugged terrain, unsuitable for agriculture. Cotton is grown mostly outside (downstream)

of the known bald eagle breeding range, in the dry region southeast of Phoenix. Thus, there would be relatively little opportunity for agricultural chemicals in runoff to enter streams and reservoirs used by breeding adults (although crops are grown in the Verde Valley and near the town of White River).

While it is unlikely that prey fish would be strongly contaminated, contamination problems may have existed with waterfowl, often taken in winter near reservoirs (BioSystems 1985). In the migrations and wanderings of certain waterfowl species, significant levels of DDE may accumulate. Eagle pairs nesting on free-flowing reaches upstream of the reservoirs take waterfowl less frequently, and may have fared better during the DDT era. However, the younger bald eagle age classes (1-4 years old) probably encounter DDE during their extensive travels before settling down to breed (see Section A4). Our studies show that some young eagles utilize reservoirs for extended periods where waterfowl congregate. However, others are attracted to more remote settings, e.g., free-flowing rivers, tributaries, and even rangeland.

In summary, we cannot know whether the Arizona bald eagle population was reduced by agricultural chemicals, indeed, whether it was reduced at all. Table A2.1-1 suggests that nest success, mean brood size, and productivity have remained stable at a level consistent with that of healthy populations today, even in the early 1970s when other bald eagle populations were still declining (Stalmaster 1987). Although the number of known pairs in the early 1970s was very low (there were only two in 1970, three in 1971, four in 1972, six in 1973, and eight in 1974; Rubink and Podborny 1976), we will never know to what extent the subsequent increase in the number of known pairs resulted from greater effort toward finding nests. In Section A5 we shall discuss several cases in which pairs have appeared in areas where we are reasonably certain that bald eagles had not recently nested.

In addition to the breeding population, Arizona receives an inflow of migrant eagles from northern states and provinces in the winter. It has been suggested that wintering bald eagles from the north select different habitats than those occupied by Arizona breeding pairs (Grubb and Kennedy 1982). For the most part, our data are in agreement, but we have telemetric data that native Arizona eagles occasionally use the lakes on the Mogollon plateau where northern migrants may concentrate. Moreover, we captured and measured eagles on the Verde River in the vicinity of an active breeding area that were apparently of northern origin (see Section A4 and C5 for details).

A2.2 NESTING HABITAT

Our study has focused on a landscape greatly altered by human activity. Cattle grazing, particularly in the late 1800s, eliminated ground cover (including many grass species) and resulted in catastrophic erosion over most of Arizona. Arroyos cut into uplands and intersected the water table, creating drier soil conditions and draining cienegas and marshes. The rivers became muddy torrents following rains, carrying eroded soil downstream, cutting deeper channels, adversely impacting fish populations, and destroying vast riparian forests, leaving the widely scattered groves and lines of trees along the streams we see today. Overgrazing continues in upland and riparian habitats of Arizona, and regeneration of riparian tree species has been almost entirely eliminated. Detailed descriptions of the changes in Arizona habitats are presented in Section D2.

The effects of widespread erosion increased Arizona's need for water storage, irrigation, and flood control (Hayden 1965). The large impoundments created in the early part of this century on most of the

major rivers altered the habitat for bald eagles in both positive and negative ways. Although large reaches of riparian vegetation were inundated, the dams stored water which otherwise would have rushed downstream at a highly unnatural rate. The dams have created habitat for waterbirds and a number of exotic fish which eagles breeding near the reservoirs now exploit. Remnant groves of riparian trees still exist where free-flowing rivers enter reservoirs.

Nine (32.1%) of the 28 currently known bald eagle breeding areas in Arizona are located in the Upper Sonoran Life Zone, 15 (53.6%) are in the Lower Sonoran Life Zone, and four (14.3%) are in the transition area of both zones (see Section D2, Lowe 1964, Brown 1982). Riparian habitats in these regions are composed of the Sonoran Riparian Deciduous Forest and Woodlands Biome, the Sonoran Riparian Scrubland Biome, and the Sonoran Interior Strands Biome. The uplands in the Lower Sonoran Life Zone are all within the Sonoran Desertscrub Biome, with species composition of the Paloverde-Cacti, Jojoba, and Creosotebush-Crucifixion-thorn Mixed Scrub Series. In the Upper Sonoran Life Zone, vegetative composition near bald eagle breeding areas includes Great Basin Conifer Woodland, Interior Chaparral, and Semidesert Grassland Biomes (see Section D2 for details).

The aquatic habitats associated with Arizona bald eagle breeding areas are variable in character, and we will show that these variations have a large effect on the types of prey which are available and the conditions of their acquisition by eagles. Of the 28 known breeding areas, five (17.9%) contain regulated rivers as well as reservoirs, two (7.1%) have only regulated rivers available for foraging, one (3.6%) has a reservoir only, six (21.4%) contain free-flowing rivers as well as reservoirs, nine (32.1%) have free-flowing rivers only, and five (17.9%) are on free-flowing creeks. Data on prey selection in these various habitats are presented in Sections A3.1 and B5, and a comparison of nest success and productivity between the settings is given in Section A3.5.

Bald eagles in Arizona nest on cliffs and in trees. Of the 111 known nests within the 28 breeding areas, 36 were on cliffs, 17 on pinnacles, 46 were in trees, 11 in snags, and 1 was built on an artificial nesting platform (see Section C2.2). Busch (1988) commented that "Although potential cliff nest sites appear to be abundant in Arizona and New Mexico, the bald eagle's proclivity toward tree nests throughout its range may indicate that cliff nests are only marginally suitable." However, in Arizona we found that at breeding areas where both cliff and tree nests were available, eagles selected cliffs in 73 percent of the 111 cumulative years of data on active nests, and trees 27 percent. Assuming an equal opportunity of the eagles to choose a tree or cliff nest in these territories, the selection of cliffs over trees was highly significant ($\chi^2 = 11.4$, $df = 1$, $p < 0.001$) (see Section C2.2).

Although eagles nesting on cliffs were slightly more successful than those in trees, the difference was not significant by Chi-Square; of 149 clutches laid in cliff nests, 97 (65%) were successful, while 41 of 72 tree nest clutches (57%) were successful. The advantages of cliff nests appear to be substrate stability and security, while the disadvantages may include greater heat stress (direct, reflected, conducted, and radiated) and parasites (Mexican chicken bugs). Live trees may, on average, offer more shade and they appear to lack Mexican chicken bug infestations, but eagles nesting in trees are more susceptible to disturbance from the ground and from inundation during floods. Snag nests, while lacking shade, probably offer more convective cooling than cliffs, and may, on average, receive less radiation from heated substrate. We discuss these points further in Section C2.

Arizona bald eagles have built 57 known nests in six tree species. Most tree nests were in Fremont cottonwoods (68%, $n = 39$), followed by Goodding willows (14%, $n = 8$). Four nests occurred in



Plate A1. Nestling bald eagle (8.5 weeks old) at the Orme breeding area, April 1988 (photo by D. Driscoll).

ponderosa pines (7%), four in Arizona sycamores (7%), one in a pinyon pine (2%), and one in a juniper (2%). Among the 11 snag nests, seven were in cottonwoods, two in willows, one in a pinyon pine, and one in a juniper.

Nests we measured in trees or snags were most often situated within linear rows of trees ($n = 9$), with 2 in groves, and 2 in isolated trees. Mean distance to the closest large tree or snag was 13 m (range = 1-43 m). Live trees containing eagle nests averaged 55 percent canopy cover, ranging from 0-100, although nests were also placed in snags with no shade available (see Section C2.2). Nest tree height averaged 21 m, with the nest placed 16 m above the ground in trees or snags with a mean DBH (diameter at breast height) of 85 cm (range = 47-126 cm). Tree nests were placed on limbs ($n = 8$) as well as on

the bole ($n = 5$), with a mean diameter of 30 cm (range = 20-43 m), and three or four supporting branches averaging 16 cm in diameter and 115 cm apart. These data and those summarized elsewhere in this section are on file at Reclamation in Phoenix.

Bald eagles built 53 known nests on cliffs or pinnacles. We tried to detect a trend in nest aspect in a sample of 40 of these sites, having removed from the sample one which was artificial, one we were unable to examine, and 11 which were located on the tops of pinnacles with a 360° view. Of the remaining 40 cliff and pinnacle nests considered in Figure A2.2-1, we found no significant departure from random aspect by Chi-square analysis. We speculate that if a preponderance of west-, east-, and north-facing cliffs were to prevail in a larger sample, the reason would be that, in spring, the duration of direct sunlight is lower than on south-facing cliffs, and the average resultant angle of solar incidence is higher, resulting in lower temperatures (see Section C3 for temperature measurements at nest sites). Nests we measured were placed in areas receiving partial shade most often ($n = 26$), followed by no shade ($n = 11$), then full shade ($n = 6$).

Nests we measured on cliffs were located on the cliff face ($n = 12$) as well as on top ($n = 3$), on ledges with a mean diameter of 205 cm (range = 55-600 cm). Nests were placed an average of 80 m above the ground (range = 27-130 m) on cliffs averaging 95 m in height (range = 50-155 m) and 373 m in length (range = 10-600 m).

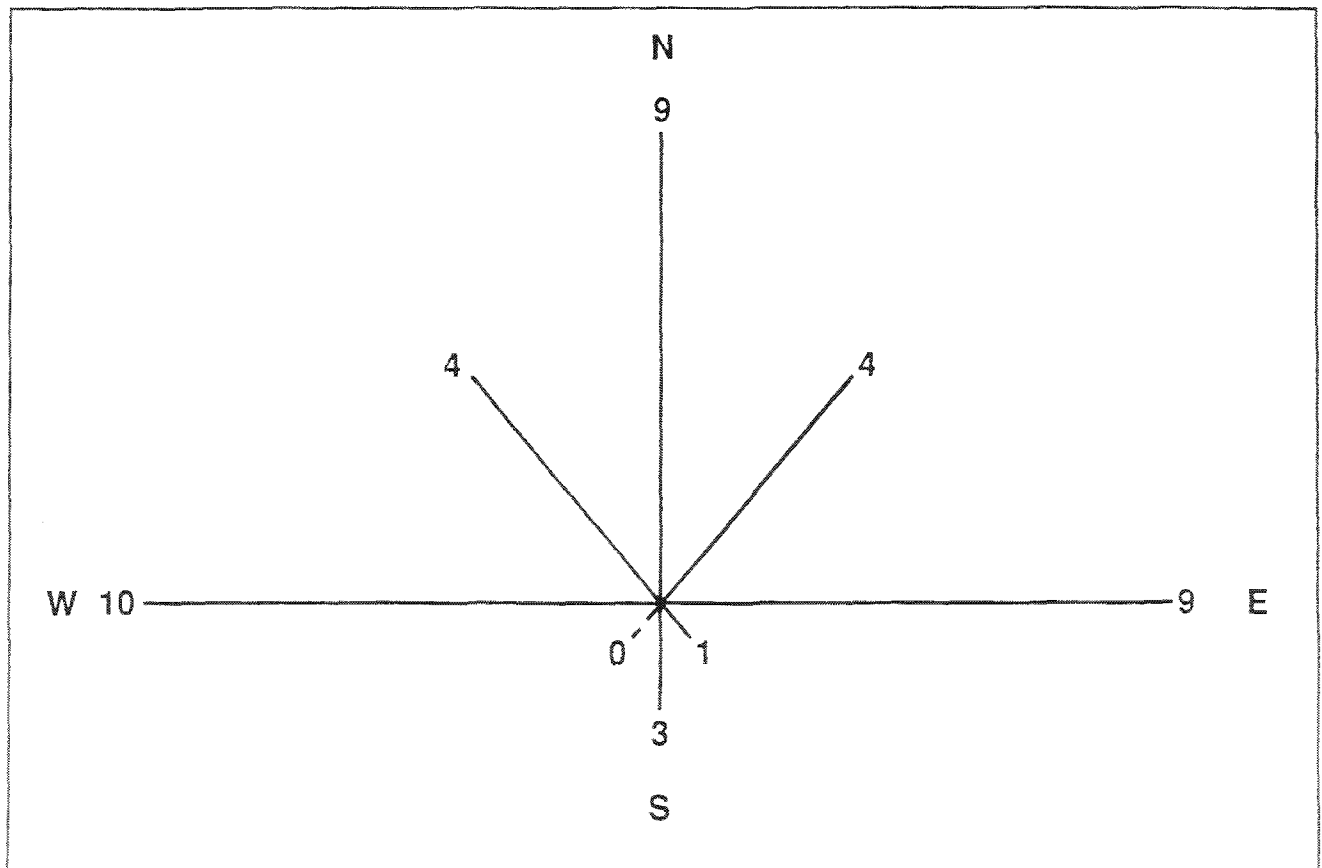


Figure A2.2-1. Aspect of bald eagle cliff nests in Arizona.

Nests on pinnacles were either on the pinnacle top ($n = 5$) or the face ($n = 3$), and the nesting ledges had a mean diameter of 240 cm (range = 86-508 cm). Nests were placed an average of 92 m above the ground (range = 20-180 m) on pinnacles 100 m in height (range = 20-180 m) and 10 m in length (range = 1-20 m). Nests were placed on free-standing pinnacles ($n = 4$) as well as pinnacles connected to cliffs ($n = 5$). Distance from pinnacles to the nearest cliff averaged 99 m, ranging from 1 to 400 m.

When the pinnacle was part of a cliff, the mean distance from the pinnacle to the cliff was 7 m (range = 1-15 m), with the nest located 30 m from the top of the cliff (range = 7-50 m), on cliffs averaging 920 m in length (range = 100-2400 m).

We collected details on nest site characteristics at 32 individual Arizona bald eagle nests we entered for the collection of prey remains and eggshell fragments after the young had fledged. The smallest nest (Coolidge 3, a cliff nest) measured 84×68 cm (2.8×2.2 ft), while the largest nest (Orme 3, a cliff nest) measured 2.9×2.4 m (9.5×7.8 ft). The nest of greatest depth (Bartlett 1) was wedged between a cliff and a pinnacle, spanning 4.8 m (15.8 ft) from top to bottom. Two nests on pinnacle tops (Orme 1, Cliff 4) were merely a few sticks arranged in a circle, with some crushed vegetation and dirt in the center. The mean diameter of the 32 nests (128 measurements) was 156 cm (range = 49-289 cm), with the soft inner-nest lining averaging 75 cm (range = 13-167), and egg bowls 19 cm (range = 10-30 cm). Egg bowl depths averaged 9 cm, depth from the nest rim to the center of the nest 13 cm, and the mean depth of the nest structure was 77 cm, ranging from 7 cm to 4.8 meters.

Arizona bald eagle nests are unusual in that many of the species of woody plants and trees utilized for nest construction are unique to the desert environment. We found 22 species which were used to form the main nest structures, including the inner skeletons of teddybear cholla and cane cholla, saguaro cactus ribs, prickly-pear pads, the stalks of yucca, sotol, and agave, ocotillo, crucifixion-thorn, jojoba, paloverde, mesquite, scrub oak, brittlebush, juniper, ash, cottonwood, sycamore, willow, cherry, ponderosa pine, and pinyon pine. In addition, we recorded a variety of species which were utilized for nest lining. Plants included sorghum (heads and stalks), corn (husks, cobs, and kernels), sotol (base leaves and the stringy fibers), various grasses, shredded inner bark of cottonwood, horsetail, mistletoe, ferns, yucca, smartweed, sedges, moss, and the needles of juniper and pine. We also found live hedgehog cactus, prickly-pear cactus, and jojoba bushes growing in the nests. The most common species utilized for nest sticks was Fremont cottonwood, followed by mesquite, juniper, palo verde, sotol, cane cholla, and ocotillo. The width of nest sticks ranged from 1-195 cm, with 320 randomly selected sticks averaging 19 cm.

Habitat surrounding the nest also varied, with 11 nests in desertscrub habitat, 10 in desertscrub adjacent to riparian areas, 7 in riparian habitat, 5 in juniper-oak scrub, and 3 in pine-cedar habitat. Nests we measured were equally distributed between canyons ($n = 18$) and open country ($n = 17$), and two were on mountains. The mean distance from 36 nests to water was 200 m, ranging from 0 to 1800 m.

A3 ECOLOGY AND HABITAT OF FORAGING BALD EAGLES

Bald eagles are known for their diverse ways of food acquisition, a quality that accounts for their wide distribution in North America and their success in a large variety of habitats, both at nesting territories and on wintering grounds. They are competent hunters of all the vertebrate classes and even take invertebrates (Hawbecker 1958, Grubb and Coffee 1982, Vermeer and Morgan 1989, Knight, *et al.* 1990). But the primary (and preferred) food of the eagles over most of their range is fish, which tend, on average, to be twice as numerous as birds (mainly waterbirds) and four times as abundant as mammals in the diet (Stalmaster 1987).

Bald eagles: (1) catch live prey; (2) steal prey items from other predators, especially ospreys; and, (3) find carrion. All three of these foraging modes are typically and commonly employed by eagle pairs during the nesting season. In winter, eagles not attached to nesting territories may concentrate in areas where fish or waterfowl carrion is plentiful. In general, juvenile and subadult eagles are far more likely to take carrion than live prey, but adults take significant amounts of both.

In our experience, nesting bald eagles are always within foraging range of water, be it maritime, a lake or reservoir, or a river. If a nest site is situated very far from water, it is likely that mature trees or other acceptable nesting substrate is unavailable nearer shore, or that human disturbance has driven the eagles away. Close proximity of perches (and nests) to water is advantageous in providing foraging opportunity without the physiological cost of remaining airborne (see Stalmaster and Gessaman 1984). Not surprisingly, in our current study of foraging eagles, the vast majority of attacks on prey were launched from perches from which prey appeared to have been seen before flight (see Section B4).

In Arizona, bald eagles nest exclusively near stream courses, including those where flows are dammed and regulated. Eagles at about half the nesting territories are within foraging range of a reservoir, while the remainder depend entirely on riverine habitats for water-related foraging. Of the 16 territories beyond foraging range of reservoirs, 9 are on free-flowing rivers, 5 are on creeks, and 2 are on a regulated river reach. Of 12 breeding areas within foraging range of a reservoir, 6 contain free-flowing reaches, 5 contain regulated reaches, and 1 has only reservoir habitat.

In this section, which summarizes and discusses the main points of our studies of foraging ecology, we will show differences among habitat settings in bald eagle prey selection, home range, and habitat use. These results can be used to evaluate the significance of water projects to bald eagles and may apply to habitat protection and management of Arizona eagles and those in other regions that nest along rivers and impoundments. Material for this discussion derives mainly from the detailed foraging and habitat studies of the seven breeding areas described in Part B. Added to these findings are analyses of prey remains we collected at 23 eagle nests active in Arizona during 1986-1989.

We then summarize ecological and life history characteristics of prey fish which contribute to their availability to eagles. We contrast the relative importance of rivers and reservoirs as eagle foraging habitat, and discuss the way in which live fish and carrion become available to eagles in reservoirs. We compare use rates of river habitat types (see Glossary) by eagles with the relative abundance of the habitats within breeding areas, and discuss the conditions under which the eagles are able to exploit the various prey species. We summarize our data on microhabitats (see Glossary) at the points where eagles attacked live fish and explain why certain river habitats attract prey fish. Finally, we describe the home

range movements of foraging adult eagles and relate the extent of these movements to prey occurrence and the particulars of habitat.

A3.1 PREY SELECTION AND HABITAT SETTING

A preponderance of fish in the diets of bald eagles has been reported throughout their range in North America by numerous authors. In Florida, for example, McEwan and Hirth (1980) found bald eagles preying mostly on catfish and American coots; fish represented 70 percent of the calculated biomass, and birds accounted for 26 percent. Dunstan and Harper (1975) reported Minnesota bald eagles consuming primarily fish; 90 percent of total individuals identified as prey were fish. Bullheads, taken as carrion or near the surface in shallow water, along with suckers and northern pike captured during spawning runs, constituted the majority of fish found in the Minnesota prey remains. Minnesota eagles preyed somewhat upon birds (mostly ducks, 8% of total individuals); however, they rarely consumed mammalian prey during the breeding season. Bald eagles nesting on Besnard Lake, Saskatchewan fed on fish almost exclusively during nesting (Gerrard and Bortolotti 1988). The Besnard Lake eagles exploited many fish as carrion, but apparently also took live, surface-feeding cisco and stream-spawning white sucker and northern pike.

In another study, we reported that Sacramento sucker contributed the greatest biomass to the diets of bald eagles nesting along reservoirs and river reaches of the Pit River in northern California (BioSystems 1985, Hunt *et al.* 1992c). Waterbirds were frequently taken during winter months, and mammals were least important. Suckers were taken as carrion in reservoirs, apparently floating downstream after spawning in river sections. We also observed eagles capturing live suckers in shallows adjoining pools in the river reaches. We also found Sacramento suckers to be important to bald eagles nesting elsewhere in northern California, along with carp, bullhead, coot, mallard, and trout (Pacific Gas and Electric Co. 1988). Several pairs nested on reservoirs dominated by hatchery trout; however, waterfowl and nongame fish supplemented trout in the eagles' diets. Trout were taken both alive and as carrion.

Swenson *et al.* (1986) observed that the diets of bald eagles nesting in the diverse Greater Yellowstone Ecosystem varied in relation to food availability. Eagles nesting on lakes (e.g., Yellowstone Lake) fed mostly on birds (68% of individuals were coots and mallards), while pairs nesting on the Snake River used mainly fish (57%), principally Utah sucker and Utah chub. Todd *et al.* (1982) found that fish comprised 79 percent (numerically) of food items collected from bald eagle nests in the interior of Maine, although birds accounted for 76 percent of the diet of eagles nesting along the Maine coastline. Interior bald eagles captured mostly brown bullhead, white sucker, and chain pickerel. The coastal eagles relied on a variety of seabirds and waterfowl, chiefly black ducks and herring gulls. Knight *et al.* (1990) compared the diets of bald eagles nesting on marine ecosystems in Washington state. Although birds (primarily western grebes, common murre, and gulls) were most common in the prey remains of all regions, eagles nesting along the coast (Olympic Peninsula) apparently utilized more birds, while eagles nesting along the more protected waters of the San Juan Island and Puget Sound regions ate more fish. Mammals were significant (11% of prey numbers) only in the San Juan Islands where eagles captured old world rabbits. Eagles in Washington eagles apparently consumed several species of shellfish, including abalone (Knight *et al.* 1990).

Mersmann (1989) reported that Chesapeake Bay eagles consumed mostly fish (gizzard shad, channel catfish, Atlantic menhaden) in the spring and summer; waterfowl and deer carrion were important in the



Plate A2. Adult female bald eagle at the Cibecue breeding area, May 1991 (photo by G. Beatty).

winter. Dugoni, *et al.* (1986) noted almost equal use of birds and fish (42% each, numerically) by eagles nesting in Louisiana. Fish prey included mostly catfish (spp.); mammals contributed 16 percent of prey numbers, primarily muskrat and nutria. Sherrod *et al.* (1976) described the diet of bald eagles breeding on Amchitka Island, Alaska as avian and mammalian (seabirds and young sea otters). Fish, often brought to nests headless, may have been poorly represented in the prey remain analysis. On San Juan Island, Washington, nesting eagles consumed large numbers of carrion rabbit (Retfalvi 1965), although fish, primarily rockfish (*Sebastes* spp.), were also important.

While studying the diet of the Arizona bald eagle population, Haywood and Ohmart (1986) found significant numbers of carp, channel and flathead catfish, desert and Sonora suckers, American coot, jackrabbits, and cottontails. In an analysis of prey remains, Haywood and Ohmart reported that fish constituted 77 percent of prey numbers but only 58 percent of estimated biomass; birds represented 11 percent of numbers and 14 percent of total biomass. The occurrence of mammals in the nest prey remains (28.1% of biomass and 12% numerically), and a greater caloric contribution of mammals over fish, led Haywood and Ohmart to postulate that mammalian prey was "essential to satisfy energy demands of bald eagles breeding in Arizona."

Interior bald eagles consume many bottom-feeding fish species such as suckers and catfish. For instance, in interior Maine, bald eagles took mostly bottom-dwelling fish: 84 percent of all fish and 64 percent of all prey numerically (Todd *et al.* 1982). Maine eagles apparently caught brown bullheads in shallow water in summer and white sucker during spring spawning runs. Mersmann (1989) found that in the Chesapeake Bay, eagles took gizzard shad, channel catfish, and white and yellow perch mostly as carrion, while Atlantic menhaden were usually captured alive. The water depths at live fish capture sites were less than those recorded for carrion or for forages of unknown status. Perch and catfish were common in carrion surveys conducted on Chesapeake Bay.

The hypothesis offered by Swenson (1979) that the downward visual orientation of bottom-dwelling fish increased their susceptibility to predation was questioned by Gerrard and Bortolotti (1988). They reported that Saskatchewan eagles took more surface feeding cisco than bottom-feeding whitefish and suggested that surface feeders were thus more susceptible to bald eagle predation.

However, the difficulty of determining whether fish are captured alive or taken as carrion has confused the issue of which type of fish is most vulnerable. For example, we observed large numbers of carrion suckers and brown bullhead on the surfaces of several reservoirs in northern California (BioSystems 1985, Pacific Gas and Electric Co. 1988). Subsequent analysis revealed a preponderance of these species in prey remains collected from nests of eagles breeding on these impoundments.

Several authors have compared analyses of raptor prey remains with observations (mainly photographic) at the nest to assess the value of prey remains in correctly describing the diet. For golden eagles, Collopy (1983) found no difference when using the two methods for estimating percent occurrence or percent biomass of prey species utilized (mostly birds and mammals), although total biomass was underestimated in the prey remains analysis. Todd *et al.* (1982) reported that food debris collections made below bald eagles nests in Maine underestimated the numbers actually observed delivered to the nest, but collections from the nest bowl were more accurate at predicting frequencies of delivered prey.

From field observations, Todd *et al.* noted that fine-boned fish such as American eel and tomcod were commonly captured by eagles; however, these species were poorly represented in collections of prey

remains. These authors also detected a bias in favor of mammalian and bird remains below nests and found that, among fish remains, only stout bones were well represented. From their prey remains analysis, Dunstan and Harper (1975) also surmised that stronger-boned fish (bullheads, sucker, and northern pike) may have been over-represented compared to the weaker-boned fish such as centrarchids, walleye, yellow perch, and cisco. Further, they observed that some fish delivered to the nest were missing anterior portions and thus identifiable bones. Other small fish were eaten whole, either by the adults in flight or by young in the nest.

Similarly, Dugoni *et al.* (1986) observed 20 gizzard shad brought to nests in Louisiana; however, remains of only two were recovered in remains collected from the nests. Retfalvi (1965) compared one breeding season's nest observations with prey remains representing several years use at one of the nests and found greater occurrence of birds and fish and fewer mammals in the prey remains versus nest observations. Retfalvi hypothesized that the differences might be explained by the eagle's behavior of bringing in whole fish (with identifying bones) while larger mammals were torn apart prior to nest delivery. In another comparison between prey remains and direct observations (47 deliveries) Knight *et al.* (1990) found birds more prevalent in prey remains collected below the nest than in actual nest deliveries. Conversely, fish were under-represented in the remains collection.

A study by Mersmann (1989) compared pellets and prey remains with the actual diet fed to two captive bald eagles. When examining the pellets alone, Mersmann found a fairly accurate representation of bird and mammal species. However, medium-sized mammals were over-represented, while large mammalian carrion was under-represented, and, as expected, fish were poorly represented in the pellets. Conclusions were also reported for the prey remains comparisons, which were biased towards birds, medium-sized mammals, and large, bony fish. Catfish left the highest percent of remains compared to the actual diet (87% of actual), followed by white perch (78%), carp (73%), gizzard shad (67%), menhaden (61%), and American eels (16%). Large fish (85%) appeared in greater percentages than medium-sized fish (69%) and small fish (49%). Mersmann speculated that the degree of catfish use by bald eagles as reported from analyses of prey remains in the North American literature may be inflated as a result of this tendency, an hypothesis supported by our data in Arizona.

A3.1.1 Prey Selection in Arizona: Overview and Biases

We investigated the diet of bald eagles in Arizona using several techniques, including: (1) an analysis of the remains of 2,601 prey items collected in nests, under perches, and just after foraging events at 23 bald eagle breeding areas (Section B5), and (2) observations of 711 prey items as they were delivered to young in the nest by the six successful pairs of eagles we studied with telemetry (see Section B5 for details). In the prey remains, we identified 19 species of fish, 26 species of birds, 16 species of mammals, and 3 species of reptiles (Section B5). Averaging the biomass proportions for each of these prey classes in the remains from each nest yielded 71.4 percent fish, 18.3 percent mammals, and 10.3 percent birds (the reptile biomass contribution was negligible when considered by this method). Four groups of fish accounted for nearly 100 percent of the biomass: most important were catfish spp. (mainly channel catfish), followed by sucker spp. (desert and Sonora suckers), carp, and perciforms (mainly black crappie, yellow bass, and largemouth bass)(Figure A3.1-1). Of these fish, only the suckers are native to Arizona.

To address the question of whether prey remains adequately represent bald eagle diets in Arizona (i.e., whether skeletal parts of some species persist longer than those of others), we compared the results of prey remains collections with data on observed deliveries of prey items to the nest at the intensely studied

territories on the Salt and Verde rivers. The results of this comparison, detailed in Section B5, suggest that, although all important taxa are identified, samples of prey remains tend to: (1) underestimate suckers and perciforms, and (2) overestimate catfish, birds, and mammals. Figure A3.1-2 contrasts the results of the two methods by averaging the mean biomass calculations for the six territories over the entire nesting season, and for three territories where subsets of prey remains collections represented only the periods of prey delivery observations. The directions of bias between remains and deliveries in biomass estimations for each prey category were consistent. Later in this section, we will show a similar consistency in direction of bias for most of the taxa when compared at each of the six studied territories where data were obtained on both prey deliveries and prey remains.

In Section B5, we also describe an analysis we made (with the help of M. Jakle, T. Gatz, and the Phoenix Zoo) of prey remains from a "blind" sample of fish fed to a captive bald eagle. The outcome of this experiment supported our field data in that soft-boned fishes tended to be under-represented. For example, while eighty percent of catfish appeared in the remains, 60 percent of the somewhat softer-boned suckers were found, and only 8 percent of the very soft-boned trout were identified. Carp, being large and hard-boned, were all identified from the remains.

Obviously, prey delivery observations give a relatively unbiased view of prey selection, but only for the specific periods when deliveries are observed. While prey remains collections tend to show all taxa that were important to the eagles, there are a number of biases, including: (1) fish are likely to be under-represented while mammals and birds are over represented; (2) suckers and perciforms are likely to be underestimated; and (3) catfish are likely to be over estimated.

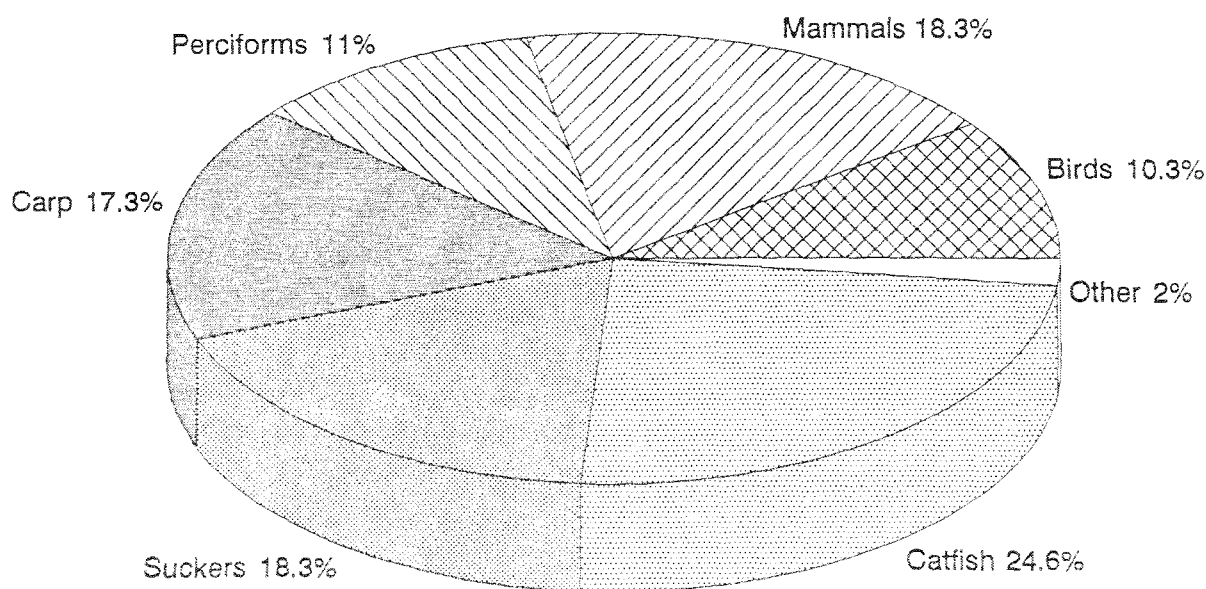


Figure A3.1-1. Relative biomass contributions to the diet of Arizona bald eagles as revealed by prey remains collections. The percentages shown are means of prey biomass contributions calculated for each of 23 bald eagle breeding areas. Biases exist here because of differences in the durability of body parts; fish tend to be under-represented in prey remains, while birds and mammals tend to be over represented.

Figure A3.1-2

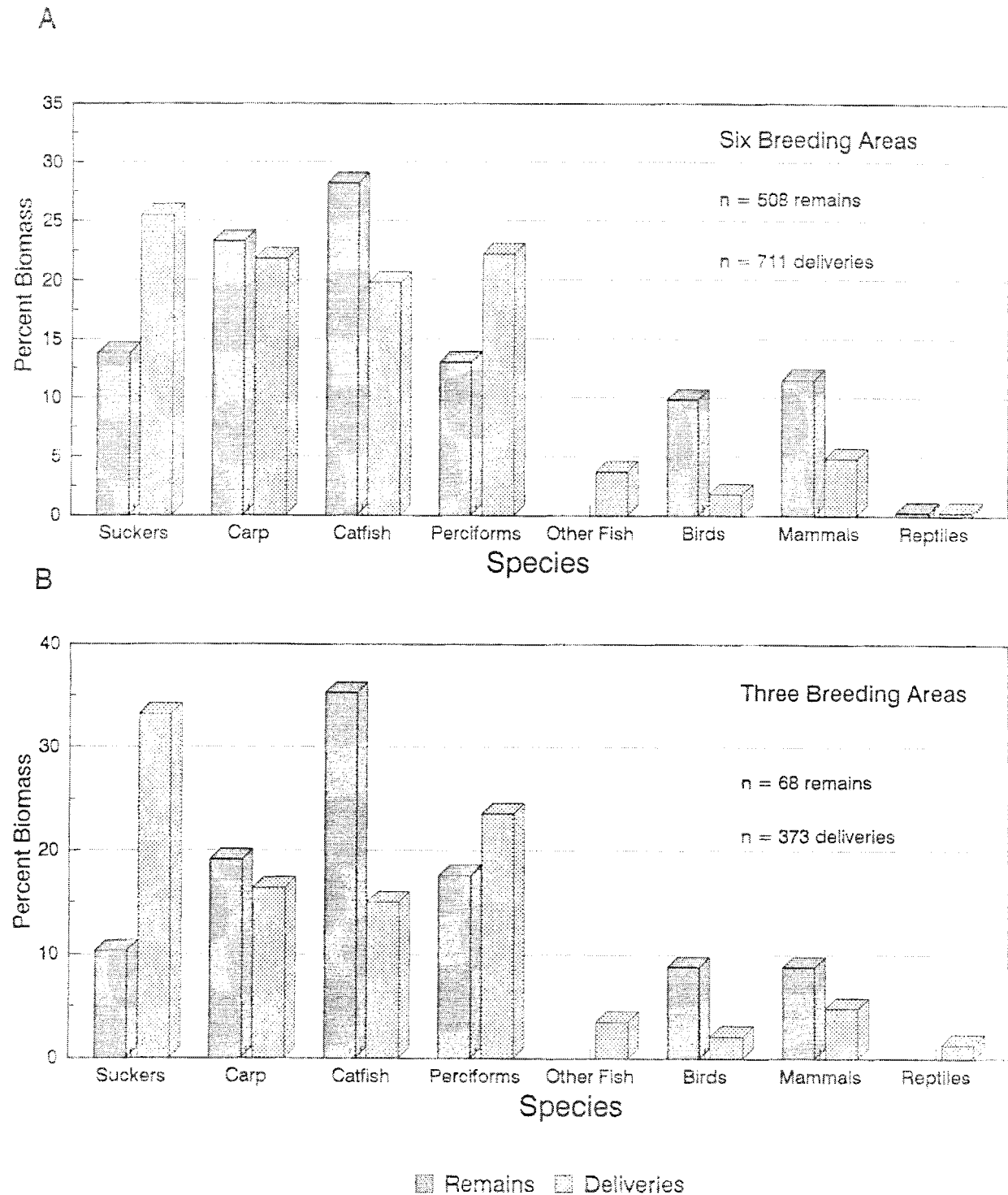


Figure A3.1-2 (a and b). Estimating bald eagle diets (biomass) with prey remains versus prey deliveries. Graph A compares results obtained at six bald eagle breeding areas where BioSystems conducted intensive foraging studies (Bartlett, Blue Point, East Verde, Horseshoe, Ladders, and Pinal). Graph A uses all prey remains collected, while Graph B considers only the time frames when prey deliveries were observed at three nests where such data were available. Note the consistency in the direction of bias.

A3.1.2 How Prey Fish Are Distributed

The diets of bald eagle pairs currently nesting in Arizona are far from uniform from a geographic standpoint, but vary rather strongly with habitat setting, largely because the varying habitats support differing relative densities of prey taxa and may present them in differing ways to the foraging eagles. The aquatic and terrestrial habitats characteristic of the various breeding territories are described in Sections B4 (for pairs studied with telemetry) and D4 (for all pairs). Factors affecting prey fish composition and density in the various habitats appear to be: (1) water temperature; (2) turbidity; (3) whether a reach is flowing or impounded; and, (4) whether it is affected by fish entering it from a nearby reservoir (see Section E2). Figure A3.1-3 diagrams how the relative percentages of suckers, carp, catfish, and perciforms might vary with the descent of a hypothetical drainage in central Arizona.

Vannote *et al.* (1980), studying free-flowing river systems, proposed that, moving downstream from the headwaters to the mouth of a river, a continuous gradient of physical and chemical factors influences fish community structure. In Arizona and in many other regions, the discontinuous effects of flow regulation and impoundment also influence fish populations. In central Arizona, trout inhabit the cool headwaters; however, bald eagles do not currently nest in these habitats. Downstream, as water temperatures increase, suckers, smallmouth bass, and then channel catfish gain in frequency. With further warming, carp and catfish become the primary species in size categories suitable for bald eagle foraging. Few suckers are present in warm water environments. If no reservoirs were present on the warm, lower reaches, carp and catfish would remain the dominant fish species.

When a river enters a reservoir, the fish community changes dramatically. Here, perciforms are most numerous, although the larger carp and catfish may contribute significantly to the overall fish biomass in the reservoir. Most of the perciforms in Arizona reservoirs are bluegill and green sunfish, neither of which are very important to the eagles, but larger species, such as black crappie, yellow bass, and largemouth bass, are used regularly. (We will describe in Sections A3.2 how each of these species becomes available to eagles.)

The fish community below the dam is influenced by the temperature of the water emerging from the reservoir. If, in spring and summer, a reservoir remains deep and somewhat stable, the top layers of the impoundment will insulate the deep layers. When water is released from the depths, as is typical in Arizona, it will be far cooler than ambient air temperatures or the water flowing into the reservoir. These cool releases favor sucker populations, just as the cool reaches nearer the river headwaters do. As the water flows downstream from the dam in spring and summer, it rapidly warms and becomes more suitable for carp and catfish. Silt loads, however, are far lower than those in free-flowing reaches upstream of the dam, and this, combined with protracted spawning opportunities for suckers near the dams (see below), may favor suckers even in areas where warming has occurred.

If, on the other hand, the reservoir is small and shallow (or unstable) and fails to maintain a cool hypolimnion, the warm releases will favor carp and catfish in the reach below the dam. During spring, these riverine populations may be augmented by spawning runs of additional carp and catfish from downstream reservoirs. The influx of these reservoir fish into both regulated and free-flowing river reaches may depress the populations of other species, such as suckers, that might otherwise become established.

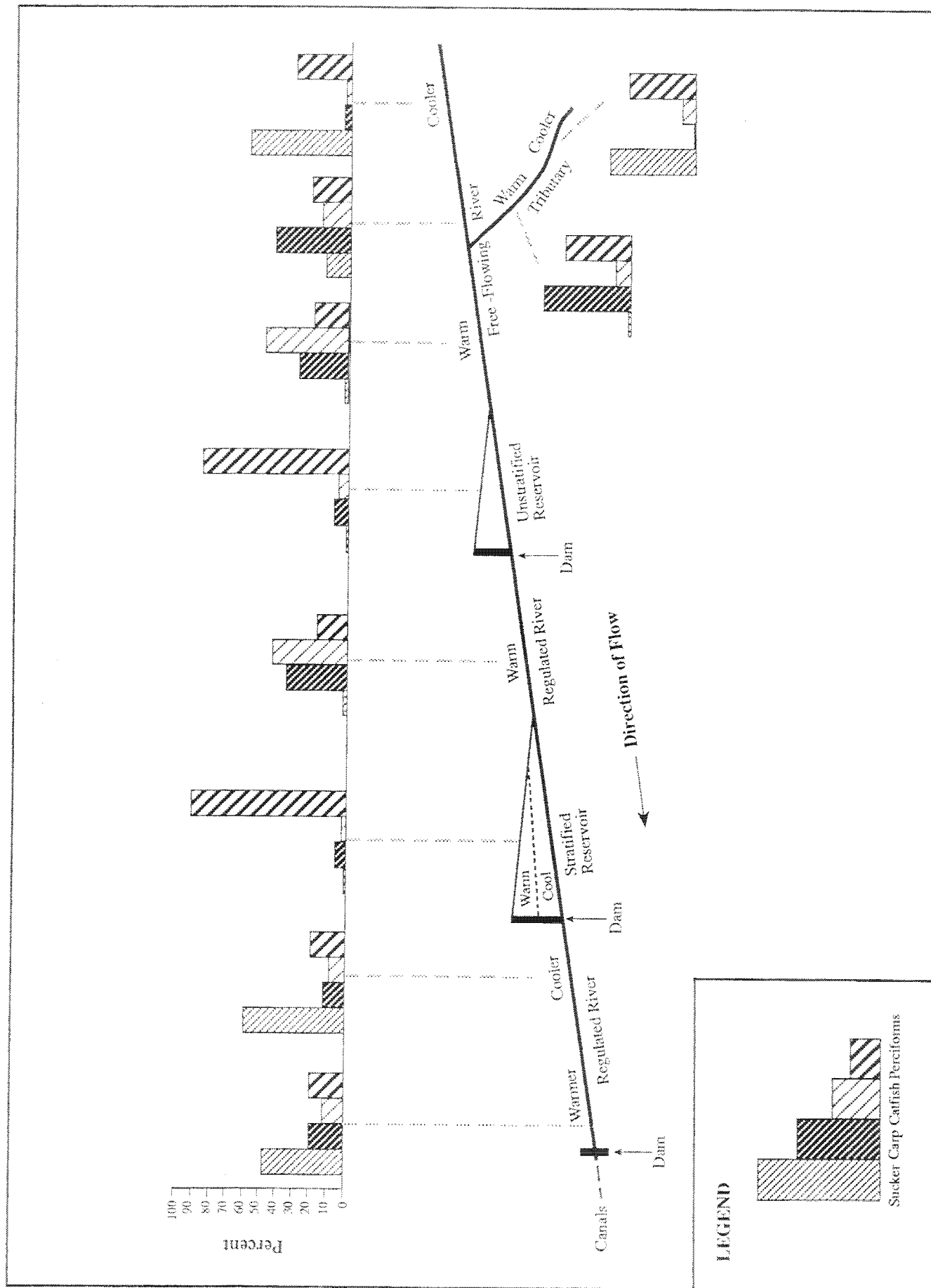


Figure A3.1-3. Estimated trends in prey fish species composition in free-flowing, regulated, and impounded reaches.



Plate A3. Depth of water releases (tunnel indicated by arrow) from a shallow reservoir (Horseshoe) without a cool hypolimnion, February 1989 (photo by D. Driscoll).



Plate A4. Depth of water releases (tunnel indicated by arrow) from a deep reservoir (Bartlett) with a cool hypolimnion, February 1989 (photo by D. Driscoll).

A3.1.3 Geography of Prey Selection

Figure A3.1-4 shows the percent biomass of the major prey groups taken by bald eagles at 23 breeding territories in Arizona as determined by analyses of prey remains and by observations of prey deliveries to six nests. In interpreting the pie-charts based on the prey remains, it is important to remember that hard-boned species, such as catfish, carp, birds and mammals were likely over-represented, while suckers and perciforms were probably under-represented in dietary significance.

The variation shown in the fish groups taken by the eagles along the Arizona rivers and reservoirs mirrors to some extent the distribution of the fish communities as shown in Figure A3.1-4 and suggests that fish are taken more or less relative to their abundance. Suckers (both desert and Sonora), for example, appear most commonly in remains (and delivery data) collected at nests situated on or near regulated reaches downstream of the last dams and in the free-flowing reaches nearest the headwaters. Perciforms were taken mainly in the reservoirs (principally black crappie, yellow bass, and largemouth bass). Those acquired in free-flowing river sections were mainly smallmouth bass and, to a lesser degree, largemouth bass. Eagles took several species of perciforms on the free-flowing Verde River upstream of Horseshoe Reservoir. Carp were taken largely in the warm reaches upstream of reservoirs and in the reservoirs fed by them, implying the occurrence of spawning migrations of carp out of the reservoirs and into the rivers. The importance of a reservoir/river association is suggested by our findings at Alamo where carp were poorly represented in prey remains and where flows into the reservoir are intermittent. Significant amounts of catfish biomass (channel and flathead) were common to almost all nests where prey remains were collected. The greatest amounts were at Alamo reservoir and the free-flowing river reaches, especially upstream of Roosevelt Reservoir.

Table A3.1-1 lists the fish we determined to be most important to eagles in Arizona. Among those listed, only seven taxa made significant contributions to fish biomass at any one site (i.e., over 15%). These species are, in order of significance, carp, suckers (Sonora and desert suckers), channel catfish, largemouth bass, flathead catfish, crappie (virtually all were black crappie), and yellow bass. This ranking is probably more useful than that suggested by a listing of aggregate biomass (remains) from all nests (as presented in Table B5.31) because of the varying sample sizes. Another consideration is that, even though yellow bass contributed significantly to the diets of only two pairs, these were the only pairs in Arizona with significant access to yellow bass. To a lesser extent, the same is true of black crappie, which occurred only in reservoirs. These seven taxa are probably taken largely as a function of their densities, but we will show below that ecological and life history characteristics of these species also influence their availability to eagles.

Mammals were more important at some sites than at others (and during high flows), and it is curious to note that their proportion appears to increase (that is, to exceed 25 percent of biomass) in sites distal to others along the Salt and Verde drainages. Note in Figure A3.1-4 the high contribution of mammals on the upper Salt River (Cibecue and Lone Pine), on Tonto Creek ("76" and Sheep), and at the confluence of the Salt and Verde rivers (Orme). The only other breeding area where mammals contributed more than a quarter of total biomass was Coolidge, the only site with a high proportion of mammals that is near a reservoir. We can only speculate that mammals increase in importance at these sites because there are fewer abundant fish species in most of these outlying habitats, thus decreasing temporal "windows" of fish availability resulting from differential spawning times (see Section A3.3.4).

Because aquatic environments are *sine qua non* for nesting bald eagles, it is tempting to hypothesize that pairs taking high proportions of mammals are in marginal habitat for nesting success. To test this

Figure A3.1-4 (a and b). Percent biomass of major prey groups utilized by Arizona breeding bald eagles as calculated from prey remains analyses and observations of prey deliveries to the nest. Because of the tendency for large, hard-boned species to persist longer as prey remains, suckers and perciforms are probably under-represented in the prey remains while catfish, carp, birds, and mammals are likely over-represented.

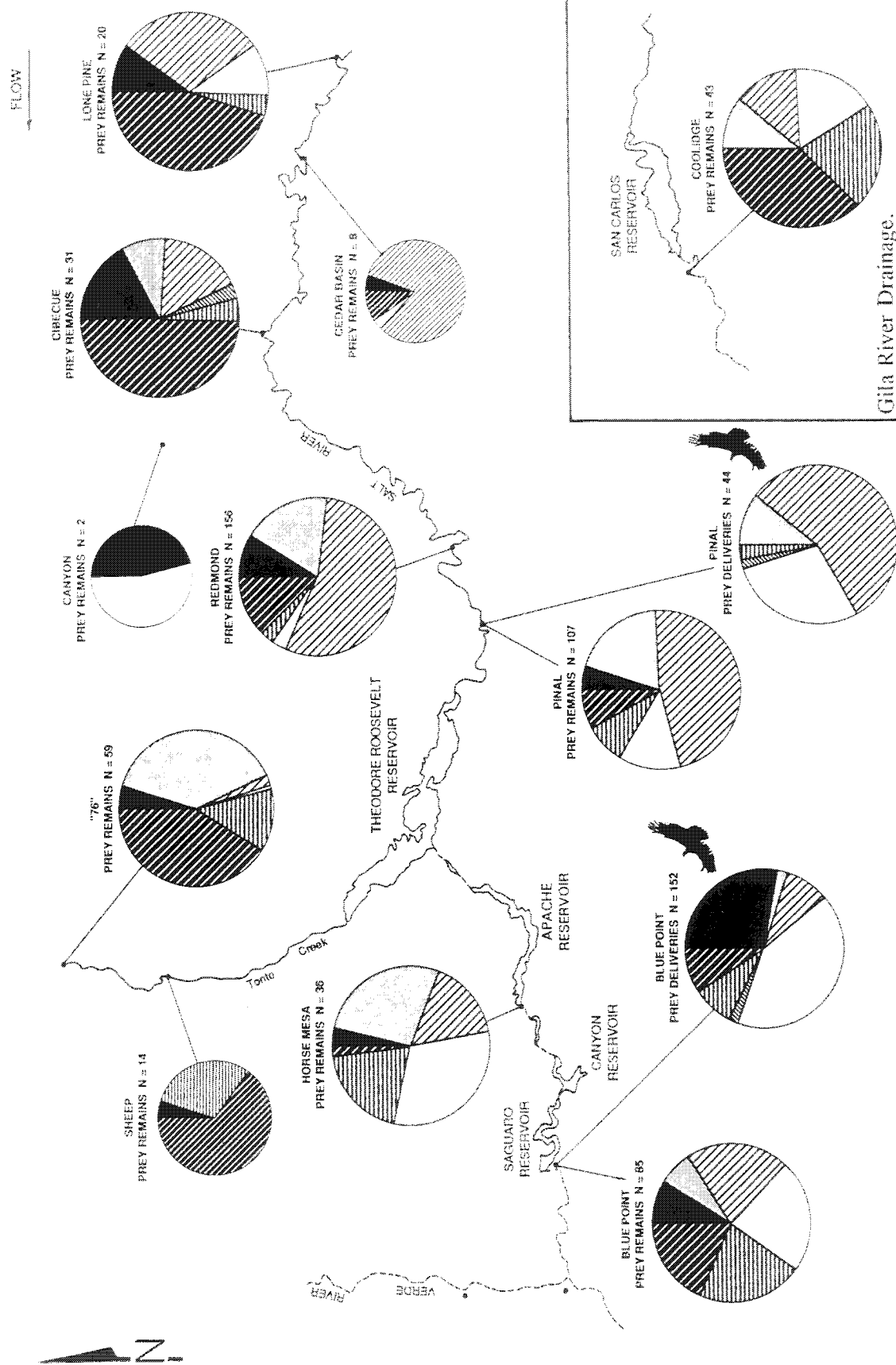


Figure A3.1-4a. Salt River Drainage.

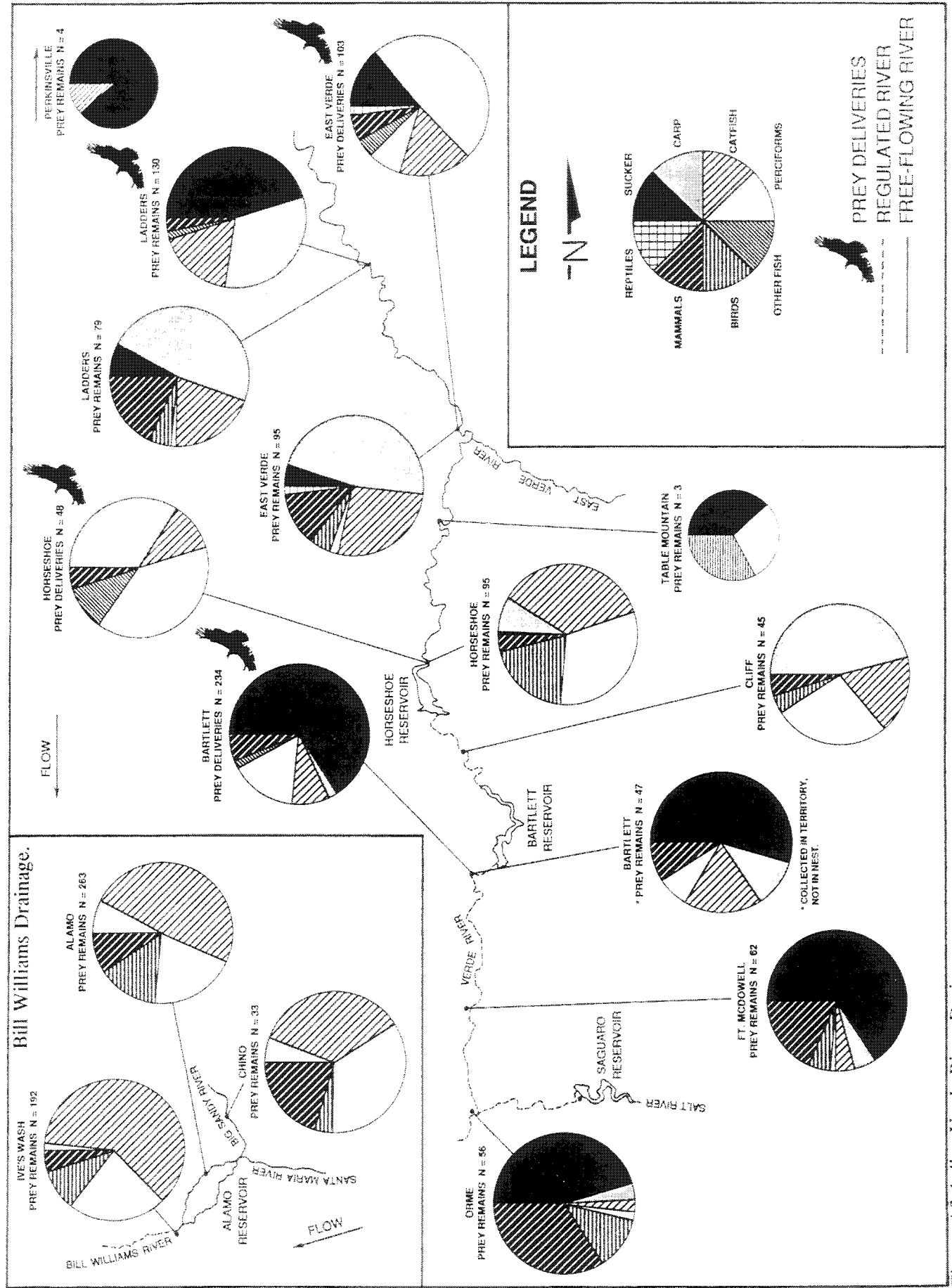


Figure A3.1-4b. Verde River Drainage.

Table A3.1-1. Fish species identified in significant frequencies (> 15% of total fish biomass) at 23 bald eagle nesting territories in Arizona. Data from the six priority sites were derived from prey observations; all others from prey remains collected from nests.

| Species | Number of Territories | | |
|----------------------------|----------------------------|---------------|---------------------------------|
| | Species Occurrence in Diet | | Species Occurrence in Territory |
| | > 15% Biomass | < 15% Biomass | > 1% |
| Carp | 12 | 7 | 20 |
| Sucker (Sonora and desert) | 12 | 5 | 17 |
| Channel Catfish | 10 | 9 | 23 |
| Largemouth Bass | 6 | 5 | 14 |
| Flathead Catfish | 3 | 6 | 12 |
| Crappie (spp.) | 2 | 8 | 9 |
| Yellow Bass | 2 | 0 | 2 |
| Bullhead (spp.) | 0 | 6 | 11 |
| Smallmouth Bass | 0 | 3 | 7 |
| <i>Lepomis</i> (sp.) | 0 | 3 | 19 |
| Walleye | 0 | 2 | 2 |
| Tilapia | 0 | 2 | 4 |
| Buffalo (spp.) | 0 | 1 | 2 |
| Razorback Suckers | 0 | 1 | ? |
| Striped Bass | 0 | 1 | 3 |

hypothesis, we compared percent mammals in the diet (estimated from prey remains) with nesting success, average young per year, and nest productivity rank among 12 breeding areas where at least six years of reproductive data were available. The results, similar to those of Haywood and Ohmart (1983), showed no significant relationship between mammal consumption and reproductive performance (Spearman's Rank Correlation).

In assessing the importance of mammals, we must reiterate their tendency to be overestimated in prey remains data. At the six breeding areas where we observed prey deliveries, mammals were very poorly represented. At five of these territories, prey delivery observations showed mammals to be over-represented in prey remains, and at the sixth, prey deliveries and remains showed almost equal biomass (5 and 4%)(see Section B5).

In all, we recorded only 32 mammals among the 711 prey items observed delivered (4.5% of items). These included 6 rock squirrels, 4 cottontail rabbits, 4 wood rats, 2 cattle carrion items, 1 deer carrion item, and 12 unidentified mammals. At least 21 of these (66%) were obtained within sight of the river (see Section A3.4), and it was our impression that the radio-tagged eagles we studied did not actively hunt

mammals, but rather took them opportunistically (often as carrion) when traveling to and from foraging sites for fish. Obviously, however, this could not have been the case at some of the sites we did not study intensively, where relatively high proportions of mammals were found in prey remains (see above).

As Haywood and Ohmart (1986) point out, the caloric content of mammals is higher than that of fish, so the actual dietary contribution of mammals in terms of *biomass*, as revealed by prey delivery observations at the six studied sites, would be increased. Out of 301.1 Kg of prey biomass observed delivered to the nest, 14.2 Kg (4.7%) were mammals. Using caloric value instead of biomass, this figure is increased to 6.2 percent. This rather low figure, at least for the six breeding areas, does not clearly support Haywood and Ohmart's conclusion that "... mammalian prey is essential to satisfy energy demands of bald eagles breeding in Arizona" (op. cit., p. 40). However, our state-wide data suggest that mammals may be more important to bald eagles during winter and early spring (Table A3.1-2), than later in the nesting season. Among 907 prey individuals identified in early and late collections of prey remains, a greater proportion of mammals (and birds) appeared in the early samples than those representing later stages of the chick cycle. Perhaps mammals help to fill a dietary gap during the early period, though it is well to remember that the figures given in Table A3.1-2 are likely overestimations of their actual dietary contribution.

Table A3.1-2. Number of individuals of four prey categories identified in early (March-early May) and late season collections of prey remains. Chi-Square tests compare each category with all other categories combined (e.g., fish vs. non-fish, etc.). These results suggest that birds and mammals are taken more frequently by bald eagles in late winter and early spring than in final weeks of the chick cycle.

| Prey Remains Collections | | | | | |
|--------------------------|-------|---------|------|---------|-----------------------------------|
| | Early | | Late | | Chi-Square Analysis |
| | No. | Percent | No. | Percent | |
| Fish | 288 | 76.4 | 453 | 85.5 | $\chi^2 = 9.81, df = 1, p < 0.01$ |
| Birds | 52 | 13.8 | 48 | 9.0 | $\chi^2 = 4.73, df = 1, p < 0.05$ |
| Mammals | 37 | 9.8 | 29 | 5.4 | $\chi^2 = 5.68, df = 1, p < 0.05$ |
| Reptiles | 0 | 0.0 | 4 | 0.1 | — |
| Totals | 377 | | 530 | | |

Like mammals, birds probably contributed lower amounts of total biomass than indicated in prey remains in nests (10.3%)(see Section B5). However, in winter, birds were far more important than during the nesting season, particularly at breeding areas containing reservoirs. Table A3.1-3 shows the overall ratios of birds to fish in our records of observed, successful forages during winter and spring months at the six studied territories. Among 30 birds identified, there were 15 coots, 8 eared grebes, 2 wigeons, 1 pied-billed grebe, 1 ruddy duck, 1 shoveler, 1 green-winged teal, and 1 cactus wren. Sixteen of these were taken alive, four as carrion, two were pirated, and eight were of unknown status. Birds are the most highly nutritious of the major prey groups (although they may contain contaminants), and would appear to contribute significantly to the well-being of bald eagles during a time (winter) when resources are needed by female eagles to build fat stores for egg formation and incubation. It is not unreasonable, in viewing Figure A3.1-3, to speculate that fish are not very available to bald eagles in December and January, and that the eagles compensate by preying on birds (still numerous in February).

Table A3.1-3. Seasonal changes in the ratios of birds to fish observed taken by bald eagles during December through May, 1987-1989.

| | Birds | Fish | % Birds |
|----------|-------|------|---------|
| December | 4 | 4 | 50.0 |
| January | 14 | 11 | 56.0 |
| February | 7 | 45 | 13.5 |
| March | 3 | 57 | 5.0 |
| April | 1 | 136 | 0.7 |
| May | 1 | 191 | 0.5 |

A3.2 LIFE HISTORY FACTORS AFFECTING FISH AVAILABILITY

The idea that differences in the life history and ecology of fish can influence their vulnerability to attack by bald eagles and ospreys was discussed by Swenson (1979), Todd, *et al.* (1982), Haywood and Ohmart (1986), and BioSystems (1985) in trying to explain why bottom-feeding fish are so common in the diets of these birds. Their reasoning was that the downward visual orientation of bottom-feeders renders them less alert to attacks from above. In this section, we will discuss this hypothesis and other life-history characteristics of fish species in Arizona that may influence their availability to eagles. Some of these factors relate to the foraging behavior of the fishes, others to spawning cycles, and still others to human factors.

Some of the fish species that the eagles preyed upon were adapted only to riverine conditions, others resided only in reservoirs, and some species occurred in both habitats (Figure A3.2-1). In general, species that occurred commonly in both rivers and reservoirs were taken by eagles in both habitats; however, our records show that in reservoirs most fish were obtained as carrion (or moribund), while, in rivers, most were alive when taken by the eagles. Figure A3.2-2 compares river versus reservoir

| River | Both | Reservoir |
|--|--|---|
| <div></div> <div>Sonora Sucker</div> <div></div> <div>Desert Sucker</div> | <div></div> <div>Carp</div> <div></div> <div>Channel Catfish</div> | <div></div> <div>Black Crappie</div> <div></div> <div>Yellow Bass</div> |
| <div>Historical</div> <div></div> <div>Colorado Squawfish</div> <div></div> <div>Razorback Sucker</div> | <div></div> <div>Flathead Fish</div> <div></div> <div>Largemouth Bass</div> | <div><i>Illustrations by Michael J. Cross</i></div> |

Figure A3.2-1. Occurrence in reservoirs and rivers of the eight principal prey fish of bald eagles in central Arizona. Also shown are two species, no longer common in central Arizona rivers that may have been important to bald eagles in pristine times.

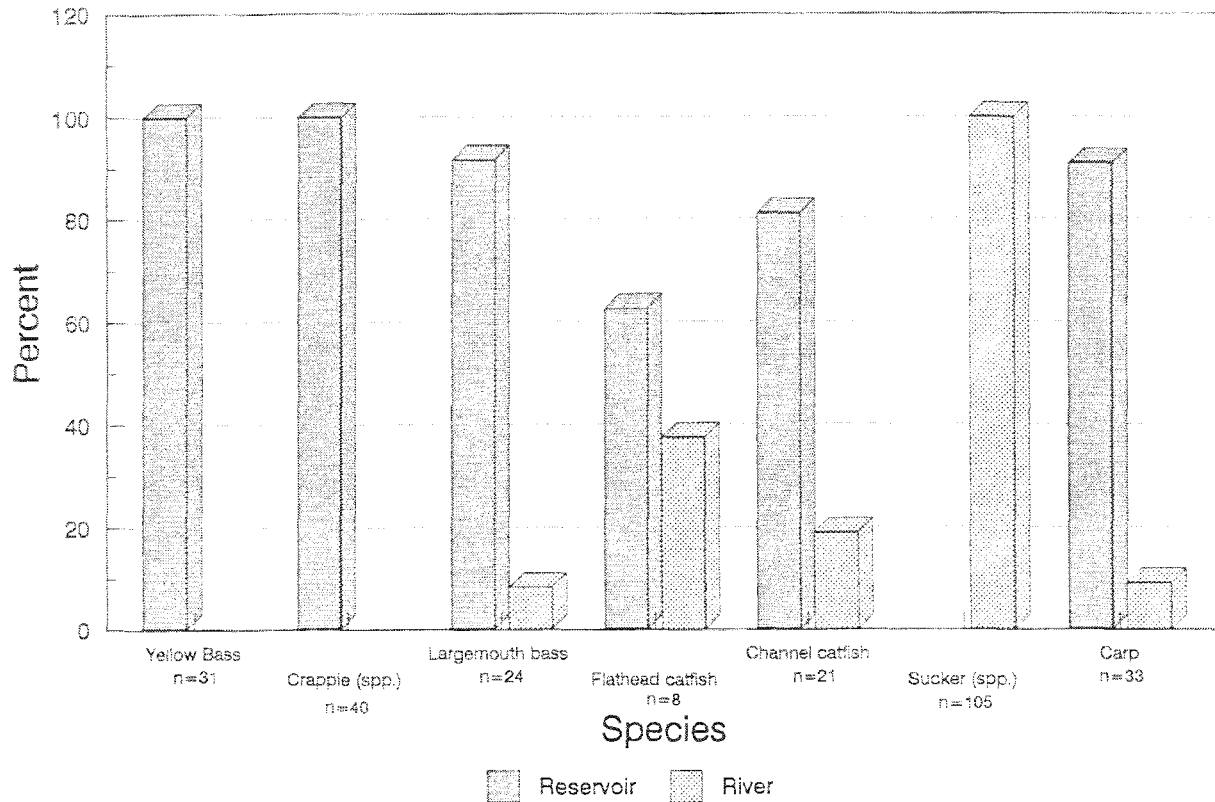


Figure A3.2-2. Origin of prey delivered to nests at four breeding areas containing river and reservoir habitats (Bartlett, Blue Point, Horseshoe, and Pinal). Not included in this graph are minor prey species (e.g., sunfish), unidentified prey items, and items of unknown origin.

origins of seven fish taxa recorded in nest delivery observations at four breeding areas where both habitats were present.

It is important to remember that fish communities currently existing in central Arizona are far different from those of pristine times. In Section E1 we describe the changes that have apparently taken place in fish communities over the past several hundred years, and in Section E3 we review the life histories of fish species no longer common in central Arizona that might have fed bald eagles in earlier periods. In Section A3.5 we will speculate on whether the pristine environment might have sustained a breeding population of bald eagles.

A3.2.1 Suckers

Suckers, the only bald eagle prey fishes native to Arizona, are adapted to life in riverine habitats. The eagles took three species, but only two in significant numbers: Sonora and desert suckers. The third species, the razorback sucker, was represented by only two individuals at two breeding areas (Pinal and Redmond). Because of the similarity of desert and Sonora suckers, we were usually unable to differentiate between them in visual observations of prey deliveries; we therefore grouped them as "sucker sp." on our field forms.

Our records show that suckers were usually taken alive and in shallow water. In 114 observed forages, at least 95 were alive when taken, 3 were carrion, 6 were pirated, and the status of 10 was unknown. Of the live fish, 79 percent were taken in water (mainly riffles) less than 30 cm deep. Suckers became vulnerable to bald eagles in two ways: while spawning and while foraging. Eagles did not appear to exploit carrion suckers when thousands were killed below Stewart Mountain dam during flow cessation.

From February to late April, Sonora and desert suckers spawn in shallow water, especially in the upstream ends of riffles ("pre-riffles") where cleaner substrate and higher oxygen concentrations favor egg survival. Courtship is often conspicuous when several males vigorously attempt to swim along side a single female, nudging her to induce egg deposition, an activity that may draw the fish into very shallow water. During the release of gametes, the tails of both sexes vibrate in unison for a few seconds. In shallow water, vigorous spawners may produce a "rooster tail," visible at a distance. During spawning, a bald eagle may approach the group undetected and even perch on an adjacent boulder, and then pounce on a nearby sucker.

The period of spawning, from February to late April in central Arizona, is largely a function of stream temperature, optimally in the range of 14–18°C. When spring water temperatures warm to these values, suckers spawn both in mainstem reaches and on tributaries into which suckers may migrate from mainstem locations. An adult male eagle we tracked in April (East Verde) took suckers both in free-flowing mainstem habitats and on tributaries, sometimes traveling many kilometers to do so (see Section B4.4). At two other territories (Bartlett and Blue Point) on regulated river reaches, nesting bald eagles captured suckers in downstream areas early in the spring, but in succeeding weeks, the eagles favored habitats farther upstream.

In Sections B4.1 and B4.2 we show that these shifts in foraging sites relate to changes in the distribution of spawning suckers, which in turn are responding to shifting zones of water temperature. This phenomenon arises from the fact that water, released from the depths of the nearby reservoirs in early spring, may be too cool for sucker spawning near the dam; however, it gradually warms to a temperature appropriate for sucker spawning some distance downstream. As spring progresses, and higher ambient water and air temperatures prevail, the zone of appropriate spawning temperatures moves closer to the dam. Several factors may modify this pattern. For example, the more water there is in the river, the more slowly the warming occurs. Also, the deeper the reservoir is, the greater the tendency for stratification, and the more insulated and cool is the hypolimnion. Hence, there may be year-to-year differences in the distribution of spawning suckers in the river.

Temperature data obtained at sites where we observed bald eagles taking suckers support the conclusion that most of the suckers were captured while spawning. The average water temperature at 77 strike points for live suckers varied from 10–25°C, but with a mean of only 14°C, the lowest in the range of optimum spawning temperatures (14–18°C). Seven temperatures were above 18°C, suggesting that some fish were not spawning when taken.

Suckers feed on invertebrates, diatoms, and other types of algae, and detritus, and may often forage in riffles and runs where photosynthesis is highest. Sonora suckers are mainly insectivorous, while desert suckers rely more on plant material (Schreiber and Minkley 1981). Both species scrape invertebrates and other material off the top and sides of rubble and boulders, pulling themselves along with their lips. They are often observed with their heads under rocks or lying on their sides as they feed, activities which make them vulnerable to eagle attack.



Plate A5. Sonora sucker near Stewart Mountain Dam, 7 November 1986 (photo by D. Driscoll).

A3.2.2 Carp

Carp were taken on river sections as well as reservoirs. We observed 33 nest deliveries of carp at four territories containing riverine and reservoir habitats (Bartlett, Blue Point, Horseshoe, and Pinal). Of these, 30 (91%) had been taken in reservoirs and three on the river. Carp were also among the major species ($n = 77$ individuals) delivered at two territories on the free-flowing Verde River far from a reservoir (East Verde and Ladders); carp was the most frequently taken prey species by the East Verde pair.

In reservoirs, eagles utilized both live and carrion carp. The former were mainly captured in shallow water near shore where they were apparently feeding. Carp normally forage by sucking up invertebrates (their main food) off the substrate, along with plant material, ooze, and detritus (see Section E3), leaving conspicuous trails of muddy water in their wake. In a cove we surveyed on Saguaro Reservoir, we observed no carp in the shallows in March and April, but by late May and June after vegetation had developed there, we saw up to 30 carp feeding in shallow water at one time; these were clearly vulnerable to eagle attack (see Section B4.2).

Carp may swim close to the surface in open water, either as a precursor to spawning (when schools of carp may swim slowly near the surface, with the dorsums of some individuals visible above it (Moyle 1976)) or to feed on floating organisms (Scott and Crossman 1973, also this study). We observed three cases in which eagles took what appeared to be live, healthy carp (ca. 20 cm) in the open water of

reservoirs. We also observed an eagle towing a live carp in open water at Britton Reservoir in California (R. Jackman, notes), but did not observe the actual attack.

In rivers, carp became available to eagles mainly in the shallows of runs and riffles where photosynthesis, oxygen concentrations, and invertebrate production are greatest; 17 of 20 forages for live fish were in water less than 36 cm deep. Most of these carp were probably foraging when taken, but we note that 17 water temperatures measured at eagle strike points for carp averaged 18°C (median = 19°C), a temperature suitable for carp spawning. In fact, all 17 of the measured temperatures fell within the range of carp spawning. Carp spawn in shallow water (typically less than 30 cm deep), preferring areas of submerged vegetation (Moyle 1976). Spawning is often accompanied by vigorous splashing.

Carp are known to travel long distances; in doing so, they may become vulnerable to eagles when they pass through shallows or aggregate in dense spawning populations. A tagged carp in Missouri was recovered 1,088 km from its original capture site (Sigler 1958), and another covered 1,629 km (Becker 1983). Large numbers of carp may migrate out of reservoirs to spawn in rivers. Large spawning migrations have been observed at Roosevelt and Pleasant reservoirs. In Arizona, carp reproduce over many months, from late February to June or July, with peak activity at water temperatures ranging from 18–24°C.

Given all these characteristics of carp that bring them into shallow water or near the surface in deep water, it is not surprising that eagles take them so frequently. Additionally, carp often appear as carrion. Their fondness for foraging and spawning in recently-flooded areas may strand them when drying occurs, but we have no information on this point. They are also intentionally killed by anglers, many of whom regard them as undesirable. Carp may occasionally be struck in open water by motor boat propellers.

A3.2.3 Catfish

Our records show that three catfish taxa were taken by bald eagles in Arizona: channel catfish, flathead catfish, and bullhead (probably yellow bullhead, but we were not confident of specific identification in prey remains analyses). Of the three, channel catfish was the most frequently taken. In the prey remains data, pooled from all 23 bald eagle nesting areas, channel catfish were represented by both the greatest numbers (32.4%) and biomass (24.7%) of all prey. Flathead catfish contributed 7.6 percent, and bullhead 0.3 percent of total biomass. In terms of biomass contribution per nest, catfish spp. ranked third after carp and suckers in the number of nests to which they contributed more than 15 percent of prey remains biomass (Table A3.1-1). To some extent, as we have said, the high representation of catfish in prey remains was an artifact of the tendency of their body parts to endure longer in nests than softer-boned species. Nevertheless, catfish, and particularly channel catfish, must be regarded among the principal prey of bald eagles in Arizona as well as many other areas.

Excluding piracies, we observed nesting bald eagles taking channel catfish on 51 occasions: 38 on reservoirs and 12 on rivers. Of the reservoir forages, 5 fish were alive when taken, 21 were carrion, and 12 were of unknown status. Of the river forages, 8 channel catfish were alive, 3 were carrion, and 2 were of unknown status.

We noted that "blooms" of carrion channel catfish (ca. 20 cm TL) appeared in late spring at two reservoirs (Horseshoe and Roosevelt), but we do not know the reason or whether it was a normal occurrence. Causes of catfish die-offs have been attributed elsewhere to viral diseases, low oxygen concentration, and toxins from ingested blue-green algae or dinoflagellates (A. Mitchell, Arkansas Game

and Fish Department, pers. comm.)(see Section B4.6). We measured dissolved oxygen at Roosevelt Reservoir during the "carion catfish bloom," but found normal levels. Another possibility is that, because 20-cm-long channel catfish are undergoing a food niche transition from bottom-living invertebrates to piscivory (Carlander 1969), they may experience a population bottleneck as a result of being marginally adapted to both niches; i.e., they may be too small to prey effectively on fish and too large to be sustained solely by invertebrates. However, many fish species undergo such a niche transition without bottlenecking (to our knowledge). Earlier in the spring, we also found large carion flathead catfish at Roosevelt. We believe many of these were angler-induced mortalities; some of these left on land were filleted remains. These were often later scavenged by ravens and bald eagles.

Four of the five channel catfish judged to be alive when taken in reservoirs were obtained by the eagles in water more than 200 cm deep, and we have no idea why these fish would have been near the surface. Van Daele and Van Daele (1982) indicated that nesting ospreys in Idaho caught bullhead (another species of *Ictalurus*) when the latter "rested near the surface of the reservoir on warm days." We occasionally saw channel catfish swimming near the surface in riverine pools in the Verde River (E. Bianchi, notes). It is also conceivable that some of the channel catfish judged alive when taken in deep water were actually injured or moribund.

The profile of habitat conditions at eagle strike points for live channel catfish in rivers was different from those noted for other species, but the sample (only 8 forages) was small. Eagles took five of the fish from pocket water, three from runs, and none from riffles. Six depth measurements ranged from 14 to 85 cm, with a mean of 58 cm (SD \pm 28.1 cm). These depths were great, compared with the mean for suckers of 22.4 cm (range = 4-80 cm, SD \pm 16.5 cm, n = 60) and for carp of 31.1 cm (range 8-100 cm, SD \pm 16.5 cm).

We found little in the behavior and life history of catfish to suggest why live ones become available to eagles as prey. Unlike carp and suckers, they are nocturnal and do not spawn in shallow water (see accounts in Section E3 of protracted catfish spawning in cave-like environments). To what extent they forage in shallows or otherwise approach the surface is unknown to us. We examined a pocket water foraging site (where an eagle had taken channel catfish) and were able to closely approach two catfish (approximately 35 cm TL) which remained for some time in fairly shallow water, with their heads under boulders but their bodies in view (see Section B4.3). The fish may have been foraging for crayfish.

A3.2.4 Perciforms

Twelve of the 20 fish species identified in our prey records were perciforms (bass, crappie, sunfish). The eagles took them mainly as carion in reservoirs. They also took them occasionally in river sections, although, in the latter case, we are less certain as to their status when taken. During prey delivery observations at four breeding areas containing reservoirs (Bartlett, Saguaro, Horseshoe, and Roosevelt), we counted 61 black bass (36.5% of all perciforms - almost all were largemouth), 51 crappie (30.5%), 41 yellow bass (24.6%), and 14 others (mainly sunfish). Interestingly, while largemouth bass occurred in all four of these reservoirs, yellow bass existed only in Saguaro Reservoir, and crappie occurred only in the other three, giving the impression that yellow bass and crappie compete for the same resources.

Differences in ecology influenced the extent to which each perciform species became available to eagles. The most numerous perciform species in the reservoirs were not necessarily those taken in the greatest numbers. For example, bluegill greatly outnumbered all other perciform species in the reservoirs, and yet only "a trace" appeared in prey remains and few were delivered. The bluegill's small size may have

resulted in its complete consumption by the adult eagles before returning to the nest. We observed bald eagles similarly consuming tule perch in our Pit River studies in California (BioSystems 1985).

Of 76 dead or moribund perciforms found in carrion surveys on Horseshoe, Bartlett, Saguaro, and Roosevelt reservoirs, there were 29 yellow bass, 15 largemouth bass, 13 black crappie, 8 bluegills, 4 smallmouth bass, 4 green sunfish, and 3 walleye.

We often judged whether or not an eagle took a fish alive or as carrion by observing it in the nest after delivery to the young. Live fish would often exhibit brighter colors and muscle contraction, while dead ones would appear lackluster and stiff. Although many perciforms were judged in this way to have been alive when taken, they had been floating spent and moribund at the water's surface as a result of spawning stress. Based on our field experience, we doubt that any yellow bass or crappie in our samples were taken as live, healthy fish (see Section A3.2.5).

In observations of 11 successful forages on largemouth bass on Arizona reservoirs, two were judged to be alive when taken, five were carrion, two were pirated, and two were of unknown status. Both "live" fish were taken in deep water, one in a cove (away from shore), and the other in open water. In both cases, the eagle made low circles before taking the fish, suggested that they were incapacitated. From this, and from our general observations, we believe that most or all reservoir forages for largemouth bass were for carrion (or moribund) fish.

In our studies of bald eagles in Arizona and California (BioSystems 1985), we did not observe moribund largemouth bass exhibiting post-spawning stress at the water's surface. Although these fish were fairly common in Britton Reservoir in California, none were found in extensive carrion surveys, whereas dead and moribund black crappie and tule perch were frequent. Some of the carrion largemouth bass we observed on reservoirs in Arizona had been hooked and lost by anglers, but others (we speculate), with undetected mortal injuries, had probably been intentionally released.

A3.2.5 Why Certain Perciforms Die From Spawning Stress

We were curious about why yellow bass and black crappie both became available as carrion to eagles as a result of post-spawning mortality, while other perciforms, such as largemouth bass, did not. The reason why yellow bass and black crappie, both predatory species, tend to die from spawning stress relates to their adaptation to open water habitats. During most of the year, they school within the pelagic zone (water column), and because this environment is without structural heterogeneity, individuals of all age classes must compete directly for food rather than for the space that holds it. Their main life-history strategy is simple: it is to obtain enough food to reproduce. In a growing population, density-dependent competition for food impacts negatively upon their ability to amass resources for growth, bodily maintenance, and reproduction. Like salmon, which also inhabit undifferentiated habitats (oceans), natural selection has favored high physiological commitment to one season of reproduction, at the conclusion of which, they may die for lack of bodily resources. We do not know what proportion of yellow bass and black crappie populations survive after spawning, but J. Warnecke (AGF, pers. comm) noted that black crappie in Arizona rarely live more than four years, and that spring die-offs of 3-4-year-old crappie are quite common on the reservoirs.

In contrast, perciforms that do not live in open water environments (e.g., largemouth bass, sunfish), but instead forage in the shallows near shore, do not exhibit post-spawning die-offs. In these more differentiated habitats, fish compete for space and the food it contains. The more structural heterogeneity

there is in these environments, the greater the likelihood that these fish can effectively defend territories. Even without territoriality, prey acquisition in structured habitats requires greater searching time, and there are more havens and escape routes available to their prey. The result is that fish living in these environments probably tend to live off the "interest," rather than the "capital" of diverse food supplies (Errington 1946), a factor which acts to dampen the oscillations of their own populations. Species inhabiting heterogeneous environments therefore have a more conservative reproductive strategy than species inhabiting open water. Rather than "going for broke," largemouth bass may budget their reproductive effort in order to survive in future years. By investing resources in size increase, rather than in reproductive output, the opportunity is increased of obtaining and holding a territory, and of eventually producing and nurturing, over their lifetimes, larger numbers of higher-quality gametes. It is no wonder that size variation is so much greater among littoral species than pelagic ones.

A3.2.6 Summary of Factors Influencing Fish Availability

It is clear from these discussions that the various fish in the diets of bald eagles become available in different ways and at different times (Table A3.2-1). Live fish become vulnerable to attack when they enter shallow water or swim near the surface. The most vulnerable species in shallow water are the bottom-feeders, i.e., suckers, carp, and catfish, because of their downward visual orientation. Species that spawn in shallow water such as carp and suckers are especially vulnerable. Suckers often spawn in riffles, the shallowest of the riverine habitats, and may be consistently exposed to attack at this stage of the life cycle.

The fact that suckers spawn early and carp spawn later in the eagles' breeding season in response to changes in water temperatures may be of considerable advantage to nesting pairs of eagles. Both fish tend to breed in shallow water, and when both species are common, the result may be a prolonged availability of food for eagles. This phenomenon of two or more fish species contributing significantly at different times during the nesting season, was frequently encountered in our studies of prey deliveries at the six intensively-studied territories. Moreover, none of the larger sample of 23 pairs specialized entirely on one species, but rather exhibited considerable diversity in prey selection where sample sizes were sufficient to show it (Figure A3.1-4).

Edwards (1988) also documented seasonal shifts in prey utilization by ospreys in Florida. When sunfish (*Lepomis* spp.) were abundant in spring and summer, the ospreys captured them preferentially in the littoral zone, but shifted to limnetic shad (*Dorosoma* spp.) during fall and winter when sunfish availability declined. Shad abundance was constant throughout the year. Jamieson *et al.* (1982) described a similar prey shift by ospreys in Nova Scotia where they captured spawning herring (*Alosa* spp.) and suckers in the early nesting season and switched to estuarine winter flounder when spawning of the former declined.

In Arizona, carp and possibly catfish sometimes swim near the surface, even in open water. During courtship, carp may aggregate near the water's surface, and at other times carp may take algae and other floating material off the surface. There are reports of catfish basking near the surface, but whether or not channel catfish do so is unknown to us.

Live fish, especially suckers and carp, are also taken while they forage in shallow water. They are attracted there by the greater densities of plants and invertebrates (see Section A3.3). We have only a small amount of data which suggests that foraging catfish become available to eagles. Since channel catfish are a major prey of bald eagles in Arizona, we regard this data gap as a significant deficiency in the overall results of our work.

Table A3.2-1. Summary of ways in which fish taxa may become available to bald eagles in Arizona rivers and reservoirs.

| | Suckers | Carp | Catfish | Large-mouth Bass | Crappie | Yellow Bass |
|---|---------|------|---------|---------------------|---------|----------------|
| Vulnerability of Live Fish | | | | | | |
| Tendency to spawn in shallow water | ● | ● | — | ? | ? | — |
| Foraging in shallow water | ● | ● | ? | — | — | — |
| Spawning migrations through shallows | ● | ● | ● | — | — | — |
| Defending spawning redds | — | — | — | ? | ? | — |
| Swimming near the surface in deep water | — | ● | ● | ? | — | — |
| Carriion Availability | | | | | | |
| Spawning stress | — | — | — | — | ● | ● |
| Hooked and lost | — | — | ● | — | — | — |
| Unintentionally wounded and released | — | — | — | ● | — | — |
| Intentionally killed and discarded | ● | ● | — | — | — | — |
| Filletted and parts discarded | — | — | ● | — | — | — |
| Unknown | — | — | ● | — | — | — |

The tendency of fish to become accessible to eagles as carrion similarly depends on ecological and life history factors. Die-offs as a result of spawning stress affect yellow bass and crappie, both of which contribute significantly to eagle diets at reservoirs where these fish are common. Angler-induced mortalities, both intentional and inadvertent, may also form a significant food resource, though the latter carry a risk to the eagle if hooks and monofilament are still attached.

It is important to consider that the probability of a particular fish becoming available to eagles as carrion may be extremely low, but among large reservoir populations and those just upstream, there is an element of statistical accrual. Even a few items appearing each day may function to sustain an eagle family. Carrion items tend to be highly conspicuous when floating dead or incapacitated on the surface of a reservoir; eagles commonly detect such items from far away.

A3.3 FORAGING HABITAT OF NESTING BALD EAGLES

Nesting bald eagles in central Arizona forage in free-flowing and regulated rivers, reservoirs, small tributary streams, and on land. Most, if not all pairs, exploit more than one of these environments during the nesting season. Plasticity in gross habitat selection, and the ability to exploit many different kinds of prey, have enabled eagles to find food despite wide variation in stream flows and reservoir elevations associated with Arizona's uncertain rainfall patterns. Eagles commonly switch forage locations and/or prey species in response to changes in the distribution of prey and carrion. For example, the adult male at one territory (Blue Point) took mainly waterfowl on the reservoir in winter, spawning live suckers in regulated riverine habitat in March and April, carrion yellow bass from post-spawn die-offs on the reservoir in late April and early May, then suckers again on the river in May, and carp on the reservoir in early June. At another breeding area (East Verde), during a period of high turbidity in the mainstem, the male routinely traveled 10-16 airline km to forage in the clear waters of a tributary.

A3.3.1 Eagle Use of Reservoir Habitat

Estimating the significance of reservoirs as foraging habitat was a main requirement of our efforts to understand the positive and negative effects of water projects on nesting bald eagles in Arizona. In this section, we will summarize our knowledge of reservoir use by the eagles we studied with telemetry.

Prior to this century, there were apparently only three natural lakes in central Arizona (Morman, Pecks, and Stoneman). In the early part of this century, the appearance of lacustrine habitats associated with the building of the reservoirs in central Arizona was sudden, as were the gross alterations of fish communities with the introduction of many exotic species. Riverine environments were changed downstream from the reservoirs by flow regulation and sediment filtration, and upstream by migrations of fish populations such as carp and catfish out of the reservoirs.

In other regions, dam construction and water impoundments have depleted habitat for bald eagles wintering or nesting along free-flowing rivers by removing perch and nest sites, inundating riverine foraging areas and gravel bars that accumulate carrion, and eliminating spawning fish runs (Craighead and Craighead 1979, Hunt and Johnson 1981, Barber *et al.* 1983). In our study of wintering bald eagles on the Skagit River in northwestern Washington, we predicted that construction of a dam would inundate 50 large deciduous perching trees and 20 gravel bars (which accumulate post-spawn salmon carcasses), and eliminate about 16 km of chum and coho salmon spawning habitat (Hunt *et al.* 1980, Hunt and



Plate A6. Pinal female (AF01) flying low over Roosevelt Reservoir, 13 December 1986 (photo by D. Driscoll).

Johnson 1981). Our carcass drift study determined that fewer salmon carcasses would be available downstream as a result of the lost salmon spawning habitat. The proposed impoundment would have displaced approximately 40 bald eagles, and an additional 11 eagles downstream, due to depleted food resources. Because we determined that the Skagit River was at carrying capacity for wintering bald eagles based on surveys of eagle numbers and available food and energy requirements, these eagles would have been displaced from the river and forced to find suitable resources elsewhere (Hunt *et al.* 1992a).

In another study, predicted effects of dam construction along the Churchill River, Saskatchewan, included the loss of 30 breeding pairs of bald eagles by the flooding of nest sites and riverine foraging areas (Barber *et al.* 1983). The Churchill River eagles foraged exclusively in rapids and riffles on spawning fish during early spring prior to ice break-up. Barber *et al.* found that nests were "... significantly closer to rapids than expected by chance." Shapiro *et al.* (1982) reported that flood control measures in Florida, including channelization and water control structures, resulted in the degradation of fish and waterfowl habitats in a complex system of lakes, creeks, marshes, and sloughs. These measures may have been responsible for a 74 percent decrease in the number of active bald eagle territories following implementation.

Beneficial aspects of reservoirs and dams for bald eagles have also been reported, including increased foraging opportunities associated with turbine-killed fish and fish stranded by fluctuating regulated river and reservoir levels (Lish 1975, Steenhof 1976, Stumpf and Creighton 1977, Craighead and Craighead

1979, Wood 1980, BioSystems 1985). Ice-free areas below dams also provide access to fish, and open water of reservoirs concentrate waterfowl for wintering eagles (Fisher *et al.* 1981a). Griffin *et al.* (1982) found that winter fish kills caused by freezing weather, low dissolved oxygen, and shallowness of reservoirs due to siltation provided food for wintering bald eagles during a February thaw. Small reservoirs along reaches of the regulated Pit River acted as large pools providing cover and increasing carrying capacity for certain fish species (BioSystems 1985).

The construction of reservoirs has greatly influenced the distribution of wintering and breeding bald eagles (Steenhof 1978, Detrich 1985, Lish and Sherrod 1985). Nineteen percent of the mainland California nest records for 1900-1940 were located near reservoirs (Detrich *op. cit.*). By the late 1970s Lehman (1979) found that approximately 70 percent of California bald eagle nests were located near reservoirs. During our studies in northern California, all fourteen bald eagle pairs along the Pit River drainage nested near reservoirs, although several foraged in regulated river sections located nearby (BioSystems 1985). Greater use of natural lakes (53%) than reservoirs by breeding bald eagles was reported for Oregon (Anthony and Isaacs 1989); however, 20 percent of the eagles in their sample nested on reservoirs. In California, Detrich (1985) calculated (from Detrich 1981) that over 60 percent of wintering bald eagle use outside the Klamath Basin was associated with reservoirs.

Detrich (1977) noted that the drought-induced low reservoir levels at Shasta Reservoir, California, had some positive effects for bald eagles by concentrating the fishery, probably increasing fish mortality, and creating shallow delta areas at tributary inflows. Fish making spawning runs into tributaries were accessible to eagles when crossing these shallow deltas. In Idaho, osprey productivity was highest during the year of lowest reservoir levels; the male osprey spent more time foraging and delivered less fish during high water years (Van Daele and Van Daele 1982). Lower-than-normal water levels at Kansas reservoirs may have been responsible for declines observed in wintering eagle use because of earlier winter freezing (Fisher and Hartman 1983). Large reservoirs attracted more wintering eagles than small ones in Kansas and Nebraska possibly because of the greater numbers of waterfowl present.

Construction of new reservoirs attracts and concentrates human activity (Fisher and Hartman 1983). Fluctuating reservoir levels also influence numbers and patterns of recreational use. While creating a buffer zone between reservoir waters and shoreline nests, the additional width of the shoreline during low water allowed vehicle access to some bald eagle nests that were previously inaccessible (Detrich 1977). See Detrich (1989) for additional information on how water projects affect bald eagles and other raptors.

Ohmart and Sell (1979) suggested that by reducing turbidity and stabilizing river flows, reservoir impoundments in Arizona increased foraging opportunities for bald eagles and stabilized the fishery. However, they also warned (1980) that reservoir inundation of riverine and riparian habitat eliminate bald eagle nesting sites and possibly impact foraging opportunities along rivers.

Most of those who studied bald eagles previously in Arizona believed that the reservoirs were relatively unimportant as foraging habitat. Rubink and Podborny (1976) speculated that, "Large reservoirs may be unsuitable as foraging habitat. Several reasons are possible: inadequate perches and shallow water areas, the absence of fish near the surface, turbidity of the water or human disturbance by boating."

Similarly, Hildebrandt and Ohmart (1978) commented that, "The lack of observed use of reservoirs by Arizona's Bald Eagles suggests little or no benefit from newly constructed impoundments, although this point needs further study."

In a more comprehensive investigation, Grubb (1986a) noted that of all observed forage events (successful and unsuccessful), only 4 percent occurred in reservoirs while the majority occurred on rivers (72%) and upland riparian areas (19%). By comparing observed river versus reservoir use at sites with both habitats available, Grubb (*op. cit.*) estimated the following percent utilization: Horseshoe (river 58%, reservoir 25%), Bartlett (96%, 0%), Blue Point (58%, 5%), Pinal Territory (40%, 0%), and Pleasant (0%, 50%). From these observations, Grubb (1986a) argued that "... there is a definitive tendency toward river foraging versus lake foraging at those sites with both habitats present."

Although these studies reported relatively little or (or no) observed use of reservoirs, the key word in each of the data sets is *observed*. As we learned in our telemetry studies detailed in Part B of this report, nesting adult eagles may travel quite far to forage. Moreover, their routes to and from foraging areas are not always direct because they often detour to exploit thermal and terrain updrafts. In each of the previous studies, the researchers noted that the eagles often left their field of view and returned with prey (see Section D4). Our data suggests that many of those prey items brought from unknown locations came from reservoirs.

Table A3.3-1 shows the results of our radio-tracking studies at breeding areas containing both riverine and reservoir habitat. In every case where broods were present, reservoir visits accounted for over 50 percent of movement to perching and foraging locations. Note in the table how the Pinal female frequented the reservoir (7 km from her nest) in 1987 when a brood was present but restricted her visits the following year when the nest failed. However, her home range truncation also resulted from the appearance of a rival female (Pinto) in 1988 who attempted to nest in the area of the reservoir that AF01 had favored most during the previous year (the inflow area of the reservoir, see Sections A3.4 and B4.6). Another male (Cliff), whose nest failed in the year we studied it, was not known to visit the reservoir. However, crappie bones in nest remains from the year before implied reservoir use when young were present.

Not only did the nesting bald eagles frequently perch at the reservoirs, they foraged on them extensively. Of 841 forage attempts recorded at the seven studied territories, 435 (51.7 percent) occurred on rivers, and 406 (48.3 percent) on reservoirs (see Section B4). These data include forages from two territories (East Verde and Ladders) that were not close to reservoirs. However, we note that foraging eagles are easier to view over long distances on reservoirs than in more enclosed riverine environments.

Prey delivery data provides a clearer estimate of the importance of reservoirs to the diet of the eagles we studied. A comparison of river and reservoir forages by eagles in territories where reservoirs occurred within their home range is presented in Table A3.3-2. Eagles foraging in reservoirs at these breeding areas accounted for between 32 percent and 96 percent of prey delivered to the nest and between 28 percent and 97 percent of biomass delivered. Interestingly, the data suggest that eagles on the Salt and Verde rivers may forage more in upstream reservoirs (Roosevelt and Horseshoe) than in terminal reservoirs (Saguaro and Bartlett). The Horseshoe nest was situated at the reservoir inflow, so it is no surprise that the reservoir contributed significantly to the diet. However, the Pinal nest was 7 km distant from the reservoir, and yet the majority of delivered items were from the reservoir. Clearly, however, the contribution of reservoir habitats to prey resources at all four territories was substantial.

All portions of reservoirs were highly productive of bald eagle food, most of it carrion fish. When post-spawn carrion yellow bass and crappie appeared, they were distributed throughout the body of the reservoir, although there were areas of concentration (channels, coves, and shores) that may have been

Table A3.3-1. Visitations of radio-tagged bald eagles to reservoirs versus rivers at territories where reservoirs occurred within the home range of nesting pairs.

| Breeding Area | Bird | Sex | Reservoir (%) | River (%) | Airline Distance from Nest to Reservoir (Km) | Brood Present |
|------------------------|----------------|-----|---------------|-------------------|--|---------------|
| Blue Point | AM01 | ♂ | 59.0 | 41.0 | 1.9 | Yes |
| Bartlett ³ | AM04 | ♂ | 51.0 | 49.0 | 3.6 | Yes |
| Horseshoe ³ | AF02 | ♀ | 84.5 | 15.5 ¹ | 0.0 | Yes |
| Horseshoe ³ | AM03 | ♂ | 85.7 | 14.3 | 0.0 | Yes |
| Pinal ³ | AF01 (1987) | ♀ | 60.9 | 39.1 | 7.0 | Yes |
| Pinal | AF01 (1988) | ♀ | 0.0 | 95.4 ² | 7.0 | No |
| Pinto | AF03 | ♀ | 63.0 | 37.0 | 0.1 | No |
| Cliff | AM06 | ♂ | 0.0 | 100.0 | 5.4 | No |

¹ 2.5% of AF02's river visitations were to the area downstream of Horseshoe Dam.

² 4.6% of AF01's total weighted visitation points in 1988 were to unknown areas downstream of the nest.

³ Visits to the nest vicinity were weighted according to the rate of foraging that occurred there (see Section B2).

associated with drift or an unknown distribution of spawning habitat. At least 92 of 144 fish taken by the eagles were carrion, and we believe that relatively few of the remainder were normal, healthy fish when taken. In these samples, judgement of live status was usually made on the basis of the observed condition of an item when delivered to the nest. Many of the items judged to be alive when delivered were actually moribund when taken. We observed these moribund fish floating near the reservoir surface, especially crappie and yellow bass which were dying from spawning stress.

We found carrion fish (e.g., catfish) around unregulated inflow areas, and much of the eagles' foraging activities took place in the upstream ends of reservoirs (inflow areas) within a few kms of the mouth of the river. In Horseshoe Reservoir (10 river Km long), perching and foraging in the inflow area

Table A3.3-2.

Origin of prey delivered to the nest, showing relative use of reservoir versus river habitat at the four priority territories where reservoirs occurred within the home ranges of nesting pairs.

| Territory | Bird | Reservoir | | River | | Unknown | | Total | |
|------------|------|------------|-------------------|------------|-------------------|------------|-------------------|-------------|-------------------|
| | | Number | Biomass delivered | Number | Biomass delivered | Number | Biomass delivered | Number | Biomass delivered |
| Blue Point | AM01 | 48 (48.5%) | 16,566 (48.4%) | 39 (39.4%) | 13,191 (38.5%) | 12 (12.1%) | 4,504 (13.1%) | 99 (100.0%) | 34,261 (100.0%) |
| Bartlett | AM04 | 45 (32.6%) | 12,121 (28.4%) | 75 (54.3%) | 23,649 (55.4%) | 18 (13.0%) | 6,941 (16.3%) | 138 (99.9%) | 42,711 (100.1%) |
| Horseshoe | AF02 | 23 (88.5%) | 6,956 (91.0%) | 3 (11.5%) | 690 (9.0%) | — (0.0%) | — (0.0%) | 26 (100.0%) | 7,646 (100.0%) |
| Horseshoe | AM03 | 21 (95.5%) | 7,408 (96.8%) | 1 (4.5%) | 247 (3.2%) | — (0.0%) | — (0.0%) | 22 (100.0%) | 7,655 (100.0%) |
| Pinal | TM01 | 30 (66.7%) | 14,016 (65.9%) | 7 (15.6%) | 5,016 (23.6%) | 8 (17.8%) | 2,223 (10.5%) | 45 (100.1%) | 21,255 (100.0%) |

comprised 62 percent of weighted reservoir visitations by the male eagle and 72 percent by the female (see Sections A3.4 and B2 for explanations of weighted visitation scores). These figures are not surprising because the Horseshoe nest was in the inflow area; however, we weighted the visitation scores according to the amount of foraging activity that occurred in the nest area (see Sections B2, B4.5, and E8). Similarly, in Roosevelt Reservoir, 82 percent of the visitations to the reservoir by the Pinal female were to the inflow area. The Blue Point male did not show as strong an affinity to the actual inflow of Saguaro Reservoir (9 Km long); 40 percent of visitations were to the upstream portion of the reservoir. Only 5 percent of reservoir visitations by the male eagle were to the actual inflow of Bartlett Reservoir (15 Km long); however, he repeatedly visited an area a few km downstream of the inflow which he had to travel 9 airline km from the nest.

Carion and live fish may be more available to eagles in inflow areas than in other portions of the reservoir for three reasons: (1) dying fish pass downstream into reservoir inflows which act as catch basins for carion produced in the river (see BioSystems 1985); (2) Since reservoir inflows fed by free-flowing river reaches typically contain large areas of shallow water produced by the deposition of suspended material from the river, the inflows are among the few reservoir areas where bottom-dwelling fish can be taken; and, (3) Large numbers of carp and catfish annually migrate from Arizona reservoirs into rivers to spawn in spring, passing through the shallow inflow areas and the riverine shallows above them. Thus, inflow areas may act as funnels which direct migrating fish into shallow water.

Eagle foraging was more concentrated in inflow areas of reservoirs fed by free-flowing rivers (i.e., Horseshoe and Roosevelt reservoirs) than in reservoirs fed by regulated rivers (i.e., Saguaro and Bartlett reservoirs). The reason is probably that less carion is produced in the relatively short regulated river sections above the inflows. In addition, the inflows of reservoirs fed by regulated rivers do not develop extensive shallows like those fed by free-flowing rivers; there is less suspended material in regulated reaches due to the filtering action of upstream reservoirs.

Most fish we observed taken from the reservoirs were captured in deep water over 200 cm (Fig. A3.3-1). (Eagles cannot reach prey at a depth greater than approximately 0.6 m; forages in deeper water are likely to be for prey floating on or swimming near the surface.) The depth profile is very similar for both "live" and carion fish, although the carion fish show a peak of occurrence in shallow water because they are often wind-blown to shore.

Reservoir fish may become available to eagles as carion due to post-spawning die-offs and human-caused mortality such as prop strikes or other collisions with boats, as well as direct and delayed mortality from angling. Human-caused mortality can result in carion fish appearing anywhere on a reservoir, obscuring natural patterns of carion distribution. Figure A3.3-2 summarizes our knowledge of the ways in which various prey species tend to become available to foraging eagles in reservoir habitats.

A3.3.2 Eagle Use of Riverine Habitat

Despite considerable attention paid to bald eagle food and foraging habits, there is little information on specific foraging habitat for eagles nesting on rivers. Recent literature reviews are available in Stalmaster (1987) and Palmer (1988); however, foraging habitat descriptions are given only in vague terms. Stalmaster (1987) describes a foraging area as "the most essential component of habitat used by bald eagles" but provides little description except to say that it must include large open areas where prey can be killed and eaten. We know of only two studies examining foraging microhabitat: our earlier study on

the Pit River in northern California (BioSystems 1985) and the Arizona study by Haywood and Ohmart (1986). Both investigations suggest that eagle foraging is strongly tied to specific riverine habitats.

In our Pit River study, we found that eagles foraged primarily in pools and visited them more frequently than expected on the basis of their abundance relative to other habitats. There was a strong positive correlation between site selection and the percent of pool area characterized as "shallow with no surface turbulence." Fish apparently became vulnerable to eagles when they moved from the deeper pool areas to the shallow areas at the tails of pools (BioSystems 1985). In comparing our results on the Pit River with those obtained in Arizona, we note that hydrology of the relatively steep Pit River differs markedly from that of the Salt and Verde rivers, where riffles were typically preceded by runs rather than pools.

Haywood and Ohmart (1986) investigated river profile characteristics at 22 observed forage locations on the Salt and Verde rivers of Arizona. They noted that forages commonly occurred in shallows adjacent to deep pools, the latter being deep enough to provide habitat for prey species. The shallow areas (runs and riffles) provided forage areas for bottom-feeding fish and increased their vulnerability to eagles by bringing them closer to the surface (see Todd, *et al.* 1982). In 127 prey captures listed by Haywood and

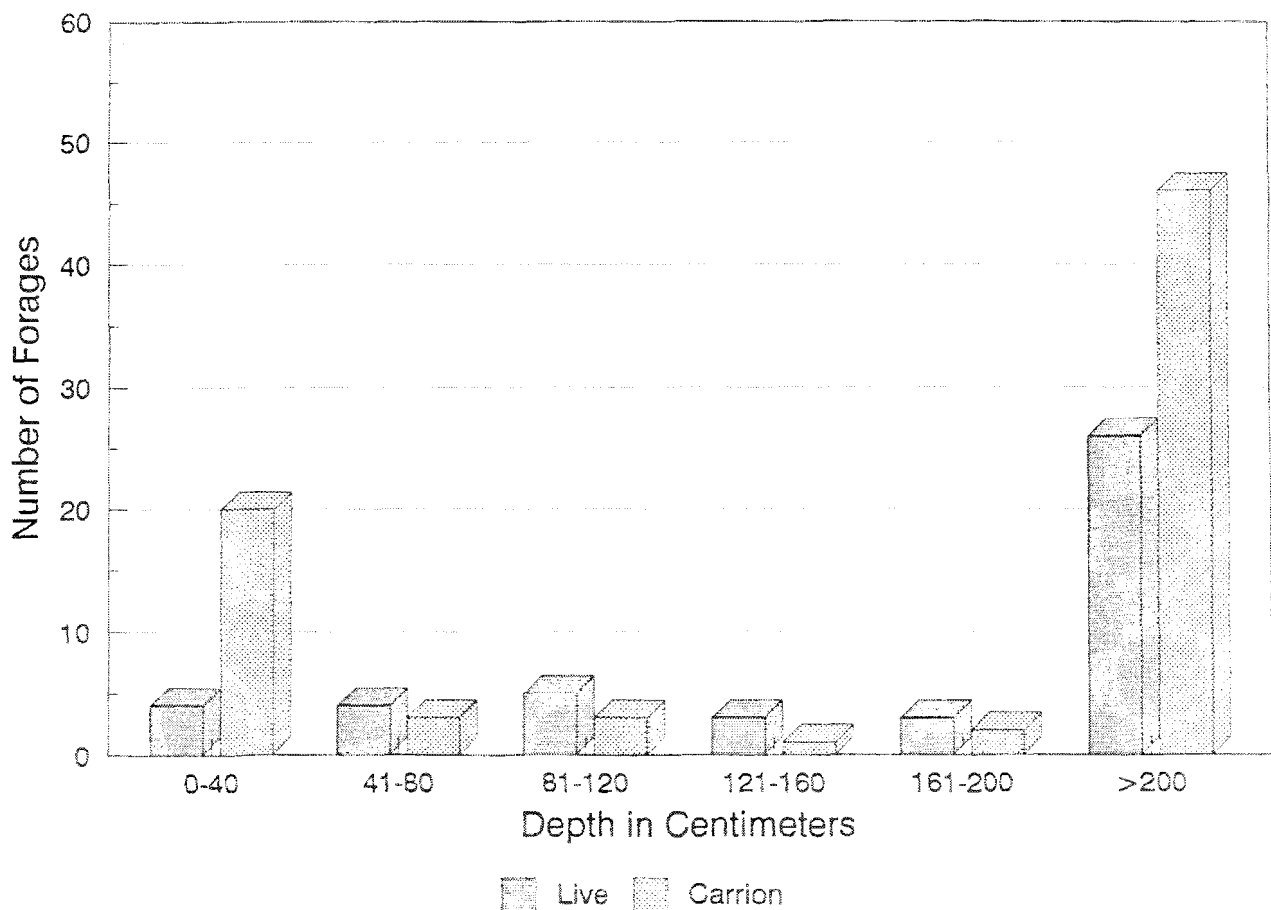


Figure A3.3-1. Depth profile for reservoir forages. The data include all fish which could be identified as live or carrion.

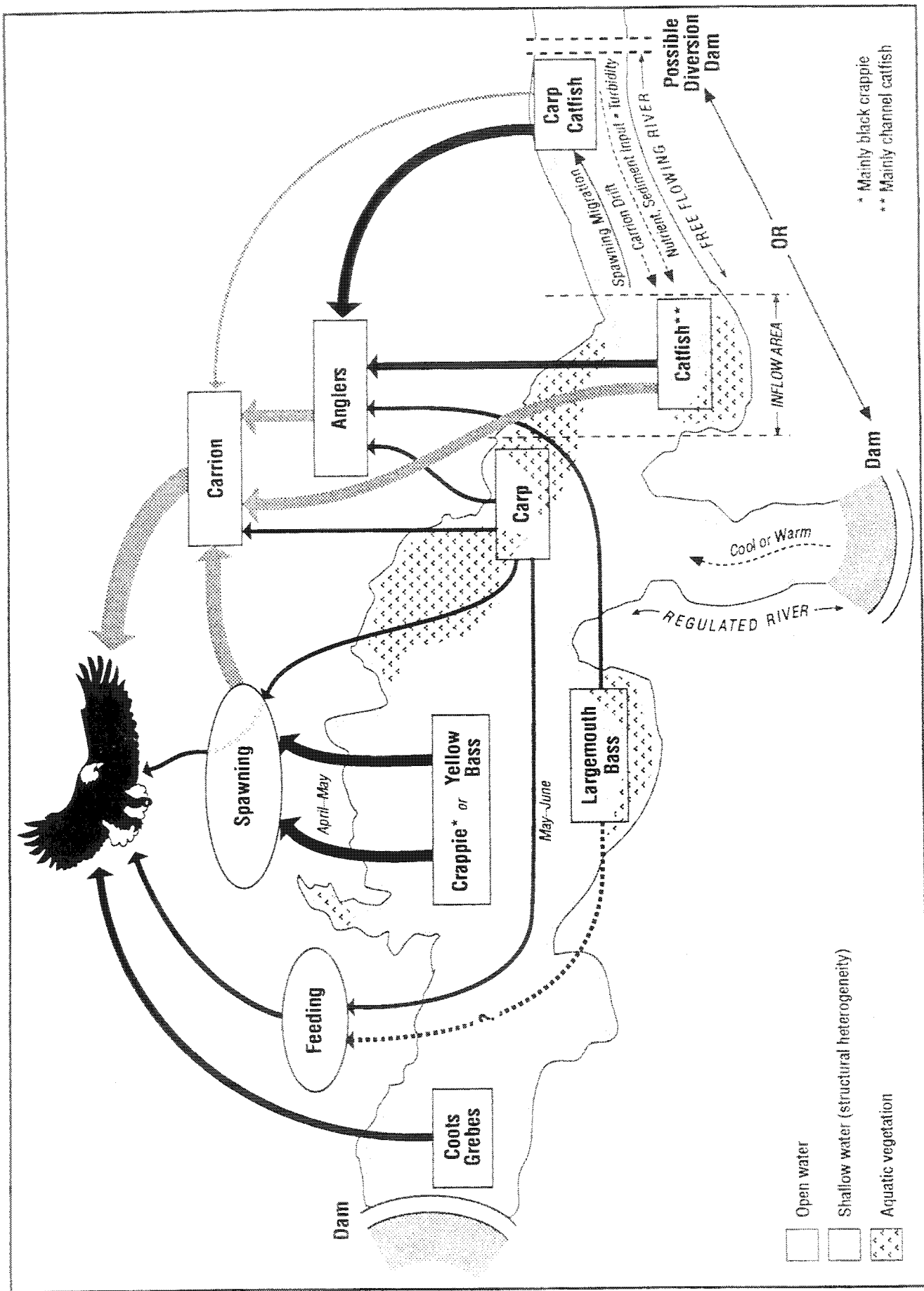


Figure A3.3-2. Conceptualization of bald eagle foraging in an Arizona reservoir receiving water from either a free-flowing river or a regulated river.

Ohmart in which river habitat was identified, (*op. cit.*, p. 40), 66 (52%) were in deep pools, 30 (24%) in deep pool/riffle habitat, 19 (15%) in riffles, eight (6%) at shallow sandbars, and 4 (3%) in other shallows and backwaters. In regard to pool use by eagles, they stated (p. 41) that:

Deep pools bounded by riffles and/or sandbars were common at all nest sites. Pool depth was such that at low flow, or even cessation of flow, water depth was maintained in excess of 3 m.... Each pool was deepest at one side and developed into broad shallows on the opposite bank.

Taken together, the two studies suggest that river foraging habitat for bald eagles is tied to pools deep enough to support a population of prey fish, and that the fish become vulnerable to eagle predation when they move into shallows. Our present study of foraging behavior of bald eagles in riverine habitats, using weighted visitation data from telemetry tracking and direct observations of 435 forages yielded somewhat different results, mainly in regard to the habitats where eagles attacked fish.

In contrast to the previous studies on foraging eagles in Arizona and California, we found that bald eagles did not forage selectively in pools. Analysis of observed versus expected habitat use revealed that they foraged in riffles disproportionate to the occurrence of riffles along the river (see Section B4). We ran this analysis for four eagle territories (East Verde, Ladders, Bartlett, and Blue Point) where we had both relative habitat abundance data and substantial riverine foraging data. A summary of habitat use by foraging bald eagles at the four territories is presented in Figure A3.3-3. Intense observation at some riffles revealed that their upstream ends ("pre-riffle areas") tended to be favored both by the eagles and the fish they preyed upon.

Among microhabitat components we measured at strike points for live fish were depth, turbidity, water velocity, and substrate characteristics. Overall, in riverine habitat, eagles tended to take live fish in shallow, clear water; during our study, these features were typical of riffles and the shallow portions of runs. Turbidity increased in the Salt and Verde rivers briefly after rains and during more prolonged periods of snowmelt (e.g., March 1987). We obtained 162 measurements of turbidity at strike points for live fish captures. In 136 (84%) cases, the water was noted to be "clear to the bottom." In eight of the 26 cases where turbidity obscured the bottom at strike points, water depth was greater than 200 cm; the 18 remaining strike points averaged 68 cm in depth ($SD = \pm 21.6$ cm) (range 35-109 cm). Keeping in mind that eagles probably cannot take prey swimming deeper than about 60 cm, we are unable to determine from these data whether bald eagles ever took live fish from beneath the surface of turbid water.

Of 134 depth measurements at strike points, 70 (52%) were in water 20 cm or less in depth (the shallowest measurement was 4 cm). Cumulatively, 77 percent were in less than 41 cm, and 92 percent were in water less than 100 cm deep. As discussed in Section A3.3.1, some of the fish judged to be live and healthy when taken in deep water (8% of total captures) may actually have been moribund, but in several cases we clearly saw carp splashing on the surface in deep water at forage sites around the time of the attacks.

Median depths at strike points for 66 suckers, 19 carp, and 10 catfish (6 channel and 4 flathead catfish) were 20 cm, 22 cm, and 67 cm respectively. Clearly, the great majority of both suckers and carp are taken in very shallow water. While our sample of depths for catfish forages suggest that they are taken in far deeper water, the number of observations is too small for us to generalize as to the conditions surrounding their vulnerability to eagles.

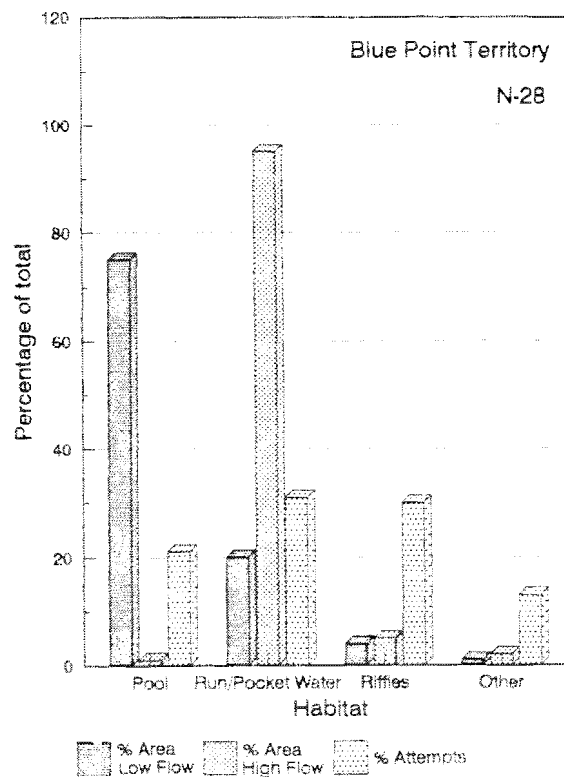
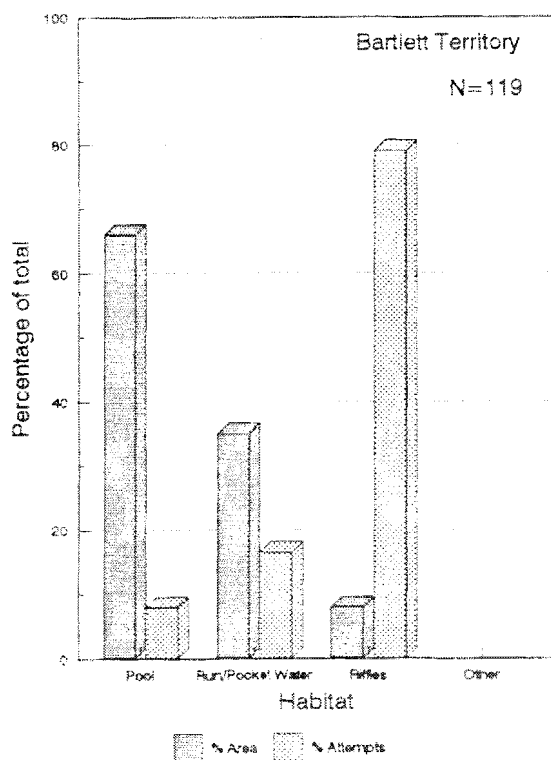
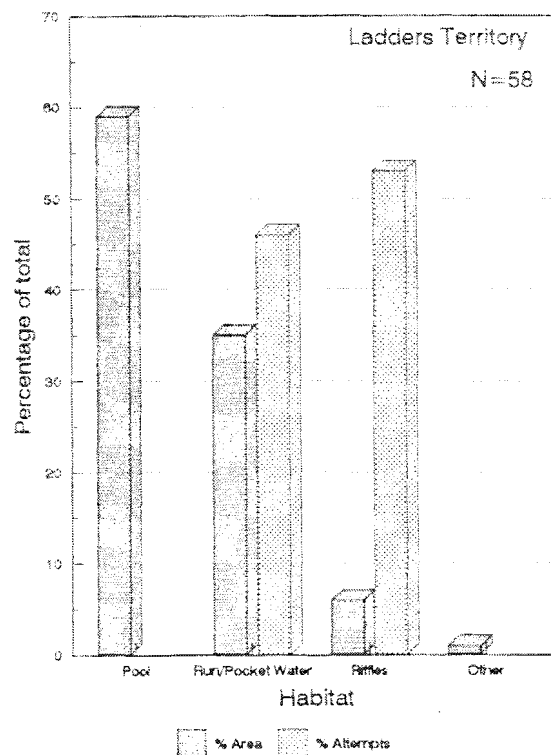
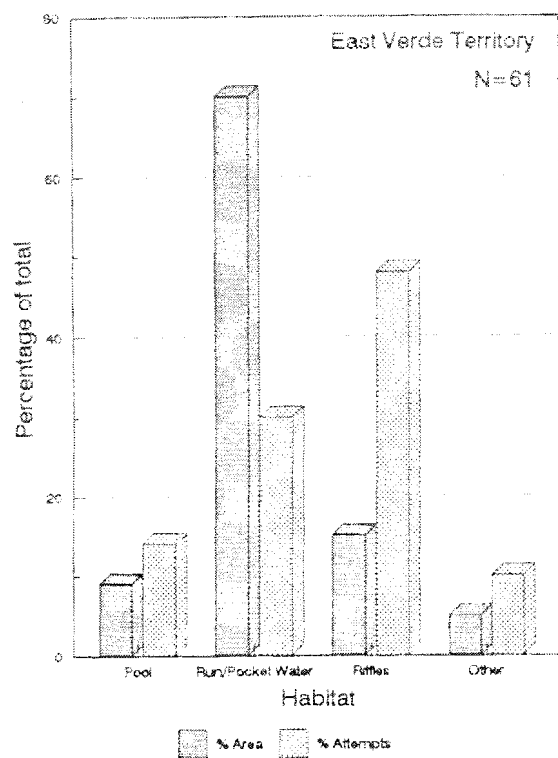


Figure A3.3-3 (a-d). A comparison of habitat availability (by percent area) and the observed distribution of forage attempts at four bald eagle territories.

To some extent, the preponderance of riffle use by eagles resulted from the fact that suckers were the principal fish taken in most of the riverine habitats we studied. Figure A3.3-4 shows that while eagles took suckers mainly in riffle habitat, carp captures were more frequently recorded in runs, and channel catfish in pocket water and runs.

Certainly, any fish is more vulnerable to attack when it is in a riffle. In this shallowest of riverine habitats, large fish are at a special disadvantage because they are conspicuous, active, and are far less able to maneuver and escape than in deeper, less structured habitats. We have little data on the frequency with which carp enter riffles, although we have made numerous incidental observations of their occurrence in this habitat. Suckers, on the other hand, are very much attracted to riffles, and the eagles regularly capture them there. Because of the great vulnerability of fish in riffles, we will discuss some of the characteristics of riffle habitat that tempt fish to enter them.

Why Riffles Attract Fish

Fish Find Food in Riffles. Riffles are prime foraging habitats for fish because primary production (photosynthesis) is higher in swift running water habitats (i.e., riffles and runs) than in slower running habitats (i.e., pools) (Cummins *et al.* 1964). Photosynthetic rates are light-dependant, so higher primary

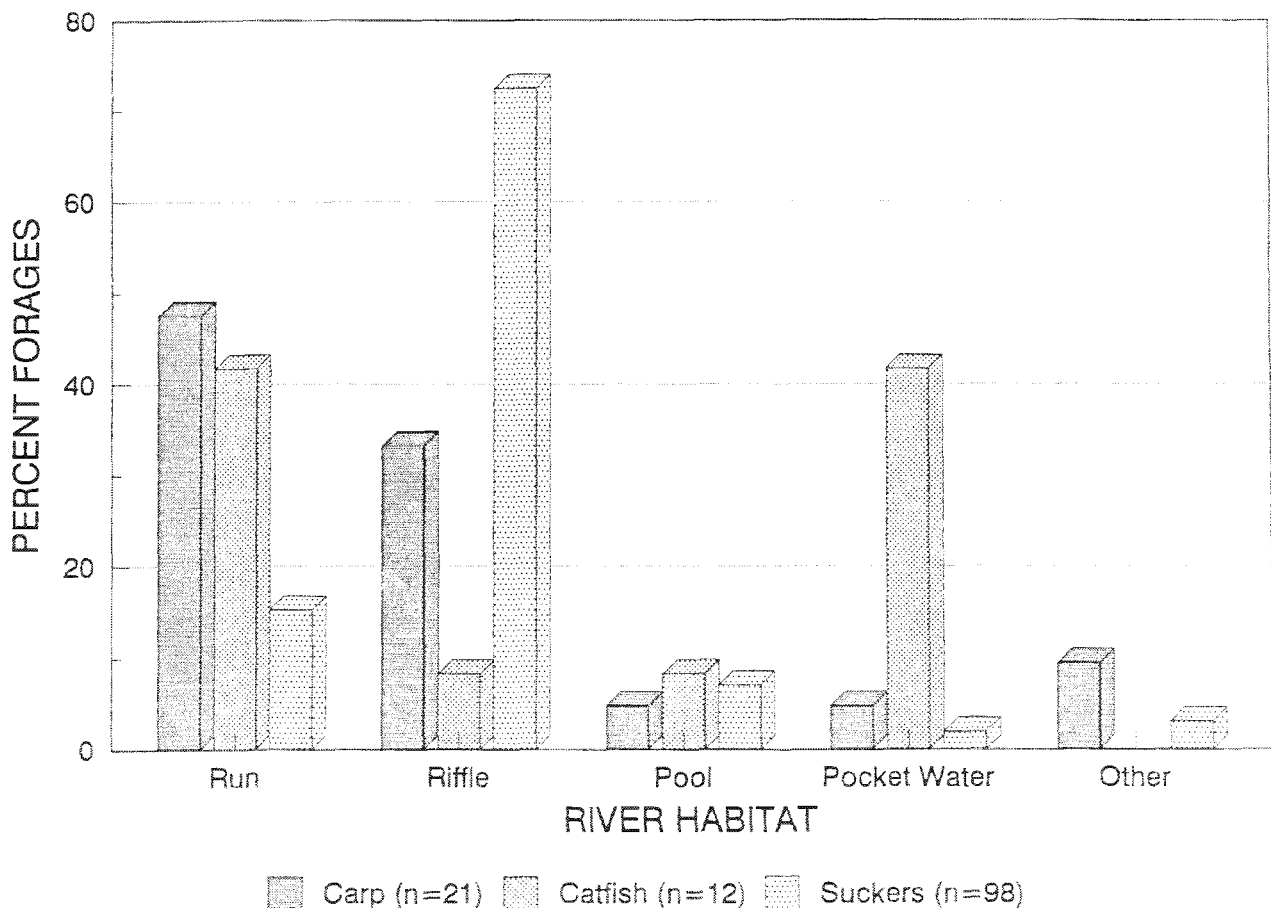


Figure A3.3-4. Habitats where eagles took live carp, catfish, and suckers.

production in riffles is a result of shallow water and large, clean substrate; more light reaches the bottom than in deeper water. The greater the complexity of the substrate, the more area is available for algal growth. In addition, high water velocity characteristic of riffle habitat prevents silt deposition from reducing structural complexity. A food web in the riffles of Arizona rivers is illustrated in Figure A3.3-5.

In general, rapidly flowing waters support a greater invertebrate population than pools (Egglishaw and MacKay 1967, Armitage *et al.* 1974, Richerson 1982, Scullion *et al.* 1982, Logan and Brooker 1983, Smith and Li 1983, and Delucchi 1988). Bottom-dwelling invertebrates concentrate in areas where their food resources (algae) are most abundant; consequently their abundance is directly related to the stream bottom composition and water current velocity found in riffles (Rabeni and Minshall 1977). Rader and Ward (1990) found a significant correlation between the abundance of aquatic insects and the amount of surface algae and detritus. In Arizona rivers, algal mats often develop in shallow riffle and run habitat. The presence of algal mats in riffle habitat has also been associated with greater total density and species diversity of invertebrates, with insects comprising the majority (Dudley *et al.* 1986, Radar and Ward *op cit.*). In Idaho streams, Maurer and Brusvin (1983) documented that insect biomass was two times greater in areas covered with green algae than on bare substrate.

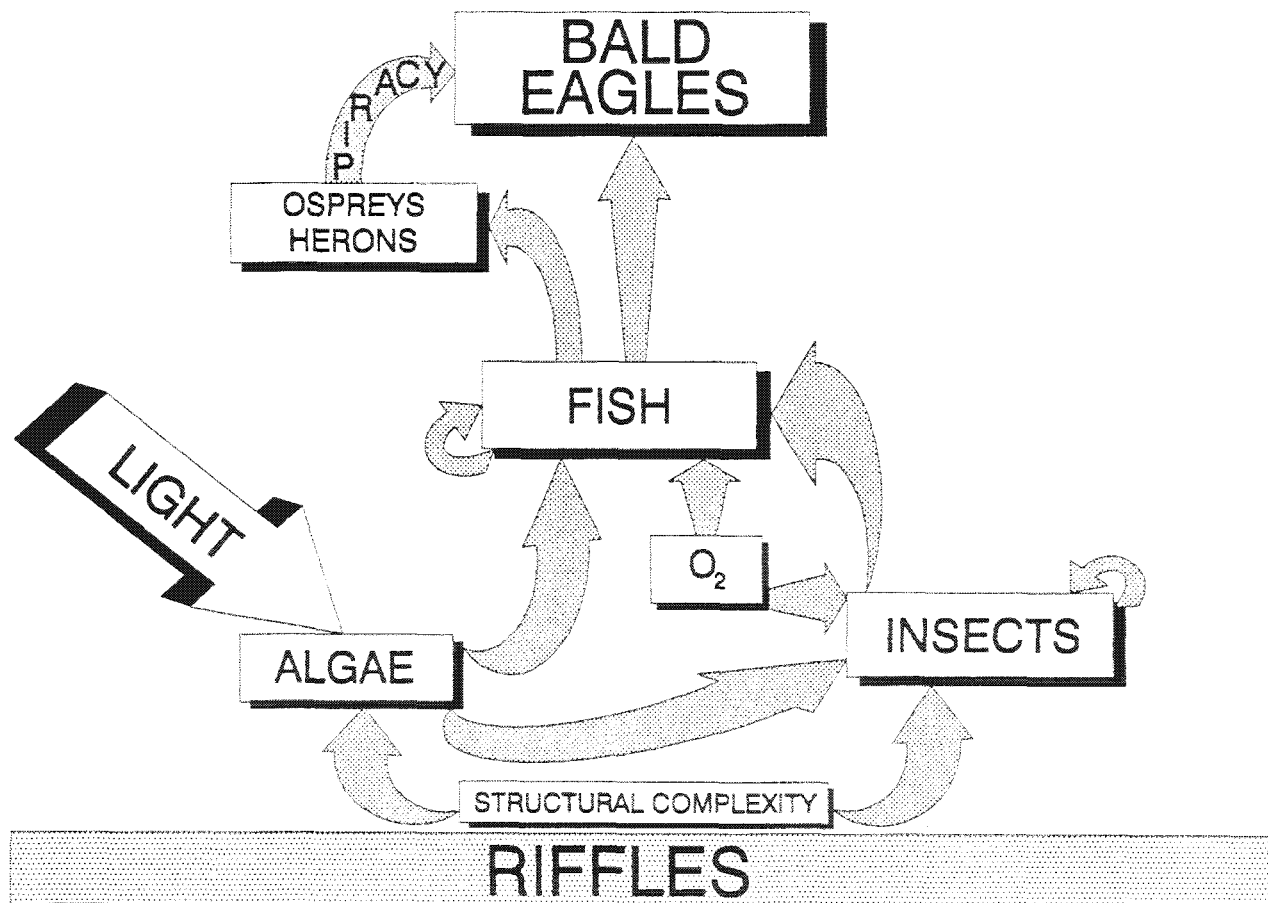


Figure A3.3-5. Food web relationships within a riffle.

Greater structural complexity in riffle and run habitat, compared to pools, also leads to higher insect diversity and abundance (Pennak and Van Gerpen 1947, Graca *et al.* 1989, Scott 1958, Allen 1975, DeMarch 1976). Different species of invertebrates may be found in different configurations of substrate. In the upper Colorado River, Rader and Ward (1990) observed *Diptera*, *Trichoptera*, and *Ephemeroptera* utilizing the tops, sides and front of rubble substrate, while *Plecoptera*, *Coleoptera*, and non-Insecta utilize the bottom surfaces and interstices. In contrast, the substrate of most pools is composed of silt, bedrock or sand, which lack the structural complexity to support a wide variety of species.

The greater abundance and biomass of insects, particularly large ones, in riffle habitat creates optimal foraging conditions for many kinds of fish. We observed both carp and suckers foraging in riffles. Foraging fish often ingest algae in riffles, but it is believed that invertebrates attached to the algae provide the bulk of calories. Since foraging on bottom-dwelling invertebrates in relatively swift water requires considerable energy, we speculate that, although riffles do have microhabitats with slower water, individual fish conserve energy by leaving the riffles when satiated. This may result in a fairly constant supply of fish moving into and out of riffles and pre-riffle areas (the relatively smooth, shallow water on the upstream edges of riffles).

High spring flows in Arizona rivers result in the loss of many shallow water habitats, restricting foraging habitat primarily to newly inundated areas of riffles (see Super-Riffles, below). If fish and eagles are to be attracted to these newly inundated areas, insects must colonize them rapidly. Downstream drift is generally considered the main mechanism for insect populations to colonize new or disturbed areas. Gray and Fisher (1981) determined that following flooding in a Sonoran Arizona stream, the majority of individuals initially establishing themselves were derived from drift and belonged to relatively few taxa (*Probezzia* spp. and Chironomids in winter; mayflies and *Cricotopus* spp. in summer). Other studies likewise support downstream drift as the major means of recolonization (Townsend and Hildrew 1976, Williams and Hynes 1976).

Recolonization studies have shown that drift alone can replenish a denuded area of substrate in as little as 10-14 days (Waters 1964) and most commonly, within 4 weeks (Mason *et al.* 1967; Coleman and Hynes 1970; Williams and Hynes 1976). In an Arizona desert stream, Fisher *et al.* (1982) determined that insect communities recovered from a flood in as little as 2-3 weeks (Fisher *et al.* 1982).

Fish Also Spawn in Riffles. In addition to being prime foraging areas for many species of fish, riffles (particularly the heads) appear to be the preferred spawning habitat of both Sonora and desert suckers. We recorded extensive foraging by eagles on spawning suckers from riffle habitat in the Bartlett and Blue Point territories (Sections B4.1 and B4.2). Although suckers were abundant in all riverine habitats in these territories, obviously they were more vulnerable to eagles in shallow riffle habitat than in deep runs and pools. Once sucker spawning was completed, the eagles usually switched to other prey species. At Bartlett, the riffles at Km 34.5 ("powerline riffle") and Km 30.3 were used extensively by spawning suckers, as was the riffle at Km 17.3 in the Blue Point territory.

Unlike many fish species, suckers do not construct elaborate redds to deposit eggs or protect the eggs or fry from predators, nor do they fan the eggs with their fins to ensure adequate water circulation during incubation. Therefore, egg survival is totally dependant on environmental conditions at the spawning site.

Several of the same physical characteristics of riffles that make them ideal foraging areas for fish (because of invertebrate production) also attract spawning suckers. The heads of riffles are selected for egg deposit



Plate A7. Jeff Simms, BioSystems fisheries biologist, measuring flows in the Verde River (photo by Ed Bianchi).

by suckers for three reasons: (1) the substrate is cleaner in riffles than in other habitats due to higher water velocity, therefore eggs are not covered up by silt or sand; (2) water circulates freely in the gravel bed allowing for removal of waste products at the outer surfaces of the eggs; and, (3) gas concentrations are higher in riffles than in pools and runs, resulting in faster diffusion of oxygen into the developing eggs.

Other researchers have identified berm or "pre-riffle" areas as important spawning habitat. Shapovalov & Taft (1954) noted that female silver salmon typically select spawning sites at the head of a riffle (lower end of a pool where the water breaks into a riffle). Briggs (1953), in a study on a coastal stream in northern California, noted that redds of salmonid species were most often located at the ends of pools where water was beginning to build momentum. Mention of this phenomena is also referenced in the USFWS "Habitat Suitability Index Models and Instream Flow Suitability Curves" for chinook salmon. In this publication the USFWS (U.S. Fish and Wildlife Service 1986) cites Vronskii (1972) as having reported that 95 percent of chinook salmon redds are located on the gravel transition areas between pools and riffles. Similarly, Vogel (1983) found that spawning chinook salmon preferred "bermed" areas by

a factor of 14 times over unbermed areas. We have observed both chinook salmon and Sacramento suckers favoring similar habitats on the Mokelumne River in northern California.

Super-Riffles. During periods of high spring flows in Arizona rivers (usually in March and early April), the abundance of shallow habitats decreases and turbidity increases significantly, reducing the ability of eagles to detect and catch fish except in very shallow water. These periods of high flow occur while there are chicks in the nest, and sometimes when the chicks are at the peak of energy requirements (5-7 weeks after hatching). Later in the spring, flows decrease in the rivers, resulting in the formation of abundant shallow foraging habitat. Given this pattern, we hypothesized that bald eagle nesting territories might tend to be situated in areas that contain shallow water habitats even during high flows.

During our field studies, we noticed differences in the morphology of riffle habitat. In certain configurations, which we call "super-riffle type," riffles provide shallow water foraging areas during a wide variety of flows (Fig. A3.3-6). The key feature of super-riffles is that as flow increases, water depth and velocity increase in only a small area of the habitat, while overall the amount of shallow water increases in the riffle due to the spreading of water across a gravel bed. Characteristics of super-riffles include: (1) maintenance of habitat integrity under a wide variety of flows; (2) presence of a gravel bar oriented diagonally or perpendicularly to flow, with most of the gravel bar out of the water at low flow but becoming increasingly inundated as flow increases; (3) substrate consisting primarily of clean gravel and rubble; and, (4) a moderate gradient so that water velocity remains relatively low even under high flow.

Use of Super-Riffles by Foraging Eagles. During our investigations of the foraging ecology of the radio-tagged eagles, we often noticed them foraging in super-riffles. Indeed, it was during these observations that we first identified this river habitat type. For example, just downstream of the mouth of Fossil Creek, within the home range of the East Verde eagles, we recorded numerous visits by the foraging adult male to a super-riffle in this location, although we had not yet recognized its special configuration. When we began looking for super-riffles, we found them in every one of the eight eagle territories we studied. We then compared the distribution of super-riffles to the distribution of perching and foraging visits by the eagles to each river kilometer segment (Km). We were able to show statistically significant selection by the eagles of Kms containing super-riffles (Section B4). Figure A3.3-7 illustrates this relationship of bald eagle visitation scores (see B2 for explanation) and super-riffle occurrence. Within-territory comparisons (with graphs) appear in Sections B4.1 (Bartlett), B4.3 (Ladders), and B4.4 (East Verde), and further discussion of super-riffle selection by foraging eagles is given in Section A4.4 (Home Range).

Super-Riffles and the Distribution of Pairs. In July 1990, we surveyed the Salt and Verde rivers to map the locations and characteristics of super-riffles. The survey was conducted from a low-flying airplane by two eagle biologists and a fisheries biologist. Flows in the river reaches surveyed were generally low but variable, ranging from 30 cfs to 1600 cfs. During the survey, we noted whether the super-riffles were associated with river bends, tributaries, or cliffs. We also determined the orientation of the gravel bars in relation to flow (i.e., whether the head of the gravel bar was pointing upstream, downstream, perpendicular or parallel to flow). During the surveys, we also identified and mapped several extensive braided areas, since they have many of the same characteristics as super-riffles (i.e., shallow water at a variety of flows). We later measured the distance of each bald eagle nest active within the past five years to the closest super-riffle.



Plate A8. Km 34.5 "Powerline" super-riffle at the Bartlett breeding area on 5 July 1986 at flows of 232 cfs. Note the shallow water habitat angling across the river (photo by D. Driscoll).

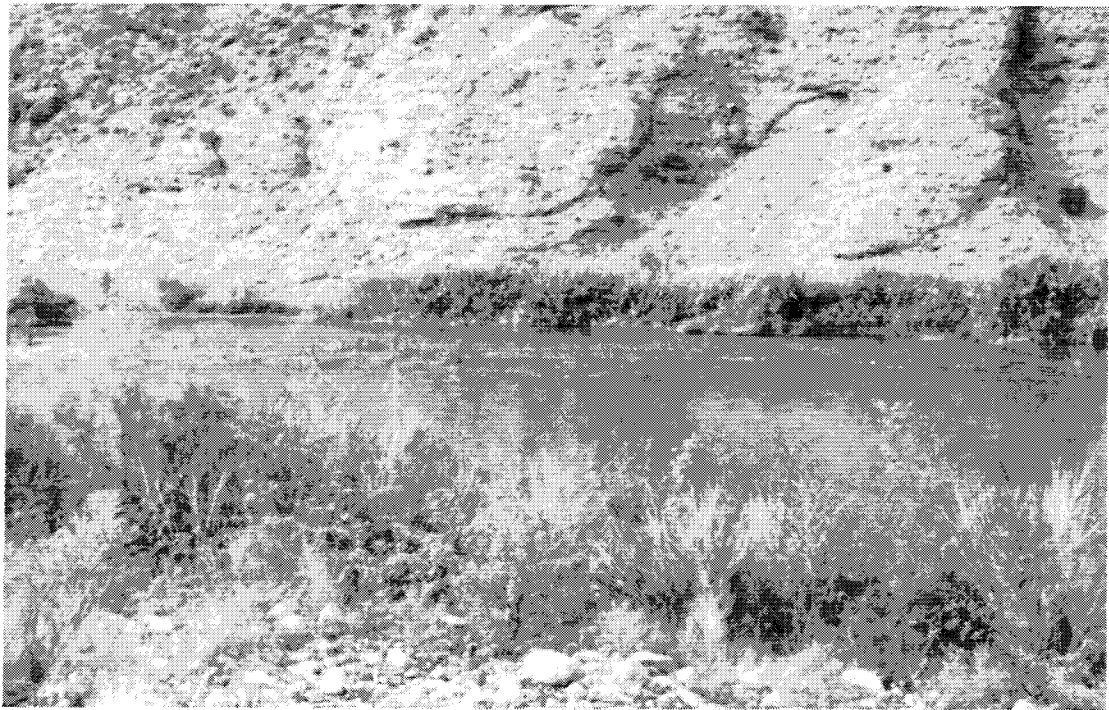


Plate A9. Even at flows of 750 cfs, pictured here on 21 August 1991, the Km 34.5 "Powerline" super-riffle below the Bartlett nest cliff still shows shallow habitat (photo by D. Driscoll).

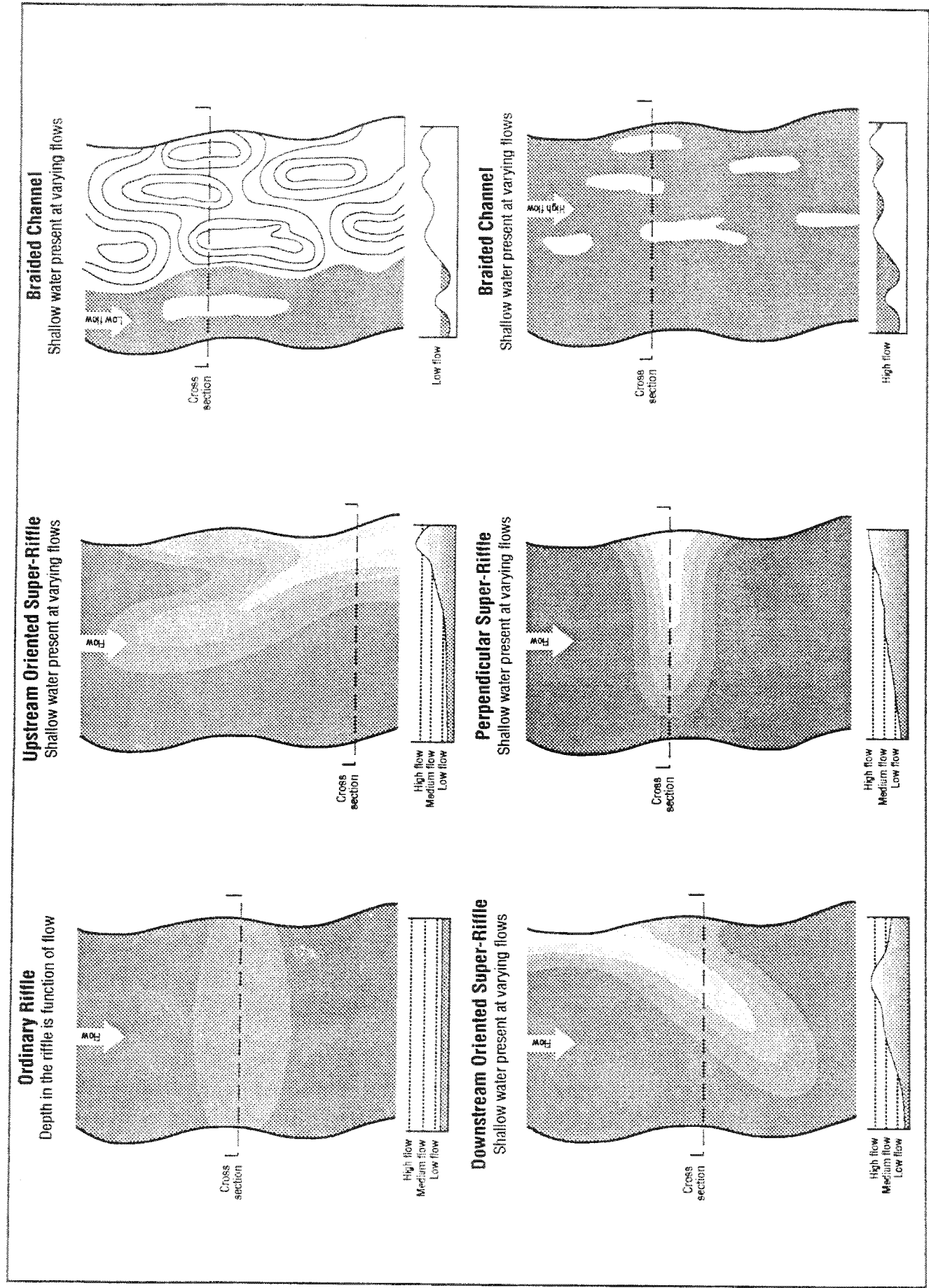


Figure A3.3-6. Comparison of super-riffles, braided channels, and ordinary riffles. The contours describe sediment bar topographic profiles.

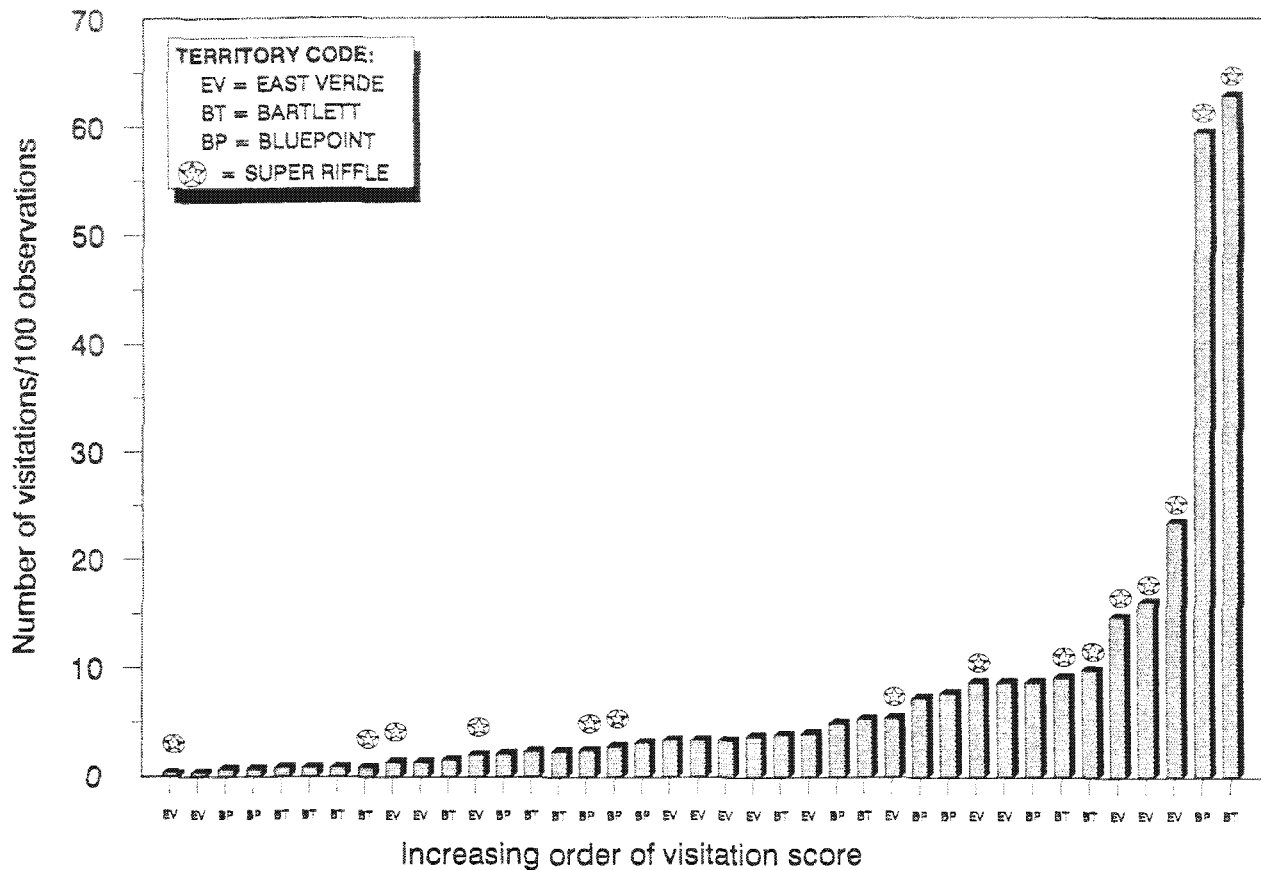


Figure A3.3-7. Summary of eagle visitation scores to river kilometer segments with and without super-riffles at three bald eagle territories in Arizona.

The distributions of super-riffles and eagle nests on the Salt and Verde rivers are illustrated in Figures A3.3-8 and A3.3-9. Only nests used by eagles since 1985 were included in the analysis because major floods occurred in 1978 and 1983 which may have changed the distribution of super-riffles. According to our surveys, the Salt River contains 25 super-riffles and 3 extensive braided areas from Granite Reef Dam to the confluence of the Black and White Rivers (Km 0.0-247.1), along with 27 bald eagle nests. The Verde River has 61 super-riffles, 3 braided complexes, and 25 bald eagle nests from its confluence with the Salt river upstream to Camp Verde (Km 0.0-186.0).

In general, super-riffles on the Verde River were oriented at an angle, either up (52%) or down (41%) with respect to flow (Table A3.3-3). However, there was no clear trend in super-riffle orientation on the Salt River. Super-riffles did not appear to be associated with river bends, tributaries or braided channels in either river. Neither was a trend apparent between super-riffle occurrence and the presence of cliffs.

The mean airline distance from nests on the Salt and Verde rivers to the closest super-riffles was relatively small (2.59 km and 0.58 km respectively). A frequency histogram of distance from nests to the closest super-riffle is presented in Figure A3.3-10.

Distance to River

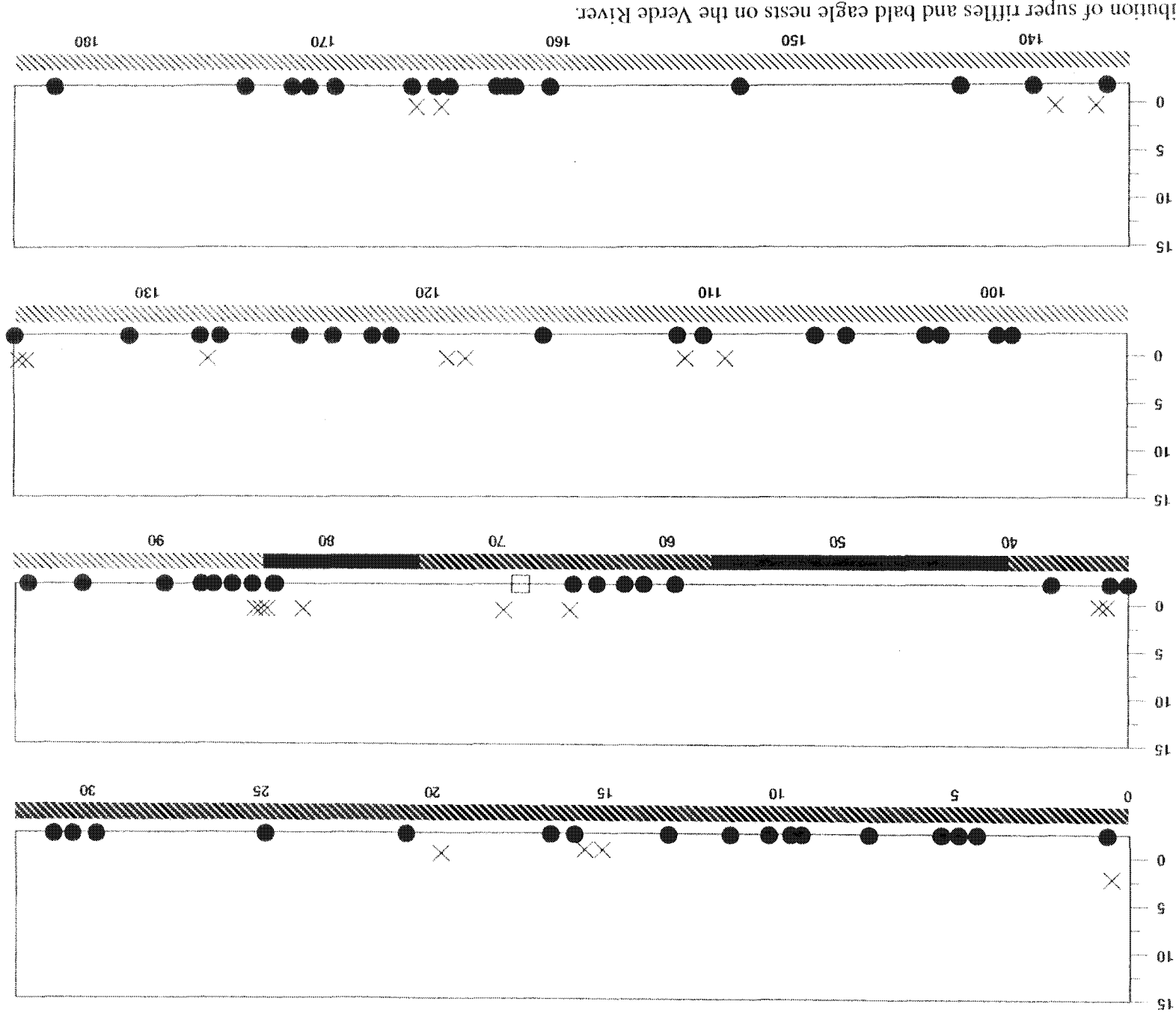


Figure A3.3-8. Distribution of super ripples and bald eagle nests on the Verde River.

Table A3.3-3. Physical characteristics of super-riffles found in the Salt and Verde rivers.

| | Orientation | | | | | Located on River Bend | | Presence of Cliff | | Presence of Tributary | | Braided Channel | | |
|-----------------------|-------------|------|------|-----|-----|-----------------------|-----|-------------------|-----|-----------------------|-----|-----------------|-----|-----|
| | Up | Down | Perp | Par | Unk | Yes | No | Yes | No | Yes | No | Yes | No | Unk |
| Salt River (n=28) | 39% | 18% | 25% | 4% | 15% | 25% | 75% | 64% | 36% | 11% | 89% | 32% | 64% | 4% |
| Verde River (n=64) | 52% | 41% | 2% | 0% | 6% | 9% | 91% | 41% | 59% | 9% | 91% | 20% | 80% | 0% |
| Combined (n=92) | 48% | 34% | 8% | 1% | 9% | 14% | 86% | 48% | 52% | 10% | 90% | 24% | 75% | 1% |

On the Verde River, the greatest distance between a nest and a super-riffle was 2.5 km; 80 percent of nests were within 1.0 km of super-riffles, and 64 percent were within 0.5 km. On the Salt River, only 39 percent of eagle nests were within 1.0 km of a super-riffle; 60 percent were within 2 km. The greater nest-to-super-riffle distances resulted from two factors: (1) considerably fewer riffles were noted on the Salt River, and (2) many nest sites on the Salt River (7 of 27) were located more than 0.5 km off the river (range 1.1–13.0 km), while only one nest on the Verde River was greater than 0.5 km from the river (distance 1.5 km).

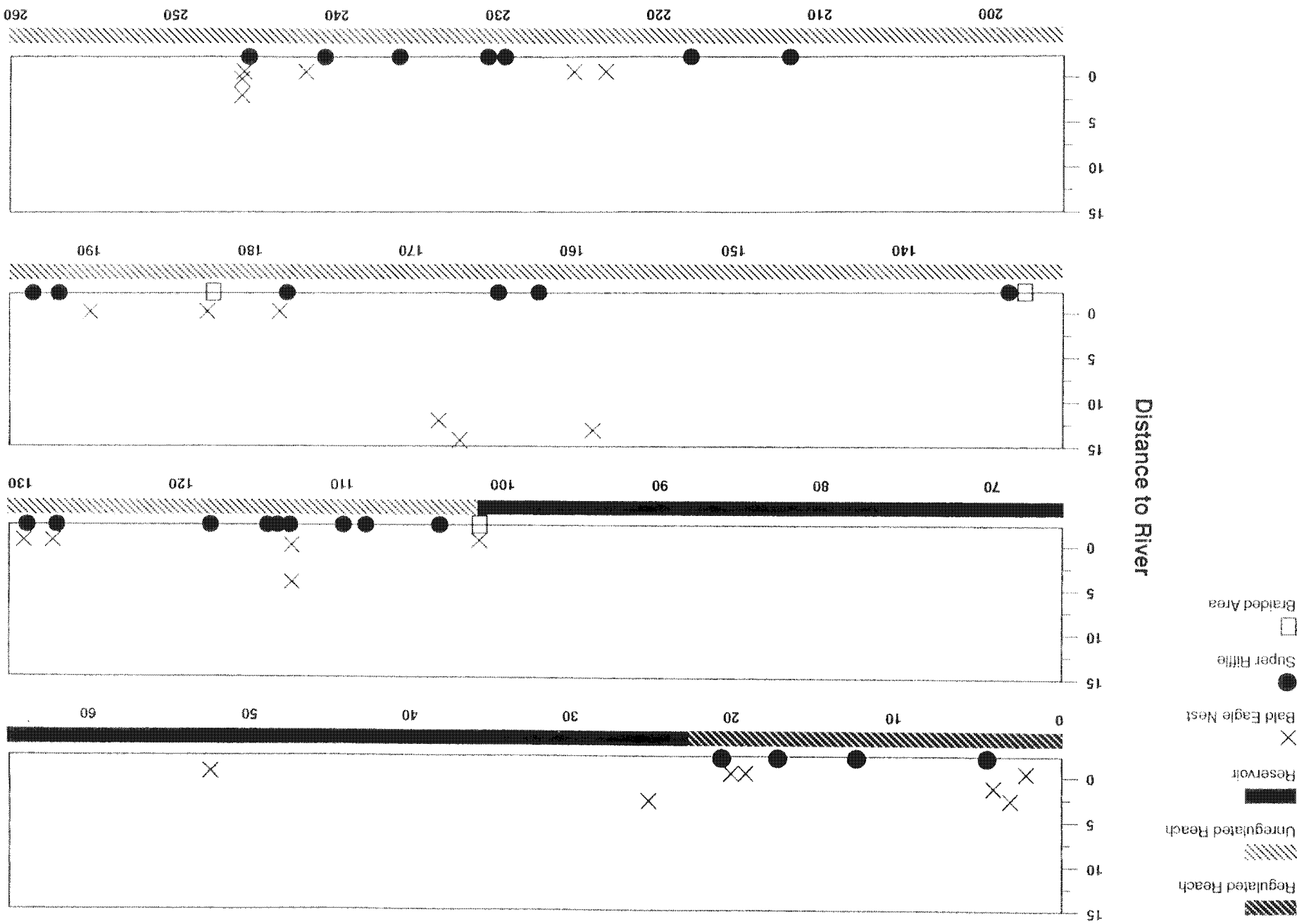
Nest sites on the Verde River were significantly closer to super-riffles than if nests were distributed randomly, but the same was not true for nests on the Salt River (Table A3.3-4). We tried three different statistical analyses. The first test included all active nests on the two rivers, regardless of whether they were located on reservoirs or off-river. The second group excluded nests located on reservoirs or more than 0.5 km off-river. We compared the mean distance of active nests to super-riffles of the first and second group to distances derived from randomly-placed nests. We generated a "random" distribution of nest sites (by computer), but restricted them to rivers (i.e., we did not allow them to be situated off-river or on reservoir). The number of "random" nests placed on a river was equal to the number of active nests. We performed the tests with three replicates of randomized nest locations on the river.

We repeated this analysis on a third group of data, but this time included only nests located within 0.5 km of the rivers *or on reservoirs*. Random nests were also allowed to be located on reservoirs. We used the distance from the nest sites (active and random) to the closest super-riffle *or reservoir inflow* for this analysis. We found that using these criteria, nests on both the Salt and Verde rivers were significantly closer to super-riffles or reservoir inflows than expected (Table A3.3-4).

A3.3.3 Eagle Use of Tributaries

Tributaries were present in several of the breeding areas where we conducted telemetry studies, but no clear trend in habitat use was apparent from the data we collected on their use by eagles. The East Verde

Figure A3.3-9. Distribution of super riffles and bald eagle nests on the Salt River.



nest was located on the mainstem Verde River near two tributaries (East Verde River and Fossil Creek); on both of them the eagles foraged for spawning suckers during April. However, the Ladders pair did not use West Clear Creek, although other eagles visited this tributary in the spring. Similarly, in the Horseshoe breeding area, the nesting eagles did not forage on two very small tributaries within their home range, Sycamore Creek or Lime Creek. Two successful bald eagle breeding areas are currently known on tributaries of the Salt River ("76" on Tonto Creek, and "Canyon" on Canyon Creek). Fish appear to figure prominently in the diets of both pairs, although the sample size from Canyon was small, and the pair may forage in the Salt River.

On the Verde drainage, we conducted fish surveys in West Clear Creek, Fossil Creek, the East Verde River, Sycamore Creek (near Horseshoe Reservoir), and Lime Creek. On the Salt drainage, we surveyed Pinal, Cherry, Cibecue, and Carrizo creeks. We found few potential prey fish in these tributaries, with the exception of the East Verde River. We believe that resident fish densities were too low in most of these streams during our surveys to have provided a reliable food source for nesting eagles.

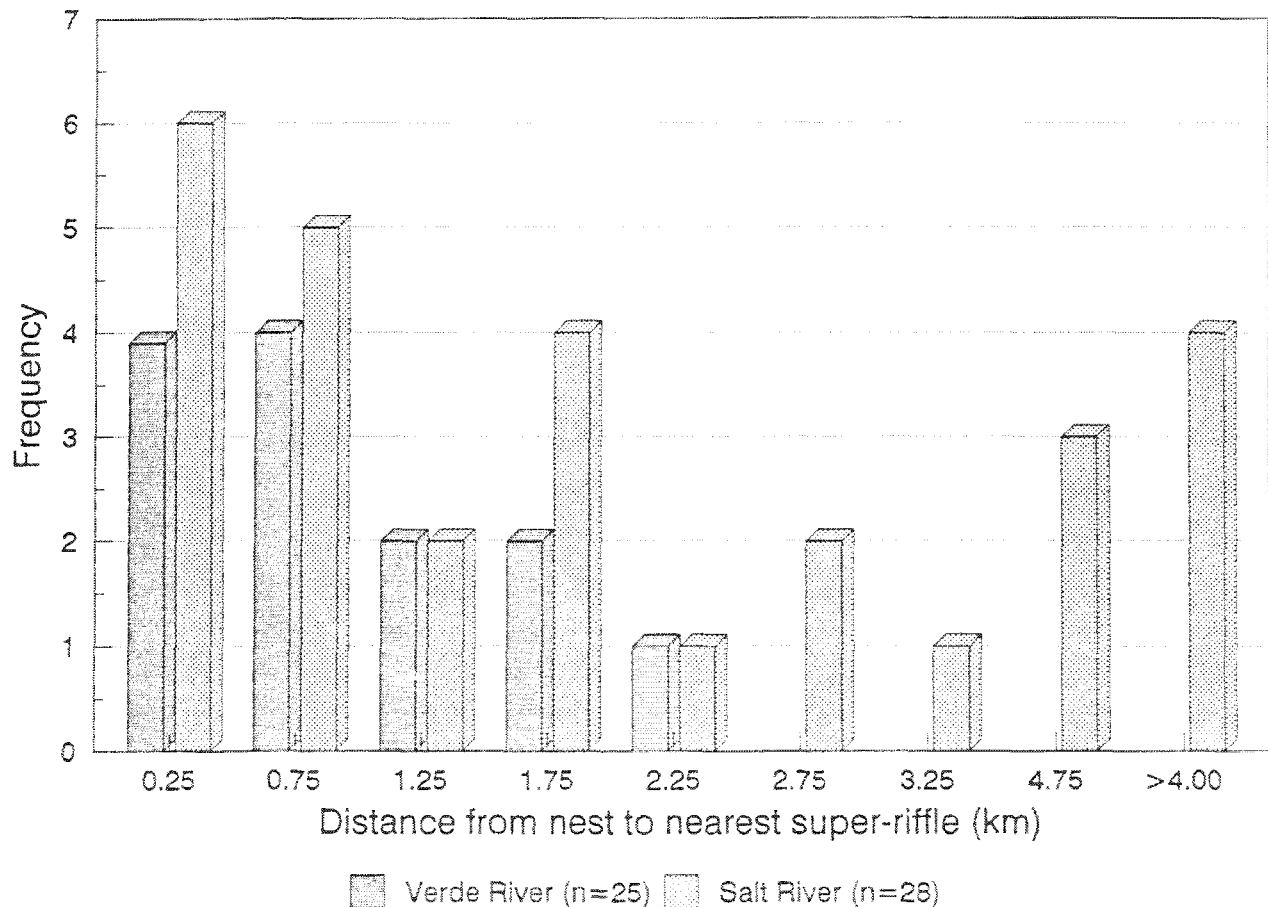


Figure A3.3-10. Airline distance (km) to the nearest super-riffle of each nest used by bald eagles since 1985 on the Verde and Salt rivers.

Table A3.3-4. Comparison of airline distances from nest to super-riffles using actual and "random" nest site locations on the Salt and Verde rivers.

| | Actual Nest Data | | | | "Random" Nest Data | | | | Kolmogorov-Smirnov Two Sample Test |
|--|------------------|------|-----------|-----------|--------------------|------|-----------|-----------|------------------------------------|
| | Distance (km) | | | | Distance (km) | | | | (significance at $p < 0.01$) |
| | N | Mean | Std. dev. | Std. err. | N | Mean | Std. dev. | Std. err. | P |
| Salt River | | | | | | | | | |
| All nests | 27 | 2.59 | 3.11 | 0.60 | 81 | 5.49 | 7.41 | 0.82 | 0.205 |
| Only river nests < 0.5 km off river | 16 | 1.03 | 0.86 | 0.21 | 48 | 1.69 | 1.46 | 0.21 | 0.109 |
| Only river nests < 0.5 km off river and on reservoir (1) | 20 | 0.99 | 1.07 | 0.24 | 60 | 4.81 | 6.55 | 0.85 | 0.004 |
| Verde River | | | | | | | | | |
| All nests | 25 | 0.58 | 0.68 | 0.14 | 75 | 1.43 | 1.36 | 0.16 | 0.004 |
| Only river nests < 0.5 km off river | 20 | 0.58 | 0.66 | 0.15 | 60 | 1.18 | 1.03 | 0.13 | 0.011 |
| Only river nests < 0.5 km off river and on reservoir (1) | 24 | 0.56 | 0.69 | 0.14 | 72 | 1.25 | 1.12 | 0.13 | 0.004 |

(1) Distances used were from nest to nearest super-riffle or reservoir inflow.

However, it is possible that some of the tributaries seasonally attract spawning fish from the mainstem. Although we did not observe spawning migrations, circumstantial evidence at Houston Creek and Fossil Creek suggested that migrations of suckers had occurred in spring 1987. Low rainfall in the following two years (1988-1989) may have generated insufficient flow for spawning migrations. Spawning runs have been reported in earlier years on Cherry and Cibecue creeks (see Section A4.2).

A3.3.4 Overview of Bald Eagle Foraging Ecology in Riverine Habitat

In summary, Figures A3.3-11 and A3.3-12 give our conception of the avenues by which the major prey fish (carp, catfish, and sucker), became available to bald eagles in riverine habitats during our study. In reviewing these diagrams (and others, such as Figure A3.1-4), it is apparent that the eagles were able to successfully exploit a wide range of biota and physiography, and that there is temporal sequencing of prey availability such that one species rarely dominates the diet of an eagle pair throughout the breeding season. This diversity of their foraging suggests that threshold levels of prey and habitat *variation* (in addition to the presence of a specific quantity of prey) may be requisite to nest site selection and nesting success. Although data are not yet sufficient to test this possibility, it is evident that no path of prey vulnerability remains constant through the breeding cycle.

In the primary riverine habitats in which live fish become accessible in shallow water (riffles and runs), temperature appears to significantly influence prey composition and vulnerability. Temperature accounts for differences in fish community structure *between* eagle breeding areas, and causes temporal differences in fish availability *within* breeding areas. Suckers dominate the fish community in cool water conditions characteristic of headwaters and hypolimnetic releases (see Figure A3.3-11), and they form a significant part of the prey base in March and April when they spawn in the shallows of riffles and, to a lesser extent, runs. In contrast, suckers are rare in downstream areas where water has warmed in response to ambient air temperatures and decreasing flows (see Figure A3.3-12). In such conditions, carp and catfish dominate, and, unlike suckers, they are obtained by eagles mainly while feeding in shallows, rather than while spawning in them. In some situations (e.g., below a dam), anglers may augment the diet of eagles by producing carrion carp and catfish. Natural mortality related to spawning migrations, possibly compounded by barriers, may also contribute to carrion.

Changing water temperatures may also influence the timing of prey availability within each breeding area. As water gradually warms during spring, optimum spawning temperatures appear earliest for suckers, then for carp and catfish. Because spawning contributes to the vulnerability of both suckers and carp, the fact that they spawn at different times prolongs the period in which spawners are available. Seasonal shifts by eagles from one prey species to another was characteristic of all six successful pairs we studied with telemetry, and the timing of eagle use of each species tended to correspond to appropriate ranges of spawning temperatures in most cases.

Temperature may also affect the frequency at which prey fish enter shallow water to forage. As water temperatures rise in spring, the metabolic rates of fish increase, resulting in greater demands for food. At the same time, increasing rates of photosynthesis sustain larger invertebrate populations in shallow water. Interestingly, suckers are the most likely of the three types of fish to become vulnerable as a direct consequence of spawning. To the benefit of eagles, they spawn early in the season when photosynthetic rates do not yet encourage maximum use of shallow water by foraging fishes. The movements of carp into shallow water to forage generally occurs after suckers have finished spawning.

At least two other factors also influence the relative abundance of carp, suckers, and catfish. One is the migration of fishes out of the reservoirs to spawn. It may be that the rarity of suckers in river sections upstream of the reservoirs is not only a function of temperature, as we have argued, but also a result of sucker populations being overwhelmed by large numbers of carp and catfish from the reservoirs. Differences in turbidity may also affect the occurrence of the three kinds of fishes. In general, carp and catfish are more tolerant of turbid conditions than are suckers, and indeed, the observed distribution of the three types of fish in the Salt and Verde rivers appears to correspond to the amount of turbidity. It

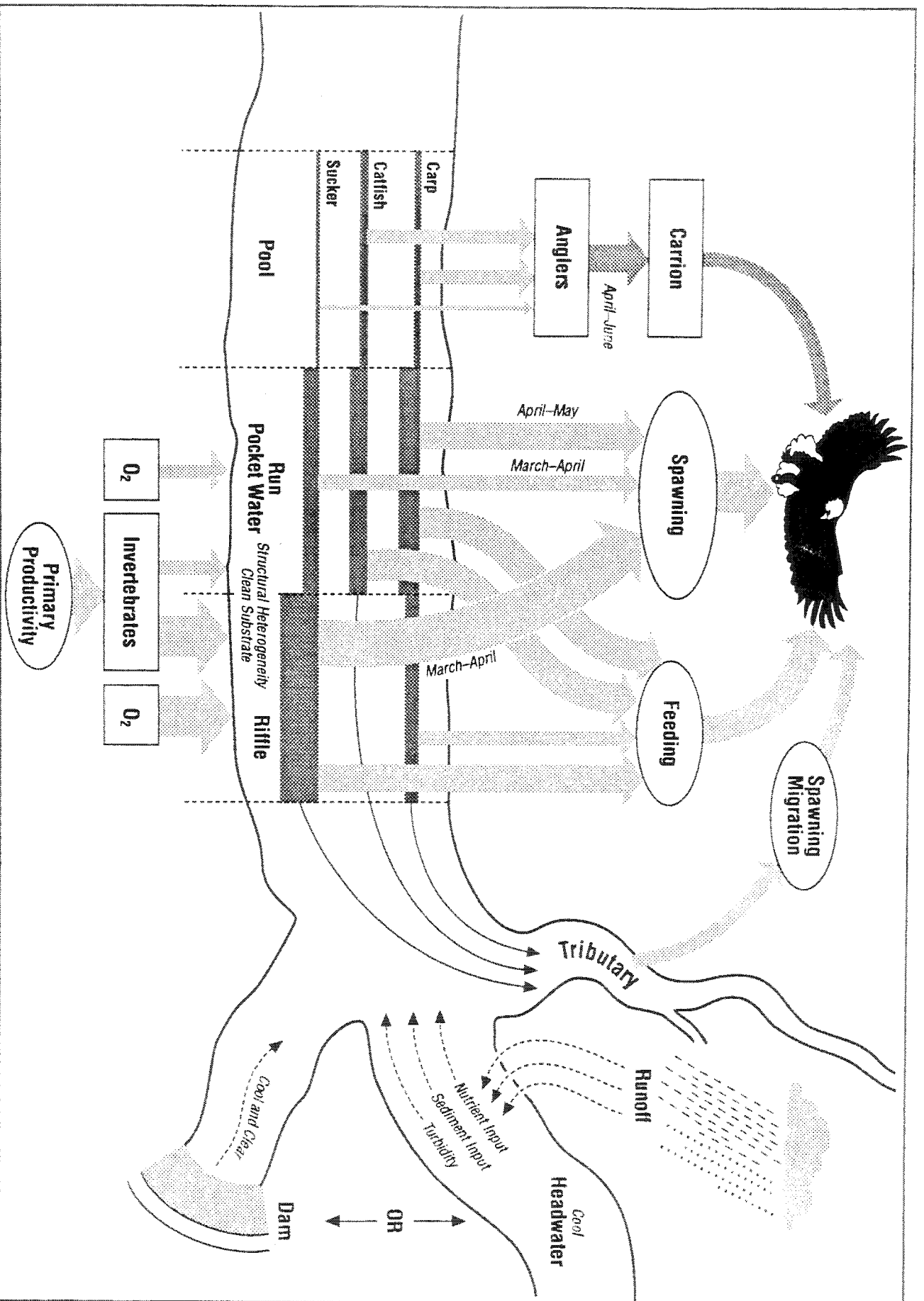


Figure A3.3-11. Conceptualization of bald eagle foraging in riverine habitat fed by: (1) a clear, cool, free-flowing river, or, (2) a regulated river receiving water from the hypolimnion of a stratified reservoir.

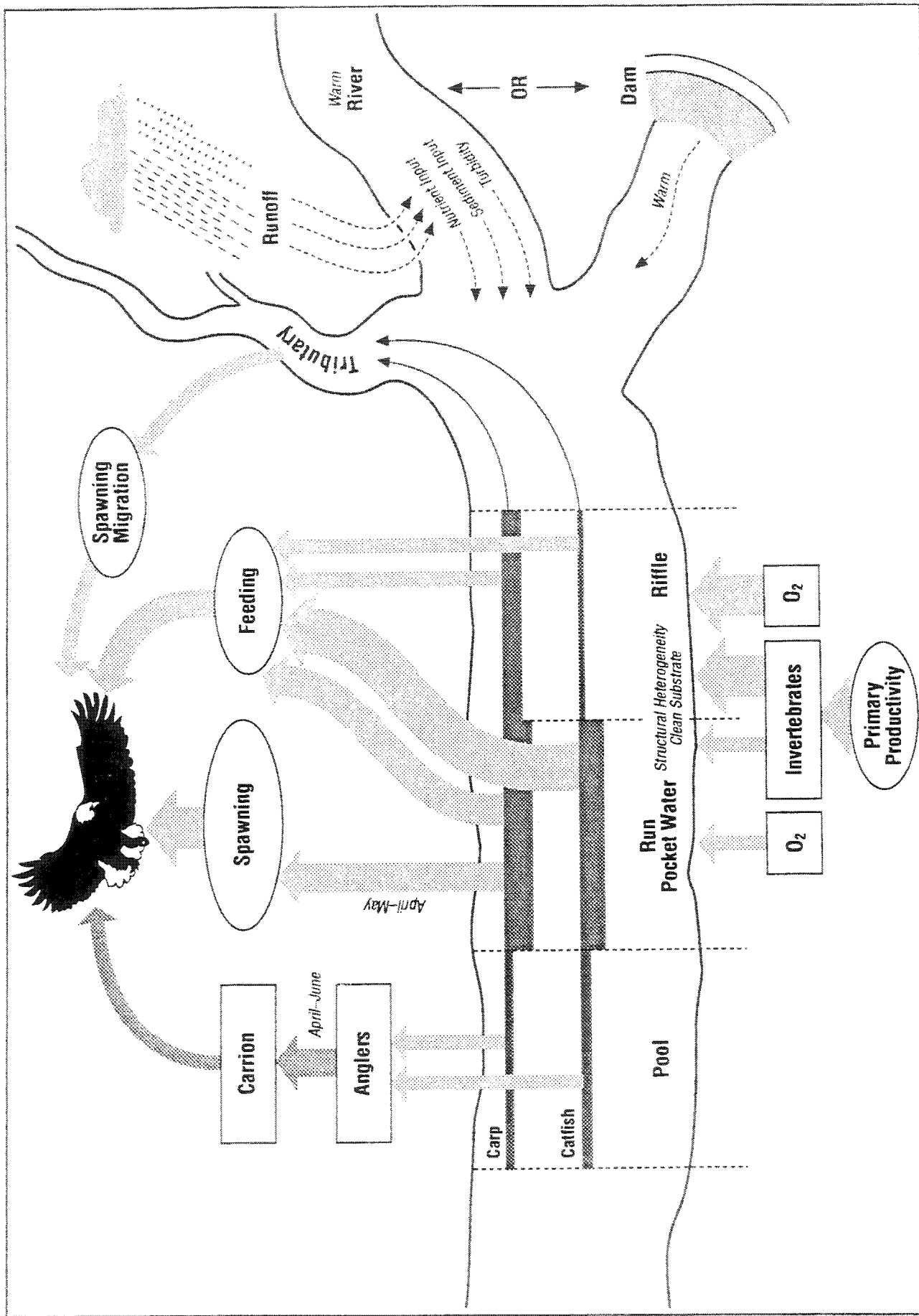


Figure A3.3-12. Conceptualization of bald eagle foraging in riverine habitat fed by: (1) a turbid, warm, free-flowing river, or, (2) a regulated river receiving warm water from the epilimnion of a reservoir or water from a run-of-river reservoir.

is probable, nonetheless, that water temperature is more influential than migration or turbidity in determining the proportions of prey fishes in riverine habitats. For example, in the warm Salt River upstream of the diversion dam (which presumably acts as a fish barrier), suckers are uncommon. Again, in the East Verde River, where a fairly strong temperature gradient exists (but not a turbidity gradient) over the lower 20 Kms, suckers are common in the upper reach, while carp dominate the lower, warmer section.

A3.4 HOME RANGE MOVEMENTS OF NESTING ADULTS

The size of the area frequented by a pair of nesting birds is often a reflection of the richness of habitat (Newton 1979). Where food is plentiful, parents need not range far to get it, but if resources are scant, their long-distance travels may be extensive. Colonial seabirds nesting on pelagic rocks often travel hundreds of kilometers for food, remaining airborne for days on end before returning to feed their nestlings (Lack 1966, page 266). The need to travel may be dictated by competitive depletion of food supplies near the nesting colonies, or may result from the circumstance of nesting rocks being situated far from the nutrient-rich upwellings of ocean currents (Ashmole 1963).

The matter of nest placement relative to food distribution is recurrent in our studies of nesting eagles as detailed in Part B of this report. At some sites, the eagles obtained a large amount of food in the immediate nest vicinity, while at others they regularly traveled long distances to forage. As in the case of the seabirds, these range variations among the pairs of eagles may have reflected differences in overall foraging habitat quality between breeding areas, or (2) circumstantial factors in the juxtaposition of available food and suitable nesting substrate.

We assume that an eagle will not normally travel long distances for food if there is a comparable supply near the nest (Krebs *et al.* 1987 discusses costs of commuting). To do so would, on average, result in less calories delivered to the young, and, were this tendency pervasive in the population, we speculate that the genes controlling it would eventually be supplanted by those effecting a more efficient strategy. Factors that influence brood quantity and quality are a main focus of natural selection (Lack 1954, Williams 1966).

In addition, there is also the risk to the young of leaving them unattended for long periods while traveling to distant foraging locations. Evolution has solved this problem for many raptor species in having the larger (more dangerous) female remain at home to protect the brood while the male forages. However, during the latter half of the chick cycle, when the young can thermoregulate and have outgrown some of their would-be attackers, the female commonly leaves the nest area to hunt. Even then, there may be a risk in traveling long distances to forage. Newton (1986, p. 184) reported that exposure to sudden rain killed nestling European sparrowhawks when adult females, breeding in habitat where prey was sparsely distributed, were foraging 8 km away. These considerations led us to several predictions regarding home range:

1. On average, if an eagle travels far from the nest to forage, the conditions present at its destination probably offer quicker (and/or safer) access to preferred prey than locations nearer the nest (see Orians and Pearson 1979, p. 165). An eagle that travels far from the nest to forage is therefore indicating that *relatively* poor foraging habitat exists near the nest, at least temporarily.

2. If suitable nesting substrate is abundant and distributed homogeneously in the landscape, nests will tend to be located at or near the "center of gravity" of prime foraging sites, minimizing traveling time (Orians and Pearson, *op cit.*, p. 170). Therefore nest placement in relation to prime foraging sites should, on average, be a measure of the abundance and distribution of suitable nesting substrate.
3. If prey abundance and vulnerability are homogeneously distributed within the range of a pair of eagles, then a frequency distribution of foraging events around the nest might approximate a bell-shaped curve for eagles nesting and foraging along a river. The degree of departure ("lumpiness") from the bell-shaped distribution would be a measure of heterogeneity in prey availability.

In this section, we will explore these relationships of home range, nesting substrate, and foraging habitat distribution in our comparison of the home ranges of the nine radio-tagged adult eagles.

A3.4.1 Definitions and Approach

Home range is defined as "... the area traversed by the individual in its normal activities of food gathering, mating, and caring for the young" (Burt 1943). In the literature, a *home range* is usually expressed as a polygon describing the outer boundary of recorded movements, often in relationship to the home range boundaries of other breeders. A more sophisticated demonstration of home range may contain sub-elements of frequency distribution detailing the animal's activities within the total area of movement.

As a measure of habitat quality, the instructive aspects of a home range polygon are size and shape. A change in home range size during the course of a nesting season might indicate greater food demand by the young or a shift in the distribution or extent of prey availability. If a home range is odd in shape, perhaps extending more in one direction than another from the nest, the difference may reflect asymmetry in habitat quality or other forces such as competition or disturbance.

In the core of a bald eagle pair's home range is a smaller, more intensely defended area called the *nesting territory* which extends varying distances from the nest (Figure A3.4-1). The extent to which the territory is defended depends on topography and the idiosyncrasies of the pair, and probably on the age of the brood. In general, the degree of territorial aggression decreases with distance from the nest (there is also a visual component), but there is probably no consistent distance at which a trespasser would not be at risk of attack. Pairs direct their aggression most strongly toward other adult bald eagles, and there is much circumstantial evidence that fights over territorial ownership between adults can result in death (Roberts 1985, R. Jackman, notes, P. Carroll, notes). Breeders also chase younger bald eagles and other large birds. Occasionally, young eagles appearing in the nest area are not attacked; these might be young from previous years (see Section D4.)

In addition to territory and home range, there is the *soaring range*: the area of soaring and territorial patrolling. We estimate its boundaries by telemetry and visual observation.

These general concepts of home range, territory, and soaring range, while interesting, are insufficient in describing the geography and dynamics of food acquisition and its relationship to habitat which are the foci of our study. Far more revealing is *foraging range*, described on the basis of where the eagles repeatedly perched outside the nest area, and where they foraged (see Sections B2 for approach and E8 for methods). If all foraging events were witnessed, foraging observations would be the only needed

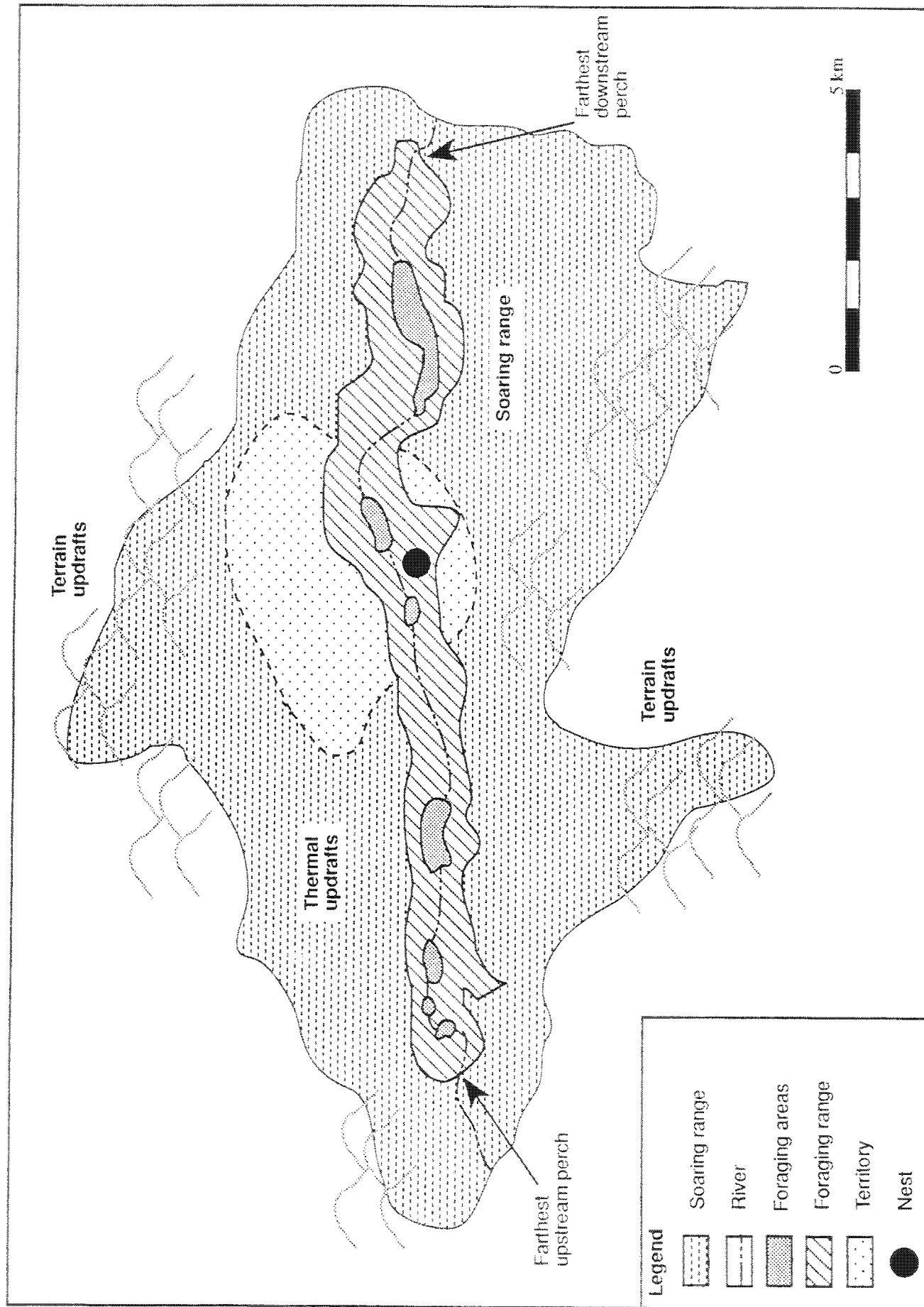


Figure A3.4-1. A hypothetical range of a pair of bald eagles nesting along an Arizona river, showing home range components. The shape of the soaring range is largely influenced by the geography of updrafts and possibly by the occurrence of other eagles.

measure of foraging range. But there is a potent bias of observer location in quantifying the distribution and relative importance of foraging sites, a bias which, even with telemetry, invalidates the results if the eagles range widely.

Basing home range estimations entirely on sightings was a limitation that led our predecessors who studied Arizona eagles to misjudge the extent of eagle movement. Although attempts were made to account for long-distance movement, the foraging areas described depended on the happenstance of observer location, a bias that resulted in small foraging range estimates, concentration on areas visible from nest observation points, and/or emphasis on rivers to the exclusion of reservoirs (Hildebrandt 1981, Sell 1982, Haywood and Ohmart 1980, Haywood and Ohmart 1981, Haywood and Ohmart 1982, Haywood and Ohmart 1983, Grubb *et al.* 1983, Grubb 1984, and Grubb 1986a). The visual tracking problem was noted by Haywood and Ohmart (1982, 1983), who explained, "Only rarely could flights be followed to their final destination."

Even with telemetry, we often found it difficult to witness foraging events. Our data revealed that the eagles covered many kilometers on hunting forays, and in the best of circumstances it was sometimes impossible to arrive within view of a foraging site before the eagle had left it, a dilemma that was compounded by difficult terrain and the frequent absence of negotiable roads. The situation significantly improved with time and experience, and when data on prey deliveries were combined with telemetric data on the location of the eagle in the minutes prior to delivery. Although the eagle's exact position was not always known, reference could be made to zones of eagle occupancy.

From a practical standpoint, data on repeated visits by telemetered eagles to perch in specific areas (visitation scores) gives perhaps the clearest view of foraging range, provided there are enough trackers stationed to anticipate movement. Our data show a positive relationship between perching and foraging; in 80 percent of observed foraging events, the eagle perched within sight of the foraging location just before the event, and in 70 percent of the total cases, the eagle appeared to have seen the prey before leaving the perch (see Section B4). Visitation scores, therefore, together with data on foraging, were a foundation of our study of bald eagle ecology.

Our experience at Blue Point illustrates the difference in sensitivity with and without the aid of telemetry. During the 1988 breeding season we radio-tracked the adult male; the female was not radioed. We recorded 147 forage attempts by AM01, of which 79 were observed by radio trackers. The remaining attempts were inferred from prey delivered to the nest. In contrast, we observed only one forage by DF02 during this period although we saw her deliver 53 prey items to the nest.

A3.4.2 Territorial Behavior

Even in areas of abundant food, territorial aggression by adult eagles results in a natural spacing of bald eagle nests, even though nests may be relatively close together. The average distance between 3,850 nests in Alaska was 2 km; however, occupied nests have been found as close as 137 m (Stalmaster 1987). In Florida, three occupied nests were within 305 m of each other, and seven nests were found in an area of 6.8 square km (*op. cit.*). The densest breeding bald eagle concentration known in California is on Britton Reservoir (northern California), with six pairs nesting along 13 km of the narrow impoundment (BioSystems 1985). The very highest reported densities of bald eagles are on the Aleutian Islands where the average internest distance was about 100 m ($n = 227$ nests; Johnsgard 1990, citing Early 1982).

Most bald eagle nesting territories in Arizona are so far apart that the adults from one nest encounter the adults from the nearest nesting area far beyond normal territorial boundaries. Territories along the Salt and Verde rivers are generally configured like beads on a string, with the ends of home ranges sometimes overlapping, but not tending to amass at foci of prey availability like they do at certain lakes and reservoirs in other areas (e.g., Britton Reservoir in California). Hence, there is less potential for territorial strife. Not surprisingly, the closest active nests in Arizona are on a reservoir; these are within 1 airline km (0.2 river Km) of one another (Alamo and Ive's Wash). The nearest nests in riverine settings were 6.9 river Kms (6.0 km) (Cibecue and Mule Hoof, 1979) and 5.9 Kms (5.5 km) (Blue Point and Orme). It seems doubtful that the current spacing of pairs is solely a result of territorial exclusion.

In our study, we frequently observed aggressive behavior on the part of territory-holding adults, but we did not attempt to delineate the defended areas because none of the studied pairs were close to other pairs. Our data contain 45 records of the breeders chasing other bald eagles, including 37 subadults, four adults, and four unidentified bald eagles. Other birds chased by the adult pairs included ravens (115 events), red-tailed hawks (32), turkey vultures (26), golden eagles (12), unidentified eagles (3), and other raptors, including Harris' hawks, (3). We saw the adult bald eagles chase ospreys 13 times and great blue herons eight times; these attacks were often attempts at piracy. The high incidence of bald eagles chasing other eagles, both bald and golden, was more a measure of hostility than frequency of intrusion (they were rarely seen). Ravens, on the other hand, were commonly seen, but not always chased.

A3.4.3 Adult Movements Within the Breeding Areas

In Section B4, we report the perching and foraging distributions of radio-tagged adult eagles during the nesting season. Our study of these distributions was based on the assumption that if an eagle moved at least 100 m to perch, it had selected that location on the basis of its quality as foraging habitat. Each time an eagle traveled to a site and perched or foraged, the location received one "point" in an accruing "visitation score." We referenced locations by using topographical maps on which the river centerlines were indexed per km and one-tenth km (see River Map Atlas). The resulting one-kilometer river segments are referred to as "Kms" throughout this report (airline kilometers are "kms"). Similarly, we indexed the reservoir shorelines (at standard water surface elevations) with one kilometer graduations, going counter-clockwise around each reservoir from the dam. We refer to these shoreline kilometers as "SKms." If we could not determine exactly which Km (or 0.1 Km) an eagle occupied, we referred to larger, specific areas called "zones" several Kms in length (examples are listed in Section E8 Methods). Because the very large number of eagle visits to the immediate nest area tended to overshadow point scores at other locations, we weighted the scores of Kms closest to the nest according to the proportion of prey obtained there.

The resulting graphs of eagle visitations show that certain kilometer segments were repeatedly attended by the eagles while other Kms were rarely if ever visited. Sometimes there were extraneous reasons for the differences in visitation (e.g., human disturbance), but in general, the eagles were attracted to riffles and other shallow water habitats in riverine settings, particularly super-riffles. Where nests were located near reservoirs, the eagles used them heavily, sometimes in preference to river sections. Outstanding perches, particularly promontory cliffs, also influenced the distribution of eagles within habitat types.

Home Range and Habitat Setting. Our telemetry studies of adult movements detailed in Section B4 allowed us to compare home ranges eagles of two pairs of eagles in each of three different habitat settings: (1) a regulated (hypolimnetic release) river section adjacent to a reservoir (Bartlett and Blue Point); (2) free-flowing river (Ladders and East Verde); and, (3) a free-flowing river section entering a reservoir (Horseshoe and Pinal/Pinto). The similarities and differences in home range patterns among

the three sets of telemetered eagles discussed below may be regarded as a measure of the degree to which the habitat differences influenced the activities of the eagles.

Regulated River (Deep Water Release) and Reservoir Habitat. The home ranges of the Bartlett (Section B4.1) and Blue Point (Section B4.2) pairs were set in similar habitat, both containing a deep-release regulated river section below a reservoir fed by a regulated reach. The most significant difference between the configurations of the two breeding areas was that the Bartlett pair nested on a promontory cliff in riverine habitat while the Blue Point pair nested in a dry canyon almost 2 km from the river channel.

At both breeding areas, the major focus of river visitation by the radio-tagged eagles was in the vicinity of the first large cliff downstream of the dam (Figure A3.4-2). The Bartlett pair actually nested in this location, and the Blue Point eagles had nested there prior to our study. Suckers were abundant in shallow riverine habitat (especially riffles) at both territories, and the eagles often used the cliff as a launch point for attacks on the suckers. At Bartlett, a large super-riffle existed in the immediate nest vicinity, and the only three Kms containing super-riffles received the three highest visitation scores. At Blue Point, there was also a super-riffle in the Km of greatest visitation (Km 20). At both territories, the eagles traveled to areas several kilometers downstream to forage on suckers in early spring, but as the zones of optimum sucker spawning temperatures moved upstream, the birds responded accordingly.

Both the Bartlett and Blue Point eagles perched and foraged significantly in reservoir habitat: 51 percent of the total weighted visitations by the Bartlett male were on the reservoir and 59 percent of the Blue Point visitations (not weighted because the nest was off the river; see Sections B2 and E8 for explanation of weighting procedure). At Blue Point, reservoir use was greatest in winter and late spring, while the Bartlett eagles used the reservoir during all months of study. Our data showed that waterbirds (mainly coots and eared grebes) attracted the Blue Point adults to the reservoir in winter; we suspect that the same was true at Bartlett, although we did not study the use of Bartlett Reservoir in winter. In spring, the main inducement for eagle use of Saguaro and Bartlett reservoirs was the presence of carrion (or moribund) fish, mainly yellow bass (Saguaro), black crappie (Bartlett), and largemouth bass (both reservoirs).

Free-Flowing River. Two other breeding areas where similarities in home range might reflect the similarities of setting were Ladders and East Verde, both situated on the free-flowing Verde River far upstream of the dams and reservoirs (Sections B4.3 and B4.4). The nests of both pairs were positioned on cliffs overlooking the river; the Ladders nest was directly over a super-riffle, but the East Verde nest was 1 km away from the nearest super-riffle (Figure A3.4-3). Not surprisingly, the kilometer segment with the highest weighted visitation score at Ladders was the nest Km (Km 162). At East Verde, the two most visited Kms were those containing super-riffles (Km 135 and 136) closest to the nest (Km 133). At both territories, the null hypothesis of random selection by the eagles of Kms containing super-riffles was strongly rejected by Chi-Square ($p < .001$ and $.005$).

Our data on the home ranges of Ladders and East Verde are probably not comparable because we radio-tagged the adult male at one site (East Verde) and the female at the other (Ladders). However, some similarities and differences obtained; for example, at both territories the telemetered adults traveled further to forage in the early part of the nesting season than they did later on (this was also true for riverine habitats at Bartlett and Blue Point). Both birds traveled further to obtain suckers, on average, than for other species such as carp and catfish. Perennial tributaries occurred at both Ladders (West Clear Creek) and East Verde (Fossil Creek and the East Verde River). The East Verde male perched

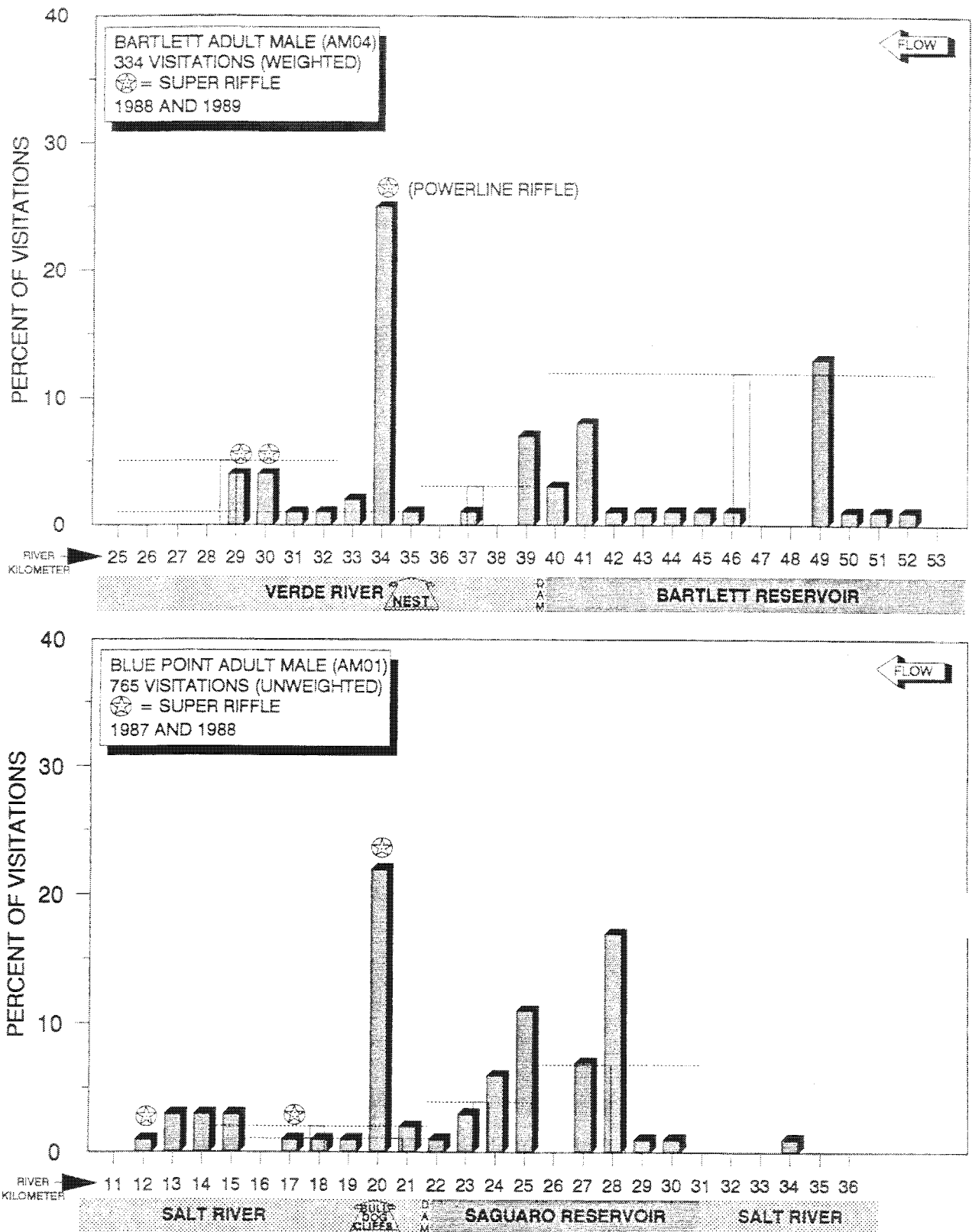


Figure A3.4-2. Home ranges of the radio-tagged adult male bald eagles at the Bartlett and Blue Point breeding areas. Visitation percentages in the Bartlett nest vicinity (Kms 34 and 35) were weighted according to the total prey deliveries to the nest by the male from those segments. We did not weight the Blue Point scores because the pair nested off-river. Open bars indicate cases where trackers could not precisely locate the eagles, and the dotted lines extending laterally from those bars indicate zones of eagle occupancy for the imprecise locations.

and foraged in both of the latter tributaries, but our data show few visitations by the Ladders female to West Clear Creek. This difference may reflect the low numbers of suitably-sized fish in West Clear Creek, as evidenced by our fisheries surveys there in 1989. In years of higher flow, West Clear Creek might attract spawning runs of suckers or other fish and might thus attract the eagles. Telemetered subadult eagles did use West Clear Creek (see Section A4), suggesting that food was available beyond the range of our fisheries surveys.

Free-Flowing River and Reservoir Habitat. The Horseshoe (Section B4.5) and Pinal/Pinto (Section B4.6) breeding areas both contain a free-flowing river section that enters a reservoir (Figure A3.4-4). The Horseshoe nest was on a promontory cliff overlooking the upstream end of Horseshoe Reservoir, but the Pinal nest was some 10 Km (7 airline km) upstream of Roosevelt Reservoir. At Horseshoe, we radio-tagged both members of the adult pair (AF02 and AM03) who successfully bred in the years of study (1987 and 1988). At Pinal, we telemetered only the female (AF01); however, we tagged a second adult bald eagle, the Pinto female (AF03) who copulated with AF01's mate (TM01) and attempted unsuccessfully to nest within his (and AF01's) home range near the reservoir inflow. The Pinal pair raised young in 1987 and 1989, but the nest failed during the early stage of the chick cycle in 1988 (see Sections C3.2 and D4.22).

The four telemetered adults at Horseshoe, Pinal, and Pinto chose the area of reservoir inflow as the primary focus of home range visitation and foraging (see Figures B4.5-5, B4.6-4, B4.6-9). For the Horseshoe adults and the Pinto female, the inflows were at or near the immediate nest areas. Even though the Horseshoe nest was near where the river entered the reservoir, the use of the river was relatively low: only 14.3 percent of total weighted visitations for the male and 15.1 percent for the female (2.5% of the female's river visits were to the area downstream of Horseshoe dam).

In 1987, the Pinal female clearly favored the reservoir, preferring the inflow area (see Section B4.6). Even though her nest was 7 airline km distant, 61 percent of her total weighted visitation points were at the reservoir. By the following year, when a new female (the Pinto female) had established her territory just upstream of the inflow, AF01 had virtually ceased to visit the reservoir. Her mate, TM01, continued to travel to, perch, and forage at the inflow where he obtained most of the food delivered during our nest observations in 1989. Parenthetically, we observed 47 prey items delivered to the nest that year, and, amazingly, all but one were delivered by the male. This extremely atypical distribution of foraging between the sexes suggests that the area from which AF01 was apparently excluded (F. Hein, field notes, February 1988) was far richer foraging habitat than the river sections that remained within her home range.

The principal difference, therefore, between the home ranges at Horseshoe and Pinal/Pinto appears to relate to nest placement. All five of the adults were attracted to the reservoir inflow. While the Horseshoe pair and the Pinto female nested near the point of inflow, the Pinal birds had to travel 7 km to reach it. As we also observed at Bartlett and Blue Point, the resources offered by the reservoirs included wintering waterbirds and carrion fish (black crappie, largemouth bass, channel catfish, flathead catfish). Most of these fish became available as a result of post-spawning die-offs and angler-induced mortality.

Like the Bartlett and Blue Point eagles, the telemetered birds at Horseshoe and Pinal/Pinto changed their patterns of home range use during the course of the nesting season. In winter, the Horseshoe and Pinal/Pinto adults all traveled downstream to the body of the reservoir where the waterbirds were

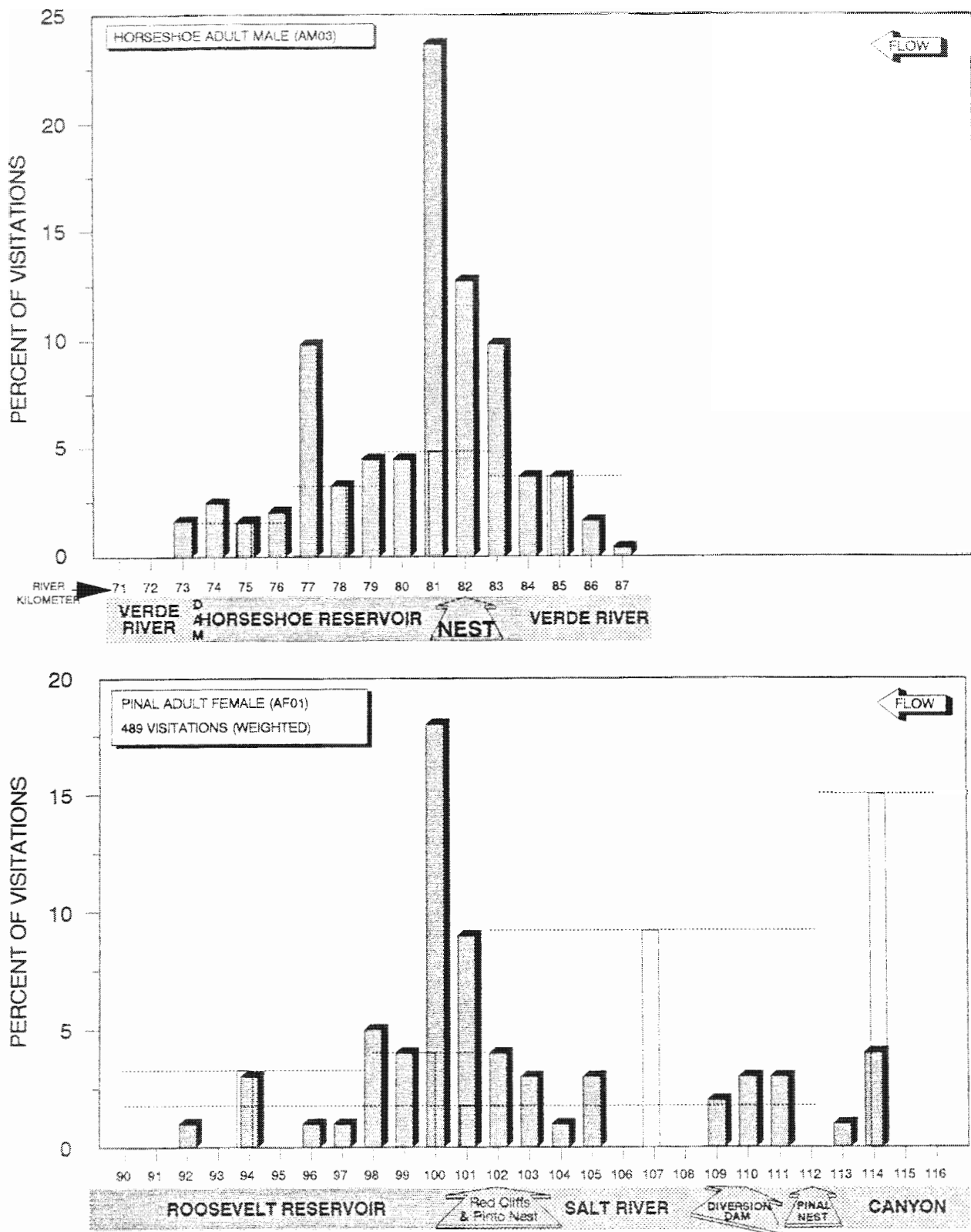


Figure A3.4-4. Home ranges of radio-tagged bald eagles at the Horseshoe and Pinal breeding areas. Visitation percentages in nest vicinities were weighted according to prey deliveries from those segments. Open bars indicate cases where trackers could not precisely locate the eagles, and the dotted lines extending laterally from those bars indicate zones of eagle occupancy for the imprecise locations.

concentrated. By March they began foraging closer to the nest, perhaps because of the relatively low food requirements of the young and their vulnerability to predators at this point of the chick cycle. In Late April and May, the Horseshoe male ranged further to forage. The Pinal male, though not telemetered, regularly traveled 7 km to the reservoir to forage in May 1989.

A difference existed between Horseshoe and Pinal/Pinto in the relative use of riverine habitat. Although the Horseshoe eagles perched and foraged almost entirely on the reservoir (85% perching and over 90% of prey deliveries), the Pinal and Pinto females used the river more extensively. While this is not surprising for the Pinal bird (given the nest location), it is significant to note that 37 percent of the unweighted visitations of the Pinto female, whose nest was at the inflow, were to the river upstream of the reservoir.

Home Range Size and the Question of Habitat Quality. In our attempts to study movement patterns within the home ranges of the telemetered eagles, we eliminated records of soaring from the data set and concentrated on perching distributions and the geography of foraging events (see above, also Sections B2 and E8). As the movement patterns emerged, we realized that direct size comparisons of home ranges could not accommodate the problem of deciding what constituted the end points of a home range. Say, for example, a bird perched once or twice at a point several kilometers beyond any other perching or foraging location. If included, that location would significantly extend our estimate of a home range size on the basis of only a few observations. On the other hand, to assign "core areas" of, say, the central 80 percent of visitations was arbitrary and would tend to overlook the potentially meaningful instances of eagles traveling long distances to forage. To solve this problem, we measured the distances in airline kilometers between the nest and the mid-point of each river kilometer segment or zone where the eagles perched and/or foraged. We then multiplied each distance by the proportion of visitations to that Km. The result was an estimate of the mean distance traveled by the eagle during the course of the nesting season to perch and/or to forage.

Another problem in comparing the territories is the possibility of a sex difference in home range use patterns. Of the nine telemetered adults we tracked, five were males and four were females. In general, female raptors, being larger and therefore more dangerous to intruders, remain near the nest during the early stages of the chick cycle to protect the young until they outgrow ravens and other potential predators. However, once the female begins hunting, her home range may equal or exceed that of the male. In Scotland, female European sparrowhawks generally displayed larger foraging ranges than those of the males (Newton 1979, p. 42-43).

At only one territory, Horseshoe, were we able to obtain a direct sex comparison of movement by tracking both members of the pair. The airline distances traveled from the nest to perching and foraging locations by the female (AF02) and the male (AM03) are shown in Figure A3.4-5. The travels of the male appear more extensive in the graph than those of the female, but the overall difference is actually slight. The male traveled a mean distance of 2.0 airline km while the female moved 1.9 km. This near parity in mean commuting range resulted from the female's tendency to perch more frequently at the extremes of the home range: the distance between her extreme perching locations was 10.9 airline km or 16 Kms, while the values for the male were 9.5 km and 14 Kms. Perhaps the female's larger size allowed her greater boldness in entering the territories of neighboring eagles.

In all, among the six radio-tagged eagles who raised young when we were tracking them (and therefore had food demands and home ranges of "normal" size), three were males and three were females. The

males traveled a mean distance of 3.5 airline km from the nest to perch and/or forage, while the females moved 3.2 km. However, in reviewing the details, we believe this difference may be more a consequence of situational differences between territories than sex related differences in home range use. The considerable movement by the Ladders adult female (AF04), when viewed in the context of the foraging data we obtained on both members of the pair, was probably not significantly less than that of her mate. Similarly, the Pinal female (AF01), who in 1987 showed a higher mean distance of travel from the nest than any of the males studied with telemetry, appears to have had a home range corresponding to that demonstrated by visual observations of the male. This very small sample suggests similar home range size between the sexes, but ecological factors were so diverse between the breeding areas we studied that, if a sex difference existed, it would have been impossible to demonstrate (however, see Bartlett home range analysis, below).

Figure A3.4-6 shows the patterns of visitations for the six breeding areas at which the eagles raised young while we were studying them. Note the relatively large mean distances traveled by the Pinal, Bartlett, and Blue Point eagles to perch and/or forage. How do these observations correspond with the assumptions regarding large home ranges given in the introduction to Section A3.4. Are the large home ranges indicative of relatively poor habitat quality near the nest? Let us examine each case.

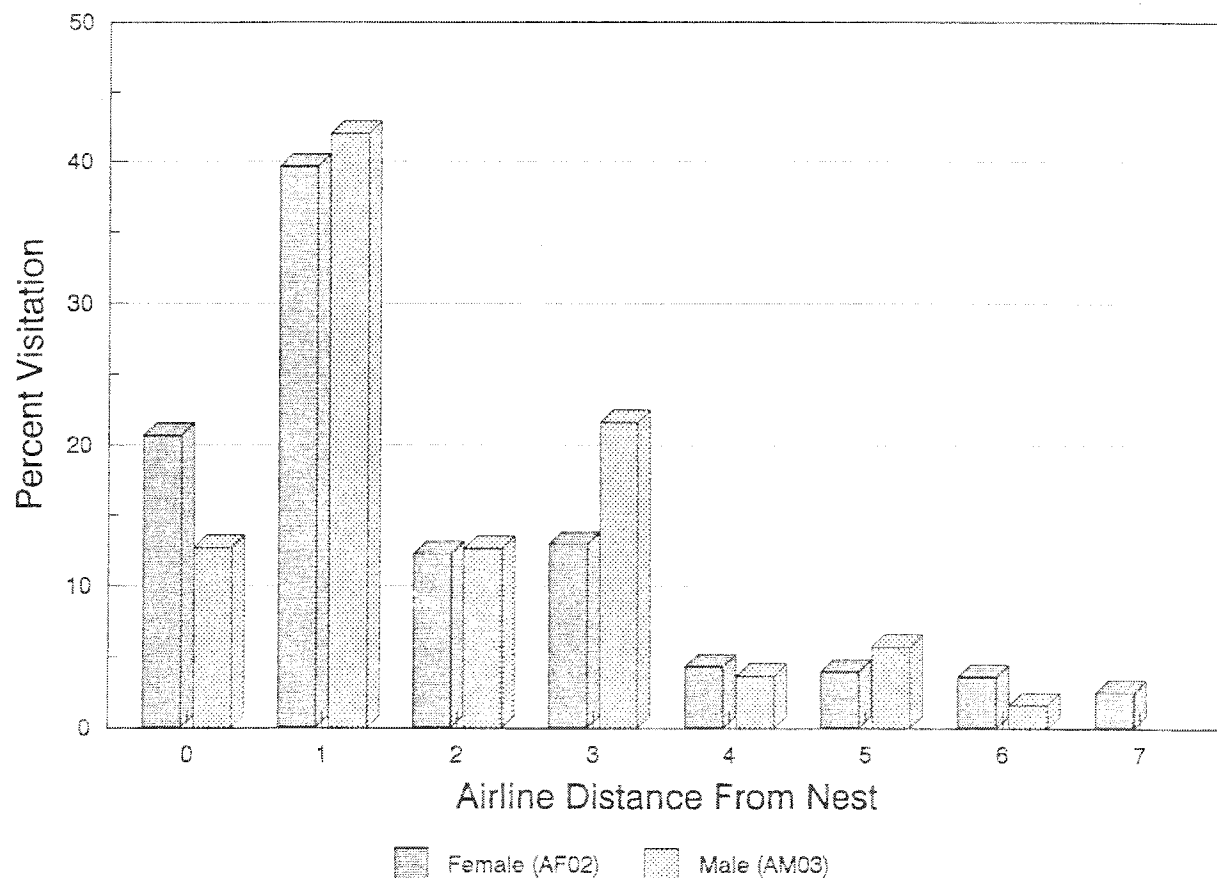


Figure A3.4-5. Comparison of airline distances traveled from the nest by the Horseshoe pair to perch and/or forage.

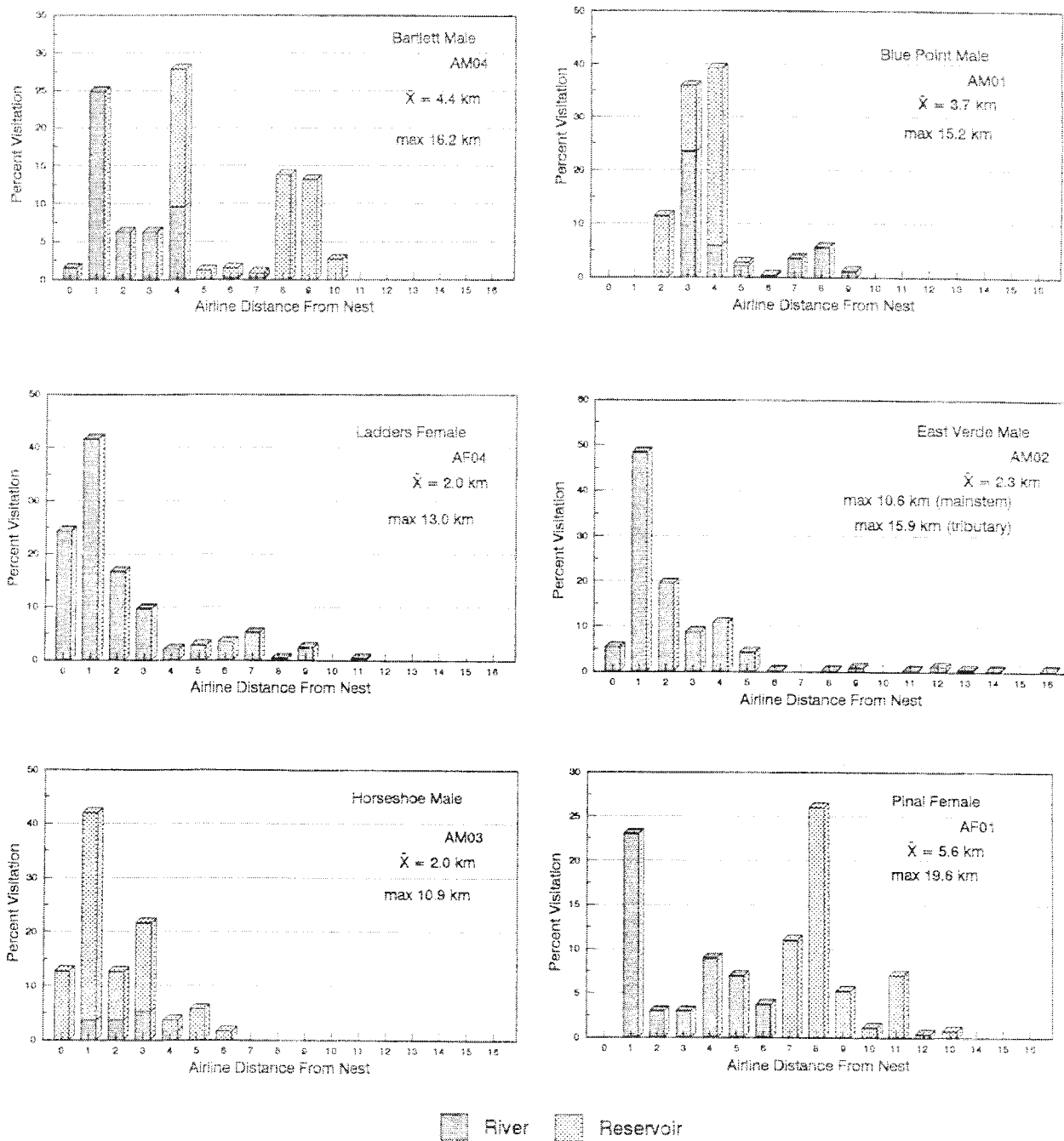


Figure A3.4-6. Airline distances traveled from the nest by radio-tagged bald eagles to perch and/or forage at six breeding areas.

Large Average Commuting Distances

Pinal. Figure B3.4-6 shows that the large mean distance traveled by the Pinal female (5.6 km) resulted from her frequent travels to the reservoir; the reservoir inflow was about 7 airline km from the nest. During 1987, 61 percent of AF01's visitations were to the reservoir (mean visitation distance = 6.6 km). The following year, when rival female AF03 set up a territory near the reservoir inflow, AF01 ceased visiting the reservoir, and her mean visitation distance shrank to 2.3 km (AF01 did not raise young that year). The conclusion that the reservoir offered AF01 better foraging opportunities than riverine habitats closer to the nest is supported by observational data on her mate (TM01) in spring 1989. Of 45 observed prey deliveries, 30 items (66% of total biomass) were known to be obtained on the reservoir, 7 on the river, and 8 were of unknown origin. As we have said, we recorded only one prey delivery by AF01 that year, and she was not known to visit the reservoir.

Since the reservoir was a main focus of foraging by the Pinal pair, we must question why they nested so far away (Assumption No. 2). The most obvious attribute of the Pinal nest cliffs is their relatively high security compared with any substrate closer to the reservoir. These substrates include trees in the Meddler Point area which are far more subject to human disturbance, and "Red Cliffs" (Km 101) which are relatively small, composed of sand, and have no apparent nesting ledges. Also, the presence of other eagles in the Campaign Bay area during winter and early spring which might result in greater numbers of territorial encounters were the nest closer to the reservoir. Whether or not the Pinal eagles have had a history of disagreeable encounters with people or other eagles is unknown.

We speculate that, at Pinal, suitable nesting substrate and prime foraging habitat were not as close together as they were at other territories such as Horseshoe and Ladders. The large home range resulted from the fact that optimum nesting and foraging places were at least 7 km apart. However, we note a similarity in the home range of the Bartlett male who also traveled a considerable distance to forage on carrion in the reservoir despite food apparently being available nearer the nest.

Bartlett. The Bartlett male (AM04) traveled some 8 or 9 km to perch and forage on cliffs at the upstream end of the reservoir. He also frequented the dam area (4 km from the nest) where he hunted the open water of Bartlett Reservoir. These trips to the reservoir were the main contributors to his high mean visitation score of 4.4 km.

As already mentioned, AM04's home range included a deep-release regulated river reach and a reservoir. Unlike Pinal, a considerable proportion of the total food came from riverine habitat in the nest vicinity. Fifty-four percent of delivered prey items (55% of total biomass) came from the river, 33 percent (28% biomass) from the reservoir, and 13 percent (16% biomass) were from unknown habitat. Although we judge that the Bartlett nest was located on the only suitable cliff in the range of the Bartlett Pair (there are a few trees downstream of the dam), we cannot make the case that the large mean visitation distance value resulted from an unfavorable juxtaposition of the nest and prime foraging habitat. Prey appeared (to us) numerous and vulnerable near the nest.

Home range use at Bartlett is therefore puzzling because, despite the prolonged availability of suckers in the immediate nest vicinity (Km 34.5 riffle) and other nearby riverine areas, the male traveled far and frequently to the reservoir. Two possible explanations for this behavior are (1) that suckers (in river habitat only) were less available during certain periods, and (2) that more biomass could be obtained if the female hunted suckers near the nest while the male foraged elsewhere.

The first possibility is not supported by the evidence given in Tables B4.1-1,2,3, or 4. Suckers comprised at least half the diet during almost all of the ten-day study periods in both years, and, in general, they were taken as commonly in the second half of the cycle as the first.

The second possibility is more plausible. At Bartlett, suckers were taken only in the river, while black crappie and most other perciforms were obtained only in the reservoir. (Prey deliveries were often therefore an indicator of habitat use even without telemetry.) Although there was no difference in sucker use by the male and female in 1988 (65% and 67% of biomass delivered), there was an apparent difference in 1989 when the male brought 53 percent suckers (biomass) and the female brought 81 percent, suggesting a greater use of the river by the female. In 1988, the male delivered 7 percent black crappie (biomass) and 9 percent other perciforms while the female brought no crappie and 8 percent other perciforms. In 1989, the male delivered 12 percent crappie and 15 percent perciforms while the female brought 3 percent crappie and 1 percent perciforms. These data strongly suggest that the male foraged on the reservoir more extensively than the female. Perhaps in situations where prime foraging areas exist in the immediate vicinity of the nest (as is the case at Bartlett and possibly at Pinal), it is advantageous for the female to forage there and the male to travel elsewhere (see also Horseshoe, Figure A3.4-5).

There are, of course, other conceivable explanations for high use of the reservoir by the male, including the possibility that dietary variation is needed to satisfy nutritional requirements (i.e., suckers alone do not form a complete diet). Such considerations are outside our scope of knowledge, but we have observed that suckers were overwhelmingly preponderant among the riverine forages. In 108 river prey delivered by the male, 79 percent were suckers, 7 percent were probably suckers, and only 14 percent were of other species. Further, it may simply be that the 9 km trips to the upper reservoir were necessary because suckers were not as available to eagles throughout the season as they appeared to us to be.

Blue Point. The rather large mean distance the Blue Point male (AM01) traveled from the nest (3.7 km) resulted mainly from the fact that the nest was located nearly 2 airline km from water. Therefore, there was no possibility of foraging near the nest, and commuting to the river or the reservoir involved considerable travel. The Blue Point male used both the river and the reservoir extensively (see Figure A3.4-2; patterns of use are discussed above in Section A3.4.3)

Unlike Pinal and Bartlett, nesting locations appear to be more widely distributed in the known home range of the Blue Point pair. A cliff nest, used in 1985, exists at Km 20.5 (Bulldog Cliffs) directly above the most frequently used foraging site in the breeding area (riverine Km 20); it overlooks the lower portion of the reservoir as well. There are several other apparently suitable cliffs along the river, one of which was used in 1989. Bald eagles also nested in live cottonwood trees 10 river Km downstream, although these may have been the recently-discovered Orme pair. Excluding these questionable outliers, Table A3.4-1 shows that the array of nests used by the Blue Point eagles is more diffuse than those exhibited by the other five pairs in our studied sample. The extreme distance between nests at Blue Point is 3.3 km compared to a mean of 2.1 km for the other pairs (range 1.2-2.9 km). The reason why the Blue Point pair nested in a dry canyon far from water, necessitating long commutes to forage, is unclear, but possibly relates either to the large amount of human disturbance along the river, or, less likely, to competition with the Orme Pair which nests about 15 Km downstream of Stewart Mountain Dam. Peregrines also nest in the Blue Point vicinity and may harass the eagles.

Table A3.4-1. Number and distribution of nests known to have been occupied during 1970-1989 in six bald eagle breeding areas.

| Territory | Years of Occupancy | Number of Nests Used | Extreme Distance Between Nests (Km) |
|------------|--------------------|----------------------|-------------------------------------|
| Bartlett | 20 | 3 | 1.2 |
| Bluepoint | 10 | 3* | 3.3* |
| Ladders | 15 | 5 | 2.9 |
| East Verde | 16 | 3 | 1.7 |
| Horseshoe | 14 | 8 | 2.2 |
| Pinal | 11 | 3 | 2.5 |

* 3 additional nests downstream (ca. km. 10) unused since the 1970s possibly belong to the Orme pair.

We thought it interesting to compare (Figure A3.4-7) the distances traveled by the Blue Point male from the nest he actually used in Willow Springs Canyon (Canyon Nest) with distances he might have traveled if he had nested on Bulldog Cliffs (Bulldog Nest). In the latter case, the mean distance traveled from the nest would have been reduced from 3.7 km to 2.4 airline km, a figure comparable to those calculated for territories with relatively small mean home ranges.

Small Average Commuting Distances

Horseshoe. The home ranges of the Horseshoe pair (both adults were radio-tagged) were among the smallest in our sample (Figure A3.4-6). The female traveled a mean distance of only 1.9 km from the nest while the male moved an average of 2.0 km (Figure A3.4-4). As in Bartlett and Ladders, a prime foraging area existed in the nest vicinity. The Horseshoe nest cliff overlooked the reservoir inflow area (lacustrine during our study but riverine in some other years). Like Pinal, carrion fish accumulated in the reservoir inflow, and the eagles obtained a high proportion of their food there. The pair also visited other parts of the reservoir where they took mainly carrion fish. The eagles were apparently not disposed toward extensive exploitation of riverine habitats, even though they nested quite near them; riverine habitats received only about 15 percent of total visitations by the pair.

Nest site availability appeared to be restricted mainly to the area around the currently used cliffs. In the past, the Horseshoe pair has nested in eight different natural locations in this area, the distance between extreme locations being about 2.2 km (Table A3.4-1). Thus, the Horseshoe territory exemplifies the situation in which the nest site and the principal foraging area are congruent. This fortuitous condition does not rule out the possibility that prey is readily available throughout the home range of the pair.

East Verde. In comparing the mean distances traveled from the nest by radio-tagged adults, we were surprised by the relatively low value (2.3 km) demonstrated by the East Verde male (AM02), especially in view of his long-distance movements (up to 15.9 km) to the East Verde River in April. Although a significant amount of food derived from upper sections of the East Verde River, the overall numbers of visitations there were relatively few, especially after the end of April (see Section B4.4). The overwhelming majority of perching and foraging foci were in mainstem Kms containing super-riffles fairly close to the nest (i.e., Kms 135 and 136).

Does the small average visitation score at East Verde indicate that habitats near the nest were relatively rich in food compared to riverine conditions at Bartlett or Pinal (from which eagles made more lengthy commutes)? It should be noted that the history of nest success at East Verde is among the highest of all breeding areas in Arizona (see Section C2.5). It has a relatively high number of super-riffles within a few km of the nest, and AM01 exploited all three of the major riverine prey species: suckers, carp, and catfish. (Riverine habitats at Bartlett contain mainly suckers, while Pinal lacks suckers and has less shallow water habitat near the nest.)

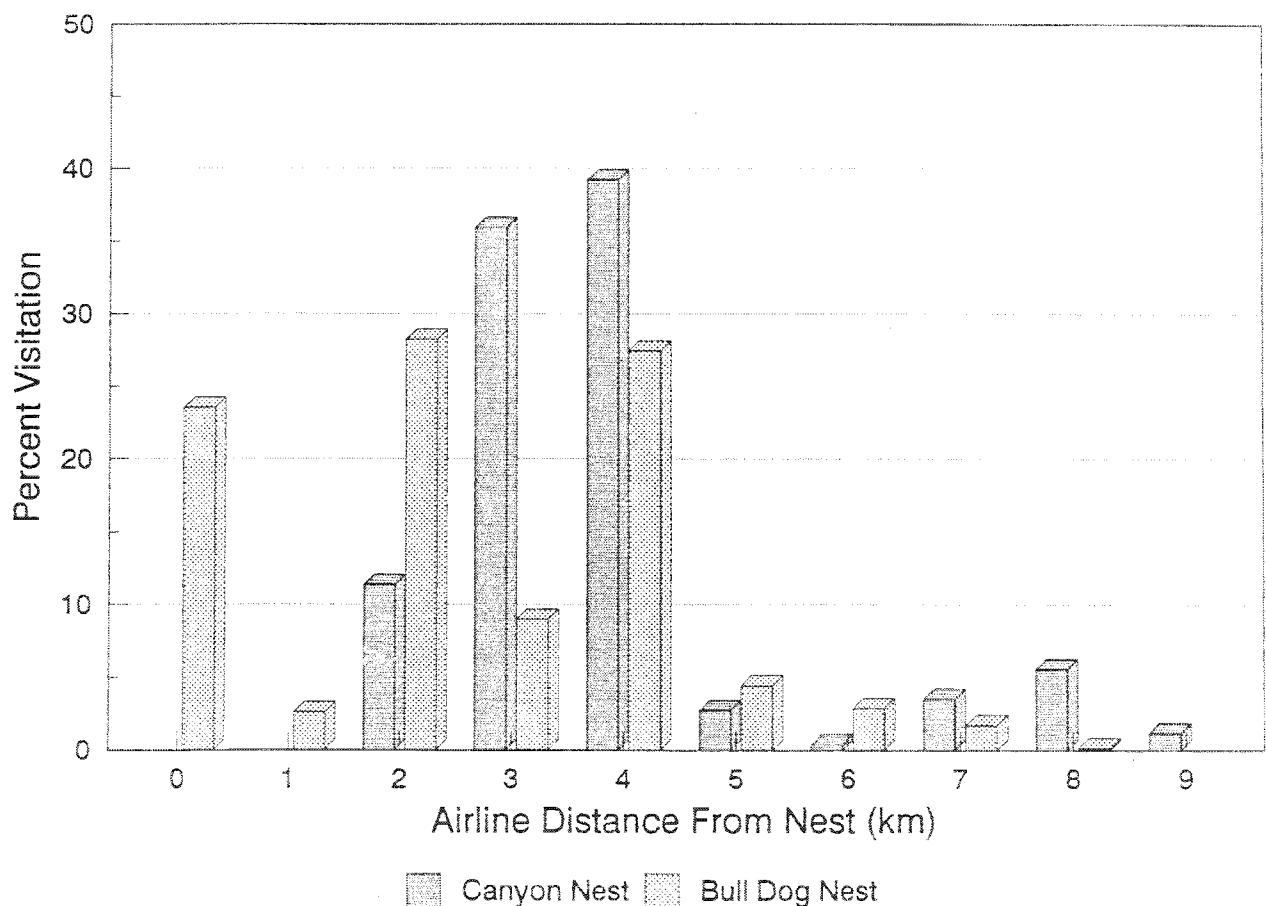


Figure A3.4-7. Comparison of commuting distances from the off-river nest used by the Blue Point adult male during our study (Canyon Nest), with the distances he would have traveled if he had nested on the river (Bulldog Nest) as he did in 1985. The use of Bulldog Cliffs would have required far less travel to foraging sites.

Ladders. The telemetered Ladders female (AF04) showed a rather small mean visitation score (2.0), rivaling that observed at Horseshoe. The extremes of her range (13 km apart) were also relatively small, again suggesting that habitat was rich enough in the nest vicinity to supply needed food, but we do not know if her mate traveled more extensively. Like East Verde, super-riffles were common within a short distance of the nest and all three major prey species (suckers, carp, and catfish) contributed significantly to the diet. In terms of productivity and nest success, Ladders ranks seventh among the 28 breeding areas known in Arizona.

Commuting Distances of Eagles Whose Nests Failed. Our data on the movements of radio-tagged adults include two cases in which we intensively tracked eagles who failed to raise young during the season of study: Cliff in 1989 and Pinto in 1988 and 1989. Figure A3.4-8 shows the visitation scores arrayed according to distance traveled from the nest.

Cliff. In 1989, the Cliff pair laid three eggs; only one hatched, but the chick died within one week. With no young to feed, foraging requirements were greatly reduced. The radio-tagged male (AM06) perched and foraged mainly in the nest Km which happened to contain a super-riffle in view of the nest cliff (Figure A3.4-9). His mean visitation distance of 0.7 km was the smallest computed among our sample of radio-tagged adults, far less than half the value displayed by the Horseshoe female (AF02) whose mean range of 1.9 km was the smallest of the successful eagles we studied. AM06 also demonstrated the smallest overall perching range (distance between extreme perches). Apparently, during the February through May tracking period, AM06 did not visit Horseshoe reservoir, located only about 5 km from the nest. Possible explanations include: (1) the riskiness of encounters with the Horseshoe pair, and (2) the presence of rich habitat in the nest vicinity including several super-riffles and a conspicuous abundance of carp. However, black crappie were found in prey remains from the previous year, suggesting use of the reservoir and a larger home range when young were present.

Pinto. It is probably unreasonable to compare the home range of the Pinto female (AF03) with other eagles because her "mate," TM01, was a member of an established pair nesting nearly 7 km away. She was unable to hatch her eggs because the male would not provision her or share incubation duties. However, her home range was comparable in size to those at Horseshoe and Ladders in both mean and

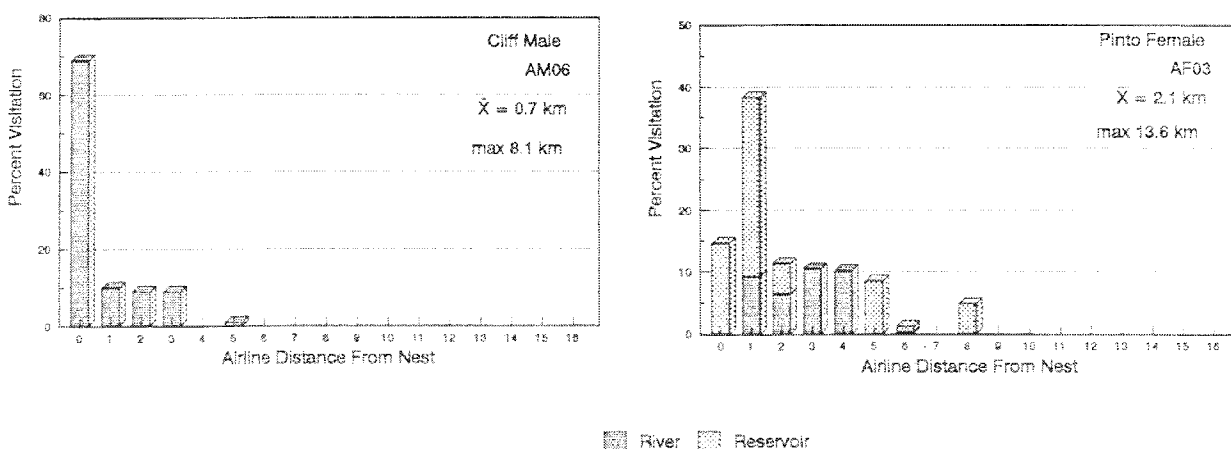


Figure A3.4-8. Airline distances traveled from the nest to perch and/or forage by two radio-tagged eagles whose nests failed.

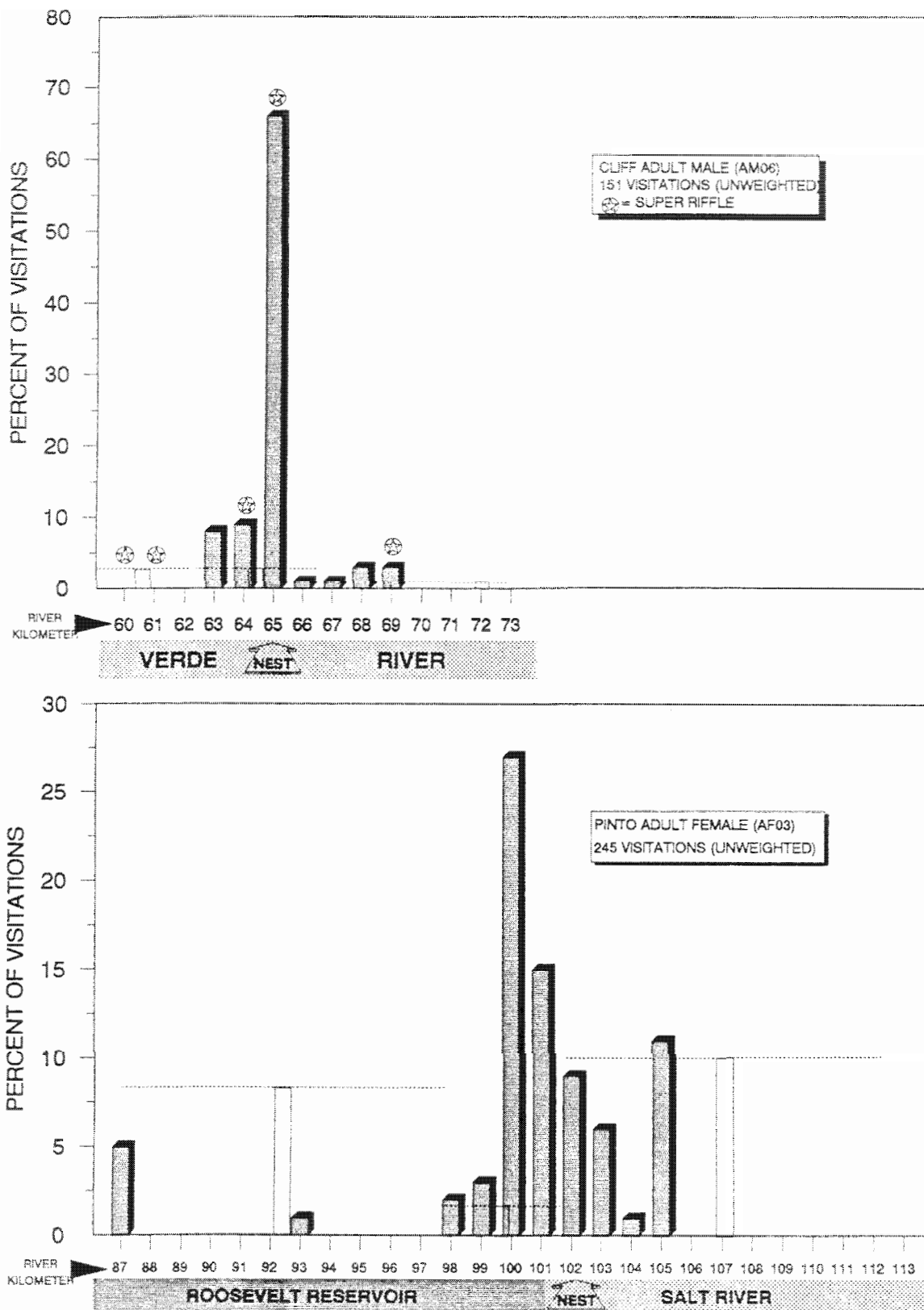


Figure A3.4-9. Home ranges of radio-tagged bald eagles at the Cliff and Pinto breeding areas (unweighted). Open bars indicate cases where trackers could not precisely locate the eagles, and the dotted lines extending laterally from those bars indicate zones of eagle occupancy for the imprecise locations.

maximum range. One of the probable reasons why she perched and foraged so much more widely than the Cliff male (who also failed to produce young in the year of study) was that she laid eggs and incubated them for weeks without relief or provision. She thus incurred a far higher physiological cost than the Cliff male.

The Pinto female's nest was near the inflow of Roosevelt Reservoir, juxtaposed similarly to Horseshoe, yet 37 percent of her visitations were to the river, as compared with 15 percent for both Horseshoe adults. That the inflow area was good habitat was confirmed by the Pinal male's frequent visits there and by the Pinal female's use of the area the year before the arrival of the Pinto female. It is clear that she used the river section between the inflow and the diversion dam more commonly than either of the Pinal adults.

Other Factors Affecting Home Range. In addition to the influence of riverine shallows and reservoir inflows, other factors exert an influence on home range distribution. Figures A3.4-10 and A3.4-11 suggest that eagles tend to visit those river and shoreline kilometers which offer the best perches and the highest levels of isolation from human disturbance. The tendency of eagles to perch along reservoir shorelines bounded by shallow water is inconsistent in Figure A3.4-11 and probably relates to the high proportion of carrion in the diets of eagles foraging on reservoirs.

Influence of Forages for Mammals on Home Range Estimates. Our estimates of bald eagle home ranges in this study are essentially linear because virtually all eagle perching and foraging activity occurred along rivers or reservoir shorelines. Although the eagles we studied rarely perched far from water, they often soared over land, posing the question: to what extent were these flights related to prey acquisition?

Although the bald eagles occasionally foraged off-river, usually on mammals or mammal carrion, Table A3.4-2 shows that the majority of these forages were fairly close to the river and would not appreciably influence our estimates of visitation/foraging range. Of 737 prey items delivered, there were only 32 mammalian items (4.3%), and at least 21 of these (66%) were obtained within sight of the river.

A3.4.4 Adult Movements Outside the Breeding Areas

From our data on radio-tagged adults, as well as observations at other breeding areas, we found no evidence that adult bald eagles leave the state. On the contrary, most paired adults appeared to remain within their nesting areas year-round. However, we did record movements out of the breeding area at four sites. The Cliff male (AM06) ventured slightly east and north of his territory in 1988 and 1989, roosting in the Mazatzal Mountains and perching along the Verde River upstream of Horseshoe Reservoir.

In a lengthier movement, the Blue Point male (AM01) twice traveled to Tremaine Lake on the Mogollon Rim just after nesting in 1988. He was in his territory at Saguaro Reservoir on 26 May, but we detected (and saw) him 135 km north at Tremaine Lake on 2 June and 9 June. He had returned to Saguaro Reservoir by 20 June but was again in the Tremaine Lake area by 8 July. On 24 July, he was soaring just south of Bartlett Reservoir, and on 26 July we found him back on Saguaro Reservoir.

The third incident involved the Pinto female (AF03) who copulated and constructed a nest with the Pinal male (the mate of AF01), but did not lay eggs in 1988. AF03 disappeared in late May 1988, and we did not see her or receive her signal until 4 October 1988. This seven-year-old eagle had apparently left the Salt and Verde drainage, as we were unable to detect her signal during our aerial surveys. AF03 occupied her territory in 1989, copulated with the Pinal male, and laid egg(s).

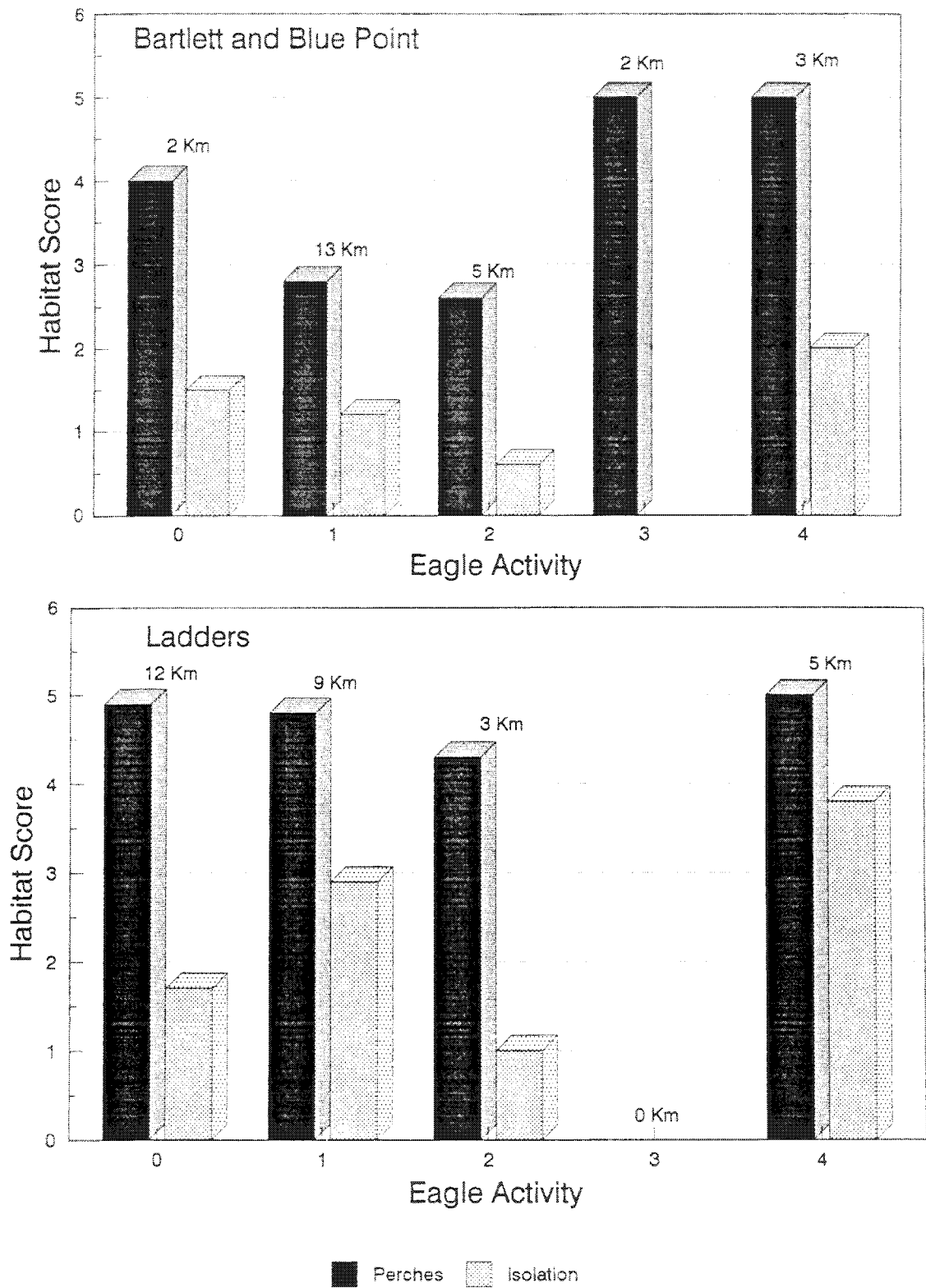


Figure A3.4-10. Eagle activity at river kilometers (Km) and the distribution of perches and habitat isolated from human disturbance at three breeding areas where we studies the movements of nesting adult bald eagles with radio telemetry. Eagle activity values were derived from standard visitation scores to each river (see Figure A3.4-11).

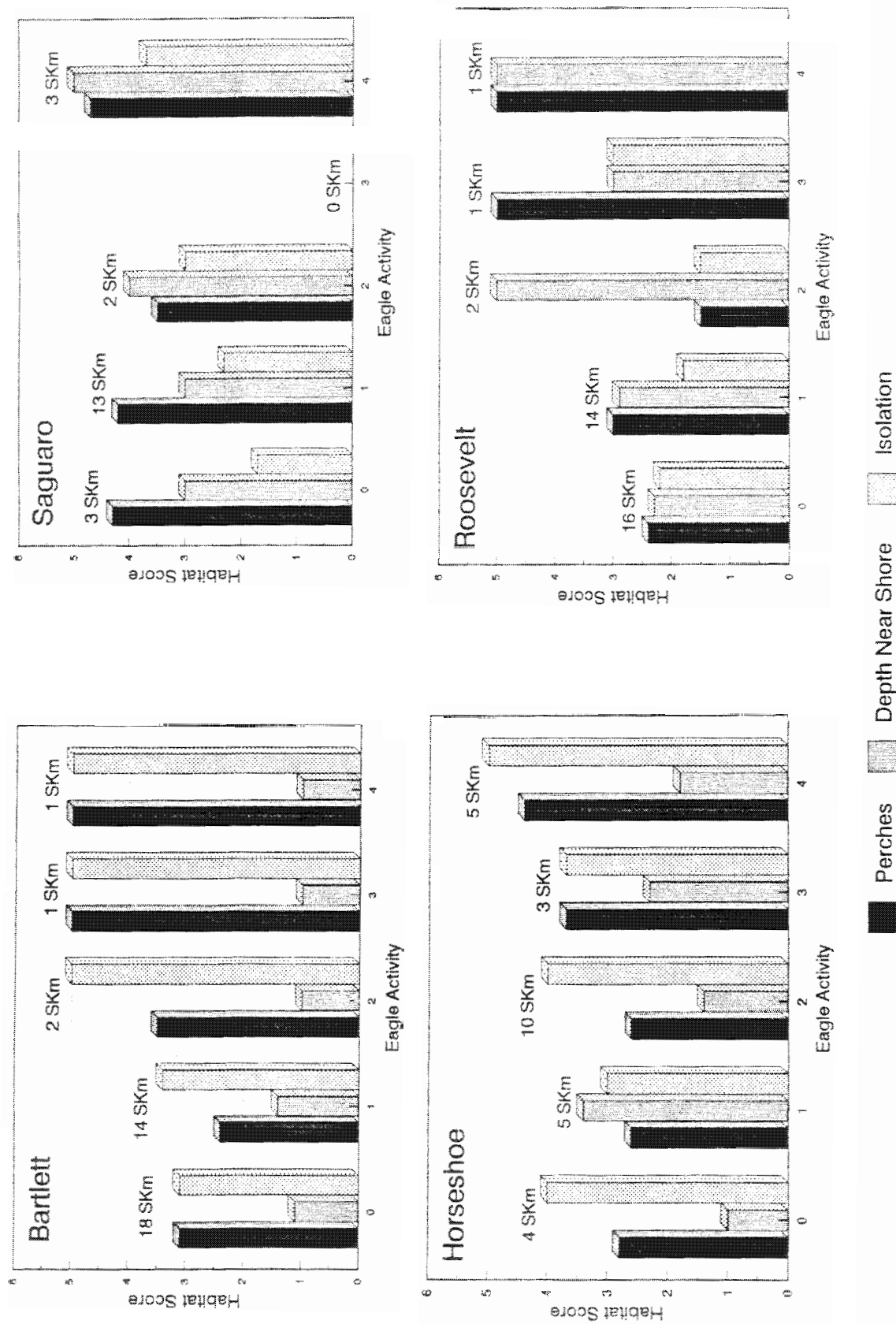


Figure A3.4-11. Eagle activity at shoreline kilometers (SKm) and the distribution of perches, shallow water, and habitat isolated from human disturbance at four reservoirs where we studied the movements of nesting adult bald eagles with radio telemetry. Eagle activity values were derived from standard visitation scores to each shoreline kilometer (see, for example, Figure B4.1-6). A score of 4 indicates a high frequency of visits by eagles to a SKm. Similarly, scores of 5 signify the occurrence of prominent perches near shore, the presence of shallow water (< 30 cm) within 7 m of shore, and high degree of isolation from human disturbance as indicated by the absence of passive disturbance features (see Glossary) within 200 m of shore.

Table A3.4-2. Origin of mammalian prey delivered to Arizona bald eagles nests as identified by radio telemetry and nest bowl observations. Large carcasses counted only once.

| Bird Number | Forage Location of Mammalian Species | | | | | | No. | Unknown | Total |
|-------------------------|--------------------------------------|--------------------------|----------|-----------------------------|-----------|---|-----------|----------------|-----------|
| | No. | Terrestrial ¹ | No. | < 200 m River/Reservoir | No. | Within view of River/Reservoir ² | | | |
| Radioed Adults | | | | | | | | | |
| AM02 (East Verde) | — | — | 1 | — | — | Cow Carcass | 1 | Woodrat | 2 |
| AF04 (Ladders) | — | — | — | — | 1 | Unknown mammal | — | — | 1 |
| AM04 (Bartlett) | — | — | 1 | Unknown mammal | — | — | — | — | — |
| | — | — | 1 | Deer carcass | — | — | — | — | 2 |
| | — | — | — | — | 2 | Unknown mammal | — | — | — |
| | — | — | — | — | 1 | Woodrat | — | — | — |
| | — | — | — | — | 1 | Cottontail | — | — | — |
| | — | — | — | — | — | — | — | — | — |
| | — | — | 1 | Jackrabbit | — | — | — | — | — |
| | — | — | 1 | Rock squirrel | — | — | — | — | — |
| AM01 (Blue Point) | 1 | Rock squirrel | 1 | Jackrabbit ³ | 1 | Rock squirrel | 1 | Rock squirrel | 6 |
| AF02 (Horseshoe) | — | — | 1 | Rock squirrel | — | — | — | — | 5 |
| | — | — | — | — | — | — | 1 | Unknown mammal | — |
| | — | — | — | — | — | — | — | — | 1 |
| Subtotal | 1 | 6% | 4 | 24% | 9 | 53% | 3 | 18% | 17 |
| Unradioed Adults | | | | | | | | | |
| LF01 (East Verde) | — | — | 1 | Rock squirrel ⁴ | 1 | Cow | 1 | Woodrat | 3 |
| PM01 (Ladders) | — | — | 1 | Rock squirrel | 3 | Unknown mammal | 3 | Unknown mammal | 6 |
| Unknown (Bartlett) | — | — | — | — | — | — | 1 | Cottontail | 1 |
| CF01 (Bartlett) | — | — | — | — | — | — | 1 | Cottontail | 1 |
| | — | — | — | — | — | — | 1 | Woodrat | 1 |
| DF02 (Blue Point) | — | — | 1 | Unknown mammal ⁴ | — | — | — | — | 1 |
| | — | — | 1 | Cottontail ³ | — | — | — | — | 1 |
| | — | — | — | — | — | — | 1 | Jackrabbit | 1 |
| Subtotal | 0 | 0% | 3 | 20% | 4 | 27% | 8 | 53% | 15 |
| TOTAL | 1 | 3% | 7 | 22% | 13 | 41% | 11 | 34% | 32 |

¹ Taken while soaring off river. ² Seen from perch or flight along water course or near nest. ³ Pirated carrion. ⁴ Taken in river.

Finally, the Bartlett adult male (AM04), present in his territory on 24 July 1988, was absent during airplane surveys on 29, 30 July and 6 August, but had returned by 16 August. We failed to locate him in airplane telemetry searches on the Salt and Verde rivers and the Mogollon plateau during this period.

A3.4.5 Discussion

In Section A3.4.3 we showed that patterns of home range use and prey selection were somewhat similar within each of three settings. By comparing distances traveled from the nest by the radio-tagged eagles to perch and forage (Section A3.4.3), we were able to shed further light on considerations of habitat selection.

The first was the significance of super-riffles in attracting foraging eagles. Our results show that at the only three breeding areas where nests overlooked super-riffles (Ladders, Bartlett, and Cliff), the nest area was the primary focus of riverine foraging. At East Verde, where there were no super-riffles in the immediate nest vicinity, the main foci of visitation were in the two nearest Kms containing super-riffles.

The second consideration is that reservoirs also strongly influenced home range patterns. In five cases where nests were near reservoirs (Bartlett, Blue Point, Horseshoe, Pinal, and Pinto), the eagles visited the reservoirs as much or more than riverine habitats, and obtained significant proportions of their total prey biomass from the reservoirs. Eagles were especially attracted to inflow areas at three of the four reservoirs. The Pinal and Bartlett eagles traveled considerable distances to perch and forage at or near reservoir inflow areas (7 and 9 km, respectively). In 1987 and 1988, the cliff nests of the Horseshoe pair directly overlooked the inflow areas where the majority of forages occurred.

As for the three predictions made in the introduction of this section (A3.4), we point to several lines of evidence indicating that neither nesting substrate nor foraging habitat was homogeneously distributed along the water courses we studied. First is the fact that the locations of nests and prime perching/foraging areas were sometimes distant from one another (Pinal, Blue Point, East Verde). However, in some cases (Pinal, Blue Point), the separation of nest sites from major foraging locations might have resulted not from the lack of suitable substrate in foraging areas but from avoidance of human disturbance or other bald eagles.

In three cases where nests and prime foraging areas were co-located (Bartlett, Horseshoe, and Cliff), the nests were situated on the only substantial cliff within the home range of the pair, and all three pairs frequently foraged near the nest. This suggests that good foraging locations might have been common along the water courses. However, the foraging sites near these nests were either super-riffles (Bartlett and Cliff) or reservoir inflow habitat (Horseshoe), and these habitats were not homogeneously distributed. At a fourth breeding area, Ladders, several potential cliff sites were available; two of them occupied during our study overlooked super-riffles.

Finally, heterogeneity of foraging habitat distribution was indicated by the marked scattering of visitation foci (rather than a bell-shaped distribution) at all but one productive territory. The exception was Horseshoe, where the female, and to a lesser extent, the male, foraged and perched in more or less decreasing frequency with distance from the nest (in both directions). The Horseshoe female was the only radio-tagged adult to show a measurable r -value in linear regression of visitation frequency with distance from the nest. This observation, together with the small mean and maximum range scores, suggests that the location at which the free-flowing Verde River enters Horseshoe Reservoir, dominated by a high cliff

with substrate for at least two alternate nests, is a particularly rich habitat among the breeding areas we studied with telemetry. It may be no coincidence that the Salt Arm of Roosevelt Reservoir, a similar free-flowing inflow habitat, supports two bald eagle territories and is frequented by wintering eagles as well.

A3.5 HABITAT AND NESTING SUCCESS

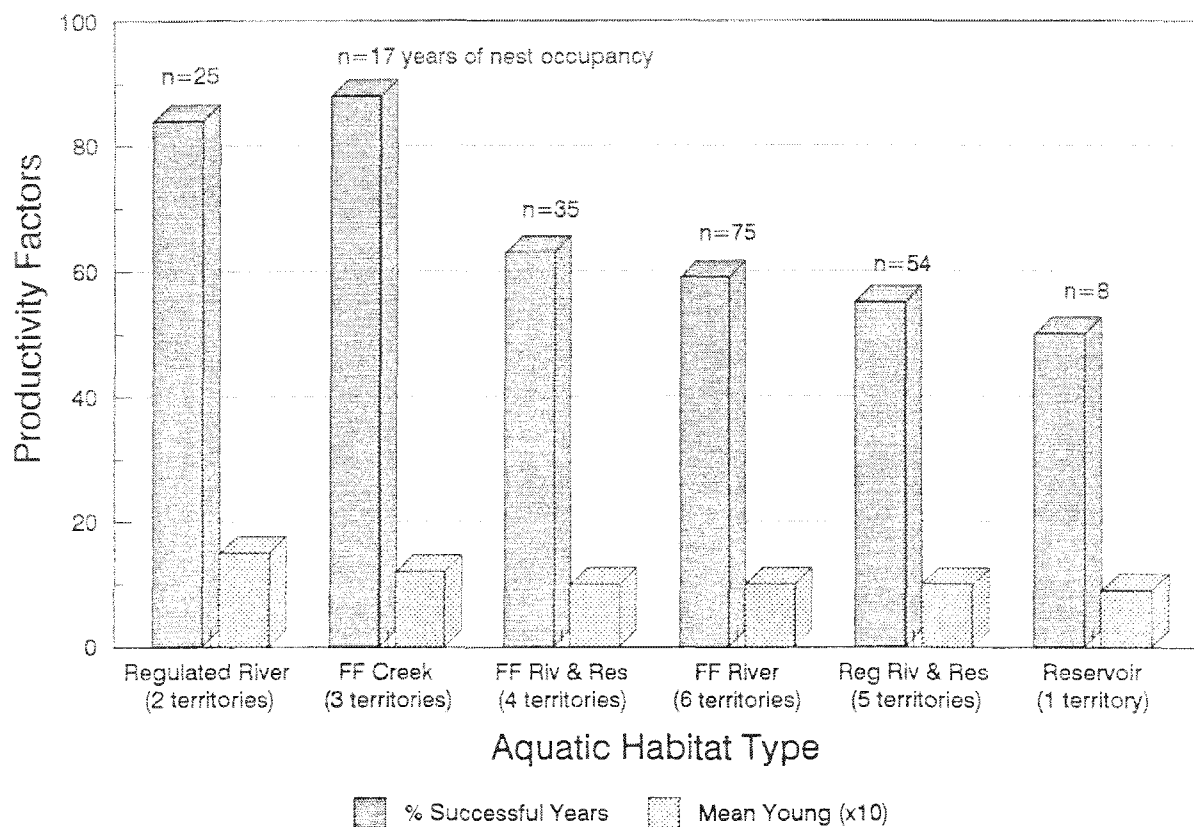
Bald eagle nesting habitat in Arizona is not only physiographically diverse, but there is also considerable irregularity from year to year in flow regimes, reservoir elevations, and ambient air temperatures. To test the effects of these spacial and temporal variations on the nesting success of bald eagles, we assembled data on 13 breeding areas where there was sufficient duration of occupancy for statistical comparison ($n = 186$ nesting/years since 1970). The territories we compared included Bartlett, Blue Point, Canyon, Cibecue, East Verde, Fort McDowell, Horse Mesa, Horseshoe, Ladders, Lone Pine, Pinal, "76," and Redmond. We chose yearly success rate (successful years/years occupied) as the dependent variable, and compared these values to the following variables (all but the last four were site-specific):

1. Nest elevation above sea level;
2. Mean river flows in February, March, April, and May;
3. Minimum and maximum spring flows;
4. Mean reservoir elevations in February, March, April, and May;
5. Human disturbance index (1 = low, 2 = moderate, 3 = high);
6. Minimum air temperatures in January and February;
7. Maximum air temperatures in March, April, and May;
8. Rainfall measured at Phoenix in January, February, March, April, and May;
9. Total yearly rainfall.

Statistical tests included discriminant function analysis and Chi-Square statistics to test for independence between successful and unsuccessful site/years for each variable examined. Like Haywood and Ohmart (1983), who also tested a number of these variables (and others as well) against nest success, we found no significant relationships. Remember, as described in Section A2, that we also found no significant difference in success rates between eagles nesting in trees and those using cliffs. These data are on file (computer disk) at the Arizona Projects Office of the Bureau of Reclamation.

We also compared success rates and productivity with habitat settings currently used by nesting bald eagles in Arizona, including: (1) regulated river habitat (without nearby reservoirs); (2) regulated rivers and reservoirs; (3) reservoirs only; (4) free-flowing rivers and reservoirs; (5) free-flowing rivers only; and, (6) free-flowing creeks. For this comparison, we used all breeding areas ($n = 21$) which successfully fledged at least one young since 1980. This avoided the bias of possibly including infertile pairs, or pairs which did not fledge young for reasons unrelated to habitat quality. However, this may have created its own bias by removing pairs which may not be able to produce young due to prey base or other habitat deficiencies. We chose what we considered the lesser of the two biases (but see Section C2.5.5 for both comparisons).

For the 21 breeding areas successfully fledging at least one young since 1980, regulated rivers ranked as the most productive habitat, having been successful in 78 percent of years, with a mean of 1.5 young per year (Figure A3.5-1). In cross-tabulation Chi-Squares between brood size values for the six habitats,



Abbreviations: FF=Free-Flowing; Riv=River; Res=Reservoir; Reg=Regulated.

Figure A3.5-1. Aquatic habitat types ranked by the productivity and nest success of Arizona bald eagle breeding areas successfully fledging at least one young since 1980.

no significant difference emerged. However, comparing success rates (successes versus failures), significant values were obtained in four cases. Nests on regulated rivers and on free-flowing creeks were significantly more successful than nests on free-flowing rivers or regulated rivers with reservoirs present (Table A3.5-1).

By lumping habitats within the six categories, we compared reproductive performance between 12 breeding areas in which habitats were artificially altered (Habitats 1,2,3, and 4) and nine on natural streams (Habitats 5 and 6). In habitat altered by dam construction, 134 young were produced at 12 sites in 122 nest-years, for a mean of 1.1 young. In "natural" habitats, the eagles produced 93 young at 9 sites in 92 occupied nest-years, for a mean of 1.0 young. The difference in nesting success between altered and unaltered habitat was not significant (nor was a comparison using all 28 breeding areas for all years since discovery; see Section C2.5.5).

We also compared reproductive success in breeding areas along the Verde River with those on the Salt River. The Verde river system ranked first, with eight breeding areas producing 120 eaglets in 107 years of nest occupancy, for a mean of 1.1 young. On the Salt drainage, there were 10 breeding areas producing 97 eaglets in 94 nest-years, for a mean of 1.0 young per occupied nest. The difference was not significant.

Table A3.5-1. Statistical comparison of reproductive success and habitat setting at 21 bald eagle breeding areas in Arizona. The Yates correction for small samples was applied in calculating significant Chi-Square values (*).

| | Regulated River | Free-flowing Creek | Free-flowing River and Reservoir | Free-flowing River | Regulated River and Reservoir | Reservoir |
|----------------------------------|--------------------|-----------------------|--|--------------------------|-------------------------------------|-----------|
| Regulated River | | 0.95 | 0.13 | 0.04 | 0.03 | 0.14 |
| Free-flowing Creek | 0.004 | | 0.12 | 0.04 | 0.03 | 0.11 |
| Free-flowing River and Reservoir | 2.254 | 2.460 | <i>Probability Values</i> | | | |
| Free-flowing River | 4.234* | 4.060* | 0.044 | <i>Chi-Square Values</i> | | |
| Regulated River and Reservoir | 4.863* | 4.625* | 0.214 | 0.030 | | 0.93 |
| Reservoir | 2.188 | 2.516 | 0.073 | 0.009 | 0.007 | |

A3.6 FACTORS INFLUENCING BALD EAGLE CARRYING CAPACITY IN THE SOUTHWEST

We sought during this study to find physical and biotic similarities between successful breeding territories that would allow us to evaluate the suitability of other river systems in the southwest as potential bald eagle nesting habitat. In this way we could estimate carrying capacity for a breeding population that might be expected to expand into currently unoccupied habitat. Also, such an evaluation would provide guidelines around which potential habitat could be managed in behalf of eagles.

As is evidenced throughout this report, we found great variation in foraging habitat, prey selection, and choice of nesting substrate. The latter included cliffs, pinnacles, trees, and snags, all of which showed considerable size diversity. A plasticity of nest site selection was further suggested by the presence of often diverse alternate nests in all but one breeding area. Isolation from large ground predators and isolation from excessive human disturbance appeared to be a common feature, but we were able to enter at least two nests without artificial aid.

However, all nests were elevated to some extent, and in our air surveys of the surroundings of rivers and reservoirs, considerable gaps in the distribution of what we intuitively defined as suitable nesting substrate were evident. For example, the regulated reach between the Bartlett breeding area and Fort McDowell appeared devoid of potential nesting locations, even though we judged that it offered adequate foraging opportunities for additional pairs. In sum, it is difficult to broadly assess the suitability of unoccupied breeding habitat on the basis of nesting substrate quality. What we can say is that, before the loss of the riparian forests and the increase of human activities along the rivers, there were likely many more places to nest than there are now, especially in areas without much physiographic relief.

Variation in prey availability *within* breeding areas may be a requisite of serviceable breeding locations for bald eagles in Arizona. Viewing the prey selection diagrams shown in Figure A3.1-4, it is clear that each pair of eagles from which we obtained a good sample of prey remains (and/or prey delivery observations) foraged on a wide variety of prey types. The distribution within each sampled diet (where $N > 10$) was never skewed toward a single taxon (say, 90% catfish and 10% all other taxa). If anything, the diagrams underestimated the degree of dietary diversity by the lumping some of the taxonomic groups. We view all this as circumstantial evidence that prey diversity is essential to nesting bald eagles.

Differences in prey availability within a breeding area stem partly from habitat heterogeneity (e.g. river and reservoir) and partly from differences in the timing of prey availability (e.g. spawning cycles). The timing aspect was repeatedly shown in our data from the seven breeding areas we studied in detail. Eagles tended to switch during the nesting cycle from one species to another as each became more available or less available (for example, see Section B4.2 for prey selection by the Blue Point male).

Variation in the timing of prey availability tends to widen the total period in which eagles can obtain food. The temperature differential along a regulated river fed by a hypolimnetic release may greatly increase the period of sucker spawning (sections A3.2.1, B4.1 and B4.2), and the presence of tributaries may have a similar effect. Suckers on a free-flowing river without a tributary may be vulnerable to eagles for a relatively short period when water temperatures warm to those optimum for spawning. Afterwards, when temperatures exceed those for sucker spawning, other species must already be available or become available in their turn, because for a breeding area to be serviceable (i.e., potential for success

outweighs risk of investment), prey sufficient to feed an eagle family must be available *throughout* the breeding season.

The environmental setting of a bald eagle breeding area obviously influences prey diversity. A reservoir supporting a warm water fishery offers considerable variation in prey (carp, catfish, and perciforms) as do territories which contain both riverine and lacustrine habitats. Streams and reservoirs too cool to support prey fish diversity may explain the current scarcity of nesting eagles around headwaters and on the Mogollon Plateau. Bearing on this discussion is that several successful pairs (e.g., Canyon, "76," Ash) are on creeks where one might expect less prey diversity than is available on rivers, but our samples and knowledge of those pairs are insufficient to draw conclusions. When spring rains or excessive snow runoff increase flow and turbidity, as is prone to happen on free-flowing reaches in some years, the availability of prey species whose vulnerability is unaffected (e.g., mammals) is likely significant. Our data suggest that the occurrence of hydrologic features (e.g. super-riffles) which maintain shallow water habitat even at high flows probably function as important components of serviceable breeding locations.

In considering carrying capacity and management strategies for other southwestern river systems, our work suggests that the features of bald eagle habitat that render it suitable for breeding include: (1) nesting substrate offering security from large predators and human disturbance; and, (2) two or more of the following fish taxa occurring in substantial numbers: carp, suckers (spp.), catfish (spp.), and perciforms (the latter in reservoirs). Factors which appear to strongly increase habitat quality include: (3) reservoirs supporting warm water fisheries; (4) reservoir inflow areas; and, (5) super-riffles.

A4 STUDIES OF NONBREEDING BALD EAGLES

The natural history and demography of Arizona's bald eagle population is better understood than many. Data exist on nest occupancy, productivity, and brood survival to the point of fledging, and there has been a focus on the factors that support and threaten the breeding pairs and their broods. However, after young eagles fledge they become relatively invisible to researchers until they enter the breeding population at a minimum of four years of age. During this multi-year prebreeding period, they must learn to subsist in a variety of conditions, and to eventually breed successfully, they must acquire foraging skills far beyond those necessary to survive.

When we began our study of bald eagles in Arizona, very little was known about the ecology or natural history of the younger cohorts. Among the questions asked were: How long do fledged juveniles remain in their natal territories before dispersing? What problems do they have obtaining food and surviving prior to dispersal? When and under what conditions do they leave? Where do they go, and what habitats do they utilize outside of central Arizona? When do they return? What habitats in Arizona are used by the returning juveniles and others in the nonbreeding component of the population? How might management action increase the welfare of the nonbreeders? The answers to these questions may be significant because minimum levels of survivorship and fat deposition among nonbreeders are ultimately necessary to sustain the breeding population through recruitment.

In this section, we describe the post-fledging behavior of a sample of radio-tagged juveniles in Arizona, their departures from natal areas, their migrations, and their return to Arizona. Some of these returning juveniles remained in Arizona during winter and spring, and we monitored their movements and use of habitat by means of airplane surveys. We also radio-tagged a number of subadult and near-adult bald eagles and searched for them as well. We refer the reader to narratives in Section C5 for details regarding the movements of each radio-tagged bird.

A4.1 ECOLOGY OF POST-FLEDGING JUVENILES

Information about eagle activity during the first few months after leaving the nest is the first step in understanding deficiencies that may occur in the recruitment of breeders. The post-fledging period is one in which all birds undergo significant mortality, at rates possibly greater than at any other period in their life cycle (Cade 1960, Newton 1979). Young bald eagles must learn to forage, protect themselves from enemies, and avoid a myriad of human-created dangers, all by trial and error. They must make long-distance migrations, often within weeks of fledging, negotiate deserts, forests, and mountain ranges, cope with a variety of adverse weather conditions, and find food within the limited time allowed by fat reserves.

In the current study, our objectives included: (1) monitoring movements of juveniles in the nesting territories during the pre-dispersal period in May; (2) following the birds by aircraft during departure and migration; (3) gathering data on the direction and distances traveled; (4) identifying the migration destinations; (5) documenting the return of the juveniles; and, (6) identifying their pattern of movements and the habitats they utilized in central Arizona.

To accomplish these objectives, we placed radio transmitters on 15 juveniles about two weeks prior to fledging (see Section E8-Methods). Eleven of these eagles departed their territories, and we were able to track the movements and routes of 10 of them by airplane. Of the remaining five, one eluded us as it departed (Horseshoe in 1988), one's transmitter failed (Bartlett in 1989), two died of complications related to heat stress about the time of fledging (Blue Point in 1988), and one was apparently killed by a predator just after fledging (Ladders in 1988). See Section C3.2 for details on juvenile mortality.

We tracked the radio signals of the soaring juveniles from high, centrally located mountain peaks (Humboldt Mountain, Mount Ord, Pine Mountain) so that several breeding areas could be monitored from one point. When a juvenile soared out of telemetry range, the telemetry observer radioed the pilots to inform them that the eaglet had departed. We tracked the migrating juveniles by airplane, some to their apparent destinations; others were still en route when bad weather or low visibility prevented airplane tracking.

A4.1.1 Previous Studies in Arizona

During the 1970s, Thomas Hildebrandt, Ronald Sell, and Robert Ohmart radio-tagged six nestling bald eagles in Arizona, two each year from 1977-1979 (Hildebrandt 1981, Sell 1982). Two of the eaglets died, and one disappeared shortly after leaving the nest. Of the remaining three, one (T04) departed on 1 July 1977, 37 days after fledging (Hildebrandt 1981), and two others left on 23 June and 4 July, at 44 and 51 days post-fledging (Sell 1982). T04 was found on 13 July, "dehydrated and exhausted" on the U.S. Marine Corps Base at 29 Palms, California. Dr. Kathy Ingram (Liberty Wildlife Foundation) subsequently rehabilitated T04, and the bird was released again on 26 July. It departed again on 31 July, and by 11 August, it had arrived in the Imperial Valley of southern California where it remained until 23 October, when it apparently flew south into Mexico (Hildebrandt 1981). T04's signal was again detected by USFWS personnel conducting a waterfowl survey in January on the Rio Sinaloa in Sinaloa, Mexico. The bird remained there for at least several days, after which no further information on its whereabouts was obtained. In 1980, T04 was reportedly shot, 96 km east of Calgary, Canada (Ohmart 1985).

One of the two nestlings radio-tagged in 1979 was detected by AGF personnel on 4 April 1980. The juvenile frequented Apache and Roosevelt reservoirs until 6 July, when its transmitter failed (Sell 1982, Haywood and Ohmart 1981).

A4.1.2 Pre-Migratory Behavior of Juveniles

Young have successfully left nests in Arizona from 60 days (8.6 weeks) to 95 days (13.6 weeks) of age (see Section C2.1). However, some eaglets may fly from the nest earlier, apparently in response to high temperatures and the presence of nest parasites (see Section C3). During the period from fledging to departure, the young learn to fly, land, assert their aggressiveness toward other species, and occasionally forage.

Just after fledging, the juveniles are clumsy, and their first landings on cliffs or branches can result in injury, or even death. We observed an eaglet (JD33, Blue Point 1988) break his neck when he crashed into the face of the nest pinnacle while attempting to land after his first flight. The eaglets are also naive about cactus, and have attempted to land on teddybear cholla. In one case, we spent 10 minutes picking cholla spines from the head, feet, and wings of JC51 (Bartlett in 1989) which flew into a teddybear cholla cactus on its first flight. The young soon become adept flyers and learn to control their landings.

While monitoring the telemetered juveniles prior to departure, in some cases we observed their post-fledging behavior. Patterns were consistent with our earlier observations on the Pit River in California (BioSystems 1985; Hunt *et al.* 1992a). Following their first flights from the nest, the Arizona birds sometimes spent the night on the ground or on low vegetation. During the first week or so, they typically perched near the nest, but soon traveled more extensively within the territory, generally staying within 3 km of the nest. They obtained food almost entirely from their parents, but occasionally found carrion. A Bartlett juvenile even took a live fish by hopping around in a shallow pool when flows ceased from the dam. A few weeks after fledging, the juveniles began soaring during the heat of the day, although they would not soar on some days (or even for several consecutive days) even when conditions were apparently favorable. Finally, at ages of 16-20 weeks, they would depart the territory unexpectedly, soaring off to begin their migrations.



Plate A10. Cliff juvenile (J126) at 14 weeks old, June 1988. At the age of 16.5 weeks this young eagle migrated 1955 km to Swan Lake, Manitoba, Canada, the farthest known distance of any Arizona juvenile (photo by D. Driscoll).

A4.1.3 Migratory Departure of Juveniles

The 11 radio-tagged juveniles (Table A4.1-1) all departed during the middle of the day at intervals ranging from 18 to 65 days after fledging ($X = 43.7$ days) and at ages varying from 16 to 20 weeks ($X = 18.5$ weeks). Interestingly, the birds in 1987 departed earlier and at younger ages than those in 1988 and 1989. Specifically, the four juveniles we followed in 1987 all migrated from central Arizona during the period 9-17 June ($X = 12$ June) at 18-42 days after fledging ($X = 34$ days). The six juveniles in 1988 departed from 12 June to 30 July ($X = 13$ July) at 18-57 days after fledging ($X = 47$ days).

Table A4.1-1. Arizona juvenile bald eagle migrations 1987-1989.

| Bird | Breeding Area | FLEDGING | | | DEPARTURE | | | Days Post Fledging | Destination |
|-------------|---------------|----------|--------|-------------|-----------|------|-------------|--------------------|---|
| | | Sex* | Date | Age (weeks) | Date | Time | Age (weeks) | | |
| <u>1987</u> | | | | | | | | | |
| JZ02 | Orme | F | 3 May | 13 | 9 June | 1314 | 18 | 37 | NW to Strait of Georgia, B.C. Lost in weather—19 June 1987. Imperial Reservoir, California (on Arizona border)—18 Dec. 1987. Arizona: Orme, near nest—4 Mar. 1988. Departed—May 1988. Arizona: Talkalai Lake, north of San Carlos—4 Oct. 1988. Last location: Carrizo Creek on Salt River—25 Mar. 1989. |
| JZ01 | Orme | M | 5 May | 13 | 12 June | 0935 | 18.5 | 38 | North to Scapegoat Wilderness Area, Montana. Lost in weather—20 June 1987. |
| JM03 | Ft. McDowell | M | 1 May | 13 | 12 June | ? | 19.5 | 42 | North to Lima Reservoir, MT (eating whitefish)—20 June 1987. East to Yellowstone Lake, WY (cut-throat trout spawn)—27 June 1987. Departed Yellowstone Lake—17 Aug. 1987. Arizona: Near Mormon Lake—20 Oct. 1987. Blue Point/Orme Area—Jan. 1988. Departed on second migration—May 1988. Yellowstone Lake, MT (cut-throat trout spawn)—20 June 1988. |
| JL20 | East Verde | F | 30 May | 13 | 17 June | 0923 | 16 | 18 | NW to Blue Mountains, OR. Lost in weather—21 June 1987. Arizona: Bartlett, near nest (transmitter failing)—27 Oct. 1987. |
| <u>1988</u> | | | | | | | | | |
| JZ24 | Orme | M | 7 May | 11 | 12 June | 0930 | 16 | 36 | NW to Washington, then SE to Yellowstone Lake, Wyoming (cut-throat trout spawn)—20 June 1988. Arizona: White Mountains, near McNary—16 Nov. 1988. Last location: Carrizo Creek on Salt River—25 Mar. 1989. |
| JJ26 | Cliff | F | 27 May | 11 | 3 July | 1230 | 16.5 | 37 | NE to Swan Lake, Manitoba—13 July 1988. Indians gill-netting "ling cod." "Trash" fish discarded. Abundant carrion on shore. |
| JP23 | Ladders | M | 14 May | 12 | 7 July | 1510 | 19.5 | 54 | NW to Washington, then south along coast to Klamath River, CA—18 July 1988. Arizona: Ladders, near nest—27 Sept. 1988. Departed—1989. |

Table A4.1-1. (Continued)

| Bird | Breeding Area | FLEDGING | | | DEPARTURE | | | | Destination | |
|------------------|---------------|----------|---------|-------------|--------------------|------|-------------|--------------------|---|--|
| | | Sex* | Date | Age (weeks) | Date | Time | Age (weeks) | Days Post Fledging | | |
| 1988 (continued) | | | | | | | | | | |
| JW30 | 76 | F | 10 June | 12 | 18 July 27 July | 1504 | 17.5 19 | 38 47 | NE to 20 miles south of Winslow. Returned next day—19 July 1988. NE to North Dakota, then into South Dakota. Lost in weather—4 Aug. 1988. Arizona: Near White River—2 January 1989. Last location: White Mountains—27 February 1989. | |
| JO35 | Horseshoe | M | 2 June | 13 | 29 July | | 21.5 | 57 | Departed ca. 330° true north—29 July 1988. | |
| JW31 | 76 | F | 10 June | 12 | 30 July | | 19 | 50 | East up Salt River to Ash Creek—31 July 1988. North to Blackfoot Reservoir, Idaho (eating carp)—10 Aug. 1988. Arizona: Salome, Bay, Roosevelt Lake—4 Oct. 1988. Last location: Cherry Creek on Salt River—12 February 1989. | |
| 1989 | | | | | | | | | | |
| JC50 | Bartlett | M | 10 May | 11 | 14 July | | 20 | 65 | North to Red Rock Lake, MT, then on to Dillon, MT, in golden eagle habitat—24 July 1989. San Carlos River, at bridge north of reservoir—15 Nov. 1989. San Carlos River, at Gila River confluence—30 Dec. 1989. San Carlos Reservoir, at Gila River confluence—9, 12, and 13 Jan. 1990. | |
| JC51 | Bartlett | F | 11 May | 11 | | | | | Transmitter failed 28 June 1989 before eagle left natal area. | |

* Sex differentiation based on body measurements.

NOTES: One 1987 Arizona juvenile (blue band on left tarsus) sighted at Point Mugu Naval Air Base, California, on 31 January 1988.

One 1989 Mexico juvenile banded on the Rio Yaqui, Sonora, Mexico, at the Rio Sahuaripa breeding area (USFWS band 629-3264?, gold band on left tarsus, J-05 or J-06) sighted at Tongue Point, Clatsop County, Oregon, from 7-15 September 1989.

In 1989, the one radio-tagged juvenile departed on 14 July, about 65 days after fledging. Also, the range of departure angles and migration courses of the four birds in 1987 were more compressed than in 1988 (335–360° True North in 1987 compared with 320–020° in 1988). Sample sizes are far too small to suggest that a trend was obtained over the period of our studies or that it was related to climatic differences, but it certainly appeared that mechanisms controlling migratory behavior were less rigidly invoked in 1988.

Detecting the departures of the telemetered juveniles required constant vigilance during the warm periods of the day, and we were often frustrated by the unpredictability of their soaring behavior. They would sometimes remain airborne for hours on what seemed (to us) perfect days for migration, only to return to the nest area and remain relatively sedentary for several days. There were a number of “false alarms” when line-of-sight telemetry signals would be lost because the birds would drop below terrain features to perch for a while.

It is difficult to be exact about the times of departure because the birds often soared for long periods at varying distances from their nests before weak or intermittent signals evidenced their emigration. Three migrants left their natal territories by 0930 hours but two others did not appear to be actually migrating until 1504 and 1510 hr. (how far they had progressed before then was unknown).

In general, birds departed during periods in the day when thermal activity was strongest. In some cases broad thunderstorms seemed to deter the departure of the migrants (e.g., JP23), but storms were common on departure and migration days and, for the most part, the eagles seemed unaffected by them and soared boldly among them. Thunderstorms, of course, verify the existence of strong currents of rising air and probably signal the eagles that conditions are favorable for soaring.

A few of the birds exhibited “false starts” in which they appeared to begin their migrations, only to turn back after traveling some distance. On 18 July 1988, the “76” juvenile JW30 departed her natal territory and traveled amid thunderstorms 90 km northwest to a tributary of the Chevelon Fork about 45 km south of Winslow. The next morning, she returned to her nest area where she remained until 26 July; then she migrated. JP23, the 1988 Ladders juvenile male, appeared to be departing on the afternoon of 3 July, but retreated to his nesting area from a massive thunderstorm north of Camp Verde; he migrated four days later. On 14 July, JC50, the 1989 Bartlett juvenile male, traveled 64 airline km up the Verde River, to river Km 162 near the Ladders nest, only to return in late afternoon to the vicinity of Table Mountain (Km 107), about 37 airline km from the nest. Finally, the 1988 Horseshoe juvenile male JO35 appeared to be migrating on 26 July when it soared to the area east of Pine, AZ where there were large thunderstorms. By 1515 hrs it had returned about halfway to the nest to perch in the hills downstream of the mouth of the East Verde River. It remained in this area about 27 km north of the nest for the next two days. Instead of then migrating, it returned to the nest area on the third day (29 July), and then migrated that afternoon at a departure angle of 300–360 degrees True North.

Nine of ten migrants were initially oriented in a northerly direction; there was one to the NNW, five to the north, one to the NNE, and one to the northeast. Oddly, the anomaly was the “76” juvenile JW31, the sibling of JW30 who had returned to the nest after traveling 80 km (see above). JW31 traveled 50 km southeast from the natal territory on Tonto Creek to an area east of the Salt Arm of Roosevelt Reservoir where she soared for the remainder of the day and spent the night. The next day she continued soaring around the mouth of Cherry Creek, not far to the east, and roosted in Ash Creek near the Salt River. The next day she assumed the behavior of the other migrants and traveled over 220 km north to roost between Holbrook and Tuba City, then continued a “normal” migration northward.

A4.1.4 Migration of Juveniles

Most bald eagles nesting in inland Canada and Alaska migrate south into the contiguous United States in winter. When waters freeze, waterfowl migrate south, and fish become difficult to obtain. Bald eagles banded as nestlings at Besnard Lake, Saskatchewan, Canada, have been recovered, sighted, or radio-tracked throughout the plains and western states of the U.S, including one which wintered in Arizona (Snow 1973, Gerrard *et al.* 1978, Gerrard and Bortolotti 1988). Similarly, eaglets banded in the Great Lakes Region migrated south into the midwest and southern Mississippi Valley states, and also into Texas. Bald eagles from the Chilkat River in Southeast Alaska mostly remained there, although some moved south along the coast to British Columbia and Washington when salmon availability declined (Hodges *et al.* 1987).

Charles Broley (1947), who banded over 1000 nestlings in Florida during the 1930s and 1940s, was the first to study the migrations of bald eagles native to southern portions of the continent (Sprunt 1955). Bands were recovered throughout the states east of the Mississippi River, but most recoveries showed the eagles moving northward up the east coast, some all the way to Canada (Broley *op cit.*). Florida's adult eagles, however, remain at or near their breeding areas year round.

Beebe (1974) thought that juvenile bald eagles left southern British Columbia soon after fledging and traveled to the salmon runs in northern Canada and Alaska. In fall, the salmon along the Pacific coast generally spawn earliest in the north and latest in the south, so that eagles following them appear in southern British Columbia and northern Washington in early winter. Using radio-telemetry, Hunt (BioSystems 1985; Hunt *et al.* 1992a) followed five juvenile bald eagles from nests in northern California on northerly migrations that were probably directed toward salmon spawns in northern British Columbia or Alaska. One bird traveled to Prince George, British Columbia in six days.

In the current study, we followed nine juveniles as they traveled northward across the continent, and we briefly tracked a tenth Arizona juvenile (JL20) as it passed through northeastern Oregon (see Section C5). Figure A4.1-1 shows the routes of each bird. Seven of them, whose roosting locations were determined at the end of the first day of their migrations, had traveled an average of 230 km (range = 137–382 km).

In Section C5, we provide more complete descriptions of the migrations of each of the ten radio-tagged juveniles. The example given below describes the post-fledging travels of the 1987 female, JZ02, from the Orme nest near the confluence of the Salt and Verde rivers, not far from Phoenix.

On 9 June 1987, the day of its departure, JZ02 traveled about 120 km northward to a cottonwood grove (or nearby cliff) near Camp Verde, Arizona, stopping before 1550 hr. The next day it traveled nearly 500 km to Sevier Lake in southern Utah and by the next evening had reached the Ruby Mountains in Nevada. The following day, 12 June, it flew northwestward to roost near the three-state intersection of Nevada, Oregon, and Idaho. It roosted the next evening just south of La Grande, Oregon. Heavy thunderstorms with rain persisted in the region over the next 48 hours and prevented airplane tracking. The eagle apparently remained in the Blue Mountains of northern Oregon during this period. On 16 June, the bird traveled over the wheatlands of eastern Washington to roost north of Moses Lake. By 18 June, it had gone northwestward across the Cascade Mountains to the lowlands near Mt. Vernon, Washington, north of Seattle. The next day, the eagle passed over the city of Vancouver, British Columbia and traveled up the eastern shore of the Strait of Georgia. Deteriorating weather conditions prevented us from tracking the

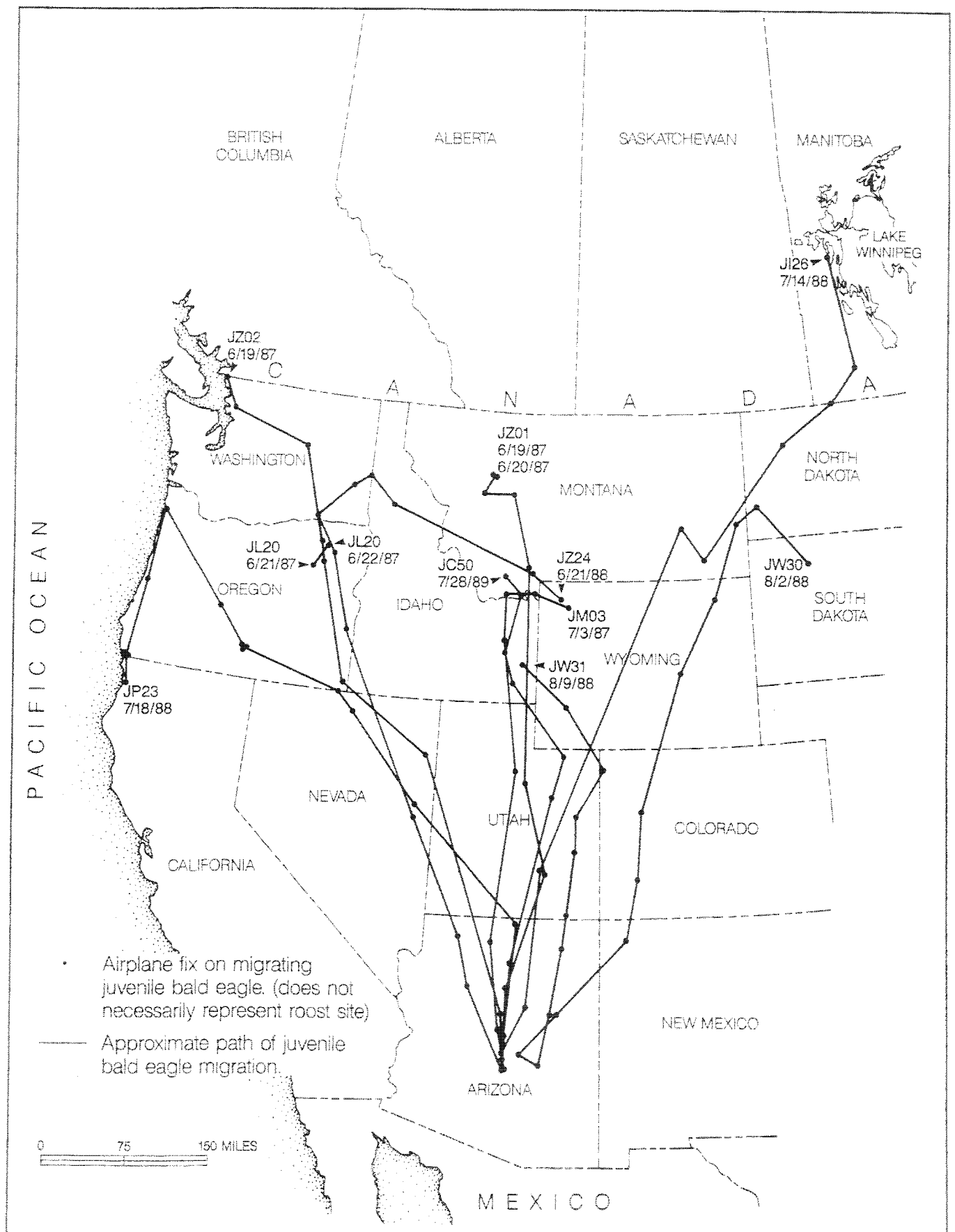


Figure A4.1-1. Migrations of 10 juvenile bald eagles radio-tagged as nestlings in Arizona during 1987-1989.

bird further. If it continued migrating in the same direction, it would have arrived in southeast Alaska in three or four days.

As is true of most migrating raptors (Kerlinger 1989), soaring was the predominant mode of travel for the Arizona juveniles. Powerful updrafts that developed during the heat of the day enabled the eagles to travel rapidly; they probably glided from one thermal to another. As expected, the eagles typically started migrating in mid-morning and stopped to roost in late afternoon, a schedule obviously related to diel thermal activity.

It was obvious during airplane tracking that the eagles also used upslope winds as soaring aids, since we found them following the windward slopes of ridges that were oriented along appropriate courses. However, where the physiography deviated from preferred directions, eagles apparently chose their direction in preference to terrain features where soaring conditions might have been better (see Baker 1984).

The migrating eagles actually seemed attracted to thunderstorms, an observation we also made during our studies of California migrants. In both studies, telemetry signals of the soaring eagles often seemed to emanate from the centers of small thunderstorms. These storms are caused by currents of rising air which no doubt benefit the migrants, but we are at a loss to explain how the advantage of the currents is not outweighed by the associated turbulence, rain, and hail. Perhaps the signals were actually being reflected (and amplified?) off the precipitation associated with the thunderstorms, and the eagles were very near them, they were not actually in or under them as it seemed. We asked William Cochran, an authority on radio-telemetry in birds, about this possibility, but he doubted our hypothesis of reflected signals.

Distances covered per day varied in accordance with the time spent migrating, and in response to weather conditions. Storms and low clouds generally slowed the progress of migrants; food occurrence or the lack of it may have also had an effect. JZ01's daily movements ranged from 193-442 km with a daily average of 254 km. It took six days to migrate approximately 1,528 km. Eleven ground speeds calculated for JZ01 averaged 37.2 km per hour (range 16-64 km per hr, $SD \pm 14.6$); eight ground speeds for JZ02 averaged 38.3 km per hr (range 24-53 km per hr, $SD \pm 9.5$). The Cliff juvenile (JI26) traveled about 660 km on 5 July 1988.

Habitat chosen for roosting by the migrating juveniles was variable and included coniferous forest in both flatlands and on steep slopes. The eagles also used trees along rivers, the unvegetated sandy shore or low cutbanks along Lima Reservoir, and mountain cliffs. The eagles seemed to prefer to roost along water courses and to select eastern exposures, although there were many exceptions. Included in these is the first night roost in the migration of JW30, who roosted on a low outcropping in a desert area almost completely devoid of vegetation.

Whether or not the eagles foraged during their migrations is unknown, but they occasionally stopped during the day and transmitter activity changes suggested that they may have been eating. Such was almost surely the case with JC50 when it stopped for the day north of Duchesne, Utah and again along the Snake River for two days near Blackfoot, Idaho. Similarly, JP23's two-day stop at Silver Lake, Oregon was no doubt food related; it twice appeared to be eating by the rhythmic changes in transmitter pulse rate.

On the other hand, the probable scarcity of food, conditions at roosting locations, and the continuous movements during the day led us to believe that most of the birds fasted for long periods.

Of the nine juveniles tracked on their journeys north, four stopped at lakes or reservoirs where dead or spawning fish were available: Lima Reservoir, Montana; Swan Lake, Manitoba; Blackfoot Reservoir, Idaho; and Yellowstone Lake, Wyoming. The first three were characterized by abundant fish carrion (e.g., carp, white suckers), and the fourth by spawning cutthroat trout. A fifth bird (JC50) stopped en route three times along streams (Duchesne, Utah; Bancroft, Idaho; and Blackfoot, Idaho).

We were impressed by how accurately some of the migrating eagles stayed "on course." For example, JZ01 remained within one degree of a course of True North from its nest to central Montana, where its signal was lost. It deviated slightly to the northeast and northwest during different segments of its migration, but taken together, these appear as a series of course corrections that functioned to maintain the long range course of True North. Maximum deviation from the $111^{\circ}41'W$ longitude line running through the nest site was $53'$ (77 km) to the east and $37'$ (51 km) to the west up until it started to make local movements within the mountains of western Montana. Migrating independently, JM03 also flew True North. We determined that the line of longitude passing through Lima Reservoir in Montana, where the bird remained for one week, also passed through the bird's natal territory. What mechanism(s) enabled these birds to maintain a true course while navigating over a mountainous route where the day length increased by several hours and magnetic variation increased by $5^{\circ}E$?

Another curious feature of the migrations of the Arizona juveniles was a tendency for course fidelity to disintegrate in the range of about $45-47^{\circ}N$ latitude; most of the birds changed course radically near this parallel. Of nine birds whose migratory paths we followed from Arizona, eight either made radical course changes (five flew southward) or stopped migrating between $44^{\circ}40'$ and $47^{\circ}40'$ ($\bar{X} = 46^{\circ}10'$). The exception was JW31 who stopped in southern Idaho at about $43^{\circ}N$ latitude. Less dramatic course changes appeared in the routes of some birds, and almost all course changes took place from the roost, rather than during the day's journey. We observe that this latitude range encompasses the Columbia River drainage which formerly contained the largest salmon runs in the world, some of which occurred in summer (Paul Hirose, Oregon Department of Fish and Wildlife, pers. comm.).

It is now clear that Arizona juveniles are not universally predisposed to migrating all the way to Canada as we might have predicted on the basis of our previous study in California (BioSystems 1985; Hunt *et al.* 1992a). The Arizona juveniles migrated northward at from 885 to 1,930 km before settling into an area. JZ02, who was still migrating northward up the Strait of Georgia in British Columbia when tracking was terminated, might have gone further.

On the basis of our data, the term "post-fledging dispersal" probably does not apply to the long-range movements of the Arizona juveniles. Instead, the relatively small angle subtended by the courses of the 10 migrants, the regularity of diel activities, the rather long distances covered over short periods, and the course fidelity of some over long distances all indicate a functional migration involving habitat destinations, most likely food-related. The fact that the eagles showed these characteristics while migrating alone is evidence for genetic control of a migratory adaptation.

While the migrations of California juveniles seemed perfectly timed and directed to exploit the summer runs of salmon in Alaska and British Columbia in late July and August (Hunt *et al.* 1992a) it would seem

that the Arizona birds did not have salmon runs as a principal destination. Only two of the courses (JZ02 and JL20) might have taken birds to the runs; six other birds terminated their migrations elsewhere.

To understand the migratory timing of the Arizona juveniles we must first realize that their strategy evolved during pristine times when food distribution and abundance may have differed from today. As to what food supplies would have been available to inexperienced juveniles at such latitudes in the summer possibilities include: (1) winter-killed ungulate carcasses emerging during snowmelt; (2) fish kills at thawing high-altitude lakes; (3) nesting and molting waterfowl; (4) the spawning salmon and other fishes (e.g., cutthroat trout); and, (5) the calving seasons of elk, bison, pronghorn antelope, and other ungulates. Together these might have acted as a selective force to maintain the adaptation among southern eagles to migrate northward (see Gerrard and Bortolotti 1988).

As waterfowl and ungulates are far less abundant now than they were 200 years ago, we might assume there is less food biomass available now for the Arizona migrants. However, there is probably also far less competition (and danger) because of fewer eagles, wolves, grizzly bears, and other competitors. Also, there are many reservoirs in the modern landscape that provide foraging habitat for the migrant eagles (see Lish and Sherrod).

The above discussion is offered on the assumption that the adaptations (genes) influencing migration among bald eagles currently nesting in Arizona derive from ancestors also native to the southwest. If, instead, bald eagles have only recently colonized the southwest (*i.e.*, within this century), then speculations on the significance of the adaptation of the observed itineraries of juveniles in relation to pristine food supplies are moot.

A4.1.6 Return of Radio-tagged Juveniles to Arizona

Knowledge on the whereabouts of the telemetered juveniles in central Arizona after their return from their migrations gives better perspectives on: (1) the annual cycle of movements; (2) habitats utilized, their seasonality, and their relative significance; and, (3) survivorship in this seemingly vulnerable age class (see Section A5).

Of the 11 radio-tagged juvenile eagles that migrated from their natal territories, at least eight (73%) had returned to Arizona by the fall or winter. Table A4.1-2 shows when and where each returning bird was first detected in our airplane surveys. The dates shown, two in September, four in October, two in November, and one in January (JZ02 returned in 1987 and 1988), are probably not the actual dates of return, because we did not begin our fall airplane surveys until late September and, after September, some of the birds may have occurred in Arizona outside our survey routes.

Section C5 provides narratives of the reappearance in Arizona of each of the eight migrants. Below is an account of the return of the 1987 Fort McDowell juvenile male, JM03:

We found the Fort McDowell juvenile (JM03) back in Arizona on 20 October 1987 at Tremaine Lake, southeast of Mormon Lake, and it remained around the highland lakes until at least 3 November. We detected it soaring near Horseshoe Reservoir on 3 January, and the next day it was near Needle Rock on the Verde River downstream of Bartlett Reservoir. From then through 7 February, it frequented the Salt and Verde rivers between Fort McDowell and Blue Point, including Saguaro Reservoir. A few days later we found it at Canyon Reservoir and then at Apache Reservoir. On 4 March, JM03

Table A4.1-2. Dates and locations of first detections in Arizona of juveniles returning from their migrations.

| Bird | Natal Territory | Last Detected on Migration | First Detected in Arizona | Last Detected in Arizona |
|----------------|-----------------|------------------------------------|-----------------------------|--------------------------------|
| JZ02 (1st yr.) | Orme | 6/19/87 Strait of Georgia, B.C. | 9/26/87 Horseshoe Reservoir | 5/26/88 Roosevelt Reservoir |
| JZ02 (2nd yr.) | Orme | — | 10/4/88 San Carlos River | 3/25/89 Carrizo Creek |
| JM03 (1st yr.) | Ft. McDowell | 7/23/87 Yellowstone Lake, WY | 10/20/87 Tremaine Lake | 5/7/88 East Verde River |
| JM03 (2nd yr.) | Ft. McDowell | 6/21/88 Yellowstone Lake, WY | Not Detected | — |
| JZ01 | Orme | 6/20/87 Scapegoat Wilderness, MT | Not Detected | — |
| JL20 | East Verde | 6/21/87 Near Baker, OR | 10/27/87 Bartlett Territory | 10/27/87 (Transmitter failing) |
| JP23 | Ladders | 7/16/88 Mouth of Klamath River, CA | 9/27/88 Ladders Territory | 5/10/89 Tonto Basin |
| JW31 | 76 | 8/9/88 Blackfoot Reservoir, ID | 10/4/88 Roosevelt Reservoir | 2/12/89 Upper Salt River |
| JC50 | Bartlett | 7/28/89 Near Dillon, MT | 11/15/89 Near San Carlos | 1/13/90 San Carlos Reservoir |
| JZ24 | Orme | 6/30/88 Yellowstone Lake, WY | 11/16/88 Near McNary | 3/25/89 Carrizo Creek |
| JW30 | 76 | 8/2/88 South of Lemmon, SD | 1/2/89 Near White River | 2/27/89 White Mountains |
| JL26 | Cliff | 7/14/88 Swan Lake, Manitoba | Not Detected | — |
| JO35 | Horseshoe | Not Detected | Not Detected | — |

was on Pinal Creek about 0.25 mi from the active nest containing one young. From then through 4 May we found it in other parts of the Pinal territory and on the north shore of Roosevelt Reservoir where it frequented Campaign and Salome bays. We twice found it on Tonto Creek in or near the "76" territory during this period. On 7 May, JM03 was on the East Verde River between the two ranches. After that date, its signal was no longer detectable in central Arizona. However, on 21 June 1988 we relocated the bird at Yellowstone Lake, Wyoming where it had summered the previous year.

The return of another juvenile eagle, JZ02 (Orme nest, 1987), was first detected at Horseshoe Reservoir in late September, but by December the bird had gone to Imperial Wildlife Refuge, north of Yuma. In March, JZ02 visited its natal territory, before touring the Salt and Verde rivers for the next several months. After 26 May, we were unable to detect its signal in Arizona, but it again frequented central Arizona rivers during January through March of the following year.

These and other data on the movements and habitat selection of the radio-tagged juveniles are detailed in Section C5, and discussed below in Section A4.2. As we shall see, most of the birds tended to move about continuously within the region, and no doubt elsewhere. This proclivity to wander was apparent in the fact that we rarely found one of these eagles (or our sample of radio-tagged subadults and near-adults) in the same place that we had found it on the previous survey.

A4.2 MOVEMENTS AND HABITAT SELECTION OF NONBREEDERS WITHIN ARIZONA

Arizona's nesting population of adult bald eagles exists because habitats have favored the survival of sufficient numbers of eagles in the younger age classes to fill breeding vacancies. Unlike the nesting pairs, whose habitats can be directly assessed, the use of habitat by nonbreeders has been largely unknown, and has to do with understanding the annual cycle of movements. We have already taken an important step in acquiring such knowledge by studying the migrations of the radio-tagged juveniles. The post-migratory return to Arizona of at least 73 percent of our sample of 11 individuals suggests that habitats outside the state are rich in food and safe enough to elicit a healthy rate of survivorship. Upon their return, these juvenile eagles traveled extensively within central Arizona from September to May, and exploited a variety of habitats.

Also using these habitats are older nonbreeding bald eagles: subadults (1-3 years old), near-adults (ca. 4 years old), and even birds in full adult plumage (acquired at about five years of age) that have not yet secured a breeding territory. The early peregrinations of these birds has been unknown and has depended on the chance locations of observers. Even then, obtaining data on the occurrence of Arizona nonbreeders has been complicated by the presence of significant numbers of winter immigrants from the north.

To learn about the movements of the nonbreeders during 1987-1989 we captured and radio-tagged five subadults and three near-adults in Arizona (Table A4.2-1). These included two near-adults we captured in Salome Bay on Roosevelt Reservoir (the male—NM01—was tagged on 2 March 1988; the female—NF01—on 4 March). NF01 had been banded as a nestling in 1984 at the East Verde breeding area (Grubb 1986a). While trapping in the Ladders breeding area in 1989, we captured a near-adult and four subadult bald eagles. Some of these appeared larger than Arizona birds and may have been wintering from a northern state or province. The first subadult male (SM01) was captured on 23 January 1989.

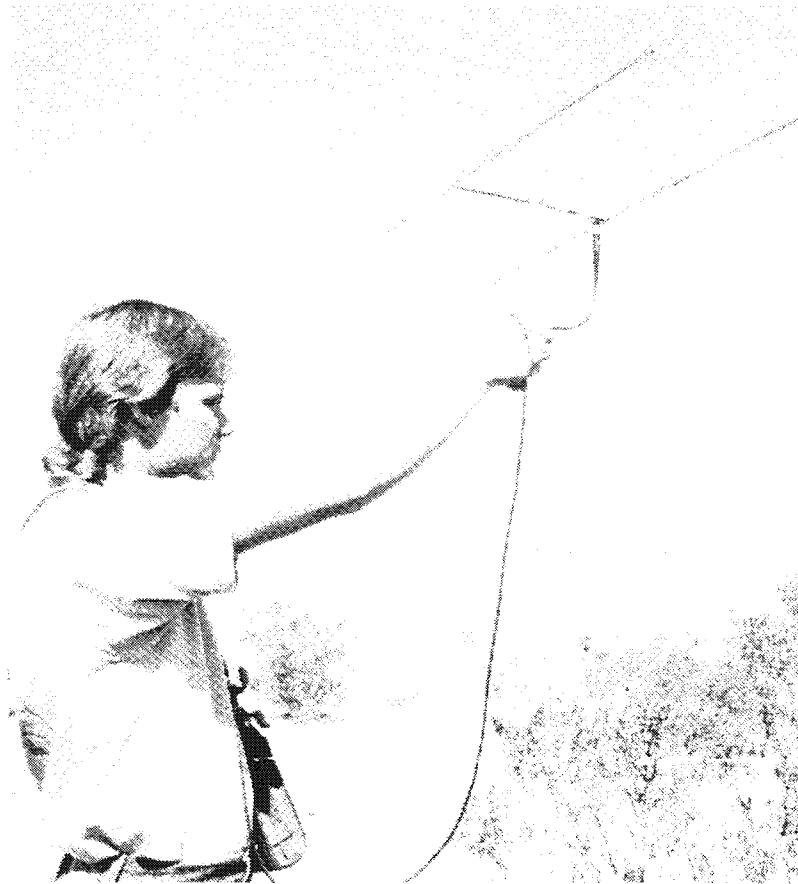


Plate A11. Daniel Driscoll radio-tracking subadult bald eagle (SF01) at San Carlos Reservoir, October 1987 (photo by Dick George).

A near-adult female (NF02) was caught on 24 January, a subadult male (SM02) on 26 January, a subadult male (SM03) on 1 February, and a subadult male (SM04) on 2 February. Included in the sample was a subadult female found injured on the upper Salt River, rehabilitated, and released. We monitored the movements of all the telemetered nonbreeders in periodic roll-call surveys (see glossary) throughout central Arizona by airplane.

Figure A4.2-1 displays the distribution of movements within central Arizona of the radio-tagged subadults, near-adults, and juveniles during fall, winter, and spring of 1987-1989. Narratives of the telemetry locations of each of these eagles are presented in Section C5.

Our surveys revealed that the distribution of itinerant eagles followed the courses of the Salt, Verde, and Gila drainages, although we occasionally found birds at off-river locations. Some of the eagles were apparently absent from central Arizona, but reappeared at later times. These birds may have traveled to other southwestern states or to Mexico. Dates of last detection of eight juveniles ranged from 13 January to 26 May, while last detections of six subadults ranged from 12 February to 10 April. Two additional radio-tagged subadults died in March. One apparently drowned in a metal stock tank, and the other was probably shot (see Sections A5 and C3.6).

Table A4.2-1. Subadults and near-adults radio-tagged by BioSystems in central Arizona during 1987-1989.

| Bird | Sex | Approximate Age | Capture Location | Date of Capture | Last Detected |
|------|-----|-----------------|---------------------|-----------------|-------------------|
| SF01 | ♀ | 3 | Upper Salt River | 06/22/87 | died ca. 04/01/88 |
| NM01 | ♂ | 4 | Roosevelt Reservoir | 03/02/88 | 04/10/_____ |
| NF01 | ♀ | 4 | Roosevelt Reservoir | 03/04/88 | died ca. 05/01/88 |
| NF02 | ♀ | 4 | Upper Verde River | 01/24/89 | 03/15/89 |
| SM01 | ♂ | 2-3 | Upper Verde River | 01/23/89 | 03/25/89 |
| SM02 | ♂ | 2-3 | Upper Verde River | 01/26/89 | 02/08/90 |
| SM03 | ♂ | 2-3 | Upper Verde River | 02/01/89 | 01/09/90 |
| SM04 | ♂ | 2-3 | Upper Verde River | 02/02/89 | 03/13/89 |

Despite extensive surveys, we did not detect any radio-tagged nonbreeders in central Arizona after the end of May. At least one, JM03, returned to northern summering grounds at Yellowstone Lake in Wyoming.

Our records on the movements of juveniles, subadults, and near-adults are insight into the relative significance to bald eagles of various habitat categories in central Arizona. Among these are tributaries, free-flowing river reaches, regulated river reaches, reservoirs fed by free-flowing rivers, reservoirs fed by regulated reaches, lakes, and terrestrial habitats.

Tributaries. Apparent in Figure A4.2-1 is that tributaries were attractive to the nomadic eagles and that some tributaries were visited more frequently than others. The East Verde River received the greatest number of radio-tagged nonbreeders of any of the tributaries and, in fact, any habitat. Six different birds in our sample visited the East Verde during January through May, mostly in 1987. A pair of adults nested on the Verde mainstem near the mouth of the East Verde River; we studied habitat selection of the telemetered male in 1987. He visited the East Verde River and foraged there extensively, primarily during March and early April when suckers were spawning (see Section B4.4). We are uncertain what prey and habitat features brought the subadults to the East Verde; fisheries surveys there in Spring 1987 recorded Sonora sucker, small mouth bass, carp, and yellow bullhead in sizes appropriate for eagle use.

It may be significant that two of the nonbreeders (JL20 and NF01) that visited the East Verde River in winter and spring had originally fledged from the East Verde nest, and two others (SM01 and NF02) were among five subadults tagged near Camp Verde. The East Verde River is a "regulated" tributary to the extent that it has artificially supplemented flows from East Clear Creek (see Sections D2 and B4.4). However, water imports to the East Verde River occur high in the drainage, and for the most part, the characteristics of this tributary conform to the criteria of a free-flowing creek. It is a long reach with relatively low flow, from high elevation to low elevation, and changes in temperature and turbidity are normal for a free-flowing regime.



Plate A12. Near-adult bald eagle (NM01) captured 2 March 1988 in Salome Bay on Roosevelt Reservoir (photo by D. Driscoll).

It would appear that West Clear Creek is also a popular tributary among the nomadic eagles, but the data may be biased by the fact that five of the birds had been captured and radio-tagged at Beasley Flat (just downstream of the confluence of West Clear Creek with the Verde River). JP23, the 1988 Ladders juvenile, after returning from its migration to Oregon and California, also frequented West Clear Creek during March 1989. This tributary is obviously serving as habitat for young bald eagles, but fish did not appear abundant in surveys we conducted there in spring and summer.

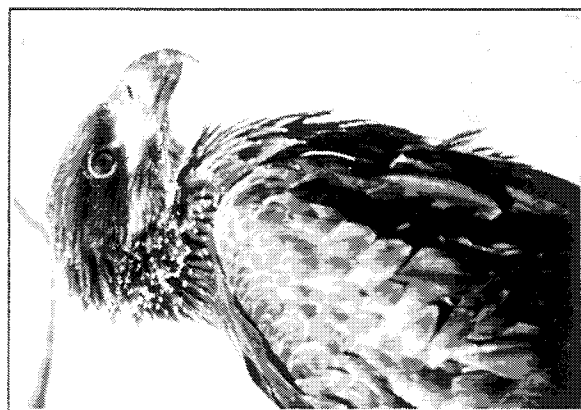
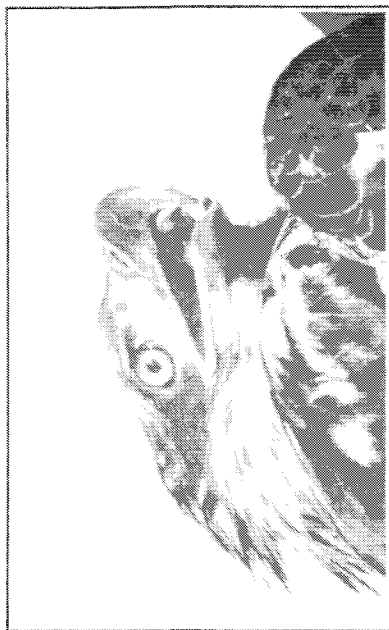
Comparing the use by the nonbreeders of the two Verde tributaries with free-flowing mainstem habitat along the Verde River, it is clear that the tributaries were not randomly chosen by the eagles. Over 120 river kilometers of mainstem received two visitations by perched nomadic eagles, while 30 kilometers of tributaries showed 16 perched visitations. We recognize that this comparison may be biased because there are other tributaries that enter the Verde River between Camp Verde and Horseshoe Reservoir. However, these tributaries are relatively small and, except for Fossil Creek (used by the East Verde nesting pair), none probably contain resident fish populations in body-size categories suitable for eagles.

Eight tributaries along the Salt River, from its confluence with the Verde to the joining of the Black and White rivers, contained enough water to presumably attract eagles. The Salt's largest tributary, Tonto Creek, was visited by the nonbreeders principally near its mouth at Roosevelt Reservoir. Here shallow braided channels probably provided foraging opportunities. Somewhat similar habitat upstream on Tonto Creek, however, apparently did not attract them, although the Fort McDowell juvenile, JM03 perched

LEGEND

PERCHED FLYING

| | | |
|---|---|------|
| ◆ | ◇ | JM03 |
| ★ | ☆ | JZ02 |
| * | | JL20 |
| ■ | ▣ | JZ24 |
| ◼ | ◻ | JP23 |
| ◀ | ◀ | JW30 |
| ▲ | ▲ | JW31 |
| ◀ | ◀ | JC50 |
| ● | ○ | SF01 |
| ★ | ★ | SM01 |
| ★ | ☆ | SM02 |
| ★ | | SM03 |
| ★ | ◻ | SM04 |
| ▲ | △ | NF01 |
| ● | ◎ | NF02 |
| ■ | □ | NM01 |



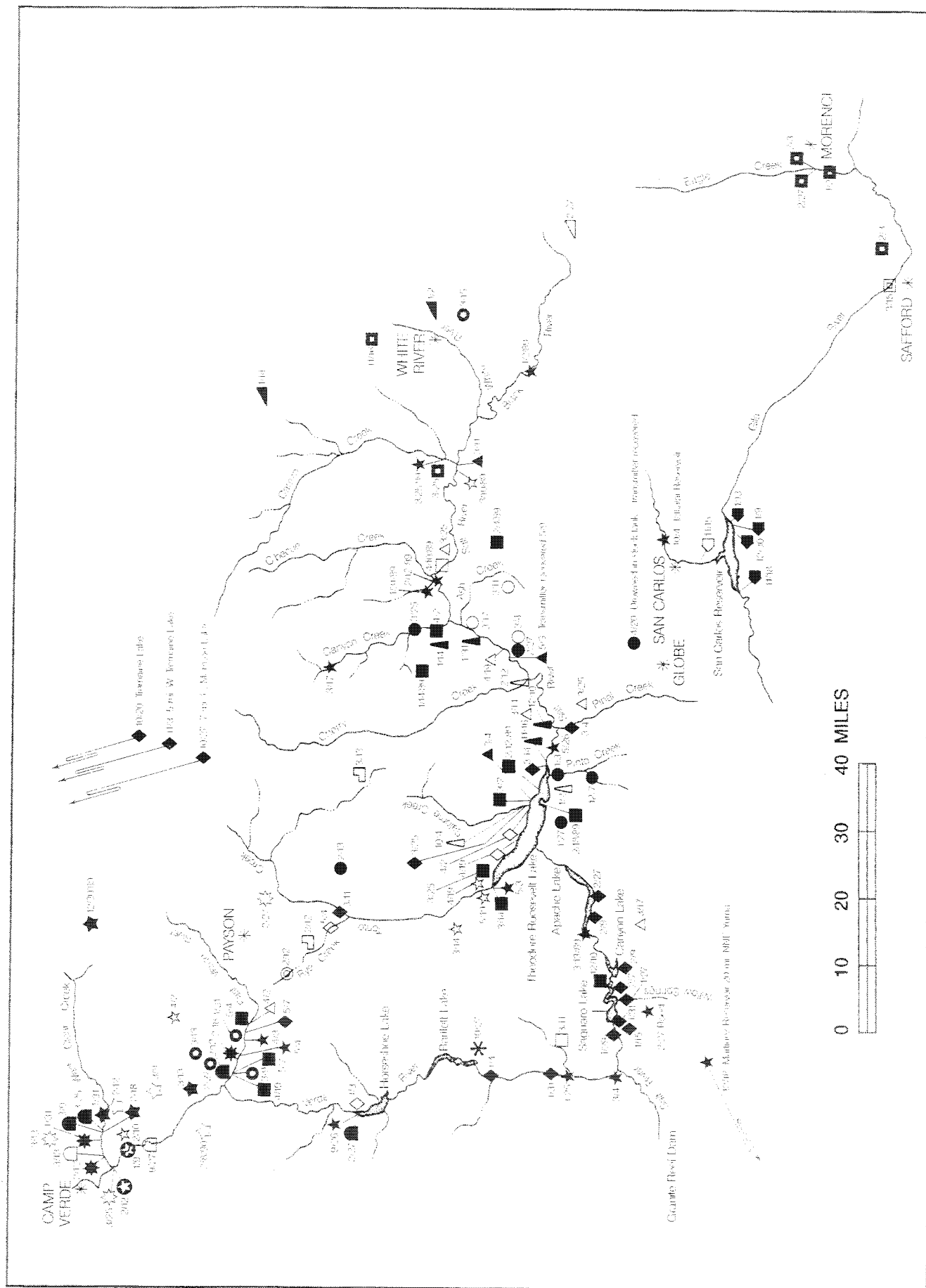


Figure A4.2-1. Movements of telemetered juveniles and subadults in central Arizona during September-May.

in the "76" territory once in early March. Several birds soared in the vicinity, so it is possible they hunted along Tonto Creek, particularly where Rye Creek joins it.

Subadult bald eagles visited Salome Creek in the vicinity of its mouth; we believe the shallow reservoir water of Salome Bay was the principal attraction. We observed nine non-telemetered bald eagles there in March 1987 (see Section B4.6.6). We never encountered a perched telemetered eagle on the creek itself, although we did observe an non-telemetered adult there. Very few resident fish large enough for eagles were observed in the creek by the fisheries team.



Plate A13. Aerial view of the Salome Creek inflow of Salome Bay on Roosevelt Reservoir, showing shallow water habitat, March 1988 (photo by D. Driscoll).

Similarly, Pinal Creek with no records of visitations, is probably poor habitat for eagles; it contains few fish, perhaps due to pollution from mines upstream.

Cherry Creek, usually with a fairly good flow, would seem to provide food for eagles. We recorded no visitations by radio-tagged eagles, although a few adults were observed during fisheries surveys in winter and early spring. These might have been attracted to waterfowl evident along the creek. We saw very

few fish during these surveys, but Driscoll (notes) saw large numbers of carp in Cherry Creek in late May, 1985 (see below).

Canyon Creek, on the other hand, received visitations by at least three radio-tagged eagles. We have little information on fish availability in Canyon Creek, but R. Mesta (pers. comm.) observed suckers there. As further evidence of its suitability as eagle habitat, a pair of nesting eagles resides in Canyon Creek some distance from the mouth. We saw no adult fish in one fish survey in the lower km in late spring.

We recorded no visitations to Cibecue Creek, but Carrizo Creek attracted several birds, all in March, near its confluence with the Salt. In helicopter surveys conducted in March over several years, up to a dozen eagles were seen on the Salt mainstem near the mouth of Carrizo Creek (see Section A4.2). Carrizo Creek may attract a run of spawning suckers which may draw eagles. Additionally, its relatively warm flows (from hot springs a few km upstream), entering the cooler Salt River in early March, provide a temperature gradient along the mainstem (from the mouth of Carrizo Creek downstream) that produces suitable conditions for a sucker spawn there. We found the remains of a gravid female sucker there in March 1989. The warmer temperatures may result in higher primary productivity and higher invertebrate biomass which may draw foraging fish to the area.

Eagle Creek, a significant tributary of the Gila River which drains the southern flank of the White Mountains, was frequented by the 1988 Orme juvenile, JZ24, during winter 1988. To what extent the area was utilized by radio-tagged nonbreeders in 1987 is unknown; we did not include it in our airplane surveys.

It is unclear why the radio-tagged eagles failed to concentrate on the Salt River tributaries as they did on the Verde River tributaries. Except on the East Verde River and Tonto Creek, we found very few resident fish on any of the tributaries we visited. Spawning runs may occur in many of the tributaries and attract eagles for short periods; we noticed a run of suckers in Houston Creek in March 1987 and P. Carroll (pers. comm.) saw one in Cibecue Creek in 1986. Steve Smith, the owner of the Dagger Ranch, told us that in previous years there had been significant spring runs of suckers and then catfish in Cherry Creek. Perhaps the lower flows during the drought years of our study attracted fewer spawning fish into the tributaries. Further knowledge of the fisheries on the Salt and Verde tributaries would help to explain the variation in their use, and might suggest ways of habitat management.

River Reaches. The two free-flowing river reaches of concern here are the mainstem Verde River upstream of Horseshoe Reservoir and the Salt River upstream of Roosevelt Reservoir. As mentioned above, the Verde mainstem received little use. The free-flowing Salt River attracted more visitations, but there were no points of strong concentration. The Gila River upstream of San Carlos Reservoir was rarely included in our airplane surveys until winter 1988 (although, we did normally survey San Carlos Reservoir); the absence of records of perched nonbreeders there is thus unsuitable for comparison.

Figure A4.2-1 suggests that the regulated reaches of the Salt and Verde Rivers downstream of Bartlett and Stewart Mountain dams were more attractive to the nonbreeders than the free-flowing reaches upstream of Horseshoe and Roosevelt reservoirs. In all, we recorded greater numbers of perch events per river kilometer (.11 perches/Km) on the regulated reaches than we did on the unregulated reaches (.03/Km). There were only two records of perchings on regulated reaches between dams (on the same river) but the overall number of river kilometers containing this habitat is small and a bias exists in the disproportionate number of visits by one eagle (JM03) to the regulated Salt River (see Figure A4.2-1).

Reservoirs. Reservoirs fed by free-flowing rivers, especially in the vicinity of inflows, attracted the radio-tagged nonbreeders. Roosevelt Reservoir between Salome Bay and the inflow at Campaign Bay was visited by the nomadic eagles. This area was also frequented by the Pinal adult pair, the Pinto female, and non-telemetered nomadic eagles (see Section B4.6). The mouth of Tonto Creek also attracted eagles as did the inflow at Horseshoe Reservoir. The inflow at San Carlos Reservoir was frequented by the 1989 Bartlett juvenile (JC50) during early January 1990.

Our telemetry data suggest that reservoirs fed by regulated reaches were less attractive to nomadic bald eagles. We suspect that the eagles utilized them primarily as a source of waterfowl in winter (the same may be true for unregulated inflows).

Ecologically, the difference between the reservoir types is probably that the unregulated inflows produce shallow, nutrient-rich bays where waterfowl and fish congregate, and the fish are vulnerable to attack. Regulated inflows contain less nutrients and less silts. However, inflows from both unregulated and regulated reaches are of special importance to bald eagles when dead or moribund fish, drifting in the river current, collect in the inflow areas.

Lakes. The 1987 Fort McDowell juvenile JM03 visited the lakes in the vicinity of Mormon Lake and Tremaine Lake (actually an unregulated reservoir) during October and November 1987. We therefore included this area as a regular part of our airplane surveys but received no signals thereafter.

Terrestrial Habitats. The nomadic eagles frequented areas away from water primarily in February and March, although many of the observations were of soaring birds. We assume that cattle carrion was widely available during this period in connection with the calving season. Cattle carrion not only includes placentas and still-born calves but also cows that die in calving (often 2-year-olds). The pair at the East Verde Territory utilized cattle carrion during 7-24 March 1987 when the river was turbid from snowmelt. Terrestrial habitats may also supply deer carrion, rabbits and other mammals of appropriate size, upland birds, and reptiles (see Platt 1976, Harmata 1984).

A4.3 SUMMARY OF STUDIES OF NONBREEDERS

During 1987-1989, we placed radio transmitters on 15 nestling bald eagles in central Arizona and observed the behavior of some of them from their first flights until departure. During the post-fledging period, which ranged from 18 to 65 days ($X = 44$ days), the juveniles received food almost entirely from their parents (the youngsters occasionally found carrion and one may have taken a live fish) and began soaring a few weeks after fledging. A few birds exhibited false starts, traveling varying distances from their natal territories in what appeared to be migration, only to return to the nesting areas on the same day or the next. We obtained data on 11 juveniles as they actually departed, tracked the migrations of nine across the continent, and followed one briefly as it migrated through northeastern Oregon. All ten migrations were northerly, and the birds traveled from 925 km (Blackfoot Reservoir, Idaho) to 1,955 km (Swan Lake, Manitoba) before stopping for extended periods; several may have traveled further. Habitats varied among stopping places; two birds went to Yellowstone Lake, but one eagle stopped in open ranchland near Dillon, Montana, and another reversed its course upon reaching the coast of northern Oregon and flew southward to the coast of northern California.

We re-detected eight of the radio-tagged juveniles in Arizona in the fall or winter following migration. Two were first detected in late September and may have returned earlier. In fall, winter, and spring, we monitored the movements throughout central Arizona of the returned juveniles, along with five radio-tagged subadults and three near-adults, in roll-call surveys by airplane. We continued to track the relocations of one telemetered juvenile (JZ02) during a second year.

In examining the movements of these nomadic birds, we found them using a variety of habitats. They frequented reservoirs throughout central Arizona (see Figure A4.2-1), particularly the inflow areas, but also zones of open water. These reservoirs provided waterfowl and fish carrion. The nomads were also attracted to certain tributaries, more so than mainstem habitats; specifically, we recorded few visitations on the mainstem Verde River from Horseshoe Reservoir to Cottonwood compared to more numerous occurrences on West Clear Creek and the East Verde River. We recorded no visitations on Cherry Creek, a prominent tributary of the Salt River, but the mouth of Carrizo Creek attracted telemetered eagles, and more were seen there. Fisheries surveys found good populations of resident fishes in the East Verde River (a tributary of the Verde) and Tonto Creek, but other tributaries seemed to hold few resident fish. We surmise that spawning runs of suckers and channel catfish ascend the tributaries in spring, but in the drought years of 1988 and 1989 these runs may have been reduced or nonexistent. We found the greatest eagle use of the East Verde River in 1987 when precipitation was highest during our study.

A5 POPULATION ECOLOGY

Assuming no immigration or emigration, the career of any population can be characterized by a simple equation involving the difference between the birth rate and the death rate. If a population begins to decline, we can be sure that natality has been exceeded by mortality, either because reproduction has decreased, mortality has increased, or both. Because the birth rate of bald eagles, even under the best of conditions, is far less robust than those of most other birds, we must assume that natural survivorship is far higher than that of most other birds. High survivorship in pristine times has left its mark on bald eagles by a long-delayed maturation process in which full adult plumage is not attained until the fifth year (see Section A5.1).

In the second half of this century, society learned an important lesson about species declines. When regional populations of bald eagles, peregrines, ospreys, and brown pelicans mysteriously plummeted in the 1950s and 1960s, conservationists and scientists scrambled to obtain data on the declines, but were too late in identifying the causes to avert the total loss of some populations. Some 400 known pairs of nesting peregrines east of the Mississippi had been extirpated by the time dieldrin and DDT were implicated and banned. These chemicals affected both central elements of demography: dieldrin caused direct mortality (Nisbet 1989), and DDT, through food-chain magnification, compromised the birth rate. If the harmful effects of either chemical had escaped detection, further losses over greater portions of the peregrine's range would have been sustained.

When peregrines began to decline in the east, no one knew which side of the demographic equation was operating, only that large numbers of eyries were vacant. When DDT was identified as the cause of nest failure, it came too late too late to avert the collapse of the population. The role of dieldrin in causing direct mortality could only be inferred in retrospect. These events clearly show that in order to prepare for the eventuality of population decline (a cornerstone of wildlife management), it is essential to understand the life history and ecological factors that influence birth rates and death rates.

In this section, we provide an overview of how bald eagle populations might have been regulated in pristine times. As a way of better understanding the implications of the demographic data presented later, we attempt to explain reproductive rates, delayed maturity, why floating populations of nonbreeding adults exist, and the adaptive trade-offs in the selection of nesting habitat. We then summarize the knowledge now available on each of the known factors affecting reproduction and mortality of Arizona bald eagles, and we consider the available evidence concerning the genetical significance of the Arizona gene pool. Finally, we estimate the status of the population.

A5.1 BACKGROUND ON POPULATION REGULATION IN BALD EAGLES

The evolutionary ecologist, Richard Dawkins (1982), would describe a bald eagle as a "survival machine," designed by natural selection with the sole function of replicating its own genetic "software" and possibly those identical software carried by close relatives. An individual bald eagle is a device programmed to maximize the representation of its genes in the gene pools of succeeding generations, while a population of bald eagles is simply the statistical biological consequence of the activities of individuals (Williams 1966).

If we accept these definitions, we would expect individual bald eagles to reproduce themselves as much as possible over their lifetimes because those that did so in the past are most likely to have imparted the genes for such tendencies to the current population. But at least two facts about the life history of bald eagles appear contrary to this assumption: (1) bald eagles usually lay only two eggs per year, and (2) individuals do not normally attempt to breed until they are at least four or five years old. Why would eagles lay so few eggs and wait so long to breed if a maximization of descendants were the strategy?

The truth, however, is that neither of these facts are contradictions. We mention them only to illustrate the accuracy of the evolutionary definition, and to explore the basis of population structure and regulation.

The issue of "small" clutch size was correctly explained by David Lack (1954), when he discovered that for many species of birds, larger-than-average clutches or broods actually resulted in fewer surviving offspring. He found that optimum clutch size was almost always related to food availability. Individual offspring in larger broods received less food, and survived less often, or failed to enter the breeding population (see also Lack 1966). We may assume (on the basis of countless studies of other organisms) that bald eagles usually lay two eggs because that number tends to produce the greatest number of surviving young (or at least produced the greatest number in pristine times when the genes controlling clutch size evolved). Two-egg clutches are characteristic of raptors having the high expected longevity associated with large body size (Brown and Amadon 1968, Newton 1979).

The second apparent "contradiction," that bald eagles do not normally assume full breeding plumage until age five, is actually a way of increasing lifetime reproductive performance. First, it is risky for a young bald eagle to resemble an adult on the off-chance of breeding at an earlier age. An inexperienced intruder in adult plumage would invoke dangerous aggression from a territory-holding adult, whereas a young-looking bald eagle might be tolerated or even fed. Second, attempts at early breeding, before foraging and defense skills are fully developed, are not only ineffective, but may compromise net lifetime reproductive performance as a result of physiological stress.

Floating Populations

Small clutches and long delays in first-breeding are common in bird species where the number of places to nest is in short supply. Oceanic birds, such as petrels and albatrosses, that nest on pelagic rocks and islands, tend to fill all available space with nests. The result is that many birds that are old enough to breed cannot do so without displacing those with nests. The would-be breeders form a "floating population" that replaces missing members of breeding pairs as they occur. The aggregate of breeders and floaters tends to deplete food supplies around the islands, and the birds are obliged to travel far and wide to forage (Ashmole 1963).

From this it is easy to see why a bird such as the short-tailed shearwater does not normally return to the breeding colony until three or four years of age, and does not breed before the age of five to eight years (Lack 1966, p. 261). The problem is partly one of amassing sufficient bodily resources for egg production and incubation, and partly one of raising young. The latter is especially difficult and costly in the face of sparse local food resources and strong competition for nesting space. Age and experience are the requirements of success.

Curiously, floating adult populations of nonbreeders have also been discovered in non-colonial birds (those whose nests are more scattered in the landscape). The existence of floaters is verified when lost mates are quickly replaced. In healthy populations, there is very rapid replacement (often within hours) following the experimental removal of members of mated pairs, as if the extra adults were "waiting in the wings" for a vacancy. If individuals are "trying," from an evolutionary standpoint, to maximize their lifetime rates of reproduction, then why would one choose to be a floater when suitable unoccupied nesting habitat is available? The answer, of course, is that suitable habitat is probably not available.

Territoriality

Many species of birds vigorously defend not only their nests, but a considerable area around their nests containing their food supply. Pairs are least tolerant of one another when food is scarce; when food is abundant, pairs occur in higher density and show less territorial strife. If habitat is homogeneous, territories border upon one another and form a mosaic in the landscape. The size of territories, and thus the densities of pairs, are a function of the degree of territorial aggression which is inversely related to the richness of the food supply (Nelson and Meyers 1976). Territorial behavior, then, is a medium by which breeding density is adjusted to food supply (Ratcliffe 1963).

Territoriality has evolved in response to what Lack (1954) termed "density-dependent factors," the influences on populations that wax and wane as functions of population density. For example, when unoccupied habitat, rich in food, becomes populated by breeding pairs, they first experience a high rate of nesting success. As they increase in number, however, the population begins to impact the food supply; not only is the resource stretched thin, but its capacity for regeneration may also be reduced as the number of consumers increases. As these changes occur, the survival rate of offspring decreases, and there may be more predation or disease, yet the population density can remain high, and competition for territories intense. Only by successfully excluding competitors, and thereby buffering the loss of food resources, can individuals succeed in reproducing.

The adaptation of territoriality, encouraged by this process of negative feedback, has the effect of dampening the numerical fluctuations of populations interacting with food supplies (populations that would otherwise periodically crash). The result is long-term stability in breeding density. Exceptions to this occur in regions where food density varies widely from year-to-year as a result of environmental homogeneity or large variation in climatic events. For example, in the arctic tundra, the densities of breeding rough-legged hawks and snowy owls may vary widely in response to lemming densities (Hagen 1969).

Bald Eagle Population Regulation in Arizona

Up to now, we have been talking about a mosaic of territories that expand and contract mainly as a function of food density in two-dimensional (length x width), homogeneous habitat. Does population regulation of bald eagles in Arizona fit this generic model? There are a number of reasons why it does not.

First, riverine bald eagle habitat in Arizona can be regarded as one-dimensional; rivers are curvy lines, so territories tend to impinge upon one another "end-to-end," but not from all sides. This should make them easier to defend, since there are, at most, only two adjacent pairs. Second, food may not be the only resource worth defending. Arizona bald eagles nest mainly on cliffs or in large riparian trees,

neither of which are continuously distributed. Therefore, territories may be separated by unsuitable habitat. Even if cliffs or trees were in abundance everywhere, a discontinuity of territories might be typical because factors affecting the occurrence and vulnerability of prey may not be equally distributed along the rivers (see Sections A3.3 and A3.4).

Another departure from the "generic" population model is that bald eagles are armed, as is typical of raptors, and are more capable than most birds at excluding other pairs. In Arizona, pairs rarely nest close together (exception: Alamo/Ives Wash), although they sometimes share reservoirs as foraging areas. Therefore, it appears highly unlikely that densities of breeding pairs of bald eagles in Arizona would increase to a point of causing density-dependent reductions in prey. On the basis of our research, we doubt that prey populations in Arizona are ever impacted by foraging bald eagles even locally.

There presumably comes a time in the life of every floater when attempting to displace a territory holder is a better strategy than waiting for a vacancy. Evolutionary theory predicts that the intensity of reproductive effort should increase with age. The reason has to do with the concept of "reproductive value," which refers, in this case, to the increasing, then declining expectation of future fecundity. When an individual reaches a certain age, the risk of a damaging or fatal encounter with another adult in a territorial dispute carries less of an adaptive consequence than at earlier times in the life cycle. Winning the nest site carries the possibility of reproducing, while being killed or injured does not differ greatly, in terms of future reproduction, from avoiding the confrontation.

It is unknown to what extent bald eagles fight over territories in Arizona or elsewhere, although there have been direct observations and inferences of mate displacement (see Section C3.7). Presumably, the higher the survivorship of each yearly age class and the higher the overall numbers of floaters, the greater is the expected frequency of territorial fighting. Haller (1982) described just such a pattern in his studies of nesting golden eagles in Switzerland following their legal protection. As the overall numbers of nonbreeding eagles increased, a greater frequency of intruding birds at nests substantially impacted the eagles' nesting success - a stunning example of a density-dependent feedback mechanism regulating natality. He mentioned that, "...pairs frequently confronted with single eagles in spring have no breeding success for years due to their increased territorial activity." Haller saw eagles kill or seriously wound one another in territorial fighting. Hansen (1987) believes that nesting interference by floaters is an important element in the regulation of total population size among bald eagles in southeast Alaska.

The unknown factor in this discussion is whether habitat is saturated in Arizona, i.e., whether all serviceable breeding locations are filled within the range of dispersal. If serviceable, unoccupied habitat exists within the southwestern United States and Mexico, wouldn't we expect floaters to found new territories rather than wait for vacancies to occur at occupied sites? The answer to this question first requires knowledge of how new nesting areas come to be occupied by bald eagles.

When a particular river section contains exceptional food resources, but lacks a tree or cliff, will eagles nest on the ground? The answer is significant because it clearly explains the phenomenon of floating populations. Because eagles hardly ever nest on the ground (but see Sherrod *et al.* 1976), we would guess that those that did so in the past left relatively few descendants compared to those who accepted only trees or cliffs. The likely reason why eagles do not nest on the ground is that it is dangerous to do so (Lack's "proximate" reason; Lack 1954), and genes encouraging eagles to do so would leave fewer replicates (Lack's "ultimate" reason). If eagles were short-lived, that is, if they had relatively low reproductive value at any age (see above), those that nested on the ground might leave more progeny than those that did not.



Plate A14. Blue Point eaglets (6 weeks old) in nest 6, with Four Peaks Mountain in the background, April 1992 (photo by D. Driscoll).

The selection of breeding habitat by an eagle is therefore a compromise between the expectation of reproductive success and the degree of risk (and other costly physiological investments). The habitat elements being selected include the nest site itself and a foraging area, and each of these contains a subset of variables (e.g., fish abundance and vulnerability, isolation from disturbance, defensibility) that add or subtract to the quality of the breeding area. From the standpoint of the eagle's life history strategy, habitat is optimal when its components allow for a maximum number of surviving young and a minimum reduction in parental survivorship and future fecundity (see Hunt 1988).

Hypothetically, if productivity, survivorship, and food supplies maintain themselves, virtually all serviceable breeding locations (SBLs) throughout the landscape will sooner or later come to be defended by pairs of eagles against a floating population of adults and near-adults. Yearly crops of young eagles will augment the floating population until the number of mortalities equal the yearly cohort of young, at which time the population stabilizes. The interesting point about this scenario is that, even if all individuals survive to old age, the population will still reach equilibrium. For example, if all individuals of a cohort live 20 years, then die, the number of mortalities in that year matches the yearly number of fledglings (if the number of nesting pairs remains the same). The absolute size of this population will be 20 times the average number of young fledging each year.

With that many bald eagles competing for food and nesting territories, there is a strong possibility that density-dependent feedback on survival and nesting success would reduce the population. However, the

hypothetical example in the previous paragraph shows that such density-dependant checks on population growth are not essential for an equilibrium to be achieved. Lack (1966, pages 292-293) incorrectly doubted this fact in maintaining that without density-dependent feedback, a population would continue to increase indefinitely.

Returning to the question of how eagles might be disposed toward occupying new nesting habitat, if fish populations and foraging opportunities in pristine periods were somewhat stable over the years, then it is likely that all SBLs would be occupied by pairs of eagles. In such circumstances, a floater's only option would be to fill a vacancy at a tenured site. The best strategy for this might be to continuously search an area with a high density of occupied sites for an opportunity of displacing a tenured adult or replacing a missing one. Wandering about the landscape in search of unoccupied breeding habitat would have been less adaptive.

On the other hand, it is unknown whether food supplies were stable in ancient times. In the arid southwest, temperature and drought cycles may have periodically rendered habitats inhospitable, that is, tipped them toward the risk of investment and away from success (see above), so that numbers of occupied territories may have varied over the centuries. In such a case, there would have been more of an adaptive premium on the *ad hoc* evaluation of habitat quality than in areas with more stable environments. (Exploiting a vacancy at an occupied site does not require such an evaluation since the occurrence of fledged young a year or so previously would more or less demonstrate the acceptability of a territory.) A wholesale occurrence of vacant habitat would probably depend mainly on how rapidly the environmental cycles increased the number of SBLs.

In any case, it may not be within the genetically encoded adaptive strategy of a bald eagle to readily settle in unoccupied breeding habitat. Vacant sites in pristine times may have been quite rare, owing to the pressure of floating populations to quickly replace missing mates. In the past, the discovery of vacant habitat might even have been suggestive to an eagle of unseen, adverse agents that had discouraged or eliminated previous tenants. It is therefore plausible that many floaters may continue to compete vigorously for tenured sites, even when suitable habitat remains unoccupied.

We describe in Sections A5.2 and C3 the known mortality factors affecting Arizona bald eagles. However, because obtaining mortality data is largely circumstantial rather than systematic, we have no current opportunity of estimating either a life table or overall population size. We can say, though, that there is no evidence (or logical expectation) whatsoever to suggest that density-dependent checks are currently operating to regulate any of the three segments of the population (breeding pairs, subadults, or floaters). The distribution of breeders is clearly a matter of physiographic and biotic events that bear no relationship to population density as an influence. It seems (to us) very unlikely that competition for food among mobile subadults and floaters is sufficient to influence survivorship. We say this because breeding habitat is relatively rare in the landscape, while survival habitat is far more abundant, given the wide food niche of the species.

The occurrence of a robust floating population is highly desirable from a management standpoint because floaters quickly replace the losses of breeding adults, and because floaters create a pressure toward occupying new habitat. We therefore regard management efforts aimed at maintaining survivorship of all age classes to be of clear benefit to the welfare of the overall population. Naturally, the survival of an adult is far more significant than that of a younger eagle because of the attrition of each cohort during

its lengthy advance to adulthood. But given the small size of the Arizona population, a basis of its stability is survivorship from egg to adult.

A5.2 DEMOGRAPHY

We do not have any direct information as to whether the bald eagle population of Arizona is augmented by the immigration of individuals from outside its borders, although it is likely that the few known outlying pairs in adjacent areas of the xeric southwest are integral. In Section A5.4 we discuss evidence for and against the idea that the Arizona population was recently founded by immigrants, and that genes currently flow into the population from sources far removed. If true, managers might be inclined to embrace a more casual approach to preserving the lives of Arizona bald eagles, since local declines might be buffered by eagles immigrating from far away. But until this idea can be verified, it is more prudent to assume that the Arizona population is indeed isolated and may contain genes and coadapted gene combinations appropriate to local conditions. To assume otherwise, in the absence of proof, is to put the population at risk.



Plate A15. Two eaglets (7 weeks old) at the Ive's Wash breeding area, March 1992 (photo by D. Driscoll).

In this section we begin with a baseline of Arizona's production of young, and then discuss the general mortality factors which operate to reduce the yearly cohorts over the various stages of the life cycle. Of particular interest in the current section is a discussion of recruitment and the apparent age structure of

the nonbreeding population as evidenced by the age of recruits. Because much of the information on mortality is circumstantial and descriptive, our overview will be brief. We urge the interested reader to consider the specific details on natality and mortality in Part C of this report.

A5.2.1 Natality

In Section A2 we showed that productivity, nest success, and mean brood size in Arizona did not vary significantly from that of other bald eagle populations. Similarly, nestling survival rates do not differ significantly (by Chi-Square) between Arizona bald eagles and other populations throughout North America. Stalmaster (1987) presented data on 433 young, of which 85 percent fledged and 15 percent died. The Arizona bald eagle data show that of 276 eaglets that hatched, 84 percent fledged and 16 percent died, a ratio very close to that of the other populations. In aggregate, the known Arizona population has produced a yearly average of 19.2 fledged young (range = 13-24) during the past five years (1986-1990).

A5.2.2 Mortality

No matter how well the aggregate of nesting pairs is reproducing, the overall mortality rate must be low enough to provide for sufficient recruitment to the breeding population. As we have explained, a healthy ratio of births and deaths results in the accrual of a floating population of nonbreeding adults from which vacancies occurring at nests are quickly filled (Hunt 1988). The existence of this largely unseen floating population is the consequence of saturation of all serviceable breeding locations by pairs (see Section A5.1). If members of pairs disappear and are not quickly replaced by floaters, then an exorbitant death rate may be implied. The excessive mortality may be occurring at any stage of the life cycle or in a combination of stages, from egg to territory-holding adult. Once the supply of floaters is exhausted, a population decline to extinction can occur rapidly and without warning, since there is little way to have detected the decline in floater numbers. For nesting bald eagles in Arizona, these matters are particularly significant because the population is small (see Section A5.4.2 for discussion of small populations).

Determining mortality in a species as wide-ranging as the bald eagle is a difficult task. If nests are monitored annually, recording nestling deaths is relatively simple, but once an eaglet leaves the nest, the chances of obtaining data on its whereabouts are minimal. Similarly, the vagrant nature of subadults and near-adults limits knowledge of mortality factors affecting these age-categories. Finally, the desert climate promotes rapid decomposition of tissues, which minimizes the chance of successfully determining the cause of death during necropsies.

Table A5.2-1 lists some of the factors that can cause or contribute to the mortality of a bald eagle from the egg stage to breeding adult; each factor is discussed in detail in Part C3. Not included are influences, such as disturbance, that can affect the adults' ability to produce eggs. As shown in the table, the most vulnerable period in the life-cycle is that from egg laying to fledging. Once the young have left the nest, the number of known agents of mortality decreases, but the net effect on the population of deaths among older eagles may be more costly, owing to differences in reproductive value (see Section A5.1).

Egg Mortality. The causes of egg mortality are rarely analyzed due to the difficulty in recovering whole eggs before scavengers enter the nest. Of the 105 eggs in the Arizona sample that did not hatch, the apparent reason could only be deduced in 17 cases (16%) (Figure A5.2-1), mostly as determined during our study (13 cases). Disturbance near the nest appeared to be responsible for the most known egg mortalities, followed by nest inundation (by a rising reservoir). Human-induced mortality results from the fact that most nests are located on rivers and reservoirs that serve recreational needs of the Phoenix metropolitan area.



Plate A16. Nestling bald eagle (7.5 weeks old) in Arizona, April 1991 (photo by D. Driscoll).

Nestling and Juvenile Mortality. Of the 276 known young hatched in Arizona, 232 (84.1%) survived to fledge and 44 died: a 15.9 percent nestling mortality rate. This figure is comparable with the 15 percent reported by Stalmaster (1987) for other bald eagle populations (Figure A5.2-2).

We know of 13 additional post-fledging eagles that died prior to departing on migration, for a total of 57 known juvenile mortalities, a 20.7 percent juvenile mortality rate from hatching to departure. It is important to note that this number represents a minimum mortality figure, particularly in respect to post-fledging juveniles because they are more difficult to monitor. Most data collection in the past (by the ABENWP) tended to cease once the eaglets left the nest. Actually witnessing the mortality of a fledged juvenile or finding its carcass is an unlikely event, unless the eagle was radio-tagged.

Table A5.2-1. Mortality factors impacting Arizona bald eagles at various stages of the life-cycle (● = Possible factor, * = Known Arizona deaths).

| Mortality Factors | | Egg Laying | Eggs | Pre-thermo- regulatory Nestlings (0-3 weeks) | Thermo- regulating Nestlings (>3 weeks) | Post- fledgling Juveniles | Itinerant Eagles (0-4 years) | Floating Eagles (4+ years) | Breeding Adults (4+ years) |
|-------------------|----------------------------|------------|------|---|--|---------------------------------|------------------------------------|----------------------------------|----------------------------------|
| Infertility | Nest Abandonment | ● | ● | — | — | — | — | — | — |
| | Nest Collapse | ● | ● | ● | ● | — | — | — | — |
| | Nest Inundation | * | * | ● | ● | — | — | — | — |
| | Human Disturbance at Nest | * | * | * | * | — | — | — | — |
| Pesticides | Egg Breakage | ● | ● | — | — | — | — | — | — |
| | Polygynous Relationship | — | * | — | — | — | — | — | — |
| | Mate Loss | ● | ● | ● | ● | — | — | — | — |
| | Freezing | ● | * | * | ● | — | — | — | — |
| Heat-Stress | Heat-Stress | — | ● | * | * | * | — | — | — |
| | Sibling Aggression | — | — | * | * | * | — | — | — |
| | Falling From Nest | — | — | ● | * | — | — | — | — |
| | Monofilament, Fish Hooks | — | — | * | * | ● | ● | ● | ● |
| Emaciation | Emaciation | ● | — | ● | ● | ● | — | — | — |
| | Nest Parasites | ● | — | * | * | — | — | — | — |
| | Disease or Infection | ● | ● | ● | ● | ● | ● | ● | ● |
| | Predation | ● | * | * | * | * | * | * | * |
| Drowning | Drowning | — | — | — | ● | ● | * | * | * |
| | Shooting | ● | ● | ● | ● | ● | * | * | * |
| Poisoning | Poisoning | ● | ● | ● | ● | ● | * | ● | ● |
| | Impact Injury | — | — | — | — | * | ● | ● | * |
| | Electrocution | — | — | — | — | ● | ● | ● | ● |
| | Intraspecific Altercations | ● | ● | ● | ● | * | ● | * | * |
| | Interspecific Altercations | ● | ● | ● | ● | * | ● | ● | * |

Heat stress was apparently responsible for most known juvenile mortalities, followed by unknown factors, falling or disappearing from the nest, human disturbance near the nest, and nest parasites. In interpreting Figure A5.2-2, the reader should be aware that the relative values in the mortality categories represent only our deductions concerning the principal cause in each case. Some or many of these deaths likely resulted from combinations of factors.

Nest parasites, specifically the Mexican chicken bug, were probably the primary agents in the deaths of five nestlings, and a contributing factor in four additional cases. This ectoparasite is a blood sucking insect of the Cimicidae family, which lives in or near the nest and feeds on the eaglets (see Section C3.4 for more information). In some cases, chicken bugs probably weaken eagle nestlings to a point where they succumb to other factors. The loss of fluids to chicken bugs may compound the dehydration problems associated with heat-stress; it may be that premature flights are efforts to reach water. Nestlings have been observed falling from nest cliffs and pinnacles while seeking shade, both in this and past studies (see Section C3.5). Adult eagles in Arizona frequently drink from streams, especially after incubating or shading young at exposed nest sites. We observed eaglets, on first flights, fly directly to shorelines and drink water; before this, the only water they received was in and on prey delivered by the adults. We found nest parasites in 39 percent of Arizona cliff nests (containing broods) we examined during 1987-1989; however, we found none in tree nests (see Section C3.4).

We have obtained evidence implicating monofilament, fish hooks, and lures as mortality factors affecting bald eagles of all ages. Although only one eaglet died from being entangled in monofilament during our study, we saved three others by removing fishing line, hooks, and lures from their legs, toes, tongues,

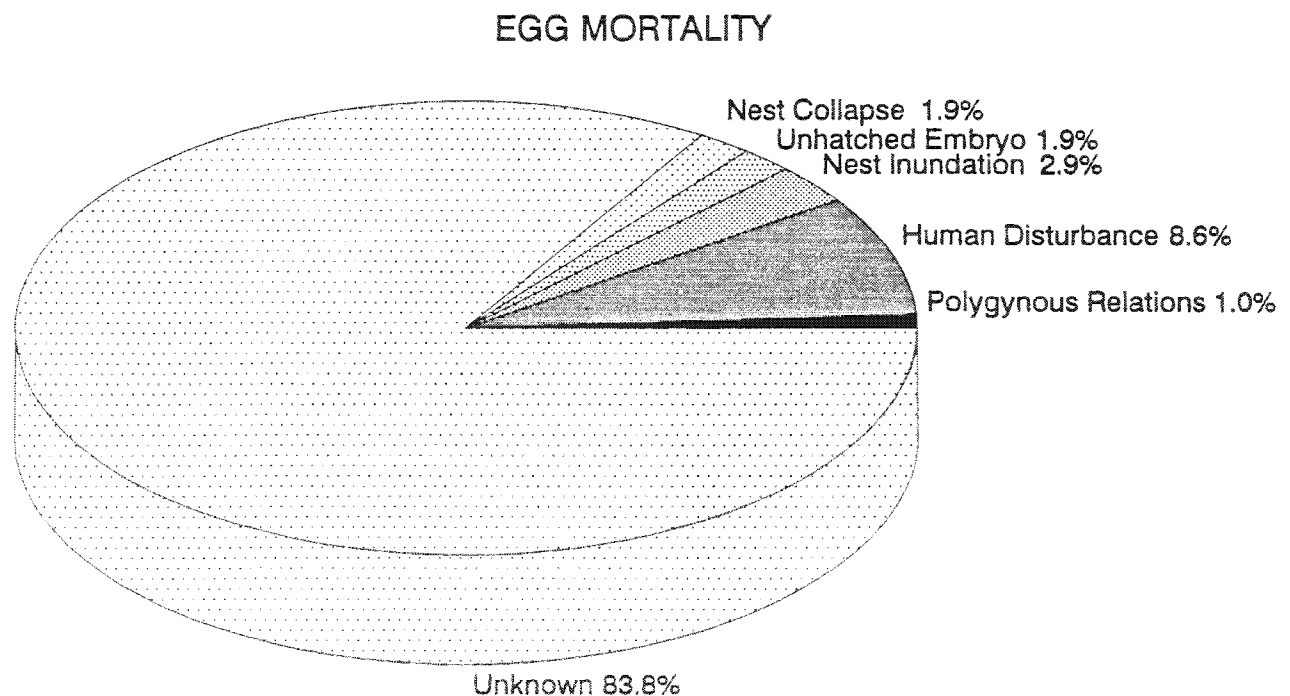


Figure A5.2-1. Causes of egg and embryo mortality in Arizona bald eagles, 1932-1990 ($n = 105$).

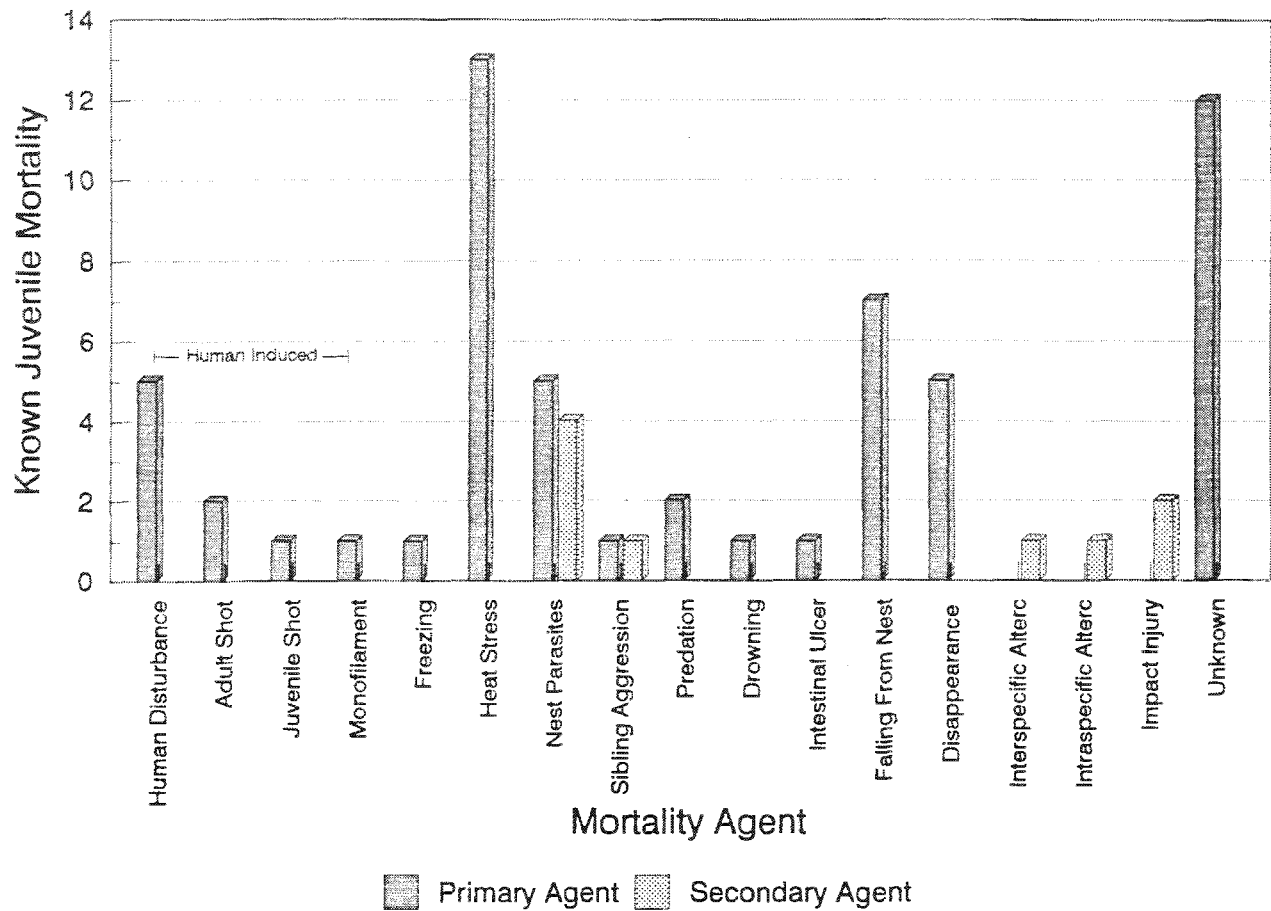


Figure A5.2-2. Causes of juvenile bald eagle mortality in Arizona, 1964–1990 ($n = 57$).

and bodies. Fishing paraphernalia is apparently brought to the nest attached to fish which have escaped from anglers. We found fishing paraphernalia in 40 percent (22 of 55) of Arizona nests (containing broods) we examined (see Section C3.3).

Falling or disappearance from the nest accounted for a large number of known juvenile mortalities ($n=12$). Although young have been blown out of the nest while exercising their wings in heavy winds, some of these young may have also been responding to heat-stress. The normal fledging age of juvenile bald eagles in Arizona and elsewhere in North America (see Section C2.1) is about 12 weeks, yet we show in Section C3.5 that in 1988 and 1989, 10 Arizona nestlings fledged prematurely (9–11 weeks of age), and an additional 10 died during periods of high temperatures (which surpassed any reported during 1985–1989).

All ten mortalities, and nine of the premature flights, were from cliff or pinnacle nests; the remaining eaglet fledging early was from a snag nest. This pattern makes sense from the standpoint of expected temperature differences at cliff versus tree nests. Nestling bald eagles on cliffs are exposed to a greater amount of heat than those in snags or live trees (Figure A5.2-3). In cliff nests, young are subject to direct heat from the sun, reflected heat off cliff or canyon walls, radiated and conducted heat from the

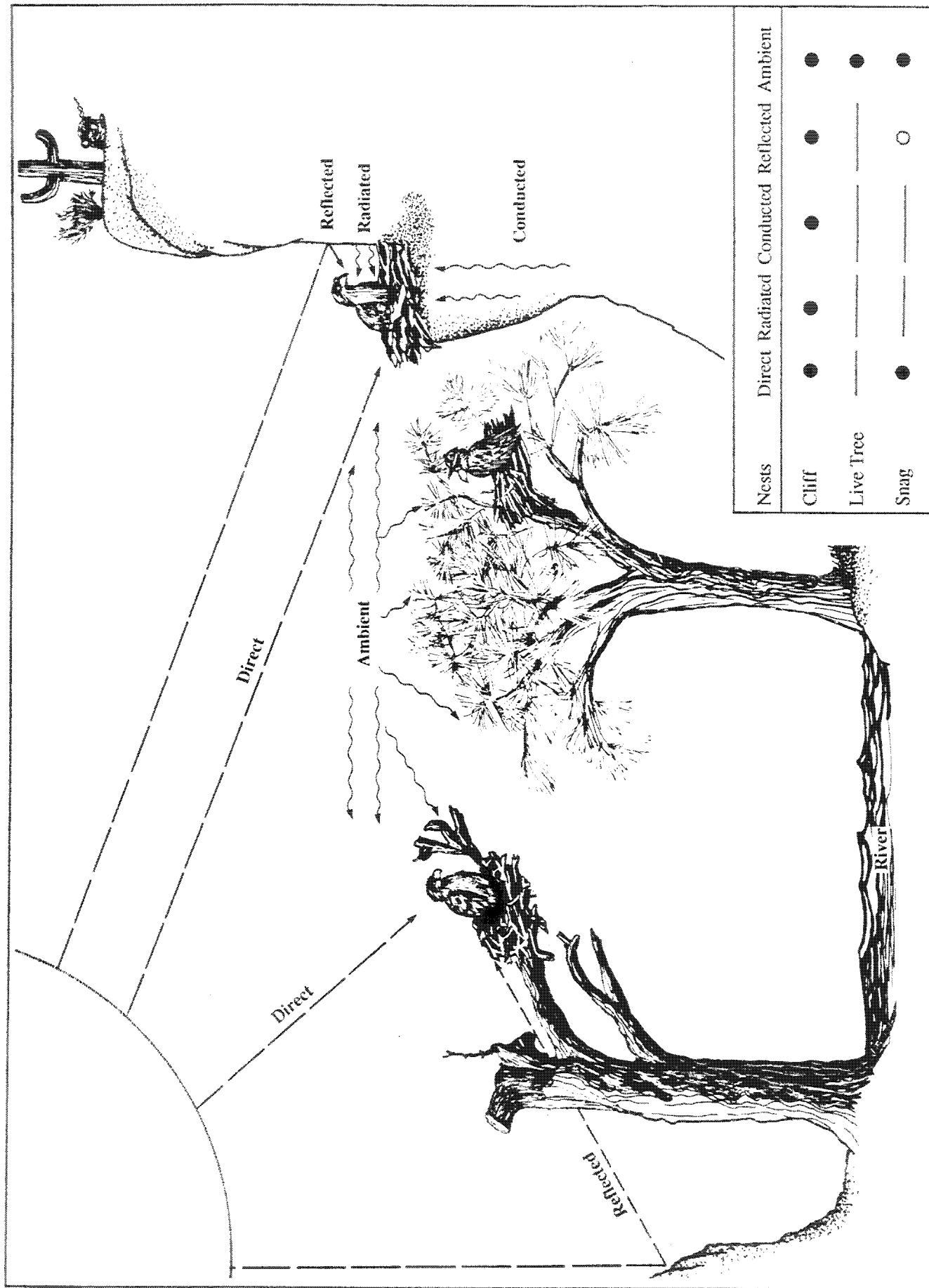


Figure A5.2-3. Various ways in which eagles in cliff, snag, and live tree nests are impacted by sun and heat.

cliff substrate, and ambient heat. In contrast, eaglets in snag nests are exposed to direct, ambient, and reflected heat from the desert floor, while young in live trees may be shaded and only exposed to ambient heat.

Mortality of Nonbreeders. There is very little information available on deaths among nonbreeding bald eagles. Only five subadult and near-adult mortalities have been recorded for Arizona bald eagles; four of these were known only because the eagles were telemetered or banded. As shown in Figure A5.2-4, all known deaths in this age class were human-induced; the one drowning occurred in a stock tank with a wire grid on top (see Section C3.6).

Adult Mortality. When nonbreeding eagles acquire a territory and enter the breeding population, it becomes easier to track their survivorship. A principal way of doing so is to record the replacement of one breeder by another and to infer from this that a mortality has occurred. However, replacement within a breeding pair may occur unnoticed, even in a monitored population, unless the new adult is banded or has plumage characteristics significantly different from its predecessor.

There have been 39 known adult bald eagle mortalities in Arizona, based on knowledge obtained both directly (from known deaths; $n=11$) and indirectly (from evidence of replacement or disappearance; $n=28$) (Figure A5.2-5). Replacements were determined by the presence of a near-adult in a breeding pair, or the presence or absence of a banded individual within the pair. Of the 39 known mortalities, 21 (54%) were recorded during our study (1987-1990) (see Section C3.7). The preponderance of recorded mortalities during these four years may have resulted from greater scrutiny of paired individuals over a larger number of sites. The breeding areas we know most about are those located close to Phoenix; the more remote sites are not regularly monitored, and, not surprisingly, we have no mortality information for them. These 21 mortalities over the four-year duration average 5.25 known adult mortalities each year, and represent 16 percent of the adult-years at monitored breeding areas. There is little doubt that more mortality has occurred than we have documented, so the data represent minimum mortality and recruitment rates for adult bald eagles in Arizona. At the four breeding areas closest to the Phoenix Metropolitan Area, there was a 22 percent ($n=7$) minimum adult mortality rate from 1987-1990.

If there was no recruitment, the 16-22 percent annual loss of adults would eliminate the breeding population entirely in about 10 years. If mortalities were evenly distributed, most sites would be barren (for lack of mates) in a much shorter period. What if, in reality, we are only aware of, say, one-half the actual adult mortalities? Apparent here is the importance of a healthy floating population of nonbreeding adults serving as a pool of mate replacements.

Summary of Causes. In assessing the agents of mortality at various stages in the life-cycle of Arizona bald eagles, it is appropriate to ask what proportion is human-related. By combining the agents into three categories (apparently natural, human-induced, and unknown), we can address the impact humans have had on mortality (Figure A5.2-6). While the cause of egg mortality is largely unknown, during our study (1987-1990) humans were judged to be directly or indirectly responsible for at least 26 percent of cases where eggs which did not hatch ($n=38$). However, in the life stages following hatching, human-induced mortality accounted for only 17 percent of all deaths, 41 percent being apparently natural. Comparing the three age classes, natural agents caused 65 percent of known mortality in juveniles, but decreased proportionally with nonbreeders and adults, as human-induced agents increased. In our opinion, a reason for the low human-induced mortality of nestlings is the protection offered by the Arizona Bald Eagle Nestwatch Program, active since 1978.

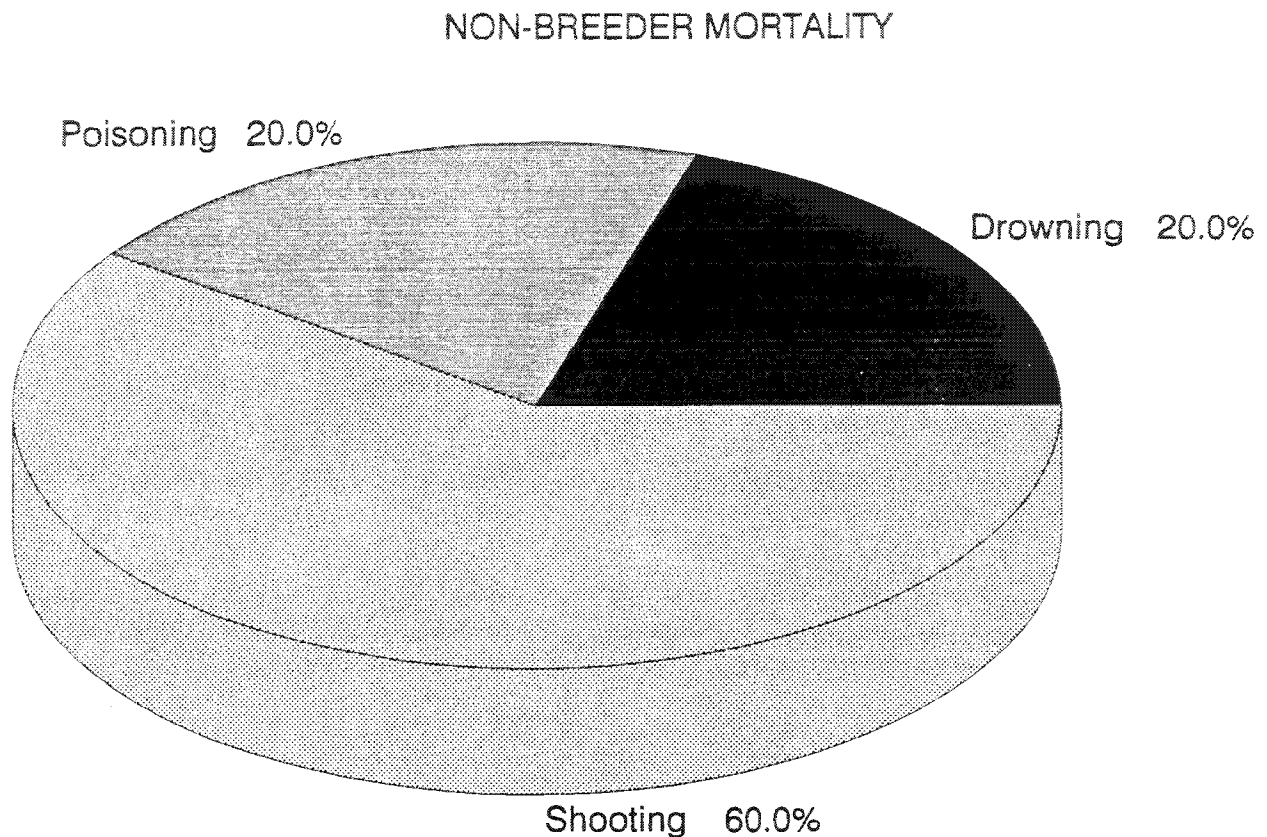


Figure A5.2-4. Known causes of subadult (ca. 1-3 years old) and near-adult (ca. 4 years old) bald eagle mortality in Arizona, 1980-1990 ($n = 5$).

Data on the mortality of breeding adults will be greatly enhanced by the Visual Identification (VID) banding of Arizona nestlings that BioSystems set in motion in 1987 (see Section C6). When these banded birds reach breeding age and acquire territories, the adults can be checked annually for the presence or absence of bands. Quantitative knowledge of breeding adult mortality, as well as insight into the mortality of nonbreeders, will increase dramatically if breeders are annually identified.

A5.2.3 Recruitment

As explained in Section A5.1, the appearance of eagles lacking full-adult plumage as members of pairs suggests an insufficiency of adults in the floating segment. The insufficiency may indicate an expanding population in which adults that would otherwise be floaters are founding new territories. Also possible is that excessive adult mortality drains the floating population and maintains the observed preponderance of young eagles. Figure A5.2-7 depicts these and other causes of small floating segments characteristic of unstable populations as compared to a stable population with a reserve of floating adults.

In reporting a near-adult male paired with an adult female, Hildebrandt and Ohmart (1978) commented:

The Arizona pair consisting of an adult and an immature suggests that the central Arizona population does not contain available nonbreeding adults.... The small size of this

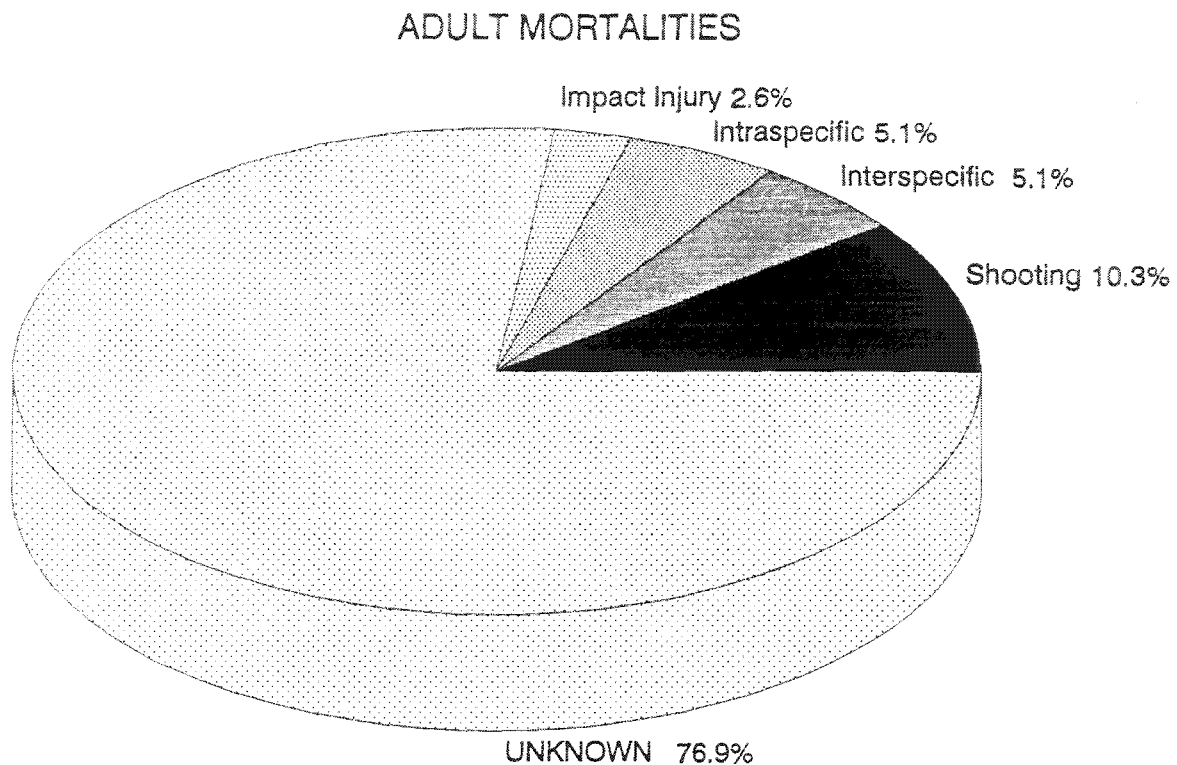


Figure A5.2-5. Causes of adult bald eagle mortality in Arizona, 1951–1990 ($n = 39$).

population may be self-limiting in that reproduction is not adequate to supply surplus breeders ... Existing evidence indicates that there is a lack of recruitable mature adults and further suggests that survival from fledging to maturity is very low or that if they are surviving they are not returning to Arizona to breed.

Hildebrandt (1981) also noted an apparent lack of floating adults: "Recruitment of at least one immature eagle into the breeding population was observed; however, the population appears to lack the postulated surplus of recruitable nonbreeding adults." In addition, Haywood and Ohmart (1980) noted that, "Our observations indicate that if one or both of the breeding pair is still in immature plumage, the pair will probably not breed until following seasons."

Grubb *et al.* (1983) observed a near-adult male (carrying a USFWS band) enter a breeding area the day after the adult male disappeared in 1983. However, their interpretation differed from that of Hildebrandt. Grubb *et al.* wrote that, "The quick replacement is indicative of a healthy population with a pool of nonbreeding adults, but unfortunately it could also be the result of coincidental circumstance." The new male was a near-adult (not an adult), with plumage typical of a four-year-old eagle (brown eye-stripes). We confirmed this point by capturing this eagle in 1987 and learning that it had been banded as a nestling in 1979 by Robert Ohmart (ASU)(see Section D4.4).

Although vacancies in Arizona's bald eagle pairs are filled rapidly, sometimes within one day, most known replacements have been young (near-adult or subadult) eagles. Of 39 known vacancies at breeding

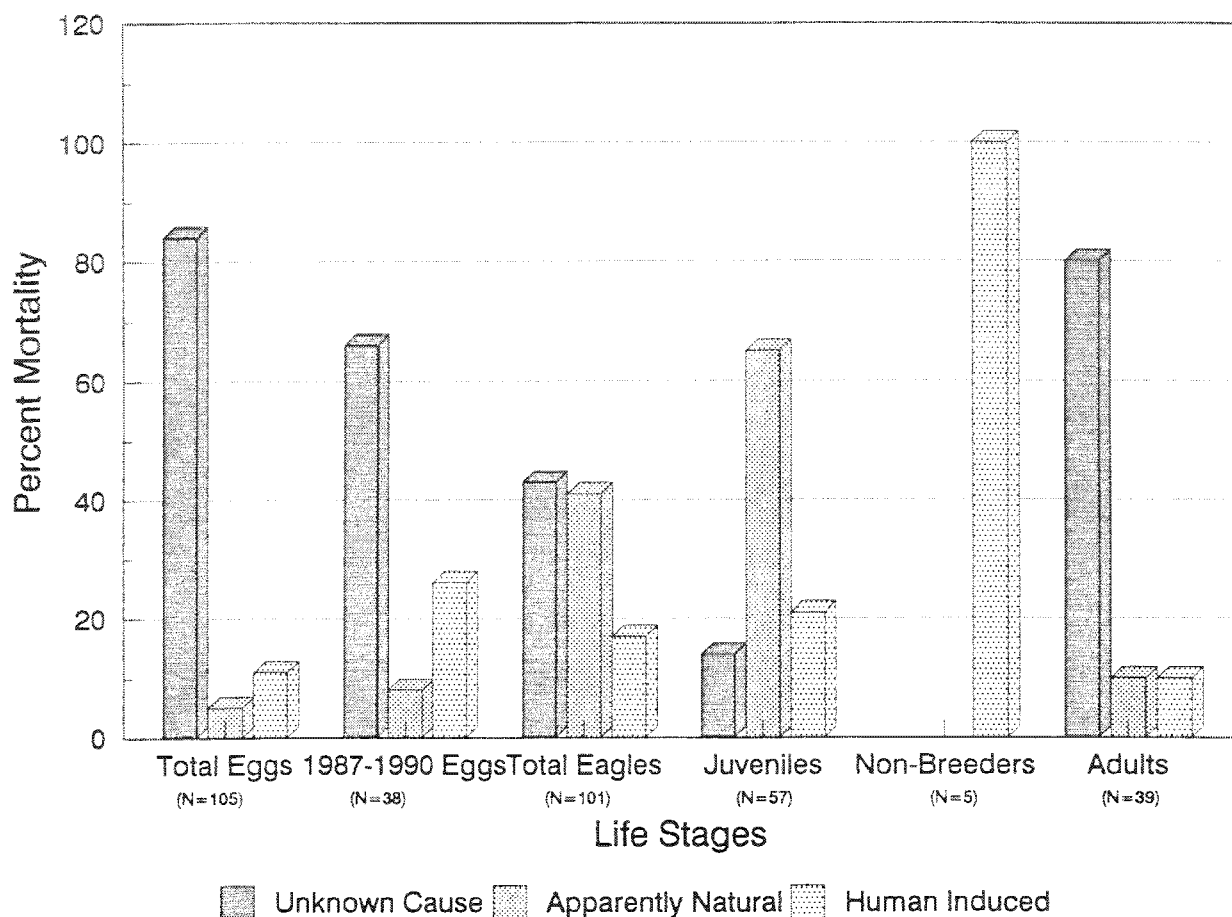


Figure A5.2-6. Causes of bald eagle mortality in Arizona.

areas, 15 (38.5%) were filled by adults, and 24 (61.5%) by near-adult or subadult eagles (Table A5.2-2). However, this data is biased because an adult replaced by a full-adult may go unnoticed unless the new adult is banded or marked, or the previous adult was banded or known to have died. Of the 15 full-adult replacements, 8 followed the known death of a previous adult, 5 were determined because the new adult was banded, and the remaining 2 were recorded because the previous adult was banded. Irrespective of this bias, however, the proportion of young eagles as members of pairs in Arizona is substantially higher than reported for any other bald eagle population (Bent 1937, Gerrard *et al.* 1978, Newton 1979, Stalmaster 1987, Swenson *et al.* 1986).

To obtain further information on the occurrence of near-adult eagles in breeding pairs, we sent questionnaires to researchers studying 14 bald eagle populations. Of the nine survey forms returned, only 14-19 near-adults outside Arizona were reported as members of breeding pairs among thousands of breeding areas in over one-hundred thousand nest-years of information (Table A5.2-3). Expressed as a percentage, the known incidence of near-adults as members of breeding pairs outside Arizona is approximately 0.02 percent.

Bent (1937) wrote that the occurrence of an eagle in a breeding pair lacking full-adult plumage was rare. In Saskatchewan, Gerrard *et al.* (1978) stated that, "In our personal observations of between 500 and

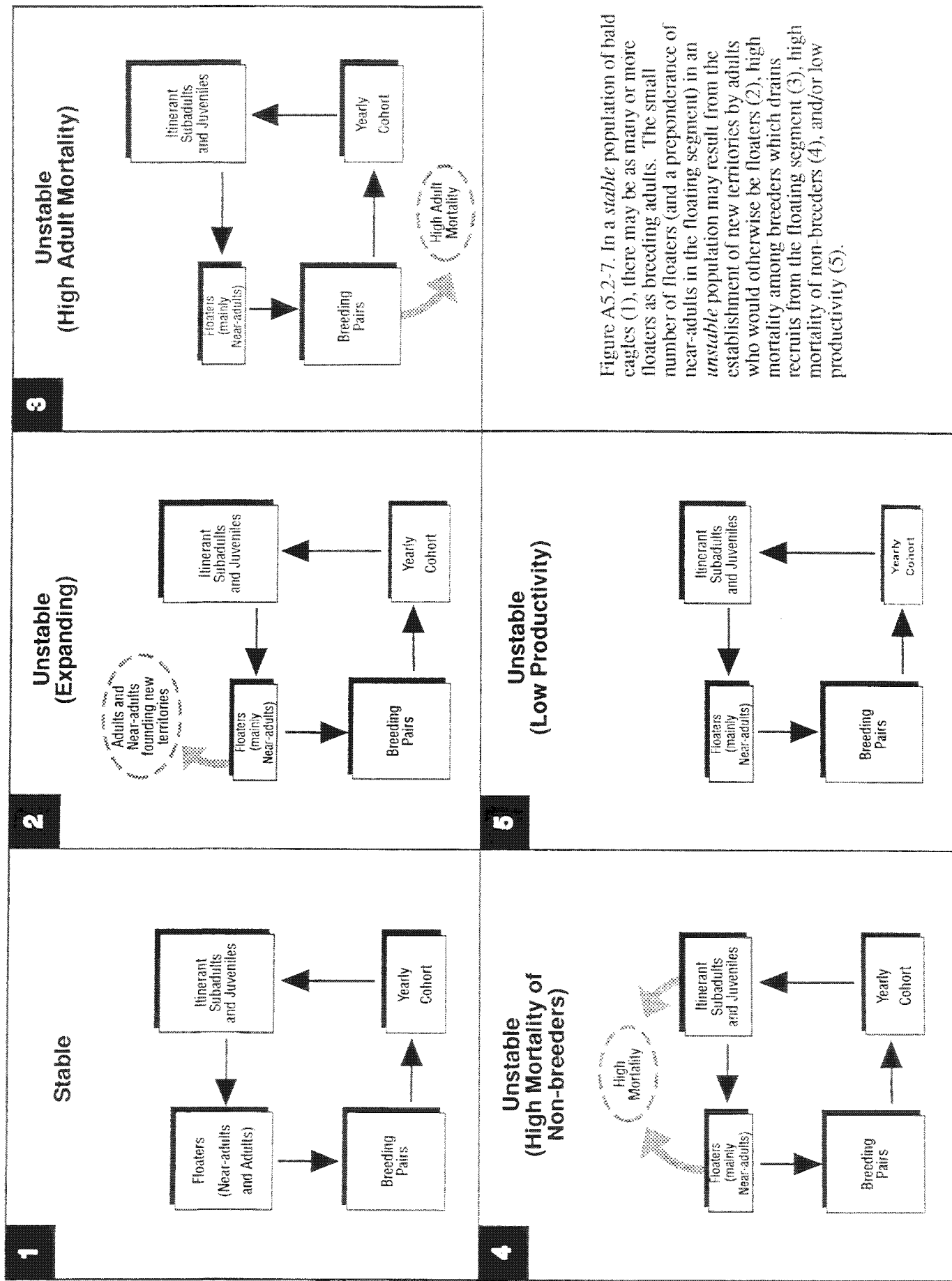


Figure A5.2-7. In a *stable* population of bald eagles (1), there may be as many or more floaters as breeding adults. The small number of floaters (and a preponderance of near-adults in the floating segment) in an *unstable* population may result from the establishment of new territories by adults who would otherwise be floaters (2), high mortality among breeders which drains recruits from the floating segment (3), high mortality of non-breeders (4), and/or low productivity (5).

Table A5.2-2. Known recruitment into nesting pairs at Arizona bald eagle breeding areas.

| Year | Breeding Area | Sex | Age* | Status of Breeding Area |
|------|--------------------------|------------|-----------|--|
| 1954 | Rock Creek | M & F | Adult | Replaced adults shot in '51-52. Occupied—unknown if eggs laid. |
| 1966 | Bartlett | ? | Adult | Replaced adult shot in 1964. Successful—fledged 1 young. |
| 1972 | Blue Point | M & F | 4, 4 | Replaced prior to 13 Nov. '71. Failed—2 young and 1 adult died. |
| 1977 | Fort McDowell Redmond | M M & F | 4 3, 4 | Successful—fledged 2 young. Occupied—no known eggs laid. |
| 1978 | Redmond Bartlett | M & F M | 4, 4 4 | Successful—fledged 1 young of 2. Possibly same male as 1977. Successful—fledged 1 young of 2. |
| 1980 | Blue Point | ? | 4 | Occupied—no known eggs laid. |
| 1983 | "76" | F | Adult | Replaced female which died in 1982. Successful—fledged 1 young of 2. |
| | Blue Point | M | 4.0 | Replaced (on 14 Feb.) male which disappeared on 13 Feb. '83. Successful—incubated and fledged 3 young of previous male. (Banded) AM01 (1979 Fort McDowell nestling). |
| 1984 | Pleasant | M | 4 | Failed—1 egg did not hatch. |
| 1985 | Pleasant Coolidge | M F | 5 4 | Failed—1 egg did not hatch. Possibly same male as 1984. Failed—2 eggs did not hatch. |
| 1986 | Horse Mesa | F | 5 | Successful—fledged 2 young. |
| 1987 | Bartlett | M | Adult | Replaced adult shot in 1986. Failed—1 egg did not hatch. |
| 1988 | Orme | M | 3.5 | Replaced prior to October 1987. Successful—fledged 1 young. |
| | Horse Mesa | M | Adult | Replaced male which died in 1987. Successful—fledged 1 young. |
| | Cibecue | F | Adult | Replaced female which died in 1987. Occupied—no known eggs laid. |
| | Alamo | F | Adult | Replaced 1987 banded female (1979 Bartlett or Ft. McDowell nestling). Successful—fledged 1 young. |
| | Bartlett | M | 4.0 | Successful—fledged 2 young. (Banded) AM04 1984 Blue Point nestling). |
| | Blue Point | F | 4 | Successful—fledged 3 young. |
| | Ive's Wash | M | 4-5 | Successful—fledged 1 young. |
| | Redmond | M | 4-5 | Successful—fledged 1 young of 2. |
| | "76" | M | Adult | (Banded) Successful—fledged 2 young. Replaced male not banded in 1987. |
| | Sheep | M | 4 | (Banded) Replaced (on 4 April) unbanded male that disappeared on 26 March. Failed—2 eggs did not hatch. |

Table A5.2-2. (continued)

| Year | Breeding Area | Sex | Age* | Status of Breeding Area |
|--|---------------|-------|----------|--|
| 1989 | Cibecue | M | Adult | Replaced 1988 banded male (AM07—1977 Bartlett nestling) that was in rehabilitation for broken wing. Successful—fledged 1 young of 2. |
| | Orme | F | 4 | Occupied—may have been in nest 3. |
| | Alamo | F | Adult | (Banded) Successful—fledged 1 young. Replaced female not banded in 1988. |
| | Fort McDowell | F | Adult | (Banded) Successful—fledged 2 young. Replaced female not banded in 1988. |
| | Perkinsville | ? | 3-4 | Site not occupied since 1960s or early 1970s. Occupied—no known eggs laid. |
| 1990 | Perkinsville | M & F | 4-5 | Possibly same pair as 1989. Occupied—no known eggs laid. |
| | Ladders | M | Adult | (Banded) Failed—2 eggs did not hatch. Replaced male that died in 1989. |
| | Pleasant | M & F | 4, Adult | (Banded) Occupied—no known eggs laid. Replaced female not banded in 1989. |
| | Alamo | M | Adult | (Banded) Successful—fledged 2 young. Replaced male not banded in 1989. |
| | Blue Point | F | 3 | Occupied—no known eggs laid. |
| | Orme | F | 5 | Successful—fledged 1 young. Possibly same female as 1989. |
| | Cibecue | F | 4-5 | Failed—1 young died. |
| Replacements documented by near-adult in pair (28-4)** | | | | 24 |
| Replacements documented by loss of banded adult | | | | 2 |
| Replacements documented by new banded adult | | | | 5 |
| Replacements documented by known death of previous adult | | | | 8 |
| Total Known Recruitments | | | | 39 |

- * Age estimations on the basis of plumage characteristics (McCollough and Krohn 1986).
 3 years old = Subadult plumage
 4 years old = Near-adult plumage
 5 years old = Adult plumage with remnants of brown in head

- ** Four near-adults possibly same bird as previous year.

Table A5.2-3. Results of a questionnaire of nine bald eagle populations throughout North America, concerning the occurrence of near-adult (ca. 4 years old) eagles as members of breeding pairs, and the emigration or immigration of banded nestlings into the breeding population.

| Population | Source | No. of Near-Adults as Members of Breeding Pairs in the Study of () Nests over () Years | Eagles Banded as Nestlings in Another Population which Immigrated into the Breeding Population (Distance) | Banded Nestlings which Emigrated out of the Population to Breed (Distance) |
|----------------------------------|---------------|---|---|---|
| Oregon | Bob Anthony | ca. 6 (180) (?) | 0 | 0 |
| Alaska (coastal) | Phil Schempf | 0 ("100s if not 1000s") (20) | 0 | 0 |
| Alaska (interior) | Skip Ambrose | 0 (17) (9) | 0 | 0 |
| Florida | Petra Wood | No Data | 1 (418 km) | 0 |
| Greater Yellowstone Ecosystem | Al Harmata | 2 (60-80) (23) | 0 | 1 (331 km) |
| Saskatchewan, Canada | Jon Gerrard | 0 (600) (25) | 0 | 0 |
| Minnesota | Jim Grier | 5-10 ("over 800") (32) | 0 | 0 |
| Washington | Harriet Allen | 1 (525) (10) | 0 | 0 |
| California | Ron Jackman | 0 (14) (9) | 0 | 0 |

1,000 nesting bald eagles, we have not seen even one in incomplete adult plumage." Swenson *et al.* (1986) noted five near-adults ("subadults in almost complete adult plumage") paired with full-adults in 11 years of breeding area data for the Greater Yellowstone Ecosystem (1972-1982); of these near-adults, only two repaired a nest or laid eggs, and none reproduced successfully.

Stalmaster (1987) mentioned that "Occasionally a bird in subadult plumage will mate with an adult, but there is no record of both parents lacking the adult plumage." In contrast, there have been four documented cases of both eagles in a pair lacking full-adult plumage in Arizona. Thus, two pairs apparently did not lay eggs while the other two pairs hatched two young each (see Table A5.2-2). These data are the first known to us of near-adult bald eagle pairs successfully producing young. Of the 28 incidents of near-adult or subadult eagles in Arizona breeding pairs at 24 occupied nests, 11 (46%) successfully fledged young, two (8%) hatched young which died in the nest, three (13%) laid eggs which did not hatch, and the remaining eight (33%) apparently did not lay eggs.

Table A5.2-4 compares the productivity of full-adult pairs with that of near-adult or mixed pairs. Of the various values compared in the table, only one showed a significant difference by Chi-Square analysis: significantly more full-adult pairs which occupied nests also laid eggs than did near-adult or mixed pairs ($\chi^2 = 7.77$, $df = 1$, $p < 0.01$). Interestingly, the data suggested no difference in nest success once eggs were laid.

Table A5.2-4. Overall comparison of productivity between full-adult pairs and those containing one or two near-adult(s).

| Nest Status | Full-Adult Pairs | Near-Adult or Mixed Pairs | Total Pairs |
|-----------------|------------------|---------------------------|-------------|
| Occupied | 234 | 24 | 258 |
| Active | 205 | 16 | 221 |
| Successful | 131 | 11 | 142 |
| Eggs Laid | 353+ | 28+ | 381+ |
| Young Hatched | 252 | 24 | 276 |
| Young Fledged | 214 | 18 | 232 |
| Nest Success | 55.98% | 45.83% | 55.04% |
| Mean Brood Size | 1.63 | 1.64 | 1.63 |
| Productivity | 0.91 | 0.75 | 0.90 |

There appears to be no sex-difference in mortality and replacement of Arizona eagles in breeding pairs. Of the 39 known recruitments, 20 (51.3%) were males, 17 (43.6%) were females, and 2 (5.1%) were eagles of unknown sex. Similarly, there was no apparent age-class-dependent sex-difference in replacement by the 15 adults (7 male, 7 female, 1 unknown) and 24 near-adults (13 males, 10 females, 1 unknown).

In populations with high mortality rates, one adult may have several mates during its lifetime. Stalmaster (1987) reported that "One female took a new partner on two separate occasions, after her previous mates had died." In Arizona, one male (Blue Point), that has resided at a breeding area since 1983 has paired with at least three females, with replacements in 1988 and 1990. Other Arizona sites with banded pairs have contained the same mates for seven years (Cliff, since 1984), at least four years (Pinal, since 1987), at least three years (Horseshoe, since 1988). See Section C6 for details on the tenure of banded adults and Section C3 for information on Arizona nest sites with high mortality rates.

Although some species of raptors have been recorded moving between breeding territories (European sparrowhawks, merlins, European kestrels) (Newton 1979), there are no known cases of mate-switching recorded for bald eagles (Stalmaster 1987). Likewise, there is no evidence for switching among Arizona bald eagles; known banded pairs have remained together over a number of years, and banded individuals have remained in the same breeding areas. Thus, any change in the adult pair is presumably due to mortality. However, Stalmaster noted that "Although rare, three eagles have been known to form "trio bonds," presumably referring to a supernumerary adult attending a nest. During our study in Arizona, we verified an allopatric polygynous relationship in which a male paired with two females (unfriendly to one another), who laid eggs in separate nests 6 km apart (see Sections B4.6 and D4.22).

The replacement of individuals in mated pairs during a nesting cycle, and subsequent raising of a brood not parented by the new member, has been documented in many species of raptors (Newton 1979). For bald eagles, if a pair member dies or disappears, a new mate may be found within a few days, but in some cases not until the following breeding season (Stalmaster 1987). Arizona bald eagles have established pair bonds quickly following the death or disappearance of a mate. Grubb *et al.* (1983) recorded a banded near-adult male at the Blue Point breeding area on 14 February, one day after the adult male disappeared. The incubating female did not eat for seven days, leaving the nest for only 25 minutes. However, she soon began courtship flights with the new male who subsequently helped incubate and raise three young, not his own (see Section D4.4).

Similarly, a banded near-adult male arrived at the Sheep breeding area on 4 April 1989, nine days after the adult male's disappearance. The female had not eaten for eight days, and left the nest only for a few minutes to drink before returning to the eggs. On the eighth day, the female ate food we supplied near the nest tree, but abandoned the eggs on 7 April. The female was not aggressive toward the new male and flew with him after the nest failed (see Section D4.27).

The rate of mate replacement may be affected by the status of the breeding area at the time of mate loss. At Horse Mesa (1987) and Ladders (1989), the males died while young were 7.5 and 9 weeks old, respectively (see Sections D4.14 and D4.17). The females, without attracting new mates, each successfully fledged two young (we provided supplemental food at Ladders). At Cibecue in 1987, the adult female was evicted and apparently killed by an intruding near-adult male on 18 April when the single nestling was five weeks old. The resident male fended off repeated attacks against himself and his young, but the latter died at eight weeks of age. No replacement female appeared that season (see Section D4.8, also Carroll and Houser 1987).

Thus, the very limited data available on Arizona bald eagles suggest that if the resident eagle is still incubating, it may accept a new mate within days of mate loss. However, if a mate is lost while young are in the nest, the remaining adult may raise the eaglets alone. In all cases where adults were known to have died or disappeared, a new eagle had entered the pair by the following breeding season.

There have been many sightings of supernumerary eagles within the breeding areas of established pairs (see Section D4). The "76" pair was observed soaring non-aggressively with another adult on numerous occasions in 1985 and 1989. The Cliff female perched and flew with a third adult (male) in 1990. Four adults were sighted near the Pleasant nest cliff in March 1988, and four adults were observed near the Orme nest cliff on 22 February 1990.

If the population of non-breeding near-adult or adult eagles is large enough, and all potentially serviceable breeding locations are occupied (the breeding habitat has reached carrying capacity), these "floating" eagles may be expected to fight with established pairs in an attempt to acquire (steal) a breeding area (see Section A5.1 and Hunt 1988). Altercations between breeders and non-breeders over nesting territories have been observed in golden eagles in Switzerland (Haller 1982) and black eagles (*Aquila verreauxii*) in Rhodesia (Gargett 1975, Gargett 1990). Territorial conflicts occasionally result in the death of an adult or the failure of the nesting attempt.

In addition to the incident at Cibecue described above, Morgan and Sudar (1985) witnessed the Fort McDowell adults kill an intruding adult near their nest. In Sonora, Mexico, we found a dead adult male below a nest being defended by a pair; bald eagle feathers clenched in the beak of the dead eagle

indicated an altercation (Brown and Olivera 1988). Ron Jackman (BioSystems) has recently documented two cases in California where mated adult females were killed and replaced by floaters. Roberts (1985) reported an adult female bald eagle killed in the territory of a breeding pair in Florida.

Twenty-two of the 39 cases of recruitment listed in Table A5.2-2 occurred during 1988-1990. The reason for the greater volume of recent documentation is that, until 1987, there was less systematic monitoring of individual breeders. Because of the difficulty of accessing remote sites and the problem of detecting a full-adult replacement where no bands or other distinguishing characters were in evidence, many more cases of recruitment no doubt went unnoticed. Whether the greater frequency of near-adults as members of pairs in recent years is also an artifact of the more intensive monitoring is unknown. It is possible that there are simply more near-adults available as a consequence of an expanding population. However, in examining Table A5.2-5, there is no suggestion that the number of near-adults observed breeding is related to the number of young produced by the known population four years earlier.

A5.2.4 Survivorship

It has been widely reported that mortality takes its greatest toll on bald eagles and other raptors during the first year of life (Broley 1947, Cade 1960, Hickey 1949, Craighead and Craighead 1956, Brown and Amadon 1968, Stalmaster 1987). In bald eagles and other long-lived species, the individuals of each cohort surviving their first year are then subjected to further mortality before reaching breeding age at 4-5 years old. Estimations of survivorship vary for different populations of bald eagles and for age classes within a population. In isolated cases nearly 100 percent of a year's hatched young may die in the nest, but on average 85 percent survive to fledge (Stalmaster 1987). After dispersal, however, estimates of survivorship are far less certain.

Early reports of age-specific mortality as revealed by band recoveries show a preponderance of deaths among the youngest age categories. Charles Broley, who banded 814 nestling bald eagles in Florida from 1939-1946, found high juvenile mortality relative to other age classes. Of the 48 bands recovered by 1946, 77.1 percent died in their first year of life and an additional 8.3 percent were found wounded (Broley 1947). Later, Brown and Amadon (1968) reported 107 band recoveries (which included the Broley sample) of which 78.5 percent had died within their first year of life; 9.4 percent survived through their second year, 3.7 percent through their third year, 2.8 percent through their fourth year, and 1.9 percent through their fifth year.

Shooting accounted for 50 percent of the 48 band recoveries reported by Broley (1947) and for 43 percent of 374 eagles autopsied from 1960-1977 (Stalmaster 1987). Much of this persecution apparently related to the myths that eagles threatened livestock, fish and game populations, and even young children (see Broley 1947 for an interesting discussion). Nowadays, as a result of research into food habitats and education (mainly television), fewer bald eagles are likely to be shot.

Gerrard *et al.* (1978) banded 296 bald eagles in Saskatchewan during 1967-1975 of which 56 were also wing-marked. Sightings of 43 wing-marked birds showed a minimum of 37 percent survival through the first year of life, 23 percent through the second year, and 19 percent through the third year. In comparison, 15 band recoveries showed 53 percent survived their first year of life, 27 percent survived through their second year, and 20 percent through their third year. Although the first year survivorship was higher in the banded sample, the second and third year data were similar.

Table A5.2-5. Recruitment of near-adult and subadult eagles into the Arizona breeding population, compared to known productivity four years earlier.

| Year | Known Breeding Areas | Known Young Fledged | Year Available As Near-adult | Known Near-adults Recruited Into Breeding Population |
|-------|-------------------------|------------------------|---------------------------------|---|
| 1968 | 2 | 1 | 1972 | 2 |
| 1969 | 2 | 0 | 1973 | 0 |
| 1970 | 2 | 3 | 1974 | 0 |
| 1971 | 3 | 4 | 1975 | 0 |
| 1972 | 4 | 0 | 1976 | 0 |
| 1973 | 7 | 7 | 1977 | 3 (1 from 1974) |
| 1974 | 8 | 6 | 1978 | 2 |
| 1975 | 10 | 5 | 1979 | 0 |
| 1976 | 10 | 7 | 1980 | 1 |
| 1977 | 10 | 6 | 1981 | 0 |
| 1978 | 11 | 9 | 1982 | 0 |
| 1979 | 12 | 6 | 1983 | 1 |
| 1980 | 12 | 5 | 1984 | 1 |
| 1981 | 13 | 16 | 1985 | 1 |
| 1982 | 14 | 14 | 1986 | 1 (from 1981) |
| 1983 | 15 | 13 | 1987 | 0 |
| 1984 | 18 | 15 | 1988 | 6 |
| 1985 | 20 | 22 | 1989 | 2 |
| 1986 | 21 | 17 | 1990 | 4 (1 from 1987) |
| 1987 | 26 | 20 | 1991 | — |
| 1988 | 27 | 24 | 1992 | — |
| 1989 | 28 | 13 | 1993 | — |
| 1990 | 28 | 14 | 1994 | — |
| Total | 28 | 227 | | 24 |

Probably the most accurate estimate of survivorship available to date for a bald eagle population was collected in Maine. McCollough (1986) color-banded 361 nestlings from 1975-1984, then monitored their survival by observations at artificial feeding stations during four winters (1981-1985). Since the winter feeding stations might artificially increase survival, McCollough calculated survivorship estimates for the sample of eagles banded prior to the initiation of feeding, as well as after. In the pre-feeding estimate, 54 percent of the eagles survived their first year of life, 43 percent through their second year, 39 percent through their third year, 35 percent through their fourth year, 32 percent through their fifth year, and 29 percent through their sixth year. In the post-feeding estimate, 73 percent of the eagles survived their first year of life, 61 percent through their second year, 56 percent through their third year, 51 percent

through their fourth year, 46 percent through their fifth year, and 42 percent through their sixth year (McCollough 1986). McCollough calculated that winter feeding increased the survival of one- to two-year-old eagles by 18 percent, and he predicted survival to "theoretical breeding age" [5 years old] was 32–46 percent.

In Arizona, 46 nestlings were banded during the studies of Robert Ohmart (ASU) during 1977–1982, and Teryl Grubb (USFS) during 1983–1985 (see Section C6). We sighted 18 banded birds (17 were breeding) during our study in Arizona (1987–1990). If all were native to Arizona, a minimum survivorship of 39 percent to breeding age (4–5 years old) would be suggested. To date, we have verified that eight of the 18 were banded as nestlings in Arizona by Ohmart or Grubb, and we have detected no immigrants (see Section C6). Among the 11 radio-tagged juveniles we studied, which left their natal areas to migrate, eight (72.7%) returned to Arizona, and none were known to have died.

At least four eagles banded as nestlings in Arizona have survived through their twelfth year (see Section C6). As a notable record of ecological longevity, Cain (1986) captured a 22-year-old male (banded at the Chilkat River, Alaska) on Admiralty Island where it was breeding. However, physiological longevity of bald eagles is believed to be much longer, possibly 40 or more years (Stalmaster 1987).

During 1987–1990, we placed VID bands on 62 (80.5%) of the 77 Arizona nestlings that survived to banding age (ca. 6 weeks). These bands will provide data on age structure without the necessity of capturing the eagle, since the symbols can be read at considerable distances with a telescope. Whether or not feeding stations in Arizona would concentrate eagles for band-reading purposes as they did in Maine (McCollough 1986) is unknown, but as VID-banded young become breeders, we will be able to construct a meaningful life-table (see Section C6).

A5.3 CONTAMINANTS

National monitoring programs for organochlorines in wildlife have consistently recorded higher levels of DDE in Arizona than in almost all other states sampled (Martin 1979; Martin and Nickerson 1972; Nickerson and Barbehenn 1975; White 1976, 1979; Clark and Krynsky 1983; Cain and Bunck 1983). In part, these residues may derive from mixtures of technical dicofol used as a miticide (Hunt *et al.* 1986; Risebrough *et al.* 1986). They may also derive from residues persisting in the soils of agricultural fields, particularly those used for cotton cultivation.

R. W. Risebrough analyzed for DDE and PCBs seven unhatched Arizona bald eagle eggs we obtained in 1986–1989 (see Section E4). Geometric mean levels (with ranges) were 5.5 ppm DDE (2.3–9.5) and 2.2 ppm PCBs (1.2–3.9) wet weight; for lipid weight comparison, this is 87 ppm DDE (31–130) and 32 ppm PCBs (21–49). DDE levels of this magnitude have been associated with a 50-percent depression of productivity in a 14-state study undertaken by Wiemeyer *et al.* (1984) in 1969–1979. However, productivity of Arizona bald eagles has been relatively high, about one (0.90) young fledged per occupied nest. This is above the level considered necessary by Sprunt *et al.* (1973) to maintain population numbers. Neither is a DDE effect on productivity apparent in the breeding areas from which eggs were obtained in this study. We estimate a threshold level of DDE effects on productivity in this population at about 8 ppm or higher, approximately twice as high as that estimated by Wiemeyer *et al.* The geometric mean level of 2.0 ppm PCBs (wet weight) is substantially lower than means of 7.2 ppm ($n = 21$) and 13 ppm ($n = 56$) recorded in successful and unsuccessful nestings, respectively, of bald

eagles by Wiemeyer. A potential PCB effect on productivity in Arizona is not, therefore, considered likely.

D.C. Bland examined the ultrastructure of the same seven eggshells (Section E5). A mean percent thinning of 4.9 percent for all samples is well below the 10 percent level associated with reduced productivity in other bald eagle populations (Wiemeyer *et al.* 1984, Nisbet 1989). Only one egg (from the Cliff breeding territory) showed disruptions in structure in both the organic and inorganic portions of the shell, although this egg showed only 1 percent thinning. Numerous large "holes" were recently observed in some California bald eagle eggs with high DDE levels and excessive water loss during incubation (R. Risebrough and B. Walton, pers. comm.). In four Arizona eggs, we found the percentage of surface area covered by these "holes" was one or two orders of magnitude less than in the California eggs. Analysis of the correlation between this structural irregularity and contaminants is currently being studied.

The USFWS in Phoenix recently analyzed data on heavy metals and organochlorines in fish obtained in central Arizona (King *et al.* 1991). Chlordane and DDE were the most frequently detected organochlorines in fish sampled near eagle nests, but the levels were below those associated with eggshell-thinning in bald eagles. However, trace elements, especially mercury, were elevated, as were aluminum, arsenic, copper, and zinc.

In a study of contaminants in the eggs of Arizona peregrines and their prey, Ellis *et al.* (1989) found high levels of DDE in white-throated swifts (a common prey of Arizona peregrines), but levels in the falcon eggs were lower than those associated with reduced productivity. The white-throated swift is a migratory species that may be incurring organochlorine contamination in Latin America.

Wiemeyer *et al.* (1989) analyzed lead, mercury, and organochlorines in the blood of bald eagles from four northwestern states. They found a few instances of elevated lead levels and attributed this to ingestion of waterfowl containing lead shot. Mercury concentrations were also elevated. A few adult bald eagles from Oregon showed elevated levels of DDE, but most had relatively low contamination.

At the present time, organochlorines do not appear to pose a significant threat to the bald eagles in Arizona. However, with the history of pesticide use on cotton and the expanding acreage in Arizona under cultivation for cotton, periodic monitoring of bald eagle prey species and, perhaps, blood and eggs of bald eagles would be prudent. Moreover, nesting bald eagles in Arizona commonly prey on waterfowl in winter, some of which might be expected to contain organochlorines and heavy metals. The findings of King *et al.* (1991) suggest heavy metals in prey fishes at some nesting areas may be a matter of concern.

A5.4 SIGNIFICANCE OF THE ARIZONA GENE POOL

One study objective identified by the agencies in their original "Request for Proposal" (RFP) was to resolve whether there is gene flow into Arizona from bald eagle populations outside its borders (Figure A5.4-1). If the Arizona pairs are, in fact, an outlying but integral part of the larger North American population, then there would be few, if any, consequences connected with the small size of the Arizona contingent. This, according to the RFP, could have "... major impacts on the way Section 7 consultations [of the Endangered Species Act] are handled." If demographic performance (low

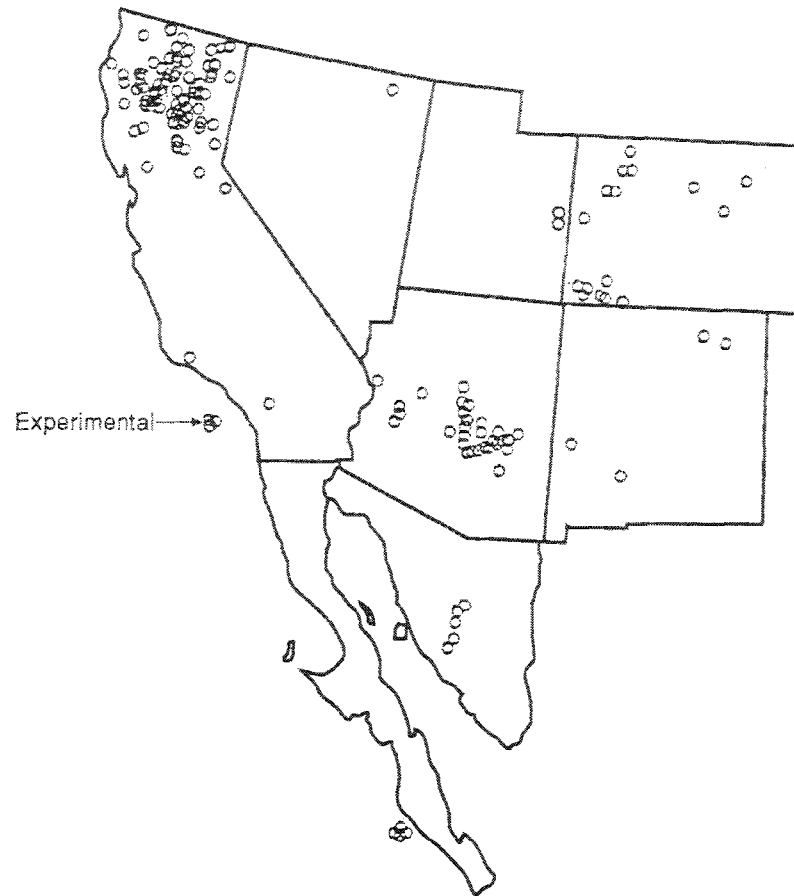


Figure A5.4-1. Location of bald eagle territories in Arizona and adjacent states known to be occupied in one or more years since 1979.

Data compiled by Tom Gatz, Bureau of Reclamation, Phoenix, AZ. Sources: New Mexico: Robert Mesta, USFWS, pers. comm.; Sonora: Mesta *et al.* 1991. Bald eagle population survey, Rio Yaqui, Sonora, USFWS draft report; Utah: Dr. Frank Howe, Utah DNR, pers. comm.; Colorado: Gerald Craig, Colorado Division of Wildlife, pers. comm.; Baja California, Conant, B. and J.F. Voelzer, 1989. Winter Waterfowl Survey Mexico West Coast and Baja California. USFWS; Nevada: Henny, C.J. and R.G. Anthony 1989. Bald eagle and osprey. Pages 66-82 in Proc. western raptor management symposium and workshop. Natl. Wildl. Fed., Washington, D.C.; California: Jurek, R.M. 1990. California bald eagle breeding population survey and trend, 1970-1990. Calif. Dept. Fish and Game.

productivity and/or high mortality) within Arizona deteriorated to a point where the population would decline on its own, it might nevertheless be sustained by recruitment from extrinsic sources.

If, on the other hand, the bald eagles now nesting in Arizona are exclusively the descendants of eagles that have long inhabited the xeric southwest - and if they possess adaptations essential to survival and reproduction in conditions substantially different from those encountered by any other population (high heat *and* low humidity) - then would immigrants or transplants from elsewhere possess the necessary adaptations to survive in the desert environment should the Arizona population become extirpated? If other bald eagles could survive and reproduce in Arizona, would population pressure by immigrants filling vacant habitat have the effect of disrupting long-evolved adaptive sequences still present in the Arizona gene pool, a process akin to destroying the paintings of a long-dead artist?

A5.4.1 Did Bald Eagles Breed in Central Arizona 500 Years Ago?

Is it possible that few, if any, bald eagles nested in Arizona before the building of the dams and the introductions of exotic species of fish? Indeed, there were no accounts of bald eagles breeding on the Salt or Verde drainages before the turn of the century, although Mearns (1890) reported a pair nesting at Stoneman Lake on the Mogollon Plateau about 40 km (25 miles) from the current Ladders nest on the Verde River. The first dam (Roosevelt) was completed in 1911, and nestings of bald eagles along the Salt and Verde were not firmly documented until the 1930s.

Some authors have suggested that the Arizona bald eagle population has recently been established by migrant eagles from other populations. Busch (1988) wrote:

One activity that continues to perplex biologists is the initiation of nesting attempts which are later abandoned. Such attempts are often classified as 'failed' but are also described as part of the courtship of 'northern' bald eagles. It is not known if such pairs renest later at a different location or if the Southwest has been colonized by wintering or migrant birds as hypothesized by Lish and Sherrod (1985).

From a foraging standpoint, the modern reservoirs have acted to broaden the niche of bald eagles both in the nesting season and during other times of year. There are now more species of fish in appropriate size categories than before. In some cases artificial water temperature regimes in regulated riverine habitat orchestrate prey life history events to the benefit of eagles. As we have shown in Section A3, the reservoirs themselves are highly productive of food for eagles, especially in the form of carrion, and every major reservoir on the Salt and Verde rivers has nesting eagles that exploit it.

However, the current benefits of regulated aquatic environments and exotic prey species assemblages in no way bear upon the question of whether bald eagles nested along these same rivers in ancient times. In assessing the possibility in the absence of direct data, there are two matters to consider: (1) whether it is reasonable to believe that a nesting population could have existed without being discovered by biologists prior to the 1930s, and (2) whether pristine habitats could have supported nesting pairs.

In our opinion, if bald eagles once bred in Arizona in comparable or even higher densities to those now existing, the paucity of historical records is not surprising. Before the building of roads along the rivers, which even now are absent in most areas, the discovery of a nest would have been fortuitous and uncommon. In view of the likelihood that nonbreeding eagles frequented the river reaches as they do today in winter and spring (the nesting season), the sighting of a bald eagle would not indicate the existence of a nest. Moreover, most of the present-day bald eagle nests in Arizona are quite inconspicuous.

Unlike other populations whose nests are often apparent in the largest shoreline trees, most current nests on the Salt and Verde rivers hardly beg discovery in the remote canyons where they occur, removed from roads of any kind. Even nests near civilization have gone unnoticed. For example, the closest nest to the Phoenix metropolitan area (Orme), located at the confluence of the Salt and Verde rivers was not discovered until 1987, even though there is ample evidence that the pair existed for many years previously (see Section D4.20). Before 1900, the likelihood of finding *and then reporting* bald eagle nests does not appear great, particularly in view of: (1) the difficulty of distinguishing native eagles from a likely far greater number of northern migrants present in early times, and (2) the probability that bald eagles would not have attracted the interest of naturalists who had so commonly encountered the species

elsewhere. We provide further information and discussion of the historical record in Sections D3, D4, and D5.

As to whether bald eagles could have found sufficient food and nesting substrate to breed along the rivers of central Arizona, we must first consider that the character of the rivers was quite different than today (see Sections D2 and E1 for discussion).

More than a century before the first dam was built, livestock grazing had reduced (and continues to reduce) the vegetation and soils throughout these drainages. In the natural, coevolved plant and animal communities of ancient times, predators likely prevented populations of large herbivores from reaching the level of carrying capacity imposed solely by food supplies. Some of these herbivores no doubt alternated between summer and winter ranges, also lessening the impact on grasslands. The far more abundant and stable grasses of pristine times allowed soils to increase over the millennia, each tuft of grass acting like a little dam. The effect of these more robust soils, containing complex root systems, was to infiltrate and slow the transport of water to the rivers. As a result, these surely maintained more consistent flows over the yearly cycle of rainfall, meaning that some stream courses, now seasonally dry, were perennial in past centuries and thus held fish populations (see Section D2.6 for early descriptions of the landscape).

Was the water in these rivers clear enough for eagles to forage in? Reviewers of an earlier draft of this manuscript commented that the dams made the rivers less turbid. This is true if one compares free-flowing reaches with those emanating from the dams. In the decades prior to the creation of the reservoirs, observers reported that the rivers ran brown with silt (Olmstead 1919, Hastings 1959, Hastings and Turner 1965, Hayden 1965), but this is hardly surprising after a half-century or more of severe overgrazing that reached its zenith during 1870–1900. But it is wrong to assert that the Arizona rivers in pristine times were more turbid, “flashy,” and unstable than present-day free-flowing reaches. Since the 1980s, nine pairs of bald eagles have fledged young on free-flowing rivers and tributaries of the Salt and Verde drainage that are now certainly more turbid than they would have been long ago. If foraging opportunities were fewer in pristine times than today, it was because of a difference in prey fish populations, not water clarity.

Today, the bald eagles nesting away from reservoirs feed primarily on four fish species: carp, Sonora suckers, desert suckers, and channel catfish. Of these, only the suckers are native to Arizona. However, in ancient times, five other species of fish of appropriate size categories were present: Colorado squawfish, razorback sucker, flannelmouth sucker, roundtail chub (still fairly common), and bonytail chub (Minckley 1973).

Colorado squawfish (and other species) apparently made spawning migrations far up the central Arizona rivers, past the farthest upstream site of nesting on the Verde River (Minckley and Alger 1968). Although some of these squawfish were probably too large for eagles to kill, we presume many would have been available to eagles when migrating through shallows, and as carrion. Although razorback suckers frequent deep, quiet water, they may spawn in very shallow water. They were recently reintroduced on the Salt River, and appeared in our samples of prey remains at two bald eagle nests (Redmond and Pinal). Flannelmouth suckers apparently enter riffles to spawn (Minckley and Holden 1980). Roundtail chub, still widely distributed in the Salt and Verde rivers, may have been rarely taken by bald eagles, as we found none in prey remains. Bonytail chub (now absent) were also possibly little used because of their tendency to inhabit deeper water. However, native cyprinids, such as Sacramento

squawfish and hardheads, were common in bald eagle prey remains in northern California, so it seems possible that, if chubs reached very high densities in Arizona in pristine times, eagles may have frequently taken them. Sections E1 and E3.1 discuss the occurrence and life histories of these fishes.

Several reports attest to the abundance of fish in historic and prehistoric times. Native Americans used them extensively for food (Rostlund 1952, Minckley and Alger 1968, Haase 1972). When the first Anglo-Americans came to the region in the mid-1800s, they found and were sustained by an "abundance" of fish (Davis 1982). Even as late as the early 1900s, fish were so common in the lower Salt and Gila rivers that they were sold for human consumption, as feed for domestic animals, and as fertilizer (Minckley 1973).

While we cannot be certain if the communities of native fishes occurring in the pristine rivers supported nesting eagles, we speculate that the four species of suckers, augmented by waterfowl and spawning runs of large squawfish and chubs, would have been suitable. The suckers' habit of feeding and spawning in shallow water, together with a relatively low awareness of eagles attacking from above, make them ideal prey for eagles. One sucker species made up 80 percent of the total diets of several pairs of bald eagles in northern California (BioSystems 1985).

Bald eagles currently breeding in Arizona tend to exploit a variety of prey species, taking them in sequence, as they become available. The vulnerability of prey fish is often associated with spawning, whether that activity takes the fish into shallow water or causes mortality (see Section A3.2). Therefore, it would probably have benefitted eagles if the native suckers and squawfish were to have spawned at different times. It would seem that any coevolved community of fishes would tend toward spawning differentials in time and space (some ascending tributaries) because of niche similarity (hence competition) of fry.

Because of the former presence of extensive riparian zones with many more large trees suitable for nesting (see Section D2), it follows that nesting substrate was more abundant in pristine times than today, a factor that may have allowed a higher density of eagle pairs. Like the grasslands and soils, the loss of the riparian trees was largely a result of overgrazing, although woodcutting was also a factor. Even today, trees are unable to regenerate in the riparian zones because cattle eat the young individuals.

We cannot discount the possibility that bald eagle fecundity and survivorship was impacted by humanity even before the arrival of the Conquistadors. While smaller in population than 20th century Arizona, Native Americans were more evenly distributed along water courses in prehistoric times, perhaps actually increasing the potential for human/eagle interaction. Eaglets in tree nests would have been conspicuously available as food and for ceremonial use of body parts. Considering the large size of eagles, efforts to trap adults for food might have been an efficient strategy in a hunter/gatherer economy (see Stalmaster 1987, citing Smith 1924, regarding the trapping of bald eagles for food by the Bella Coola Indians in the Pacific Northwest). On the other hand, Native Americans may have been protective of bald eagles. Recall that the native fisheries were still intact, but were soon destroyed by the European immigrants, a pattern that suggests a philosophy of wildlife husbandry by the aboriginal people.

In summary, little is known about the historical population of eagles that occurred in Arizona. Clearly, the landscape has changed significantly, and we assume eagle numbers have changed. Fewer large trees are available to serve as nesting sites, waterways are diminished in volume, stability, clarity, and extent, and the relative abundance and distribution of fish species have been altered (however, lacustrine habitats

favorable to eagles have greatly increased). On the basis of studies of bald eagle foraging ecology, we believe it more parsimonious to hypothesize that bald eagles nested on rivers throughout the southwest in pristine times, than to suppose Stoneman and Mormon lakes supported the only pairs in the state. The reported nature of the rivers and the assemblage of prey fishes both seem conducive to nesting success and suggest a richer and more extensive habitat in the lower desert than might have been available on the Mogollon Plateau.

A5.4.2 Small Populations

Given the larger extent of the pristine rivers and the greater number of large trees, it seems likely that, if Arizona supported bald eagles before the age of overgrazing, numbers exceeded those of today. The current number of nesting pairs, amounting to only 21 known sites productive since 1980, is rather small. No more than 15 known pairs have been productive in any one year ($\bar{X}=11.2$ per year during 1985-1989). In this section, we will review the general consequences to a population becoming small.

Three kinds of dangers face small populations: environmental, demographic, and genetic. Environmental problems are large-scale problems, sometimes affecting entire populations catastrophically. In 1916, a fire swept through the last remaining breeding grounds of the heath hen in Martha's Vineyard Island. It was an event that proved pivotal in the final decline and eventual extinction of the species (Pettingill 1970, Shaffer 1981).

Demographic dangers are manifest in very small populations only through the actions of chance. For example, a disproportionate number of individuals at a given time could be the same sex, making the effective size of the population smaller than the actual size (see Glossary; also Franklin 1980 for a discussion of effective population size). A high ratio of male to female heath hen chicks hatching after the fire is also implicated in the extinction of this species. The last five known dusky seaside sparrows were male (Simberloff and Cox 1987). Without hybridization the population was doomed to extinction.

Small populations are clearly susceptible to demographic and environmental problems, but questions regarding genetic problems are controversial. How small can a population get and remain viable? How often can it be reduced to low numbers, and for how many generations? Are genetic problems actually of any consequence?

Recently, it has been suggested that populations rarely persist in numbers small enough for genetic factors to be influential (Pimm *et al.* 1988, 1989). Pimm and colleagues assert that when populations are very small they are likely to go extinct due to demographic accidents or stochastic environmental events. In arguing against this hypothesis, other authors maintain that populations can be shown to suffer from genetic bottlenecks (Templeton and Read 1984, Templeton 1986) or even multiple genetic bottlenecks (O'Brien and Evermann 1988; for a recent exchange see Trends in Ecology and Evolution, Vol. 4 for Pimm *et al.* 1989, O'Brien 1989). Generally, ten pairs is considered the threshold below which extinction is likely in nine to twelve generations, due to environmental or demographic factors.

The most critical genetic problem facing small populations is inbreeding and the resultant homozygosity (both alleles at a locus being identical). Increasing homozygosity of alleles at many loci may result in inbreeding depression—the loss of fitness (fertility and survival) of an organism as a result of inbreeding, whether the inbreeding is due to small population size or to frequent matings between close relatives in a large population (Lande and Barrowclough 1987). Upon inbreeding, lethal recessive alleles have a higher chance of being paired with identical copies of themselves, resulting in the death of organisms

bearing two copies of such alleles. Recessive alleles that have a mildly detrimental effect on an organism also increase in frequency during inbreeding. When two identical, mildly deleterious recessive alleles are present at each of several different loci, the result can be an organism with lowered fertility and/or shortened lifetime. Thus, inbreeding can further reduce population size.

While rapid inbreeding can cause problems, gradual inbreeding may create relatively little permanent inbreeding depression because it allows natural selection to purge deleterious alleles from the population as they become homozygous (Lande 1988). However, in plants, the evidence indicates that even normally inbreeding species show some inbreeding depression (Charlesworth and Charlesworth 1987).

Inbreeding may have another type of consequence. As more and more loci have two identical alleles at each locus, the variability necessary for long-term adaptation to changing environments is lost, and as conditions change, individuals are removed from the population by natural selection. The individuals that are removed are those which do not possess the lucky combination of traits that might have allowed them to cope with a different environment. The less genetic variety maintained in the population, the lower the chances are that the lucky combination of traits will occur in some individuals before the population is completely eliminated. The maintenance of genetic variability in populations acts as a sort of insurance policy.

The severity of the consequences of small population size greatly depends on how quickly the population can recover. In the extreme example of only one pair surviving, if the population grows extremely large within one generation and stays so for many successive generations, two thirds to three quarters of the amount of the original genetic variability of that population can be retained (Franklin 1980, Carson 1990). Unfortunately, most mammals and birds cannot recover at the high rate necessary to preserve large amounts of genetic variability. And if the same population should pass through a succession of bottlenecks, each followed by slow recovery, a high degree of inbreeding will accumulate, with deleterious results (Carson 1990).

Population bottlenecks can lead to reduced genetic variability in another way. Small population size increases the probability that rare deleterious alleles will increase due to random fluctuations in gene frequencies (random genetic drift). These random changes in gene frequencies can also lead to the loss of genetic variability through the loss of alleles due to the random chances inherent in the formation of gametes and zygotes.

Outbreeding depression is roughly the opposite of inbreeding depression. Instead of a reduction in fitness due to mating with relatives or as a consequence of small population size, outbreeding depression is a reduction in fitness due to hybridization between populations which may be geographically distant (Templeton 1986). While outbreeding can increase genetic variability, the fitness reduction occurs because the group of genes that are adapted to one microhabitat (a coadapted gene complex) are mixed with another group of genes adapted to a different microhabitat. Hybrid offspring are less well adapted to both microhabitats than are the parent populations because of the mixing of these two different groups of genes. The short-term consequences of outbreeding depression can put the entire population at risk. Templeton (1986) points out that this should be a temporary phenomenon. If a population can weather outbreeding depression, the long-term outlook is favorable if the trait combination of one parental population is retained. Templeton also observes that occasionally a new trait combination can be produced through outbreeding (by genetic recombination during gamete formation) that is even more favorable than either of the parental combinations.

A5.4.3 Genetical and Morphological Comparisons With Other Populations

The small size of the Arizona bald eagle population and the question of genetical uniqueness led Reclamation to provide for genetical analyses of Arizona bald eagles as part of our study. We collected blood samples from 52 juveniles and 21 older eagles. We sent one set of samples to Donald Morizot (University of Texas) and Maureen Schmidt (Genetical Analysis, Inc.) for enzyme electrophoresis, and a second set of samples to Jonathan Longmire (Los Alamos National Laboratory) and Ernie Vyse (Montana State University) for DNA fingerprinting. Reclamation also supported biochemical analyses of blood samples collected in other regions by James Seegar (Maryland), Robert Anthony (Washington/Oregon), David Mabie (Texas), Allen Jenkins (Florida), John Aiken (California), and Ronald Jackman (California). We were aided in the interpretation of the electrophoretic results by Ellen Holstert and Gerard Zegars of the University of California (Santa Cruz). In Sections E6 and E7 of this report, we provide the results of both the electrophoretic and the DNA fingerprinting studies (summarized below). To augment the biochemical results, we measured the tarsus, culmen, wing-chord, and other mensural characters of almost every bald eagle we handled in Arizona.

Enzyme Electrophoresis. In an earlier study, Morizot *et al.* (1985) subjected 60 bald eagle blood samples to starch gel enzyme electrophoresis. The samples were from four bald eagle populations in the west: 16 from Arizona, 19 from Alaska, 15 from Oregon, and 10 from Washington. Finding "no significant discontinuities in gene frequencies or unique alleles among some 40 loci (only 5 of which were polymorphic), the authors suggested that the northern and southern populations might demonstrate a "gradual" cline rather than a discontinuity suggestive of disjunction.

Despite the larger number of blood samples in the BioSystems study (see Section E7), no significant heterogeneity of allele frequency was detected between the Arizona group and the six other samples (Maryland, Florida, Washington, California, Texas, or Minnesota), nor did we find alleles unique to any population. Nei's analysis of genetic distance (excluding the Alaska samples) vaguely suggested that eagles from Arizona were most similar to those from Maryland. However, all samples in that comparison were close in value, ranging from 0.0288 to 0.0396, whereas the Nei's statistic for some of the samples from outside Arizona appeared to differ more from one another than they did from Arizona (range 0.0003 to 0.0587). We caution against interpreting these results as significant because of the few number of polymorphic loci examined ($n = 5$). Interestingly, however, the Arizona population showed the highest level of genetic heterozygosity among the samples tested.

DNA Fingerprinting. Because of greater sampling of the genome, DNA fingerprinting is regarded as more useful than electrophoresis in assessing the genetics of endangered populations (see Section E6). Additional advantages over electrophoresis are that only a few drops of blood are needed, and samples can be stored indefinitely and later probed with as yet undeveloped DNA sequences.

In comparing DNA from Arizona, California, and Florida (breeding adults and nestlings), Dr. Vyse was unable to identify constant population-specific DNA markers. However, using combinations of bands, he was able to assign most individuals to their respective populations. Intrapopulation similarity was highest in the Florida samples, suggesting they were the most inbred of the three populations. Using two enzyme probes, the California eagles appeared more inbred than the Arizona birds, but the opposite was the case when using a third probe. The standard error of the mean of similarity coefficients showed a corresponding pattern: again, the Florida eagles appeared more inbred than those in Arizona or California.

Comparing similarity coefficients between populations showed a large difference between the Arizona and Florida eagles, indicating that they are the most distantly related of the populations tested. Furthermore, the California population appeared more closely related to the Florida birds than to the Arizona eagles. Analysis of a fourth sample from Canada indicated a relatively large genetic distance from the other three populations.

Morphological Comparison. In the northern hemisphere, according to Bergmann's Rule, animals in warmer, southern environments are generally smaller than their counterparts in cooler northern climates (Dasmann 1981). This rule tends to hold true for bald eagles. In a comparison of specimens from Alaska to Virginia (29 males and 42 females) with samples from Georgia, Florida, and Baja California (16 males and 11 females), there was no overlap apparent in (within-sex) wing-chord measurements (Palmer 1988, citing Freidmann 1950). Amadon (1983) stated that there is "... a gradual cline of increasing size from south (Florida) to north (Alaska). ..." In this section, we will compare standard measurements collected from eagles in Arizona with those from Alaska, California, and the Greater Yellowstone ecosystem.

In comparing measurements, we used only data from breeding adult bald eagles. Although we collected numerous measurements of nestlings, the values varied so strongly with age that interpopulation comparisons with measurements obtained by others were generally useless. Neither were we able to compare measurements of subadults, near-adults, and adults captured outside their territories because of the uncertainty of their origin. Lastly, there was difficulty in comparing weights because of a yearly cycle of variation; weights of both sexes in Arizona were up to 0.5 kg higher in winter than during the breeding season. However, there was still no overlap between male and female weights within the Arizona sample.

Within these limits, we compared morphological characteristics of Arizona bald eagles to those of three other bald eagle populations where researchers had data on breeding adults of known sex: Alaska (P. Schempf and T. Bowman, USFWS, unpublished data); Greater Yellowstone Ecosystem (A. Harmata unpublished data); and California (R. Jackman unpublished data). We sought, but were unable to locate, measurements for breeding adults in other populations.

A comparison of the means of nine standard morphological measurements between the four populations revealed that Arizona adults were smaller than the means in all morphological characteristics of the other populations except in two cases: (1) the dorsal/ventral tarsus width of Alaska males and females (which were sexed by body measurements), and (2) the arc of the wing cord, which was slightly smaller in Greater Yellowstone Ecosystem males (Table A5.4-1). No trends were apparent in coefficients of variation calculated for the various morphological measurements of the four populations.

We then compared the means of the nine morphological characters by a t-Test (Table A5.4-2). Of the 26 comparisons for males, Arizona eagles were significantly smaller than males of the other three populations in 21 cases. One characteristic, dorsal/ventral tarsus width, accounted for three of the five cases where differences were not significant. In addition, Arizona males were not significantly different from Greater Yellowstone Ecosystem males in arc of the wing cord and beak depth.

Arizona females were significantly smaller than females of the other three populations in 14 of 26 comparisons. As with males, dorsal/ventral tarsus width was not significantly different between Arizona females and females of the other three populations. In addition, Arizona females did not differ

Table A5.4-1. Comparison of variance among morphological characteristics of adult bald eagles from four populations.*

| | | Hallux Length (Arc) | Tarsus Width Dorsal/ Ventral | Tarsus Width Lateral | Wing Cord (Arc) | Eighth Primary (Flat) | Tail Length | Culmen Length (Arc) | Beak Depth | Weight |
|--|------|---------------------------|---------------------------------------|----------------------------|-----------------------|-----------------------------|----------------|---------------------------|---------------|--------|
| Arizona Males | | | | | | | | | | |
| | MEAN | 37.4 | 15.2 | 12.4 | 555.0 | 372.2 | 237.0 | 48.3 | 31.6 | 3.3 |
| | VAR | 1.8 | 0.8 | 0.4 | 119.4 | 295.0 | 383.8 | 1.1 | 0.6 | 0.0 |
| | CV | 3.6 | 5.9 | 5.1 | 2.0 | 4.6 | 8.3 | 2.2 | 2.4 | 0.0 |
| | N | 10 | 10 | 9 | 7 | 5 | 8 | 10 | 10 | 12 |
| California Males | | | | | | | | | | |
| | MEAN | 40.4 | 15.6 | 13.0 | 595.7 | — | 265.1 | 52.4 | 32.6 | 4.1 |
| | VAR | 0.2 | 0.7 | 0.2 | 317.6 | — | 102.3 | 1.2 | 0.8 | 0.1 |
| | CV | 1.1 | 5.4 | 3.4 | 3.0 | — | 3.8 | 2.1 | 2.7 | 7.7 |
| | N | 7 | 9 | 9 | 3 | — | 9 | 9 | 7 | 10 |
| Alaska Males | | | | | | | | | | |
| | MEAN | 41.3 | 15.1 | 13.2 | 612.9 | 433.7 | 278.8 | 52.4 | 32.9 | 4.7 |
| | VAR | 1.2 | 0.8 | 0.4 | 168.3 | 295.2 | 328.1 | 3.0 | 0.7 | 0.1 |
| | CV | 2.6 | 5.9 | 4.8 | 2.1 | 4.0 | 6.5 | 3.3 | 2.5 | 6.7 |
| | N | 33 | 33 | 33 | 29 | 27 | 33 | 33 | 33 | 32 |
| Greater Yellowstone Ecosystem Males | | | | | | | | | | |
| | MEAN | 41.0 | 15.8 | 13.8 | 542.5 | 420.4 | 273.0 | 51.3 | 32.3 | 4.1 |
| | VAR | 2.3 | 0.8 | 0.7 | 1626.4 | 89.3 | 83.8 | 2.1 | 1.2 | 0.6 |
| | CV | 3.7 | 5.6 | 6.1 | 7.4 | 2.2 | 3.4 | 2.8 | 3.4 | 18.9 |
| | N | 7 | 12 | 12 | 11 | 3 | 8 | 12 | 12 | 10 |
| Arizona Females | | | | | | | | | | |
| | MEAN | 42.3 | 17.4 | 14.8 | 558.7 | 404.0 | 265.0 | 54.1 | 34.0 | 4.5 |
| | VAR | 3.8 | 0.4 | 0.4 | 1234.9 | 0.0 | 197.0 | 1.7 | 0.2 | 0.1 |
| | CV | 4.6 | 3.6 | 4.3 | 6.3 | 0.0 | 5.3 | 2.4 | 1.3 | 7.0 |
| | N | 3 | 4 | 4 | 3 | 1 | 4 | 4 | 4 | 6 |
| California Females | | | | | | | | | | |
| | MEAN | 44.8 | 17.8 | 14.9 | 621.1 | — | 286.3 | 57.5 | 35.2 | 5.1 |
| | VAR | 1.1 | 0.7 | 0.4 | 348.1 | — | 246.6 | 3.3 | 2.5 | 0.1 |
| | CV | 2.3 | 4.7 | 4.2 | 3.0 | — | 5.5 | 3.2 | 4.5 | 6.2 |
| | N | 6 | 11 | 11 | 8 | — | 11 | 11 | 6 | 6 |
| Alaska Females | | | | | | | | | | |
| | MEAN | 46.1 | 17.3 | 15.4 | 652.3 | 459.5 | 289.2 | 57.7 | 36.3 | 5.8 |
| | VAR | 1.8 | 0.9 | 0.7 | 261.5 | 351.2 | 3487.4 | 3.3 | 1.0 | 0.2 |
| | CV | 2.9 | 5.4 | 5.4 | 2.5 | 4.1 | 20.4 | 3.1 | 2.8 | 7.7 |
| | N | 27 | 27 | 27 | 24 | 21 | 26 | 27 | 27 | 26 |
| Greater Yellowstone Ecosystem Females | | | | | | | | | | |
| | MEAN | 44.5 | 17.5 | 16.0 | 595.8 | 472.9 | 296.8 | 54.9 | 35.8 | 4.9 |
| | VAR | 1.9 | 1.1 | 0.5 | 235.4 | 419.8 | 273.5 | 1.5 | 2.2 | 0.1 |
| | CV | 3.1 | 6.0 | 4.4 | 2.6 | 4.3 | 5.6 | 2.2 | 4.1 | 6.4 |
| | N | 4 | 6 | 6 | 5 | 3 | 6 | 6 | 6 | 4 |

* All measurements in mm except weight (kg).

CV = Coefficient of Variation.

Arizona, California, and Greater Yellowstone Ecosystem eagles were breeding adults of known sex. Sex of Alaska breeding adults was based on body measurements (T. Bowman pers. comm.). Data for the Greater Yellowstone Ecosystem was supplied by Al Harmata, and Alaska data by Tim Bowman and Phil Schemph, USFWS.

Table A5.4-2. Comparison of morphological characteristics of adult bald eagles from four populations.^{1*}

| | Hallux Length (Arc) | Tarsus Width Dorsal/ Ventral | Tarsus Width Lateral | Wing Cord (Arc) | Eighth Primary (Flat) | Tail Length | Culmen Length (Arc) | Beak Depth | Weight |
|---|---------------------------|---------------------------------------|----------------------------|-----------------------|-----------------------------|----------------|---------------------------|---------------|--------|
| Arizona Males | N 10 | 10 | 9 | 7 | 5 | 8 | 10 | 10 | 12 |
| California Males | N 7 | 9 | 9 | 3 | | 9 | 9 | 7 | 10 |
| Alaska Males | N 33 | 33 | 33 | 29 | 27 | 33 | 33 | 33 | 32 |
| Yellowstone Males | N 7 | 12 | 12 | 11 | 3 | 8 | 12 | 12 | 10 |
| Arizona Males vs California Males | | | | | | | | | |
| t-Test | 5.5583 | 1.1727 | 2.2874 | 4.4064 | | 3.7758 | 8.26478 | 2.5214 | 6.421 |
| df | 15 | 17 | 16 | 8 | | 15 | 17 | 15 | 20 |
| p < | 0.0001 | | 0.05 | 0.01 | | 0.01 | 0.0001 | 0.05 | 0.0001 |
| Significance ² | **** | NS | * | ** | | ** | **** | * | **** |
| Arizona Males vs Alaska Males | | | | | | | | | |
| t-Test | 9.0564 | 0.0508 | 3.4377 | 10.91 | 7.3533 | 5.7677 | 7.12666 | 4.43617 | 13.208 |
| df | 41 | 41 | 40 | 34 | 30 | 39 | 41 | 41 | 42 |
| p < | 0.0001 | | 0.01 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| Significance | **** | NS | ** | **** | **** | **** | **** | **** | **** |
| Arizona Males vs Greater Yellowstone Ecosystem Males | | | | | | | | | |
| t-Test | 5.1721 | 1.586 | 4.3063 | 0.8045 | 4.4748 | 4.7125 | 5.44021 | 1.5699 | 3.2844 |
| df | 15 | 20 | 19 | 16 | 6 | 14 | 20 | 20 | 20 |
| p < | 0.001 | 0.2 | 0.001 | | 0.01 | 0.001 | 0.0001 | 0.2 | 0.01 |
| Significance | *** | NS | *** | NS | ** | *** | **** | NS | ** |
| Arizona Females | | | | | | | | | |
| N | 3 | 4 | 4 | 3 | 1 | 4 | 4 | 4 | 6 |
| California Females | | | | | | | | | |
| N | 6 | 11 | 11 | 8 | | 11 | 11 | 6 | 6 |
| Alaska Females | | | | | | | | | |
| N | 27 | 27 | 27 | 24 | 21 | 26 | 27 | 27 | 26 |
| Yellowstone Females | | | | | | | | | |
| N | 4 | 6 | 6 | 5 | 3 | 6 | 6 | 6 | 4 |
| Arizona Females vs California Females | | | | | | | | | |
| t-Test | 2.5511 | 0.903 | 0.4155 | 3.7983 | | 2.3851 | 3.48256 | 1.51087 | 3.0353 |
| df | 7 | 13 | 13 | 9 | | 13 | 13 | 8 | 10 |
| p < | 0.05 | | | 0.01 | | 0.05 | 0.01 | 0.2 | 0.02 |
| Significance | * | NS | NS | ** | | * | ** | NS | ** |
| Arizona Females vs Alaska Females | | | | | | | | | |
| t-Test | 4.4622 | 0.2671 | 1.4556 | 7.9525 | 2.9628 | 0.8145 | 3.85001 | 4.69524 | 7.8409 |
| df | 28 | 29 | 29 | 25 | 20 | 28 | 29 | 29 | 30 |
| p < | 0.001 | | 0.2 | 0.0001 | 0.01 | | 0.001 | 0.0001 | 0.0001 |
| Significance | *** | NS | NS | **** | ** | NS | *** | **** | **** |
| Arizona Females vs Greater Yellowstone Females ³ | | | | | | | | | |
| t-Test | 1.7988 | 0.1131 | 3.0077 | 2.0584 | 3.3629 | 3.1641 | 0.92217 | 2.43023 | 2.2926 |
| df | 5 | 8 | 8 | 6 | 2 | 8 | 8 | 8 | 8 |
| p < | 0.2 | 0.02 | 0.10 | 0.10 | 0.02 | 0.05 | 0.10 | | |
| Significance | NS | NS | ** | NS | NS | ** | NS | * | NS |

* All measurements in mm except weight (kg).

¹ Arizona, California, and Greater Yellowstone Ecosystem eagles were breeding adults of known sex. Sex of Alaska breeding adults was based on body measurements (T. Bowman pers. comm.). Data for the Greater Yellowstone Ecosystem was supplied by Al Harmata, and Alaska data by Tim Bowman and Phil Schempf, USFWS.

² Significance; NS=Not Significant; * Significant; ** Very Significant; *** Highly Significant; **** Very Highly Significant

³ The lack of significant difference in morphological characteristics of Arizona and Greater Yellowstone Ecosystem females is likely due to low sample size.

significantly from Alaska and California females in lateral tarsus width; neither did they differ significantly from California females in beak depth, nor from Alaska females in tail length. (We speculate that natural selection allows little variation in tarsus width because large tarsi would encounter more water resistance during attacks on fish, a factor that would not vary geographically). Arizona females did not vary significantly from the Greater Yellowstone Ecosystem females in six measurements: hallux length, dorsal/ventral tarsus width (as mentioned above), arc of the wing cord, eighth primary length, culmen length, and weight. However, it is evident from the table that for Arizona females ($n = 4$) and Greater Yellowstone Ecosystem females ($n = 6$), the lack of significance may be due to small sample size. Similarly, small sample size for Arizona females likely accounts for some lack of significance in comparisons with California and Alaska females.

These comparisons show that Arizona bald eagles are significantly smaller than those in Alaska, California, and the Greater Yellowstone Ecosystem, and that among these populations, Arizona eagles are more similar in size to those of the Greater Yellowstone Ecosystem than to those of California or Alaska. We also measured one adult male bald eagle found dead below a nest on the Rio Yaqui, Sonora, Mexico in 1988; its morphological characteristics were similar to those of Arizona males.

A5.4.4 The Question of Inbreeding

The chances of an incestual pair bond (brother/sister, or parent/child) are greater in a small population such as occurs in Arizona. Newton (1979) writes that incestual matings are rare, but when they do occur, the pair tends to be less productive than unrelated pairs. We have observed 17 eagles within Arizona pairs that were banded prior to our study (see Section C6.4). We have read the bands of six of these, none of which was nesting in its natal area. Of the remaining 11 birds, only three could possibly be breeding in natal territories because no nestlings had been banded at eight of the sites.

Bald eagles have been known to return to their natal areas after dispersal, and occasionally remain near the nest area for extended periods (Stalmaster 1987). We recorded five instances of juveniles perching near nest sites following migration; two were visiting their natal areas (see Sections C5 and A4). The Orme (JZ02) and Ladders (JP23) juveniles returned to their natal breeding areas and perched near the nest after migration, while three others were found near nests in other breeding areas. The Fort McDowell juvenile (JM03) perched throughout the Orme and Blue Point territories, adjacent to his natal area, while the East Verde juvenile JL20 perched near the Bartlett nest. A 1989 nesting (purple band) perched near the Ladders nest following migration. In addition, subadult eagles have been observed attempting to enter nests, or perching near nests, at Cliff in 1985 (see Section D4.9), Ladders in 1985 (see Section D4.17), and Fort McDowell in 1987 (see Section D4.13).

Both the electrophoretic (Section E7) and the DNA fingerprinting data (Section E6) suggest that the Arizona population has a healthy level of genetic heterozygosity. In fact, the Arizona samples demonstrated equal or higher variation when compared to the other populations surveyed. Since it is possible that the current small eagle population has only recently rebounded from an even smaller one, and that the effective population size in Arizona is much lower than the actual number of pairs holding territories, such a result must be regarded as pleasingly unexpected. If the high genetic variability is more than just an artifact of the sampling of enzymes and DNA fragments, the Arizona eagles would appear to have low chances of being immediately reduced by inbreeding effects, and the population may have a fair chance of surviving environmental change.

The higher-than-expected variation has four possible explanations: (1) that genes have recently infused from outside sources; (2) that DDT did not reduce the southwestern bald eagle population to levels at which alleles would drift to fixation; (3) that there have not been enough generations since the occurrence of a population bottleneck for genes to drift to fixation; and, (4) that chance events have maintained heterozygosity among the relatively few loci examined.

It is tempting to embrace the first explanation, that heterozygosity in the Arizona population is a result of recent immigration of genes from other populations – Arizona being a sort of “melting pot” of genes from elsewhere in North America. But would not this explanation demand correspondingly high variances in mensural characters, given the discrepancy in size between Arizona eagles and those of most other populations? According to our data, Arizona bald eagles are significantly smaller than eagles native to Alaska, California, or the Yellowstone, and there is no overlap in some characters (see Section A5.4.3). Intrapopulation variance in measured characters is somewhat similar among all four regions.

If bald eagles from more northern areas were remaining to nest in Arizona, we would certainly have encountered larger birds among the breeding adults we captured and have noted more obvious size variance among the many nestling eagles we examined. A size discrepancy is obvious when comparing winter migrants in Arizona with native eagles.

There is, of course, the possibility that environmental factors influencing development of Arizona bald eagles consistently reduce body size despite a large genetic component of variance due to immigration. However, since they exploit a variety of habitats (*e.g.*, altitudinal variation) and food supplies, a position which favors “nurture” over “nature” as an explanation of small size seems far-fetched.

The possibility of recent immigration from the east seems unlikely on the basis of known or probable movement patterns of eastern populations. There are considerable gaps in bald eagle habitat distribution between the southwestern population and any population in the east or northeast. The electrophoretic data does suggest a greater affinity of the Arizona eagles to the Maryland sample than to the other populations. However, as the authors point out, the electrophoretic comparisons dealt with only a few loci and fairly small samples.

Another strike against the “melting pot” hypothesis is that, despite the large numbers of bald eagles that have been banded throughout this continent, the only banded eagles thus far encountered breeding in Arizona are those which were banded as nestlings in Arizona by Robert Ohmart and Teryl Grubb. During our study, we sighted 18 eagles banded prior to 1986, 16 of which were breeding when we sighted them (see Section C6). We read the bands of eight of the 18 birds, all of which were banded as nestlings during previous studies in Arizona.

To test the idea that bald eagles tend not to breed far from their natal sites, questionnaires were sent to and received from researchers studying nine populations of bald eagles (see Table A5.2-2). Their responses indicated that only two nestlings out of thousands banded were found to have bred in other areas. One moved 331 km (205 miles) north from its natal site in the Greater Yellowstone Ecosystem (Al Harmata, *in litt.*); the other travelled 418 km (260 miles) south from its natal site near Charleston, South Carolina to nest in Ocala National Forest, Florida (Tom Murphy, pers. comm.; Petra Wood, *in litt.*). In contrast, the tendency for banded nestlings to breed within their natal populations is well known (see Section A5.2).

In our opinion, an equally fertile hypothesis for the healthy observed degree of heterozygosity in Arizona is that the southwestern bald eagle population was never seriously reduced during the DDT period. Remember, that we have circumstantial evidence of only three "new" pairs among the twenty-eight breeding areas known and there are unknown numbers of pairs in adjacent Mexico. The situation may be analogous to that of the peregrine, another raptor that experienced large-scale population declines as a result of DDT. At the time of this writing, the center of distribution of nesting peregrines in the contiguous United States is in Arizona and southern Utah where nearly 300 known pairs are breeding, and many more are thought to be undetected (Tim Tibbitts and Richard Glinski, unpublished). Peregrines and bald eagles may feed on some of the same species of (contaminated?) waterbirds, and yet peregrines in the southwest obviously survived in significant numbers, if indeed they were ever seriously reduced. Like bald eagles in Arizona, peregrines may have escaped detection by nesting in wilderness (see Hunt 1977).

Finally, it seems possible that ambient levels of heterozygosity in bald eagles living in the southwest may have been high in pristine times because of the shifting selective pressures characteristic of the wet and dry cycles of desert environments.

A5.4.5 The Question of Adaptation to the Desert Environment

Have specific adaptations evolved in Arizona that enable bald eagles to cope with conditions that appear to us substantially different from those encountered by other populations? The most striking feature of the Arizona environment is the combination of high temperature *and* low humidity.

Water loss during incubation is a critical factor in the successful hatching of raptor eggs in the laboratory. The rate of water loss can be manipulated by regulating ambient humidity and by actually adjusting shell porosity through adding or subtracting thickness. Staff of The Peregrine Fund, Inc. often wax shells to add thickness, or sand them down if necessary to increase rates of water loss.

If the environment was really as abnormal for eagles as it appears, the forces of natural selection, acting through egg hatchability and nestling survival, might well have been powerful enough to create local adaptations even in the face of a small amount of gene flow between populations. However, the infusion of genes from extrinsic sources is a powerful force opposing the evolution of local adaptations.

Evolutionary changes involving eggshell morphology, embryonic metabolism, and the adaptations of nestlings to heat stress and dehydration might involve a relatively small number of genes. It is very highly unlikely that such genes would be detectable in the broad studies of genetic variation reported in Sections E6 and E7 (neither of which display great numbers of loci). In neither study were alleles or fragments detected in Arizona that were not also detected in other populations. Our studies of eggshell morphology (Section E5) did not demonstrate differences in shell porosity between eggs collected in Arizona and elsewhere. If differences existed, they would have apparently been obscured by structural irregularities apparently resulting from contamination (see Section E5).

In sum, we cannot show a quality of uniqueness among the Arizona eagles that implies the existence of adaptations to the desert environment, even though the Arizona bald eagles are smaller than those from California and the Greater Yellowstone. The Florida birds are known to be small as well (no adequate sample of measurements of breeding adults in Florida is available). However, the similarity coefficients calculated from the DNA fingerprinting data, suggested that Arizona and Florida eagles were not closely related.

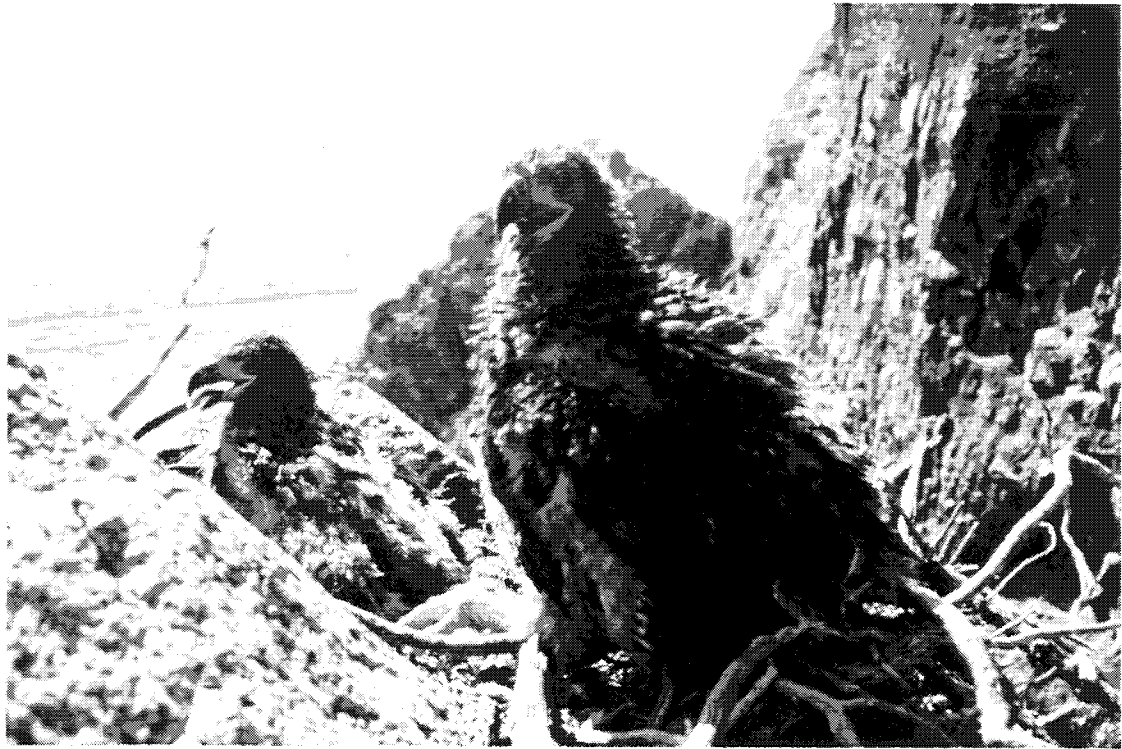


Plate A17. Nestling bald eagles at the Orme breeding area, April 1992. Note the VID band on the left tarsus (photo by D. Driscoll).

In reviewing the evidence at hand, we believe it unjustified to hold the opinion that the Arizona population has been recently founded, say, since the dams were built, or since 1970 when people began finding more and more pairs. First of all, we can say with some assurance that the current population did not recently derive from a collection of migrants from the north or northwest, since these are larger in body size than the Arizona birds (we discount the environment/heredity argument). The only "credible" scenario for recent founding is that bald eagles from the southeastern United States arrived in Arizona in sufficient numbers to have carried with them the currently observed high levels of genetic variability, and also escaped the early loss of alleles through inbreeding (it might be helpful to calculate linkage disequilibrium values to test the "melting pot" concept). Is it not more parsimonious to imagine that a population, even one thinly distributed throughout Arizona and northern Mexico, was large enough to survive intact from pristine times?

We speculate that, in the cooler and wetter post-glacial period (and even to some extent historically), Arizona bald eagles were part of a larger western population that extended from Alaska southward through the continent and along the Pacific coast to the Baja peninsula, including the Sea of Cortez. Its distribution probably included the rivers of mainland Mexico and the Colorado drainage. The great environmental clines, extending from the wet forests of Alaska and British Columbia to the arid southwest, would have strongly encouraged morphological differentiation just as they did for other far-ranging birds, such as the peregrine. The latter species is highly mobile, and yet polytypic over this same

range (*Falco peregrinus tundrius* → *anatum* → *pealei* → *anatum*, from northern Alaska through Mexico). *F.p. pealei* has clearly adapted to the very wet environment of coastal British Columbia and Alaska (Beebe 1960). Among these adaptations is a striking ability to shed water from its plumage through the manufacture of copious amounts of powder down (T. Cade, pers. comm.). It seems equally logical that physiological adaptations could have evolved among bald eagles inhabiting the southwestern deserts, but there is no evidence for or against it.

A5.4.6 Discussion

Although we are encouraged by the robust levels of variability suggested by the genetic analyses, there is no reason to believe that population bottlenecks occurring in the future would not be highly deleterious. The current retention of heterozygosity among the Arizona bald eagles may be largely a matter of good fortune (see Section A5.4.2), and if the population maintains itself, there seems no obvious specter of genetic difficulties.

Because the Arizona eagles may contain adaptations related to desert conditions (small size would appear to be one of them), a decision to release birds into Arizona from elsewhere should be considered only as a last resort because foreign genes might disrupt coadapted gene complexes specific to the desert population (see "outbreeding depression" in Section A5.4.2).

In the event that bald eagles were reduced to a point where release of extraneous birds became necessary, it would be well to know in advance which population would be most appropriate as a donor. Since Dr. Vyse (Section E6) has been able to retain the DNA samples provided him through this project, we recommend he be encouraged to learn more about them as additional probes become available.

A5.5 THE STATUS OF NESTING BALD EAGLES IN ARIZONA

Bald eagles continue to be officially listed as endangered over most of the 50 states, even though some regions, like Florida or Chesapeake Bay, now appear to contain healthy populations that might be downlisted to "threatened" status, or removed from the list altogether. The 1982 amendments to the Endangered Species Act made it clear that the decision to reclassify a species must only be made for biological reasons, never for economic or other non-biological considerations. A species is listed as endangered when it is determined biologically that it is in danger of becoming extinct over a significant portion of its range in the foreseeable future. The criterion for threatened status is whether the species is soon likely to become endangered.

When a species is officially listed as endangered, the USFWS usually develops a formal recovery plan that specifies the management tasks necessary to restore the species and the recovery goals required for downlisting and delisting. For endangered raptors, recovery goals for regional populations are usually stated in terms of a minimum number of occupied sites, a minimum proportion of reproductively successful sites, and, a minimum number of young per occupied site.

For Arizona, whose bald eagle population is currently being considered for downlisting, the recovery goals written in the 1982 Southwestern Bald Eagle Recovery Plan were: (1) the achievement of an overall reproductive output of 10-12 young per year; and, (2) that one or more pairs occur in a drainage other than the Salt and Verde rivers (U.S. Fish and Wildlife Service 1982). These goals have clearly been met (see Sections A2, C2, D4); however, it would be well to consider the demographic information gained

from this study before decisions are made to reduce the level of protection and management now allocated to the Arizona Bald Eagle.

Believing they had observed more than 90 percent of the Arizona bald eagle population by 1975, Rubink and Podborny (1976) estimated its size at 30-34 individuals, consisting of 18 adults, 11 subadults, and 5 juveniles. Similarly, Hildebrandt and Ohmart (1978) appraised the population at 30-35 eagles, consisting of 17-18 adults, 8-12 subadults, and 5 juveniles. Hildebrandt (1981) later estimated the population to be about 30 individuals: 20 adults and 7-10 subadults. A figure of 25-30 individuals was used when the Southwestern Bald Eagle Recovery Plan was written (U.S. Fish and Wildlife Service 1982). Population estimates were not given in documents stemming from the research of Haywood and Ohmart (1981, 1982, 1983), Grubb *et al.* (1983), or Grubb (1984, 1986a).

The number of known occupied bald eagle nesting territories in Arizona has increased from 13 sites when the recovery plan was published in 1982, to 23 in 1988. As discussed in Section A2, no change has been apparent in nest success per occupied site. There were 14 known young produced in 1982, compared to 24 in 1988, although productivity was lower in 1989 (13 young) and 1990 (14 young).

It will never be known to what extent the increase in the number of known pairs was an artifact of sampling. Some sites (i.e., Cliff, Alamo, and Sheep) are very likely newly occupied. However, some of the "new" sites discovered during surveys in the 1980s may have been active for many years (see sections C2, D3, and D4). It is one thing to locate a nest in an area where eagles are known to have bred in years past, but quite another to find one in an unfamiliar area. In our opinion, many or most active nests would be difficult to locate without prior knowledge that a pair existed in the area (*e.g.*, Blue Point, Orme, Canyon, Ash, Lone Pine, Cedar Basin). What percent of the currently active nests could a visiting biologist find via helicopter without prior knowledge of their locations? Even biologists working closely with the Arizona population for several years, and having nest maps in hand during helicopter surveys, often find it difficult to locate nests.

In any case, the occupancy and reproductive data suggest that the Arizona population of bald eagles may be viable over the long term. Adding strength to this view is that electrophoresis and DNA-fingerprinting of blood samples from the current population show a level of genetic variability comparable to that of apparently healthy bald eagle populations elsewhere. If the genes assayed truly represent the gene pool, then these healthy levels of heterozygosity imply that the Arizona eagles are not currently experiencing inbreeding problems and may be capable of adapting to future environmental change.

In assessing population status, we must also evaluate the significance of the population with respect to other bald eagle populations. Is the Arizona population merely a scattered fringe of outlying pairs radiating from a larger population centered outside Arizona? Or is the population unique, somewhat isolated from immigrant genes, and adapted to a desert climate?

As discussed in Section A5.4, the possibility that Arizona bald eagles may differ from other populations in possessing adaptations relating to the desert environment remains unresolved. The desert environment is truly extreme for the species. Circumstantial evidence suggests that heat stress may impact brood survivorship of some years (see Section C3.5), and would no doubt exert powerful selection for genes appropriate to such an environment. Arizona bald eagles are smaller than their counterparts from California, but are biochemically more similar to those in California than those from Florida, where eagles are also small (Section E6). We found no overlap in certain mensural characters between Arizona

eagles and those from California or the Yellowstone, but there is little dissimilarity in variance. No banded individuals from elsewhere have been detected breeding in Arizona. These points suggest little or no recent gene flow into Arizona from other regions.

Until adults banded as young elsewhere are observed breeding in Arizona, there is sufficient justification to reject the notion that the Arizona bald eagles are part of a larger population elsewhere whose status assessment would apply to Arizona. The Arizona population appears viable from a genetic standpoint, but were the population extirpated, there is no firm reason to believe that bald eagles released into Arizona from elsewhere would possess the adaptations required to increase their numbers. Furthermore, releases to augment a reduced population in Arizona could be deleterious because of genetic disruption of existing adaptations.

The 1982 Recovery Plan did not address the issue of bald eagle mortality in Arizona. Our data on deaths among all age classes (Section A5.2 and C3) illustrate numerous and diverse examples of human-related mortality. We have also found a high frequency of mate-replacement at some nests (indirect evidence of mortality), and the recurrence of subadults and near-adults as members of pairs (Section A5.2).

Understanding the possible consequence to a population of a reduced floating segment requires an understanding of how populations of bald eagles are naturally regulated (see Section A5.1). In a normal population which is expanding, pairs will come to occupy all serviceable breeding locations (SBLs); these will generally support eagles year after year because it is mainly the physiographic aspects of a territory that influence its quality as habitat (Hunt 1988). Where food and nest sites are abundant, pair densities will be limited by territoriality and otherwise by a particulate distribution of SBLs, each supporting one pair. When virtually all SBLs are occupied, a floating population of nonbreeding adults will accumulate until the death-rate and birth-rate of the population are the same. Floaters may attempt to displace members of breeding pairs, and in doing so may cause reduction in breeding success (Hansen 1987). This, in turn, may reduce the number of floaters through effects on natality. However, this density-dependent feedback mechanism would not reduce the number of pairs attempting to breed because the latter is a function of habitat availability with somewhat stable elements.

Populations regulated by such a process have the appearance of being quite stable (Figure A5.2-7). As long as floaters are numerous enough to fill breeding vacancies as they occur, the number of breeding pairs will be more or less constant from year to year. But if the mortality rate becomes excessive in any age class or among a combination of classes, the first sign of a problem is the appearance of young individuals as members of pairs. If the trend continues, the breeding population will *suddenly* begin to decline, and in the worst case will collapse.

The occurrence of young individuals as members of pairs may also characterize expanding populations. In this case, the floating populations may not have had time to develop a stable age structure, and territories might be occupied by individuals just old enough to breed. Under these conditions, there is comparatively little likelihood of risky encounters with older, more dangerous individuals competing for the same sites. With normal rates of survivorship, however, adults will come to dominate the breeding population virtually to the exclusion of younger birds, and will consistently occupy long-established sites in favorable habitat.

As discussed in Section A5.2, the Arizona population currently differs from other populations in North America in having greater numbers of near-adults as members of pairs. The higher frequency of near-

adults may be signaling an expanding population. It is curious, however, that eagles nesting on Chesapeake Bay or in Florida, for example, have not also shown significant numbers of near adults, since both these population have rapidly expanded in the recent past. Despite observations of large numbers of pairs in both areas, very few near-adults have been noted as breeders (see Section A5.2.3).

It is our opinion, on the basis of mainly circumstantial data, that bald eagle mortality in Arizona is currently high enough to warrant concern for the future of this possibly unique population. If the rates of adult turnover at sites near Phoenix during our study are representative of the entire population, then there is no question that the population is in danger of decline. Because the population is already small, a decline would exacerbate the dangers inherent in small populations.

Therefore, we argue that despite a presumed increase in the number of known breeding areas, Arizona's bald eagle population continues to show signs of vulnerability. The summary points include: (1) no evidence of gene flow from outside sources; (2) an effective population size perceived small enough to be susceptible to genetic, demographic, and environmental threats (see A5.4.2); (3) evidence for high adult mortality at some sites; and, (4) indication of deficient age-structure in the floating population.

The latter factor is pivotal, for it indicates the absence of a buffer. If, in the future, there is a reduction in the occurrence of near-adults as members of pairs at long-occupied sites, the status of the population may be considered more secure. Management efforts should be focused toward this end, i.e., encouraging survivorship, especially the survivorship of breeding adults.

A6 GENERAL MANAGEMENT RECOMMENDATIONS

In Section B4, BioSystems offers specific recommendations on management strategies to benefit bald eagles at seven nesting territories in Arizona. These recommendations are based on analyses from telemetry studies of home range, foraging observations, fisheries investigations, habitat mapping, and observations of human disturbance. In the current section, BioSystems makes recommendations of a more general nature, basing these on an overview achieved during the work at each of the nesting territories and on accumulated knowledge of the population as a whole.

A6.1 PREY POPULATION MANAGEMENT

A6.1.1 Flow

Decisions on whether or not to allow additional water diversion or projects that may affect the riparian community should consider the potential impact on bald eagle prey. For example, current fish communities and species abundances in Arizona river reaches supporting nesting bald eagles may be altered if instream temperatures significantly change, although it is unknown whether such changes would affect bald eagle occupancy and reproduction. In unregulated reaches, instream temperatures may increase if riparian habitat is lost or if additional water is diverted. In regulated river reaches, temperatures may be significantly altered if: (1) withdrawal depth changes; (2) reservoir elevation changes such that water is withdrawn from a different layer of the reservoir; or, (3) discharge is modified. Changes in water management in the late spring and summer when reservoirs are stratified and ambient temperatures are high would be of greater concern than changes during the winter. We recommend study of how each of these factors influence carp, sucker, and catfish populations in riverine habitats used by eagles.

In past years, SRP has routinely shut off flow below Bartlett and Saguaro reservoirs but seepage from the dams maintained a base flow of at least 9 cfs. The leaks in the dams have recently been repaired, so that, presently, when SRP closes their valves, the Verde and Salt rivers stop flowing, leaving only isolated pools. When large areas of the rivers are dewatered, the invertebrate community significantly declines. Fish are also concentrated into relatively small areas increasing competition and predation. In 1989, we found oxygen concentrations in isolated pools on the Salt River that had fallen below 1 mg/l when flows were stopped for several weeks. Although suckers are adapted to low oxygen conditions, we observed many dead and dying suckers in pools on the Salt River in 1989. While immediate effects of low oxygen concentrations may be to increase carrion for bald eagles, we are unsure of the long-term effects on prey populations. We recommend further study.

During our study, we identified several tributaries on the Salt and Verde rivers that are regularly visited by eagles. Future diversions from these streams should be evaluated carefully to ensure maintenance of fish populations and riparian communities. Important tributaries to protect on the Verde River include West Clear Creek, Fossil Creek, and East Verde River; continued supplemental water imports to the latter are probably essential to maintain the character of this tributary as habitat for nesting and wintering eagles (see Section B4.4). The important tributaries on the Salt River are Tonto Creek, Cherry Creek, Canyon Creek, Ash Creek, Carrizo Creek, and Cibecue Creek.

A6.1.2 Pollution

An important management strategy favoring bald eagles over the long term is to monitor concentrations of heavy metals, chlorinated hydrocarbons, and other pollutants (see Risebrough, Section E4). Fish store some of these contaminants in their tissues and may contaminate bald eagles. Fish populations are also negatively impacted by pollution; in this study we suspected pollution problems when we found very few fish in certain tributaries, *e.g.*, Pinal Creek and Carrizo Creek. We should be especially sensitive to contaminants in watersheds draining into the Salt and Verde rivers, although some of the contamination may be natural. We were unable to detect impacts of contamination on bald eagle productivity in Arizona.

Contaminants in waterbirds are harder to prevent since they may migrate out of Arizona. Waterfowl are good indicator species of pollution in the larger ecosystem, and levels should be monitored on a periodic basis. Recent steps to prohibit the use of lead shot for waterfowl hunting in Arizona may also be important in reducing potential impacts.

A6.2 BALD EAGLE HABITAT MANAGEMENT

Habitat improvement for nesting bald eagles may be more feasible and effective than for many species because eagles are contained within identifiable and somewhat narrow bounds. Compared to other species whose habitats are measured in hectares or square miles, the bald eagle's habitat is distributed along one dimension, that described by a river; nesting and foraging are usually close to the water.

Enhancing habitat could benefit bald eagles in Arizona because the breeding population is small. Each pair tends to use exactly the same area year-after-year. Habitat improvement in a particular area would therefore continue to benefit eagles and, through yearly accrual of effect, be of significant and lasting benefit to the population. Survivorship is naturally high among eagles, so that increased natality at a single site might tend to affect a population gain.

In the balance, tree nests and cliff nests are both serviceable as components of nesting habitat for bald eagles in Arizona. In this study, we found no significant difference in nesting success between the two substrates. Advantages of live trees over open cliff sites as nesting places for bald eagles are that trees are generally cooler because they may offer shade to adults and young and are less likely to distribute heat to the nest through conduction or reflection; trees do not appear to support infestations of chicken bugs. Both heat and chicken bugs may compromise productivity among Arizona bald eagles. A drawback to trees is that eagles using them are often closer to human disturbance, and thus tree nests may require more protection by managers. Trees are also less stable in holding nests and trees eventually die and fall down. Finally, trees are more accessible to predators and not as easily defended from other eagles.

Our first recommendation regarding nest tree management is that trees and stands currently supporting nesting eagles should be rigorously protected from loss, encroachment, and stand reduction. Successful nesting demonstrates that good foraging habitat is present. The quality of foraging habitat is largely physiographic and therefore may be long-lasting, but preservation of historically-used nest trees and groups of trees may be necessary to the preservation of the breeding area. It would be wrong to assume that because other apparently suitable trees exist a few miles away that the eagles can simply relocate.

There are a number of areas where husbanding new trees for the benefit of bald eagles might aid in the establishment of new pairs. For example, much of the Verde River between Bartlett Dam and the Salt River confluence appears to contain good foraging habitat for bald eagles. We recommend fencing some areas and planting trees, especially in areas with nearby super-riffles.

The planting of fenced cottonwood and willow groves could benefit bald eagles in areas devoid of trees. Fences, however, must be strong and well maintained in order to keep out grazing cattle. Chicken wire may be needed to restrict access by beavers. To be functional as bald eagle nesting habitat, the groves would have to be placed in areas of minimal human impact.

In some bald eagle breeding areas, nest trees (or snags) are senescent, and regeneration has been retarded by cattle. The Sheep breeding area is in immediate danger of loss. The pair has never been successful, although two young hatched in 1986. The nest tree is falling apart, as are other large cottonwoods along Tonto Creek. This area also receives heavy disturbance from recreationists (shotgun shells and beer cans are picked up annually under the nest). A posted and fenced-in cottonwood plantation would benefit eagles in this area.

The Fort McDowell breeding area is another site where a fenced plantation is needed. The mesquite bosque below nest 11 has been thinned by wood-cutters, and many of the other cottonwoods in the area are falling apart. Fort McDowell has had 13 known nest trees, most of which have fallen. Fort McDowell has been the most productive breeding area in Arizona and its loss might be significant to the population.

The Alamo nesting site may also be in need of nest tree management. The snags currently used by the pair are not in very stable condition and may fall in the near future. Since cattle have been removed from the north end of Alamo Lake, cottonwoods and willows are returning; however, tamarisk thickets have also erupted. A plan of tamarisk control may be needed in some areas to allow the current renewal of cottonwoods and willows a better chance of survival; however, the almost impenetrable stands of tamarisk may also operate as an effective deterrent to would-be nest visitors.

The old willow nest trees in the Horseshoe breeding area are no longer suitable for nesting. Most of these trees have fallen, although some snags (lacking branches) are still standing. The pair built nest 9 in the only remaining suitable nest tree in November-December 1989. Recreation pressure from Ister Flat to Sheep Bridge may be discouraging eagles from nesting in this stretch of the river. A fenced plantation opposite the nest cliff might be beneficial, although fluctuating reservoir levels may preclude tree survival and occasionally cause nesting failure.

Gleason Flat on the Salt River may be an ideal site for a fenced cottonwood plantation. The U.S. Forest Service has planted cottonwood poles here in the past, although a fenced grove would likely have a better chance of survival. Adult bald eagles have been sighted here in the winter and during the breeding season. The Ash and Canyon pairs may utilize this section of river (Driscoll 1985b). Both Ash and Canyon Creeks enter the Salt River just upstream of Gleason Flat.

Another area which may benefit from the planting of cottonwoods is the confluence of Salome Creek and Roosevelt Reservoir. Bald eagles used this area in the winter of 1988, and four adults (one being the Pinto female) foraged in Salome Bay. Artificial nesting structures may be important where nesting

locations are nonexistent, as will likely soon be the case at the Sheep breeding area. The reconstruction and stabilization of tree nests could have positive results.

Our data on nest failure due to heat stress suggests that shade management might reduce nestling mortality at some sites in years with high spring temperatures. A shade structure was installed at the Redmond breeding area and utilized by the eaglets the first year (Haywood and Ohmart 1983). The following year, the adults built the nest up to the shade level rendering it unusable, so the structure was removed (T. Grubb, pers. comm.).

The provision of a shade structure may prevent the eagles from using a site. Care must be taken to insure the eagles are not disturbed by the presence of the shade structure, and that the structure does not draw human attention to the nest location. One way around such problems might be to avoid altering recently-used nest sites, but rather provide long-lasting shade structures at ledges elsewhere within the area normally defended by the eagles. In selecting sites for shaded nests, isolation from predators and a commanding view of the landscape would both increase the likelihood of selection by the eagles and the potential for nesting success.

Mexican chicken bugs may cause nestling bald eagle mortality at cliff nests in Arizona and probably reduce the effective rate of reproduction to some extent (see Section C3.4). Fumigation of nests with pyrethrins might reduce infestations, at least in the years of application; pyrethrins are highly toxic to insects. Although more information is first needed on the invertebrate communities of bald eagle nests to determine if natural enemies of chicken bugs operate to reduce the probability of chicken bug infestations or to lessen their intensity, our opinion is that pyrethrins might benefit eagles if they were applied during routine banding operations. These chemicals, often used to spray canaries and other caged birds, are naturally produced by plants, and have been used for feather lice control on bald eagles in Alaska where researchers spray the eagles themselves with pyrethrins (M. Gibson, pers. comm.).

Insecticides other than pyrethrins are routinely used on poultry and caged birds and may possibly be safe for use with bald eagles (K. Ingram, DVM, pers. comm.). All, including pyrethrins, have the problem of being washed away by rain, and all must be applied at concentrations that are known to be appropriate. We recommend further study of parasites because of their probable effect on productivity among Arizona bald eagles, a matter of potential advantage to the population should the eagles decline to small numbers. Such studies would investigate (1) ways of safely reducing the incidence of Mexican chicken bugs in bald eagle nests; and, (2) the costs (if any) to bald eagles of reducing the numbers of other invertebrates living in nests.

A6.3 MANAGEMENT OF HUMAN FACTORS

In the sections below, we recommend a number of management strategies that might ameliorate human impacts on bald eagles in Arizona. It is important to remember in reviewing them that nest occupancy and success is only part of the demographic equation, albeit a major part. Healthy numbers of floaters can sustain bald eagle populations through periods of considerable adversity. In order to be effective in preserving Arizona's population of bald eagles, management decisions aimed at ameliorating human impacts must not only address site occupancy and productivity by the breeding segment, but must also seek to preserve the nonbreeders.

A6.3.1 Disturbance

BioSystems repeatedly emphasizes in this report that human disturbance at bald eagle nests in Arizona may be of real consequence to nesting success. We believe that the main impacts are from incidents in which adults are kept from eggs or young, particularly before they can thermoregulate. Other difficulties arise when eagles are discouraged by public users from nesting or foraging in otherwise favorable locations.

One general recommendation regarding disturbance management in behalf of eagles is to begin the Nest Watch Program early enough to protect incubating birds from being flushed, especially at territories subject to high levels of public use. Another consideration is to inform people regarding the specific difficulties eagles have with disturbances.

Eagles foraging in reservoirs are often attracted to shallow water, the extent and distribution of which may depend on reservoir elevation. It would probably be of benefit to eagles that future development of campgrounds, "beaches," and other facilities that attract public users to shorelines be situated away from shallow areas and inflows, especially those where perches are available. The same is true in areas along rivers where important eagle foraging sites are located. Such sites are not necessarily in the immediate vicinities of nests, but may be identified on the basis of known eagle use (see Section B4), or in the case of "super-riffles," by hydrological characteristics (see Section A3.3). Development should provide a buffer against disturbance of eagles on their foraging perches.

A6.3.2 Fishing

Anglers may disturb eagles at nests or foraging sites, or they may endanger eagles by leaving monofilament and fish hooks in the environment. We recommend an information program to alert anglers to these problems.

A6.3.3 Ranching and Farming

One impact of ranching on eagles is that cattle prevent the regeneration of riparian trees that would benefit eagles as nests and perch sites. We have no solutions to offer for this problem that have not already been expressed by others. We regarded it as probable that more eagles could nest along the rivers and be less susceptible to heat problems if there were more trees available. Fencing large areas for trees would probably help, as would removing livestock from the river environs.

Certain techniques of livestock predator control probably kill bald eagles in Arizona; these methods include poisoned carcasses and those with leg-hold traps placed around them. Because of the high use of carrion, bald eagles and some other raptor species are particularly vulnerable to these methods. Telemetry data on the movements of subadult bald eagles (Section A4.2) show that these birds commonly frequent areas some distance from the rivers in late winter and spring where we believe they forage on cattle carrion (see also Section B4). For this reason, we recommend that the use of poison or traps around animal carcasses be forbidden.

In Section C3.6, we describe the configuration of stock watering tanks that may trap eagles who enter them. The wire grids on top (see Figure C3.6-1), which prevent the eagles from escaping, are designed to secure a plastic lid during winter months; however, these lids are no longer used and the wires serve no functional purpose. This type of tank could be made safer for eagles simply by removing the wires, and safer still for eagles and other wildlife by placing a "ladder" at a shallow angle into the tank and

connecting it to the side and bottom. Such a ladder could be made from two parallel lengths of reinforcement bar with wire mesh between.

Farming has the potential of being highly detrimental to bald eagles in Arizona if certain chlorinated hydrocarbon pesticides are ever again used. We believe it wise to continue to periodically monitor pesticide levels in waterfowl, great-tailed grackles, starlings, and other indicator species, keeping in mind that some contaminants used south of our borders may enter the food web of eagles in the bodies of migrant waterfowl. Very high levels of DDE have been detected in cotton-growing areas in the southwest, even in the 1980s (Hunt et al. 1986). Finally, the possibility that new chemicals will appear, whose effects on eagles are unknown, should not be discounted.

Farming may also directly affect bald eagles on a territory-by-territory basis. Agricultural fields at Ft. McDowell are probably too close to the active nest, and wood-cutting is reducing the nest grove. We suggest a management program that provides a buffer zone of protection.

A6.3.4 Shooting

Although there is ample evidence that bald eagles in Arizona are at least occasionally shot (see Section C3), the overall magnitude of impact on the population is largely conjectural. When nesting adults disappear, particularly in areas of high human use, shooting is often the most parsimonious explanation.

Two main motives for shooting bald eagles come to mind: (1) casual and spontaneous recklessness with no over-riding appreciation for eagles; and, (2) the desire to obtain dead eagles. The later incentive might relate to the use of eagle parts in rituals or to profiting from the sale of eagle parts.

It is difficult to conceive a management strategy that would be completely effective in protecting eagles from people who want to shoot them. One possibility would be to reduce the desire to do so through information. In this regard, we recommend an information program that fills the imagination with positive images of eagles and compassion for them. A campaign designed to reduce the loss of bald eagles to shooting might be ineffective if approached directly; that is, by recommending that people refrain from shooting eagles, because, in our opinion, mentioning shooting and eagles in the same context might engender very inappropriate mental associations.

We do not know if eagles are commonly shot in Arizona for the use or sale of their parts, although there is evidence that feathers and feet are taken from dead eagles (see Section C3). We are at a loss to recommend a helpful management strategy in this regard; but again, a campaign to promote an appreciation of living eagles would probably help. Guarding the nesting areas for longer periods might be of benefit, but is perhaps impractical from a cost standpoint. Imposing stricter penalties for shooting within a designated closure might decrease the mortality rates of eagles, but we are far from certain of this.

A6.3.5 Survivorship of Non-breeders

The non-breeding segment of Arizona's native bald eagle population is largely nomadic, seasonally visiting a variety of habitats both within and outside Arizona. While we encourage the preservation of these habitats, we can identify only a few areas where the eagles tend to concentrate. These include: (1) the East Verde River; (2) the lower five miles of West Clear Creek; (3) the Salt arm of Roosevelt Reservoir from Salome Bay to the diversion dam; and, (4) the mouth of Carrizo Creek. Discussions of these areas are provided in Sections A4 and C5, but in the case of the tributaries, we are partly at a loss

in determining why they attract eagles. To what extent habitat programs designed to increase food availability to nonbreeding bald eagles might actually result in increased survivorship among them would be difficult to discover.

Far more concrete is the issue of direct mortality among nonbreeders. Sources of direct mortality, most of which are discussed elsewhere (see Section C3.7), include shooting (Section A6.3.5), poisoning and trapping, drowning in metal stock tanks (see Section A6.3.3), and electrocution. Our most significant recommendations regarding the welfare of nonbreeders include: (1) stimulating a greater public appreciation for bald eagles; (2) prohibiting the use of poison or traps around carcasses; (3) modifying certain stock tanks (see Section C3.6); and, (4) configuring powerlines to avoid the possibility of electrocution. High survival among nonbreeders is important to the welfare of the Arizona bald eagle population.

Our work thus far has shown that mortality is higher than expected. This conclusion is based on: (1) direct data on mortality as revealed by telemetry; (2) the incidental discovery of dead or critically injured birds; and, (3) mate replacement by near-adult eagles. Causes of the mortality are largely unknown, although human activities are often implicated. In the light of this, we recommend the acquisition of more data on the causes of mortality. We advise capturing and radio-tagging a reasonably large sample of subadult eagles (at least 20) in central Arizona, followed by frequent roll-call airplane surveys conducted from October through May in central Arizona for the main purpose of identifying mortality factors. Secondary data from such a study would yield a more detailed picture of habitat selection by the non-nesting segment.

A6.4 FUTURE PROGRAMS BENEFITING BALD EAGLES

During the course of this study, we have been aware of an extraordinary effort on the part of state, tribal, and federal agency personnel and a private utility in seeking to preserve Arizona's bald eagle population. At the periodic meetings of the Southwest Bald Eagle Management Committee we attended, there was communication, a sensitive processing of new information, the solving of real problems, the physical implementation of solutions ("action items"), acquisition and assignment of needed funds, and a spirit of cooperation. There can be no doubt that bald eagles benefit from the activities of the committee.

A6.4.1 Arizona Bald Eagle Nest Watch Program

The Arizona Nest Watch Program, started in 1978, has been a positive force in preserving bald eagles in Arizona. It is well known that the presence and activities of the nest watchers has resulted in a substantial increase in breeding success. For example, in 1984 when 15 young fledged, nine of them (60%) were saved by the nest watchers. On average, the nest watchers are thought to increase yearly productivity by 10-20 percent.

On the basis of our experience in the field, it is clear to us that some nests, such as Bartlett, Cliff, and "76," would hardly ever produce young without the aid of the nest watchers. Moreover, it is our opinion that adults would disappear from some sites at even greater rates if nest watchers were not present to protect them. For these reasons, we believe that the Nest Watch Program may be essential to the survival of bald eagles in Arizona.

Because of the vulnerability of eggs to exposure and predation, it is important to prevent incubating adults from being disturbed and flushed. We recommend that the nest watchers begin their vigils just prior to incubation at sites where disturbance is most anticipated. While eagles are incubating and brooding small young, we recommend continuous protection, rather than the "ten-days-on, four-days-off" schedule currently in use.

During pre-laying, incubation, and early brooding, it is important to advise the nestwatchers themselves not to approach the nest for any purpose. This is not only because of problems associated with exposure and predation, but because of adaptations that naturally long-lived birds such as eagles possess regarding site tenacity at the early stages of the reproductive cycle. Briefly, since its own reproductive value is high due to its expected long life, an adult is likely to suspend its reproductive attempt in the face of perceived risk when the reproductive value of eggs or small young is relatively low. The earlier disturbance occurs during the nesting season, the more likely nesting failure is to occur because of facultative reductions in reproductive effort.

Nest watchers are not only needed at breeding areas with high disturbance potential, but at certain other sites as well, particularly those with chronically low success rates or those where situational causes of failure are suspected. For example, we think that heat stress and Mexican chicken bugs frequently cause the Redmond pair to fail, but evidence has been largely "after the fact." Careful observations of the behavior of adults and young might reveal more easily recognizable symptoms. Thus, if direct management action is someday needed on a populational basis (i.e., if the survival of every nestling is deemed crucial), a diagnosis of impending mortality would be available and suggestive of intervention.

The Arizona bald eagle population collectively produces rather low numbers of young annually. Before entering the breeding population, these eagles are subject to a barrage of natural and recently derived mortality agents. These small cohorts inevitably dwindle, so the survivorship of each eagle may be significant. We recommend the continuance of the Nest Watch Program, its direct efforts in protecting eagles, and its acquisition of useful information about bald eagles, especially that regarding human and other factors affecting survivorship.

A6.4.2 Color Banding Program

The majority of mate turnover events presumably occur without anyone's knowledge. Two real consequences of this are: (1) there are no cues to managers for better protection of the birds; and, (2) chronic high adult mortality at specific sites may form drains through which significant numbers of floaters pass unnoticed out of the population. Mate switching is unknown in bald eagles in Arizona or elsewhere, so a turnover probably indicates that a mortality has occurred. Mate replacements happen very quickly, usually within the same season of loss, thus the cost to the floating population of repeated loss of one or both pair members to undetected mortality may be very high.

The Visual Identification (VID) Banding System (color/symbol) employed by BioSystems during this study makes it possible to identify individual eagles from distances of over 100 m with a telescope. The main purposes of the banding program are to estimate the age structure of the breeding population, and to ascertain mate replacement (recruitment) at specific territories. Neither of these kinds of data are meaningful within the time-frame of our study, but in the long term, the value of detecting mortality, especially at specific sites, is inestimable.

For example, even without bands, we have found *minimum* turnover rates for breeding adult eagles at the Bartlett and Blue Point territories to be alarmingly high (see Section C3.7). In five breeding seasons (1987–1990), there have been at least three different males at Bartlett and at least three different females at Blue Point. We come upon this information primarily because we intensively studied both sites. The cause of the turnover at Bartlett and Blue Point is probably related to the high levels of public use at these sites; the birds are very likely being shot.

To be successful, the VID banding program must continue into the future. We recommend that the agencies take it upon themselves to continue the banding of nestlings each spring for at least the next decade. The program would have several ancillary results including a fuller display of movements, habitat use, and age structure of the non-breeding population, a matter currently obscured (among non-telemetered birds) by their sharing of Arizona habitats with winter-visiting bald eagles from the north.

More importantly, the identities of all banded territory-holding adults can be verified each spring by competent observers. Such data would provide direct evidence of mate replacement, and therefore indirect data on adult mortality, given the assumptions of no mate exchanging or displacement (assumptions that would be clarified by reading the bands at many sites). Such information would also be of value in assessing the status of the floating population, using age of first breeding as a measure. The continued occurrence of four-year-old eagles as mate replacements would indicate a smaller-than-desirable floating population rather than an expanding population of breeding pairs. Finally, the ratio of banded to unbanded four-year-old replacements can be used to estimate the effective size of the breeding population by extrapolating the number of unknown pairs.

A6.4.3 Information

Ultimately, the fate of Arizona's small and possibly unique population of bald eagles will depend on whether people value it sufficiently. Our experience in the field clearly suggests that most people do regard bald eagles with admiration, respect, and interest. This probably has partly to do with the frequent celebration of the species by the media and the fact of it being our national bird. There can be little doubt that television specials, newspapers, and magazines directly benefit eagles, not only by invoking our appreciation, but also by producing pleasing images in our minds of the lives and habitats of wild eagles, thus educating us to the realities of their ecological needs.

The public has not always considered eagles to be wonderful. Only a few decades ago, it was common that all predators were thought of in highly negative terms, an opinion based on a profound lack of knowledge. The state of Alaska, for example, had placed a bounty on bald eagles because it was thought they competed with man for salmon. In the early 1950s, after 128,000 bald eagle bounties had been paid (Gerrard and Bartolotti 1988), it was finally concluded, based on studies, that the eagles fed on dead, post-spawned salmon and only rarely ate live fish. The results of this research made available to the public, had a strongly positive effect, and formerly depressed populations of eagles in Alaska have rebounded.

Agencies and land managers can help bald eagles in a number of ways. For Arizona, the issue of human disturbance at nests may be one with serious implications. If this fact becomes clear in the public mind through information, the impulse to violate a closure might be replaced by a real consideration for the birds. In our opinion, a sign explaining the consequences of disturbance to the eagles would be more effective than a sign listing the legal consequences to a person who might violate the closure.

Information may be the only way to help with the problem of monofilament and fish-hooks described in Section C3.3. The process of making anglers more aware of the danger to bald eagles might help to decrease the tendency people seem to have toward leaving these materials in the environment. We recommend an approach that arouses compassion for the plight of afflicted nestlings.

An interesting and productive program in Great Britain has benefitted a population of ospreys. At certain lakes where conditions are appropriate, the public is allowed to observe the breeding birds from distant viewing stations. The program continues to attract numerous visitors who become informed during their visit and who contribute substantially to the funding needs of the osprey management program. Whether such an arrangement would be appropriate and helpful in Arizona is probably worth considering.

A6.4.4 Augmentation?

There has been some thought that Arizona's population of bald eagles might benefit by the release of birds from other areas. Such a program has been used elsewhere to reestablish extirpated populations; for example, numerous bald eagles from Alaska were released in New York.

The matter of whether a release program should be initiated in Arizona brings to mind two questions: (1) Is such augmentation needed? and (2) Would the immigrant eagles disrupt coadapted gene complexes that may have evolved in response to Arizona's desert climate? This second question is distinct from that of whether the immigrants would possess the appropriate adaptations to survive in Arizona.

Several lines of evidence suggest that the release of birds from outside Arizona would be both unwarranted and unwise at this time. Reasons for it being unwarranted include that: (1) a healthy level of genetic variability is suggested by the DNA and enzyme studies; (2) there is no other evidence of inbreeding depression; and, (3) the population currently appears to be maintaining itself and is possibly expanding. A release would be unwise because alien birds might disrupt regionally evolved adaptations.

If, at some point in the future, the Arizona population of bald eagles appears unable to maintain itself, it may be well to consider a release program in time to preserve the genes that remain. For now, we cannot, on the basis of genetical profiles, suggest a candidate among other bald eagle populations for release into Arizona. Dr. Vyse (see Section E6) has retained the DNA samples, and if in the future he is able to identify and examine sufficient numbers of additional genetic loci, he may be better able to answer the question of which among the other populations has the greatest affinity to the Arizona eagles.

It would be advantageous for a population of captive Arizona eagles to accrue at an appropriate facility as they become available as unreleasable birds. With proper husbandry, such eagles would likely be long-lived as captive pairs and might contribute to productivity at failed sites in the wild.



Plate A18. Robert Mesta, U.S. Fish and Wildlife Service biologist, rappelling from Redmond nest pinnacle (photo by D. Driscoll).

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The following Arizona Bald Eagle Nest Watch Program personnel collected data at nest sites from 1987-1990, providing information on emergencies and nesting progress:

1987 Nest Watchers

Trish Carroll, Michael Cross, Nancy Nahstoll, Austin Weiss, Ann Housser, Tim Anderson, Barbara Prescott, Henry Miller, Bill Campbell, Ken Berger, Mark Collie, Florence Knoll, Pete Engman, Bill Smillie, Frank Hein, Paula Becker, Pat Sudar, Max Morgan, Jim Brashear, Robert Toco, Deborah Von Gonten, and Veronica Behn.

1988 Nest Watchers

Richard and Judy Newbolds, Brian Bock, Steve Fettig, Pete Dixon, Karen Maack, Ernest Victor, Doug Shepherd, Wendy Krueger, Maria Farrara, Rick Sweitzer, Sherri Moller, Mark Collie, Florence Knoll, Greg Beatty, Ann Housser, Colleen Lenihan, and Neal Lucas.

1989 Nest Watchers

Peter Adams, Diane Bond, Mark Collie, Andy Day, Maria Farrara, Florence Knoll, Wendy Krueger, Jenni Kuder, Steven Linskens, Tracy McCarthy, Ann McLuckie, Linda Moller, Richard Newbold, Judy Newbold, Brand Phillips, and Doug Sinor.

1990 Nest Watchers

Brian Bock, Ann McLuckie, Kimberley Kime, Kelly Upton, David Kershaw, Chris Mehling, Tim Fenske, Joe Flesch, Brent Richey, Katie Kennedy, Todd Thiesfeldt, Steven Linskens, Mark Collie, Florence Knoll, Karen Fawcett, Cara Staab, George Gilsdorf, Chris Olsen, Jim Berkelman, and Louis Armstrong.

A8 GLOSSARY

ABENWP - Arizona Bald Eagle Nestwatch Program.

Aborted Forage Attempt - a foraging-related event in which an eagle drops its legs with the apparent intention of seizing a fish, but breaks off the attack at the last instant, and does not touch the water (see perlustration).

ACE - United States Army Corps of Engineers.

Active Disturbance - potential disturbance to eagles by humans present in a sensitive area either on foot, in road vehicles, aircraft, boats, etc.

Active Nest - a nest in which eggs have been laid.

Adult - eagle with full white head and tail, usually at least 5 years of age.

Agencies - "The Agencies" that directed this study: the U.S Bureau of Reclamation, the U.S Fish and Wildlife Service, and the Arizona Game and Fish Department.

AGF - Arizona Game and Fish Department.

AGL - above ground level.

Airline kilometer - straight line distance from point to point, as opposed to "river kilometer" or "Km", which refers to kilometer indices along the river channel centerline, as depicted in the BioSystems River Map Atlas (Section C9).

Alternate Nest - a nest in a territory in addition to the existing active nest; usually constructed and used during previous years, it may be occupied again in the future.

ASU - Arizona State University.

Attack Distance - see Perch Distance.

Attack Mode - the method of attack, *e.g.*, the eagle saw its prey while perched, then attacked from the perch. Other examples include the eagle seeing and attacking its prey while on the wing, the eagle pirating prey from another eagle or from another species, or the eagle displacing another eagle or another species from carrion.

Backwater - a body of still water formed behind or adjacent to an obstruction (gravel bar, island, point of land) in the current of flowing water.

Berm - see Pre-riffle.

BIA - United States Bureau of Indian Affairs.

Biomass Delivered - the weight (in grams) of that portion of a prey animal that is brought to the nest by an adult.

Black Bass - largemouth and smallmouth bass.

BLM - United States Bureau of Land Management.

Boulder-Strewn Habitat - river habitat with many boulders throughout the stream channel, with water flowing around and under them (see Pocket Water). "Fine boulder-strewn habitat" has no boulders extending more than 2 ft above the surface; "medium boulder-strewn habitat" has one to four boulders extending more than two ft above the surface; "course boulder-strewn habitat" has five or more boulders extending more than two ft above the surface.

Breeding Area - an area containing one or more nests within the range of one mated pair of birds.

Cascade - river habitat with very steep slope over short distance.

Catfish - refers to channel catfish and flathead catfish (bullhead spp. were also taken by Arizona bald eagles).

Centrarchid - a member of the family of teleost fishes (Order Perciformes) that originated in eastern North America; commonly referred to as sunfish or black bass.

DNA Fingerprinting - a technique which allows the demonstration of genetic polymorphisms in DNA fragments. The process involves the fragmentation of high molecular weight genomic DNA with restriction enzymes. The fragments are then separated according to size by electrophoresis and transferred to a membrane where they are rendered single-stranded. The membrane is then probed with cloned DNA singled-stranded sequences marked with radioactive nucleotides. The latter bind to homologous strands of DNA on the membrane, and the locations of the DNA fragments which have bound to the probe sequences are revealed as chromatographic bands by autoradiography. These are interpreted as Mendelian.

D.O. - Dissolved oxygen concentration in water.

Effective Population Size - the average number of individuals in a population that actually contribute genes to succeeding generations.

Electrophoresis - for our purposes, a process by which enzymes (and certain structural proteins) are made to migrate differentially in an electric field. The process may reveal allelic variation in the genetic loci which code for the enzymes. Enzyme substrates and dye couplers are used to create chromatographs displaying the differential mobilities of the enzymes.

Epilimnion - the upper (warmer) layer of a stratified reservoir

Eyrie - a raptor nest site.

Failed Nest - an active nest in which eggs did not hatch, or young died before reaching an advanced stage of development.

Fledge - to leave the nest for the first time.

Fledgling - an eaglet that has recently left the nest.

Floater - a member of the floating population of nonbreeding adults and near-adults.

Floating Population - that population segment containing adults and near-adults that are not members of breeding pairs or defending a serviceable breeding location.

Forage or Forage Attempt - an attack on prey, whether or unsuccessful, in which the feet of the eagle strike the water.

Forage Fish or Prey Fish - fish in appropriate size categories for utilization as prey by bald eagles.

Foraging Macrohabitat - the type of relatively large environmental components surrounding a foraging event by a bald eagle, such as river habitat (run, riffle, pool, etc.) and type of perches available (cliff, snag, etc.).

Foraging Microhabitat - habitat components specific to a foraging strike point, measured soon after a bald eagle foraging event, *e.g.*, substrate and vegetation, water temperature, depth, turbidity, velocity.

Foraging Range - see Home Range.

Home Range - the area frequented by a pair of eagles during the course of the nesting season. In this report, we distinguish it from the soaring range as the area containing all known foraging locations and those perching locations that are presumably related to foraging (See also, soaring range).

Hypolimnion - the deep (cooler) layer of a stratified reservoir.

Isothermal Reservoir - a reservoir condition in which temperatures are similar throughout the water column; unstratified.

Juvenile - an eagle in its first calendar year, from fledging (when it leaves the nest) through migration.

Kleptoparasitism - see Pirating.

Km - see River Kilometer.

km - see Airline Kilometer.

Lake-Loc - see Shoreline Kilometer.

Littoral Zone - the area of a body of water near shore characterized by sunlight penetrating to the bottom.

MSL - above mean sea level.

Mute - raptor excrement; "whitewash."

Mean Commuting Distance - the average airline distance (km) from the nest traveled by an breeding bald eagle to perch and/or forage.

Near-adult - eagle with brown mottling in predominately white head and tail, ca. four years old.

Nest Effect - a bias in calculating eagle foraging range distribution. The normally high frequency of visits by an adult eagle to the nest area score tends to grossly overshadow its visits to other locations. Because the nest area may be an important foraging area, visits there cannot be discounted. The solution to this dilemma lies in weighting the nest area according to the proportion of total foraging observed there.

Nest-Years - number of nests in a sample multiplied by the number of years.

Nestling - a baby eagle (eaglet), from hatching to fledging.

Obsform - Observation form—BioSystems principal field form used to record observations of bald eagles, their use of habitat, and the occurrence of public users.

Occupied Breeding Area - an area containing a nest at which at least one of the following occurred: (1) young were raised; (2) eggs were laid; (3) an adult was observed sitting low in the nest, presumably incubating; (4) two adults were observed perched on or near the nest; (5) an adult and a bird in immature plumage were observed at or near the nest, if courtship behavior occurred; or, (6) recent repairs (fresh sticks or lining), mute, or feathers were visible at or near the nest.

ORA - occupancy and reproduction assessment of bald eagle nests conducted during the breeding season.

Passive Disturbance - an existing human development fixed permanently or semi-permanently on the landscape (e.g., road, campground, house).

Pelagic - deep open water region of a lake or reservoir.

Perciforms - spiny-rayed fish (e.g., bass and perch).

Perlustration - a foraging-related event in which an eagle flies or circles low over the water and appears to scrutinize a potential prey item, but does not lower its legs (see aborted forage attempt).

Perch Distance - the horizontal distance from the attack perch to a foraging strike point, in meters. This measurement does not include any additional distance which might accrue due to the eagle circling before striking, nor does it measure the diagonal distance from the attack point to an elevated perch.

Pirating - the act of stealing a prey item from another animal (see Kleptoparasitism).

Pocket Water - river habitat characterized as boulder-strewn; habitat dissociated, moderate slope (see Boulder-Strewn).

Pool - river habitat that has slow water velocity, water surface elevation gradient near zero, and holds significant amounts of water at zero flow. A "shallow pool" is < 4 ft deep, a "medium-depth pool" is 4-8 ft deep, and a "deep pool" is > 8 ft deep.

Pre-Riffle - the relatively smooth, shallow water on the upstream edge of a riffle (berm).

Prey Delivery - a prey item is brought to the nest by an adult eagle.

Prey Disposition - describes what the eagle did with the prey item.

Prey Item - a prey animal, or a part thereof that is utilized by a bald eagle and identified by researchers through observation or analysis.

Prey Status - describes whether a prey item was taken alive, as carrion, was pirated, or was sick or injured prior to discovery by the eagle.

Public User - one person on foot, one road vehicle, one boat, one low-flying aircraft, etc. (each is recorded as one public user).

Public User Type - refers to whether the public user is fishing, camping, boating, working cattle, conducting research, idling, etc.

Public User Mode - refers to whether the public user is a person on foot, or is a road vehicle, a boat, an aircraft, etc.

Public User Position - refers to the location of the public user relative to the river channel, reservoir, or eagle nest.

Reclamation - United States Bureau of Reclamation, a part of the Department of the Interior.

Redds - a nest excavated in a stream or lake bed in which fish (usually salmonids) deposit eggs.

Regulated River - a river whose flows are normally released artificially from a dam impounding a reservoir.

Reservoir Stratification - the tendency for a reservoir to form discrete water layers differentiated on the basis of temperature. Deep reservoirs are more likely to stratify than shallow ones.

Riffle - river habitat of fast, shallow water, moderate slope, turbulence, and exposed substrate.

River Habitat - refers to hydrologic features including runs, riffles, pools, pocket water (= boulder-strewn), cascade, and backwaters.

River Kilometer Segment (Km) - distance indexed along the river channel centerline, as depicted in the BioSystems River Map Atlas (see also airline kilometer and shoreline kilometer).

Roll-call Census - a telemetry survey, normally conducted by airplane at a fairly high altitude (to maximize reception) along a standard route, in which the transmitter frequencies of all eagles are scanned (for 3 seconds each). Upon detection of a transmitter, the biologist "locks in" the frequency, locates the transmitter, then continues the survey in scanning mode.

Run - river habitat characterized by moderate current, nonturbulent surface, moderate slope. Runs are typically too deep to be riffles, too fast to be pools, and few large boulders. A "slow run" has a relatively smooth surface; a "fast run" has noticeable surface turbulence.

Run-of-River Reservoir - one in which large volumes of water are not stored behind the dam.

Salt River Recreation (SRR), a lessee of the U.S. Forest Service which rents inner tubes to recreationists in the Blue Point breeding area.

Soaring Range - the area of soaring and territorial patrolling by a pair of bald eagles; the soaring range may extend beyond the home range.

Secchi Disk - a device used to measure water clarity on the basis of its depth of visibility in centimeters beneath the surface.

Segment - refers to one full river kilometer (Km).

Serviceable Breeding Location (SBL) - an area, containing a nest site and foraging habitat, in which the expectation of reproductive output outweighs, in evolutionary terms, the risks of death and physiological exposure inherent in a nesting attempt. An SBL is optimal where its various components (habitat, food supply, absence of predators, etc.) combine to produce a maximum number of surviving young while minimizing reductions in parental survivorship and future fecundity (see Hunt 1988).

Shore Distance - the distance in meters between an foraging strike point and the shore.

Shoreline Kilometer (SKm) - locational indices depicted along reservoir shorelines in BioSystems' River Map Atlas.

Side - river side, facing downstream.

SKm - see Shoreline Kilometer.

SL - see Standard Length.

SRP - Salt River Project, a nonprofit water and power utility which operates the dams built by the U.S. Bureau of Reclamation on the Salt and Verde rivers in central Arizona.

SWBEMC - Southwest Bald Eagle Management Committee.

Subadult - one- to three-year-old eagle in various plumages of brown and white mottling. One year old bald eagles are typically dark, and two to three year old birds have white bellies with an inverted white triangle on their back. However, we (BioSystems) observed a ten-month old telemetered nestling in the white belly phase.

Successful Foraging Attempt - an attack in which food is obtained by an eagle.

Successful Nest - an active nest in which at least one young survived to an advanced stage of development.

Suckers - refers to both Sonora and desert suckers. We were only rarely able to differentiate between these two species as they were delivered to the nest.

Surface Turbulence - wave disruption of the surface of a water body affecting visibility from air to water

Standard Length (fish) - distance in centimeters from the tip of the snout (or lower jaw, which ever sticks out farther) to the end of the vertebral column (Moyle 1976).

Strike Point - the exact location at which a foraging eagle's feet strike the water in an attack on prey.

Super-riffle - a riffle which maintains habitat integrity under a wide variety of flows. As flow increases, water depth and velocity increase in only a small area of the habitat, while overall the amount of shallow water increases in the riffle due to the spreading of water across a gravel bed. A normal riffle becomes a run with moderate increases in flow.

Territory - specifically, the area around the nest that is defended by a pair of adult eagles, or generally, an entire breeding area (the territory plus the rest of the home range), *e.g.*, "we surveyed the Bartlett and Blue Point territories."

Time Line - an uninterrupted, minute-by-minute record of the movements and activities of a radio-tagged bald eagle over a long period of the day.

TL - see Total Length

Total Biomass - the live weight (in grams) of a prey animal.

Total Length (fish) - the greatest distance that can be measured, usually from the tip of the snout to the longest ray of the caudal fin, when the upper and lower lobes can be squeezed together (Moyle 1976).

Transmitter - a small radio unit attached to the back or tail-feather of an eagle which emits a radio pulse that is used to locate the eagle and determine its behavior.

Turbidity - in this report, the opposite of water clarity. Expressed as the distance in cm that a Secchi disk is visible from the water surface.

Unoccupied Breeding Area - an area containing a nest where none of the criteria of occupancy are fulfilled (see Occupied Breeding Area).

Unsuccessful Foraging Attempt - typically, a failed attack on a fish in which the eagle's feet strike the water.

USBR - United States Bureau of Reclamation, a branch of the U.S. Department of the Interior.

USFS - United States Forest Service, a branch of the U.S. Department of Agriculture.

USFWS - United States Fish and Wildlife Service, a branch of the U.S. Department of the Interior.

USGS - United States Geological Survey.

VID Band - a visual identification band placed on the leg of an eagle; unique symbols are engraved on each color-anodized aluminum band which, read from a distance, allows recognition of each banded individual bald eagle.

Visitation Score - a method of measuring habitat selection based on the number of visits by radio-tagged eagles to specific locations. Each time an eagle traveled to a location and perched or foraged, the location received a score of one point. If the eagle left the location and traveled 100 meters or more along the river, but then returned, the location received another point in an accruing score. Large numbers of visitations to the nest tended to overshadow point scores of other locations, but because the nest vicinity was often an important foraging area, it was inappropriate to exclude it from analysis. We therefore weighted the score in the nest vicinity according to the proportion of the bird's forages occurring there.

Weighted Visitations - see Visitation Score

Zone - a standardized area, usually larger than one kilometer in length, that functions to accommodate locational data in which the geographic positions of telemetered eagles are not precisely known.

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