Exxon Valdez Oil Spill
State/Federal Natural Resource Damage Assessment Final Report

Effects of the *Exxon Valdez* Oil Spill on Bald Eagles

Bird Study Number 4
Final Report

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December 1993

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Study History: This final report for Bird Study 4 was prepared 13 December, 1993. A journal article regarding the project was published as: Bowman, T. D., P. F. Schempf, and J. A. Bernatowicz. 1995. Bald eagle survival and population dynamics in Alaska after the *Exxon Valdez* oil spill. J. Wildl. Manage. 59:317-324.

Abstract: We estimated that about 8000 bald eagles (Haliaeetus leucocephalus) inhabited the area affected by the spill at the time of the *Exxon Valdez* oil spill. We conducted a 3-year study to determine effects of the spill on the bald eagle population and reproduction and survival of adults and fledglings. The greatest injuries to bald eagles occurred in 1989 and were manifested by direct mortality of bald eagles throughout the spill area and significantly reduced reproduction in PWS. We could not discern negative effects on the population or reproduction of eagles after 1989.

Stratified random plot surveys and island censuses of adult bald eagles within PWS provided indices of population size. Indices of the adult eagle population for 1982, 1989, 1990, and 1991 were 1565 ± 437, 2089 ± 308, 1941 ± 283, and 2088 ± 273, respectively. Population size did not change significantly from 1989 to 1990 or 1991. However, because confidence limits on estimates ranged from 13-15% for these 3 years, we could not have detected a statistically significant difference given the estimated magnitude of mortality caused by the spill.

Survival was high for eagles radio tagged in PWS 4-5 months after the spill. We found no differences in survival between groups using any of the 3 schemes. Any adverse effect of the spill on survival likely occurred before we tagged the eagles.

We believe that the adverse effects of the oil spill on bald eagles were limited to direct mortality throughout the spill area and impaired reproduction in PWS during 1989. We predicted that the eagle population in PWS will require <4 years to return to the level it would have been in 1989 had the spill not occurred.

Key Words: Alaska, bald eagle, *Exxon Valdez* oil spill, Haliaeetus leucocephalus, petroleum hydrocarbons, mortality, nesting, population dynamics, population surveys, Prince William Sound, productivity, radio telemetry, survival, visibility bias.

Citation: Bowman, T. D., P. F. Schempf, and J. A. Bernatowicz. 1993. Effects of the *Exxon Valdez* oil spill on bald eagles. *Exxon Valdez* Oil Spill State/Federal Natural Resource Damage Assessment Study Final Report (Bird Study Number 4), U.S. Fish and Wildlife Service, Anchorage, Alaska.

PREFACE

Bird Study 4, the effects of the *Exxon Valdez* oil spill on bald eagles, was one of several damage assessment studies conducted under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) following the 1989 oil spill in Prince William Sound (PWS), Alaska. Bird Study 4 was a major study with several distinct components intended to meet the following objectives: 1) determine if changes in population size of bald eagles occurred in PWS after the oil spill; 2) determine effects of the spill on bald eagle productivity; 3) test the hypothesis that survival rates were the same for bald eagles in oiled and non-oiled areas; and 4) provide documentation of hydrocarbon exposure for bald eagles and identify possible pathways by which contamination, death, or impaired reproduction occurred.

This study represented an unprecedented effort to intensively study a large population of bald eagles about which little, or nothing, was previously known. Consequently, the study provided information valuable not only for assessing injuries from the oil spill, but also contributed greatly to the knowledge of bald eagle biology in southcentral Alaska. Greater emphasis was placed on studying the PWS population of bald eagles because this population evidently suffered greater losses than populations in other areas affected by the spill.

In presenting our findings, we have divided the report into 6 chapters. Each chapter relies in some way on one or more of the other chapters for general information or supportive data. This preface briefly describes the content and major conclusions of each chapter and is intended to serve as a guide to the report.

A thorough analysis and interpretation of hydrocarbon data was not available at the time of this writing and these results will be published separately later.

In Chapter 1, Estimated Bald Eagle Population Residing In The Area Affected By The *Exxon Valdez* Oil Spill, we estimated that about 8000 bald eagles were potentially at risk due to the oil spill. This estimate was needed to put into perspective any loss to bald eagle populations caused by the spill.

Chapter 2, Estimate Of Initial Mortality And Lost Production Of Bald Eagles Due To The *Exxon Valdez* Oil Spill, summarizes injury to the bald eagle population in the immediate aftermath of the oil spill. We estimated that about 900 bald eagles died throughout the spill area as a result of the spill and that losses to productivity were probably limited to PWS, where at least 223 fewer young were produced because of the spill. These losses were incorporated into a population model (Chapter 6) to determine how long the population would take to recover.

In Chapter 3, Bald Eagle Nest Success In Prince William Sound, Alaska, Following The *Exxon Valdez* Oil Spill, we compared productivity between 1989 and 1990 for a sample of bald eagle nests in PWS. We concluded that bald eagle reproductive success was significantly impaired in 1989 and that reproductive failures were correlated with the distribution of crude oil on beaches.

Chapter 4, Bald Eagle Productivity In Southcentral Alaska In 1989 And 1990 Following The *Exxon Valdez* Oil Spill, presents the results of bald eagle nest surveys conducted in the Copper River Basin, Kenai Peninsula, Kodiak archipelago, Katmai National Monument, and Alaska Peninsula in 1989 and 1990. The objective of this element of the study was to gather, collate, and re-analyze all available data on bald eagle productivity in the region affected by the *Exxon Valdez* oil spill during 1989 and 1990 to determine if the spill influenced reproductive success. This study provided the first estimates of bald eagle productivity for many areas in southcentral Alaska. Only general inferences regarding the effects of the oil spill could be made because of the biases and limitations of the data. Impaired reproduction could not have been measured for Kenai Peninsula, Kodiak, or the Alaska Peninsula given the available field data.

In Chapter 5, Bald Eagle Population Of Prince William Sound, Alaska, Before and After the *Exxon Valdez* Oil Spill, we present the results of bald eagle population surveys and compare indices for the adult bald eagle population of PWS before and after the oil spill. Because confidence limits on population indices were wide, we were unable to detect a significant difference in population size after the spill. We incorporated a correction factor for adult eagles not seen and for immatures not counted during surveys to estimate the total population size in PWS.

Chapter 6, Survival And Population Dynamics Of Bald Eagles From Prince William Sound, Alaska, After The *Exxon Valdez* Oil Spill, summarizes the results of a radiotagging study of more than 160 bald eagles from PWS. The objective of the survival element of the study was to determine if the oil spill had an effect on survival of radiotagged eagles that had survived the initial effects of the spill. We found no differences in survival between eagles "exposed to oiled areas" and eagles "not exposed to oiled areas". The study also enabled a determination of factors that might regulate and influence population dynamics. The cumulative effect of the known injuries caused by the oil spill to the eagle population was simulated by a population model, which showed that it will take about 4 years for the PWS eagle population to recover to its pre-spill level.

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EXECUTIVE SUMMARY

In March, 1989, the tanker *Exxon Valdez* ran aground and spilled more than 11 million gallons of Prudhoe Bay crude oil, fouling shorelines from Prince William Sound (PWS) to the Alaska Peninsula, Alaska. We estimated that about 8000 bald eagles (Haliaeetus leucocephalus) inhabited the area affected by the spill at the time of the spill. We conducted a 3-year study to determine effects of the spill on the bald eagle population and reproduction and survival of adults and fledglings. The greatest injuries to bald eagles occurred in 1989 and were manifested by direct mortality of bald eagles throughout the spill area and significantly reduced reproduction in PWS. We could not discern negative effects on the population or reproduction of eagles after 1989.

One hundred fifty-one eagle carcasses were recorded at wildlife collection centers. These carcasses probably represented a small fraction of the total mortality. We adjusted the number of carcasses found for carcasses not found, scavenged, or otherwise lost and estimated that about 900 (range: 600-1800) eagles, or about 11% of the population, died as a direct result of the spill.

The PWS bald eagle population was the only population for which productivity data was adequate to demonstrate a decline due to the spill. Reproductive failures in PWS were directly related to the extent of shoreline oiling near nests. We could not

differentiate between the effects of shoreline oiling and the effects of disturbance caused by shoreline cleanup operations. Reproductive success in PWS in 1990 was typical for bald eagle populations in coastal Alaska. The lack of observed reproductive failure in other areas could have been due to the later arrival of oil during the nesting season, a decreased toxicity due to weathering of oil, or changes in consistency of the crude oil which made oil less adherent as the slick moved westward along the coast.

Stratified random plot surveys and island censuses of adult bald eagles within PWS provided indices of population size. Indices for 1982, 1989, 1990, and 1991 were 1565 ± 473, 2089 ± 308, 1941 ± 283, and 2088 ± 273, respectively. These indices represented approximately 47% of the total population size because they did not include immature eagles or account for adult eagles not seen during surveys. Population size did not change significantly from 1989 to 1990 or 1991. However, because confidence limits on estimates ranged from 13-15% for these 3 years, we could not have detected a statistically significant difference given the estimated magnitude of mortality caused by the spill.

Survival was high for eagles radiotagged in PWS 4-5 months after the spill. We used three schemes to group eagles into oiled or unoiled categories and compared survival between groups. These groupings were based on: 1) whether the eagle was tagged in

eastern or western PWS, 2) presence or absence of oil at the capture site, and 3) the percentage of time spent in oiled areas after tagging. We found no differences in survival between groups using any of the 3 schemes. Any adverse effect of the spill on survival likely occurred before we tagged the eagles. We believe that the adverse effects of the oil spill on bald eagles were limited to direct mortality throughout the spill area and impaired reproduction in PWS during 1989. We modelled the PWS bald eagle population and estimated that the population was increasing before the spill at a rate of about 2% per year. The eagle population in PWS will require about 4 years to return to the level it would have been in 1989 had the spill not occurred.

Key Words: Alaska, bald eagle, *Exxon Valdez* oil spill, Haliaeetus leucocephalus, petroleum hydrocarbons, mortality, nesting, population dynamics, population surveys, Prince William Sound, productivity, radio telemetry, survival, visibility bias.

ACKNOWLEDGMENTS

This work was funded by the *Exxon Valdez* Trustee Council for the purpose of assessing injuries due to the spill and planning restoration. An additional grant was provided by the National Foundation to Protect America's Eagles (A. L. Cecere, president).

This comprehensive study required the cooperation of many individuals from many agencies and private organizations. We thank the following people for participating in bald eagle reproductive and population surveys, assisting with trapping and tagging eagles, or providing data or other essential information pertinent to specific regions in the oil spill area: M. Amaral, K. Beck, M. Bill, F. Bird, D. A. Boyce, D. Burgess, D. E. Driscoll, J. Driscoll, D. Dewhurst, L. J. Dubuc, K. Faber, J. B. Gray, J. I. Hodges, A. Hoover-Miller, J. Hughes, M. Jacobsen, R. King, K. Kozie, R. Leedy, R. N. Lehman, M. Macone, R. Mesta, H. Nowicki, P. Oswalt, M. Phillips, M. Portner, B. Route, C. Roy, T. V. Schumacher, G. Stewart, M. Tetreau, S. L. Wilbor, D. Williamson, G. Wheeler, K. Wynne, R. E. Yates, M. Yurik, and D. Zwiefelhoffer.

Helicopter pilots in PWS, the Copper River Delta, and the lower Copper River Basin included C. M. Adkins, J. B. Gray, and H. White. L. Lobe, J. Olexa, D. G. Ranney, and S. C. Ranney served as fixed-wing aircraft pilots during radio telemetry flights. J. I. Hodges flew the turbine Beaver during population surveys. J. McClung served as captain of the M/V Surfbird, which we used as our base of operations when trapping eagles.

We thank C. M. Bunck for helpful advice on analysis of survival data. D. Bowden and S. P. Klosiewski provided statistical advice.

T. W. Jennings, B. A. Boyle, and J. Welch performed most of the tasks involving geographic information systems. D. Mortenson and C. Wilder assisted with preparation of graphics.

J. C. Franson, L. E. Hayes, N. J. Thomas, and R. M. Windingstad, U.S. Fish and Wildlife Service, National Wildlife Health Research Center, conducted necropsies and histological analyses of dead eagles.

We thank D. Buehler, J. D. Fraser, D. M. Fry, J. I. Hodges, G. Hunt, K. L. Oakley, D. Roseneau, B. E. Sharp, and R. Lehman for helpful reviews of drafts of various portions of this report.

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CHAPTER 1

ESTIMATED BALD EAGLE POPULATION RESIDING IN THE AREA AFFECTED BY THE EXXON VALDEZ OIL SPILL

EXECUTIVE SUMMARY

We estimated the number of bald eagles (*Haliaeetus leucocephalus*) residing in the area affected by the *Exxon Valdez* oil spill in 1989. This estimate was needed to put into perspective the injury to bald eagle populations caused by the spill. Population estimates were based on stratified random plot surveys of adult bald eagles, adjusted for adults not seen and the proportion of immatures. We estimated the spring population for Prince William Sound (PWS), Kenai Peninsula, Kodiak archipelago, and a portion of the Alaska Peninsula numbered 8886 bald eagles and that about 8000 were potentially at risk due to the oil spill.

INTRODUCTION

The oil tanker *Exxon Valdez* ran aground on Bligh Reef on 24 March 1989, spilling more than 11 million gallons of Prudhoe Bay crude oil into the waters of PWS, Alaska. Oil moved southwest and contaminated much of southwestern PWS, the Kenai Peninsula, Kodiak Archipelago, and the Alaska Peninsula (Fig. 1-1). Bald eagles are closely associated with shoreline environments in this part of Alaska. Most nests are within 200 m of the shoreline, and eagles forage extensively in the intertidal and shoreline areas. Adverse impacts to bald eagles in the spill area were expected.

An estimate of the bald eagle population residing in the area affected by the *Exxon Valdez* oil spill was needed to understand the overall impact of the spill on eagle populations. These estimates may help put into perspective the mortality and reproductive failures resulting from the spill (Chapters 2 and 3). We adjusted indices of adult bald eagle population size for adults not seen during population surveys, and for immatures in the population, to estimate the size of the bald eagle population that was residing in the area and therefore potentially at risk from the oil spill in 1989.

METHODS

We defined the resident bald eagle population of the spill area as all eagles inhabiting coastal areas in PWS, the southeastern shore of the Kenai Peninsula, the Kodiak archipelago, and the southern shore of the Alaska Peninsula between Cape Douglas and Kupreanof Point (Fig. 1-2).

Our approach to estimating the population at risk began with an estimate of the number of adults in each geographic area, which we adjusted for unseen adults and the proportion of immatures in the population.

Population Surveys

Estimates of the population at risk were based the number of adults counted during population surveys (Hodges et al. 1984, Chapter 5) conducted in late April and early May. We used the most recent population estimates available for each geographic area, which were 1989 for PWS and for Kenai Peninsula (Cape Puget to Kachemak Bay, but not including Kachemak Bay), and 1983 for the Kodiak archipelago and Alaska Peninsula (Cape Douglas to Kupreanof Point) (J. Hodges, USFWS, Juneau, Ak, unpubl. data). During these stratified random plot population surveys, all white-headed eagles were counted. Although some of these eagles were probably not fully mature, they were classified as adults. Perched immatures without a white head have a lower probability of being seen and therefore could not be reliably tallied. We assumed that any flying eagle had an equal probability of being seen and eagles of all ages had an equal probability of being in the air. The number of adult and immature eagles seen flying was recorded and assumed to reflect the age structure of the population. The number of adult eagles we saw on spring population surveys represented an index to, rather than an estimate of, the population size.

Adjustment For Unseen Adults (Visibility Bias)

The detectability of bald eagles during aerial surveys may be influenced by bird activity, time of day, weather, snow cover, topography, observer experience, type and speed of aircraft, age and sex of birds, season, and habitat (Fuller and Mosher 1987). Recognizing that not all adults are seen during population surveys, the number of adults should be corrected for visibility bias to improve the estimate. We developed our own estimate of visibility bias because none existed for bald eagles for this type of population survey in this type of habitat.

Using a sample of radiotagged bald eagles, we estimated that in 68% ± 7% (95% CI) of observations, we would have seen the eagle during a typical population survey (Chapter 5).

Percentage Of Immatures In The Population

The ratio of adult to immature eagles seen flying was assumed to give an unbiased estimate of the proportion of immatures in the population. The ratio of immatures to all eagles seen flying in PWS, pooled for population surveys in 1982, 1989, 1990, and 1991, was 105/344, or 30.5% ± 4.9% immatures in the population.

Estimation of Total Population Size

We assumed that our estimates for unseen adults and the percent immatures in the PWS population were representative of eagle populations throughout the spill area. An estimate of total population size was made by adjusting the adult index for unseen adults and by the proportion of immatures in the population. Confidence limits on the percentage of adults not seen and percentage of immatures were calculated according to Fowler and Cohen (undated). Confidence limits on corrected estimates were constructed using methods of DeVries (1986).

RESULTS

Estimates of population size for each area are presented in Table 1-1. The population surveys included some areas that were not directly affected by the oil spill, therefore not all of the population was "at risk" due to the oil spill. We believe it more likely that about 8000 bald eagles were potentially at risk due to the oil spill.

DISCUSSION

Although some mortality due to the spill might have occurred in PWS between the time the oil spill occurred (24 March) and population surveys were conducted (late April and early May), we believe the difference between the 1989 population estimates in PWS and the pre-spill population was insignificant (see Chapter 5). We think it was unlikely that significant mortality occurred in areas farther to the west because of the later arrival of oil, in relation to the timing of nesting events, at those areas.

This estimate of the bald eagle population of the area affected by the oil spill is the best estimate based on available data. The estimates should be used with caution, however, for several reasons. The confidence interval for the population estimate is wide (24.6%). For the Kodiak Archipelago and the Alaska Peninsula, we used population indices that were 6 years old. We believe that bald eagle populations in PWS are increasing at a rate of about 2% per year (Chapter 6). If eagle populations in the other areas are changing at the same rate, then the population estimates for Kodiak and the Alaska Peninsula may be low.

We applied correction factors for adult visibility and the proportion of immatures that were calculated for PWS, and these correction factors may not be valid for eagle populations in other areas. We suspect that the percentage of adults seen during surveys in non-forested areas such as the Alaska Peninsula and parts of Kodiak archipelago would be higher than in forested areas. Hancock (1964) estimated that he undercounted adult bald eagles in British Columbia by 10-15% during surveys conducted primarily in winter, but he used less reliable methods of determination. Estimates of the proportion of immatures in other coastal areas are consistent with this figure (Stalmaster 1987). Hodges et al. (1984) estimated that 27% of the eagles in coastal British Columbia were immatures.

The estimated 8000 bald eagles within the oil spill area represent about 18% of Alaska's bald eagle population and 9% of the total North American population (Stalmaster 1987, Johnsgard 1990).

CHAPTER 2

ESTIMATE OF INITIAL MORTALITY AND LOST PRODUCTION OF BALD EAGLES DUE TO THE EXXON VALDEZ OIL SPILL

EXECUTIVE SUMMARY

The 1989 *Exxon Valdez* oil spill contaminated extensive areas of bald eagle (Haliaeetus leucocephalus) habitat in coastal southcentral Alaska. We estimated that 902 (range = 614-1871) bald eagles died as a direct result of the spill in the 5 months after the spill. This mortality represented about 11% of the area's bald eagle population. We evaluated the effects of the spill on bald eagle productivity for nests with known fates in both 1989 and 1990 that occurred in oiled areas. Productivity of eagles nesting in Prince William Sound (PWS) was significantly reduced in 1989, but eagles nesting in the Kodiak archipelago, or along the coasts of the Alaska Peninsula or Katmai National Monument had no loss of production. Data were insufficient to determine effects on bald eagles nesting on the Kenai Peninsula. At least 223 fewer young were produced in 1989 than in 1990 within oiled areas of PWS. Decreased production in unoiled areas of PWS was also noted in 1989, suggesting that injuries were more extensive and that we underestimated lost production. This minimum lost production represented about 28% of the total annual production expected.

INTRODUCTION

On March 24, 1989, the oil tanker *Exxon Valdez* ran aground and spilled more than 11 million gallons of Prudhoe Bay crude oil into Prince William Sound (PWS), Alaska. The oil moved southwest through PWS and along the coast of the western Gulf of Alaska, fouling extensive areas of shoreline in PWS, along the Kenai Peninsula, within the Kodiak Archipelago, and along the southern shore of the Alaska Peninsula (Fig. 1-1). The area affected by the spill was occupied by about 8000 bald eagles (Haliaeetus leucocephalus) at the time of the spill (Chapter 1). Bald eagles in this part of Alaska feed extensively in intertidal areas and nest almost exclusively within 200 m of the beach (Hodges and Robards 1982). Significant direct mortality and reduced productivity of eagles as a result of the spill were therefore expected. Eagles were most likely killed by the direct or indirect effects of physical oiling and ingestion of oiled prey. The reproductive rate of the population could have been reduced by the spill because eagles failed to initiate or abandoned nesting, one or both parents were killed by the spill, or due to embryotoxicity after incubating adults transferred crude oil from their feathers to eggs. To assess the population level effects of the spill on bald eagles, the magnitude of mortality and reduced productivity had to be determined.

After the spill, 142 bald eagles were found dead by bird rescue and cleanup crews and delivered to collection centers in

Valdez, Seward, Homer, and Kodiak. Nine additional eagles that had been taken to rehabilitation centers died. The number of carcasses recovered was dependent on search intensity and frequency (Ford et al. 1991). We believed that the number of eagles recovered during these activities represented only a fraction of the total mortality because some carcasses were overlooked, scavenged, not reported, drifted out to or sank at sea, or were otherwise lost. Therefore, we attempted to quantify the total number of eagles killed by estimating the number lost but not recovered.

Here, we estimate that the 151 eagle carcasses recovered following the spill represented only 17% of the actual number of eagles killed directly by the spill. We also assessed the effects of the spill on bald eagle productivity and concluded that effects were probably limited to PWS, where an estimated minimum of 223 fewer chicks were produced in 1989.

Throughout this paper, we present estimates of injuries to the eagle population within the entire spill area and also specifically for PWS. We have done this because most injuries occurred in PWS and a partitioning is useful to assess the effect of the spill on this population of eagles.

METHODS

Estimation of Direct Mortality

We estimated the total number eagles killed directly by the *Exxon Valdez* oil spill as

$$\left\{ \underline{a} / (1-\underline{b}) / (1-\underline{c}) / (1-\underline{d}) \right\} - (\underline{e} * \underline{f})$$

where a = number of carcasses found,

b = proportion of beached carcasses missed or otherwise not reported by searchers,

c = percentage of oiled shoreline not searched,

d = percentage of carcasses in woods,

e = expected natural mortality along all shorelines,

f = the percentage of all shoreline that was oiled.

The values or estimates used were:

Number Of Carcasses Found (a).--One hundred forty-two bald eagle carcasses were found and reported to receiving stations during search and rescue operations. Nine eagles died in rehabilitation centers. Records of capture sites for these 9 eagles do not exist; we assumed that they their distribution was the same as that of the carcasses. Of these 151 eagles, 49 came from PWS, 37 from the Kenai Peninsula (Homer or Seward stations), and 65 from Kodiak Island and the Alaska Peninsula.

Proportion Of Beached Carcasses Missed Or Otherwise Not Reported By Searchers (b).--Eagle carcasses on searched beaches could have been missed because the carcasses were scavenged, badly decomposed or partly or completely buried. Carcass fragments could have been disregarded, or carcasses may simply not have been seen by searchers. Some carcasses were apparently burned at remote beaches and not reported to the morgues (Piatt et al. 1990). Our estimates of eagle carcass undercounts were adapted from the estimated undercounts of seabirds calculated by Ford et al. (1991). Ford et al. (1991) estimated that 50% of beachcast seabird carcasses were lost to scavengers within 1 or 2 days, and the remaining carcasses were lost after 4 or 5 days. They also estimated that 10-30% of seabird carcasses were buried within several days of beaching. We assumed that scavenging and burial rates for seabirds were probably greater than for bald eagles because eagles are larger with fewer potential scavengers. Although the magnitude of undercounts of carcasses is uncertain, a reasonable estimate is that up to 40% of all carcasses were not found by searchers. We used low, best, and high estimates of 5%, 20%, and 40%.

Percentage Of Oiled Shoreline Not Searched (c).--Search effort in the spill area was variable and influenced by the type of shoreline as well as location and accessibility. Ford et al. (1991) estimated the percentage of oiled shoreline actually searched from unpublished reports and telephone interviews with participants of bird search and rescue efforts. PWS was apparently searched more intensively than other areas. Based on estimates by Ford et al. (1991), a reasonable estimate is that 10-50% (best estimate 25%) of the oiled shoreline in the entire spill area was not searched, and that within PWS, 10-30% (best estimate 20%) was not searched. We used low, best, and high estimates of 10%, 25%, and 50% for the entire spill area, and

10%, 20%, and 30% for PWS.

Percentage of Eagle Carcasses In The Woods (d).--Anecdotal information and interviews with persons who participated in search and rescue efforts indicated that crews usually searched only the tidal portion of the beach; grassy flats and the forested edge adjacent to the beach were not searched. Therefore, we expected that eagles in the woods would not have been found during shoreline cleanup operations. Since July 1989, 162 bald eagles were radiotagged in PWS to monitor survival and document movements and exposure to oiled areas (Chapter 6). Transmitters were equipped with mortality sensors that allowed dead eagles to be located. For 34 dead radiotagged eagles recovered, the distance to the high tide line, elevation, and distance into the woods was recorded. Based on the location of the carcass, we recorded whether the carcass was likely to have been found by a cleanup or bird rescue crew searching the shoreline. We estimated that at least 74% of 34 radiotagged bald eagle carcasses recovered would not have been found by searchers because the carcasses were in the woods, far from shorelines, or completely concealed in cavities. The proportion was independent of season.

Expected Natural Mortality along all shorelines (e).--We subtracted from the estimate of total mortality the expected natural mortality within PWS, Kenai Peninsula, Kodiak archipelago, Katmai National Monument, and Alaska Peninsula that occurred during the time crews were searching beaches. An estimate of natural mortality was made using survival rates for more than 100 radiotagged eagles during 1990-92 (Pollock et al. 1989, Chapter 6). Survival rates from 1 April to 31 August were 0.83 for first-year eagles and 0.95 for older eagles. Numbers of first-year and older eagles within the population were calculated by a life table, which incorporated estimates of the total population at risk at the time of the spill (Chapter 1), the proportion of immatures in the population (Chapter 5), and age-specific annual survival rates. Four hundred ninety-three eagles were expected to die during that time period in the four areas combined. Within PWS alone, an estimated 274 eagles would have died (Table 2-1). These estimates are for all shoreline, oiled or not, within the areas defined in Figure 2-1.

Percentage Of Shoreline Oiled (f).--The percent of shoreline within PWS, Kodiak archipelago, and along the Kenai Peninsula, Katmai National Monument, and Alaska Peninsula that was oiled, multiplied by the expected natural mortality for all shoreline, was used to determine the expected natural mortality "available" for discovery (i.e., the number of eagle carcasses along oiled shorelines that were searched). Of 9637 km of total shoreline in these areas, 1297 km (13.5%) were oiled (*Exxon Valdez* Oil Spill Damage Assessment Geoprocessing Group 1991). Within PWS, 17% of shoreline was oiled. Therefore, the expected natural mortality within the spill area was 67 eagles (47 in PWS alone).

We made the following assumptions regarding the estimate of direct mortality: 1) natural survival rates determined for PWS eagles using telemetry were the same for eagles from other areas in the spill area; 2) natural mortality was distributed evenly throughout the region; 3) natural mortality continued at a constant rate throughout the summer; 4) estimates of search effort and recovery rates reflected average rates for the entire period in question; 5) emigration and immigration of eagles were equal; 6) dying radiotagged eagles behaved the same as eagles that died from the effects of oil; 7) the distribution of carcasses among collection sites reflected the distribution of the kill; and 8) all eagles dying from natural causes and available for discovery were recovered.

Estimation Of Lost Production

We initiated reproductive surveys during summer 1989 to assess impacts to the productivity of bald eagles in PWS, along the Kenai Peninsula, within the Kodiak archipelago, and along the southern shore of the Alaska Peninsula. We repeated these surveys in 1990. The locations and status of nests were entered into a Geographic Information System and compared with data on the distribution of oil along shorelines (*Exxon Valdez* Oil Spill Damage Assessment Geoprocessing Group 1991).

To evaluate the effects of oiling on bald eagle reproduction for each geographic area, we compared reproductive success between 1989 and 1990 for a sample of nests in oiled areas, and for a sample in unoiled areas. We restricted our analysis to nests of known oiling status that had known fates for both years. By this definition,our dataset for these areas was more comparable and less biased, but much smaller, than datasets used in Chapters 3 and 4. Nests were considered oiled if there was any oiling within 483 m and unoiled if there was no oiled shoreline within 483 m of the nest. The distance of 483 m was chosen because it represented the area around the nest used most intensively by nesting eagles (Chapter 3).

The oiling datasets used in the analysis varied among areas, and were chosen to portray the maximum extent of oiling during the reproductive period. For PWS and the Kenai Peninsula, we used cumulative oiling through August 1989. For Kodiak and the Alaska Peninsula we used oiling through June 1989.

Two measures of reproductive success were used in these comparisons: 1) total number of young produced, and 2) nest success, defined as the percentage of all nests in the sample that produced at least one young.

We assumed that the oil spill had no lingering effects on bald eagle reproduction in 1990 because reproductive rates for eagles in PWS in 1990 were within the expected normal range for Alaskan bald eagle populations. However, our ability to assess the validity of this assumption was impossible because of the lack of either pre-spill or post-1990 reproductive surveys in

PWS.

RESULTS

Direct Mortality

We estimated that between 614 and 1871 bald eagles, with a best estimate of 902, were killed directly by the spill in the 5 months following the spill (Fig. 2-1). Mortality within PWS alone was estimated between 174 and 402 (best estimate is 247).

The estimated mortality due to the oil spill was about twice the expected natural mortality for the spill area. The number of dead eagles retrieved from beaches represented 8-25% of the actual kill due to the spill.

Lost Production

Reproductive success within PWS was substantially lower in 1989 than in 1990. Our subsample of 169 nests within oiled areas of PWS produced 32 young in 1989 and 157 in 1990 (Table 2-2). We found 261 nests within oiled areas in 1989, but not all of these nests were surveyed again in 1990, nor were all oiled areas surveyed in 1989; we estimated that there were about 300 nests in oiled areas of PWS. Therefore, our sample of 169 nests represented 56% (169/300) of the total nests in oiled areas. An estimate of "lost production" is the difference in production for the subsample of nests, extrapolated to the total number of nests in oiled areas in PWS. This estimate is 223 young (157 young in

1990 - 32 young in 1989 = 125 young X 100/56 = 223 young). The estimated production of eagles in PWS in 1990 was about 800-1000 chicks (USFWS, this study, unpubl. data). Assuming that 1990 was a normal year for eagle production, then a loss of 223 chicks in 1989 represented 22-28% of the annual production in PWS.

We did not find a negative effect of the spill on bald eagle reproduction for Kodiak, Alaska Peninsula, or Katmai National Monument. The number of young produced, and nest success, in oiled areas was higher in 1989 than in 1990 (Table 2-2). Nests within unoiled areas of PWS produced more young in 1990 than in 1989, but at Kodiak and Katmai National Monument however, production was greater in 1989 than 1990 within the unoiled areas. Data for Kenai Peninsula were insufficient, and no comparisons were possible.

DISCUSSION

An important observation from this study was the high percentage of radiotagged eagle carcasses found in the woods. Our estimate of spill-related mortality is particularly sensitive to this adjustment, but we have no data to evaluate the assumption that dying oiled eagles behaved like dying radiotagged eagles. If the distribution of radiotagged eagle carcasses was similar to the distribution of oil-killed eagle carcasses, then this observation strongly supports our belief that the number of beached carcasses reported represented only a small fraction of the total number of eagles killed.

The adjustment for natural mortality within the equation for total mortality assumes (falsely) that all oiled shoreline was searched, and that all carcasses of eagles that died from natural causes would have been found, which is unlikely. This suggests a conservative estimate of total mortality, but may be offset partly if carcasses of eagles that died before the spill remained on beaches after the spill and were also recovered by cleanup crews.

Population surveys of bald eagles in PWS (Chapter 5) did not show a decrease in population size from 1989 to 1990. However, confidence limits on these population estimates varied from 14% to about 30%. Although these confidence limits are typical for raptor surveys (Kochert 1986), we concluded that they were insufficient to document short term effects of the magnitude resulting from the *Exxon Valdez* oil spill.

Our classification of eagles into oiled and unoiled treatment groups, based on oiling near the nest site, is undoubtedly imperfect. First, productivity for nests in unoiled areas was less in 1989 than 1990, suggesting that impacts related to contamination extended beyond the boundaries of the area directly oiled. Secondly, radiotelemetry studies (see Chapter 3) have shown that eagles will make occasional forays to feeding areas outside their most intensively used area of 483 m around the nest. Therefore, eagles nesting in unoiled areas could have been exposed to oiled prey or substrate. Because we estimated losses only within oiled areas, we likely underestimated the production lost due to the spill.

This may have been a conservative estimate of lost production because 1989 was an apparently exceptionally good year for eagle production in most other areas of Alaska (M. Jacobsen, USFWS, Juneau, Ak, unpubl. data). Although based on a small number of nests, the number of young produced within the spill area (except PWS) was greater in 1989 than 1990, suggesting that either 1989 was a good year for production or that 1990 was not. Nest success and number of young produced increased within unoiled areas of PWS from 1989 to 1990, which may reflect the difficulty of accurately classifying eagles to oiled and unoiled areas, and again supports our contention that we underestimated losses in PWS.

Adverse effects on reproduction in areas outside PWS may not have been observed because of the decreased toxicity and consistency of oil by the time it reached those areas. However, we were not able to assess reproductive success on the Kenai Peninsula because of the small number of nests with complete survey information.

It is noteworthy that a higher number of carcasses as a percentage of the population were found on the Kenai, Kodiak, and Alaska Peninsula coasts, even though search effort was lower. This suggests greater mortality and presumably decreased reproduction, although we were not able to document a drop in production given the available data.

Although no information on the annual variability in productivity is available for PWS, the observed decrease in productivity in 1989 was outside the range of variability observed in a 10-year study of bald eagle nesting in southeast Alaska (M. Jacobsen, USFWS, Juneau, Ak, unpubl. data). We believe it is unlikely that the decreased productivity in 1989 was due simply to natural variation. We found a close relationship between nest fate and the presence of oil near the nest area (Chapter 3), which supports the hypothesis that the observed reduction in productivity was due to the oil.

Young (1968) and Grier (1980) used hypothetical rates of reproduction and survival to show that the population dynamics of bald eagles hinge more on survival than on reproduction. Rates of reproduction may be relatively inconsequential to this long-lived, slow breeding, species. Results of other elements of the bald eagle damage assessment study suggest that there were no long term effects on survival of bald eagles in PWS (Chapter 6), and that reproductive success rebounded to apparently normal levels in 1990.

Fortunately, bald eagle populations in coastal Alaska are dense and are believed to be increasing or stable in most areas (Hansen and Hodges 1985). The direct mortality and lost production of eagles is unlikely to have a lasting effect on bald eagle populations in the spill area. This conclusion is supported by the results of a population model for bald eagles, which simulated the effects of the estimated direct mortality and lost production (Chapter 6).

CHAPTER 3

BALD EAGLE NEST SUCCESS IN PRINCE WILLIAM SOUND, ALASKA, FOLLOWING THE EXXON VALDEZ OIL SPILL

EXECUTIVE SUMMARY

Bald eagle nesting in Prince William Sound, Alaska, was monitored for two years following the *Exxon Valdez* oil spill on March 24, 1989. Each nest was surveyed at least twice from the air, once early in the breeding season to determine nest occupancy and once late in the breeding season to determine nest fate. The nest occupancy rate in oiled areas was lower than in unoiled areas in 1989. Occupancy rates for the entire study area were equal between years. Nesting success in oiled areas was significantly reduced in 1989 with few successful nests and reduced production in those nests that were successful. Nest failure rates were significantly higher in 1989 at nests near heavily oiled beaches compared to unoiled beaches and significantly lower in 1990 at nests along oiled beaches. Nest fates in 1989 and, to a lesser extent in 1990, were related to the linear extent and concentration of oil in the vicinity of the nest. A decrease in crude oil toxicity or availability may have been responsible for improved nesting success in 1990.

INTRODUCTION

On March 24, 1989, the tanker *Exxon Valdez* ran aground on Bligh Reef in northeastern Prince William Sound (PWS), Alaska, and spilled more than 40,000 kiloliters (11 million gallons) of Prudhoe Bay crude oil. The oil was pushed southwest by winds and currents for more than 750 kilometers and eventually reached Kodiak Island and the Alaska Peninsula (Piatt et al. 1990). Thousands of cleanup workers followed the oil to the beaches with a vast array of equipment and scoured the shorelines for the next two summers.

This coast is largely undeveloped and sparsely inhabited by humans. The once pristine habitats of the affected area are occupied by at least 8000 bald eagles (Haliaeetus leucocephalus) (Chapter 1), about twice the number of pairs of bald eagles breeding in the rest of the United States (Stalmaster 1987).

Prior to the spill, population surveys of PWS and adjacent areas were conducted by the U. S. Fish and Wildlife Service in 1973 and 1982. The 1973 survey data were not usable due to problems in survey design, but the 1982 survey provided comparative data for our studies. Nest surveys in PWS were conducted in 1980 to locate nests in areas proposed for logging (Hodges et al. undated). Bald eagles along the coast of southern Alaska are closely associated with intertidal habitats. Bald eagles in this region obtain essentially all of their food from the intertidal zone or surface of adjacent waters (Imler and

Kalmbach 1955), and nest sites average 37 m from the tide line (Hodges and Robards 1982). The area around the nest used by breeding bald eagles in Alaska has been variously estimated at 0.23 (Hensel and Troyer 1964) to 12.69 km^2 (Corr 1974), but probably averages 1-2 km^2 (Stalmaster 1987). Following the spill, areas used by bald eagles became extensively fouled as oil drifted ashore. Severe impacts to bald eagles nesting in the path of the spill were expected.

The potential threat to bald eagles and other coastal raptors from a major oil spill has been recognized for a long time (Schempf 1982, Todd et al. 1982). No literature exists on the impact of crude oil on nesting bald eagles, but there are numerous studies available for other species (Hooper et al. 1987). Generally, birds come into contact with oil through ingestion of contaminated food, direct contact with oil or transfer of oil from contaminated individuals, such as from adults to their eggs or nestlings (Hartung 1965, Birkhead et al. 1973, Albers 1978, 1980, Clark and Gorney 1987). Oil in microliter quantities has been found to be extremely toxic to bird embryos (Hartung 1965, Szaro and Albers 1977, Albers 1978, 1980, Albers and Szaro 1978, Hoffman 1978, 1979, Szaro et al. 1978a, 1980; Coon et al. 1979, King and Lefever 1979, Szaro 1979, Couillard and Leighton 1990a, b). Ingestion of oil has been demonstrated to interfere with normal incubation and to decrease fecundity (Hartung 1965, Szaro 1977, Leighton et al. 1985).

Birds are also subject to injury by oil through damage to feather structure leading to hypothermia or loss of flight and pathological effects from ingestion (Szaro et al. 1978b, Flemming et al. 1982, Pattee and Franson 1982, Lee et al. 1985, Leighton 1985, 1986).

We initiated a study to determine the impacts of the spill on bald eagles nesting in PWS. We report our observations of bald eagle nesting success at 304 nests within PWS in 1989 and 1990 and discuss how reproduction was influenced by the extent and intensity of crude oil contamination of nesting habitat. We concluded that nest occupancy, nest success and the number of young produced per successful nest were all negatively affected by the spill in 1989 and that these effects were related to the linear extent and concentration of crude oil on beaches near the nests. Nest failure rates were higher than expected in 1989 and lower than expected in 1990 at nests along oiled shorelines. Otherwise, productivity statistics were within what we assume to be normal bounds in 1990.

METHODS

Study Area

PWS, located on the southcentral coast of Alaska, encompasses about 39,000 km^2 including 4800 km of convoluted shoreline with many islands, particularly in the western portion. A temperate rain forest dominated by Sitka spruce (*Picea* sitchensis) and western hemlock (Tsuga heterophylla) covers most of the land to an elevation of 500 m. Summer temperatures range between 7° and 25° C, winter temperatures rarely fall below -20° C, and more than 500 cm of precipitation falls in some areas annually. The area is sparsely populated by humans with communities at Valdez, Cordova, Whittier, New Chenega and Tatitlek. PWS supports productive commercial fisheries for salmon (Oncorhynchus spp.), herring (Clupea harengus), and various bottom fish. Five hatcheries support the commercial salmon fishery. Other industries include logging and tourism. Since 1978, almost daily oil tanker traffic passes through PWS between the Trans-Alaska Pipeline System terminal at Valdez and west coast refineries.

Collection of Nesting Data

We collected initial nest occupancy data in 1989 during a bald eagle population survey flown with fixed-wing aircraft from April 18 to May 5, following methods presented by Hodges et al. (1984). This survey was flown primarily to count adults, but nest occupancy data collected secondarily supplemented later helicopter surveys. We surveyed the shoreline of all islands in PWS and 23 random plots, each 16,828 ha, along the mainland of PWS. The aircraft was typically flown 90 m above the ground and 90 m offshore at an air speed of 160 km/hour. The location and status of all bald eagle nests seen during the population survey were recorded.

A helicopter is preferred for reproduction surveys because slower air speeds and better maneuverability allow the collection of more accurate data on nest occupancy and productivity (White and Sherrod 1973, Carrier and Melquist 1976). We therefore searched shorelines for previously observed nests and new nests with a Bell 206 helicopter flying at an altitude of 15-150 m at speeds of 65-110 km/hour. Two observers were present in the helicopter during surveys. The front observer served as navigator and recorded new nest locations on field maps. The back seat observer recorded a nest identification number, status, and comments on field forms. We minimized the time spent in the air near each nest to reduce disturbance during surveys (Fyfe and Olendorff 1976).

In 1989, helicopter surveys began on 20 May. We concentrated our search effort on the islands in the western part of PWS because of the immediate need for data on bald eagle nest locations and breeding status in relation to shoreline cleanup operations. Surveys were repeated throughout the summer until the fate of each nest was determined. Due to the late start and hectic conditions after the spill, data on some nests were fragmentary or otherwise unsuitable for analysis. The only nests included in this analysis were those nests surveyed at least once before the end of May to determine occupancy, and at least once again to confirm that the nest had either failed or had young near the age of fledging.

In 1990, helicopter surveys began on 10 April. Nests were surveyed at least once each month. Nests not occupied by 1 June were dropped from the survey. Occupied nests that were empty on two consecutive surveys after 1 June were also deleted from the survey. Final surveys were flown in August when nestlings began leaving the nests. The survey area encompassed approximately 80% of bald eagle nesting habitat within PWS and included nearly all of the area directly affected by the oil spill. Most of the nests surveyed in 1989 also were surveyed in 1990. More nests were found in 1990 and the survey area was expanded to include more nests in eastern PWS. However, we included in this analysis only nests with complete data for both years to eliminate potential biases caused by inclusion of nests surveyed in only one year, particularly the large number of nests surveyed in eastern PWS in 1990 compared to 1989.

During occupancy surveys, we determined nest status as empty, occupied or active, following the terminology of Postupalsky (1974). We classified a nest as occupied if we observed a pair of adult eagles in the immediate vicinity of the nest. We classified a nest as active if we saw an adult in incubating posture, eggs or nestlings in the nest. Final nest fate was listed as empty, failed or successful. Failed nests were those observed as occupied or active on an earlier survey, but found empty on subsequent surveys. We classified a nest as successful if we saw older nestlings (generally >5 wks old) we believed would survive to fledging. We recorded the number and age of young at successful nests.

We calculated occupancy rates as a percentage of all of the sample nests. We believe our estimate of nest occupancy in 1989 was lower than the true rate due to the late initiation of surveys. In 1990, repeated surveys were flown early in the season and nest occupancy was well documented. To eliminate potential bias between years due to different survey intensity, we calculated nest success as a percentage of all nests rather than using the standard practice based on occupied nests only. Nest failure rates were calculated using all nests and using only occupied nests.

Effect of Oil

To assess the influence of oil contamination on breeding success, we estimated the size of the area around nests that was used by nesting adults. We then developed an index of shoreline contamination within this core area.

Core Area.--We had no knowledge of how eagles used the area around the nests surveyed for this study. We assumed, however, that use would be focused around the nest, that eagles would use areas of similar size within the study area, and that this area could be approximated by a circle around the nest. We determined average nest site use patterns using multiple observations ($n \geq$

10) of nesting, radiotagged adults at 15 nests in PWS from 18 April through 27 August, 1990, or until the nest failed or the young fledged. We assumed that oil contamination did not influence the behavior of eagles in 1990. We plotted telemetry relocation points and measured the maximum distance between two points for each adult. Occasionally a point fell far outside the cluster of relocations about the nest. These outliers were eliminated from the data set because such movements were unpredictable and infrequent. We defined a "core area" as a circular area with a center at the nest and a radius equal to one-half the maximum distance between relocation points. The core area radius for 15 nesting adults was 483 meters.

The area used by nesting eagles was not circular, but was roughly elliptical, oriented along the shoreline. The radius of the circle, however, was comparable to half the major axis of the ellipse and included similar amounts of shoreline, our variable of interest. The circle included additional areas of uplands and open water, but the inclusion of these areas did not influence the analysis. We believe this is a conservative estimate of the area actually used by breeding eagles, but represents the area they used most intensively.

Oiling Classification.--The length of shoreline within a radius of 483 meters of each nest was calculated using a geographical information system. Each shoreline segment was subdivided into oiling classes based on shoreline assessment data collected in 1989 by the Alaska Department of Environmental Conservation (ADEC) that reflected the extent of oiling prior to any cleanup activities (*Exxon Valdez* Oil Spill Damage Assessment Geoprocessing Group 1991). We used the following classes for our analysis: heavy, moderate, light or unoiled. ADEC classified as heavily oiled beaches those with more than 50% of the intertidal area covered by oil or a band of oil greater than 6 m wide. Beaches with 10-50% coverage or a band of oil 3-6 m wide were considered moderately oiled. Beaches classified as lightly oiled had 1-10% coverage or a band of oil 1-3 m wide. Unsurveyed shorelines were assumed to be unoiled because extensive efforts were made to survey all oiled shorelines.

Data Analysis.--Some core areas included shoreline segments that were unoiled, lightly oiled, moderately oiled and heavily oiled. Therefore, comparisons were made between unoiled core areas and core areas with three different combinations of oiling classes: (1) core areas with any heavy oil, (2) core areas with any heavy or moderate oil, and (3) core areas with any oil. For example, a core area with 100 m of heavy oil and 100 m of moderate oil would be included in all three analyses: one based on heavy oil, one based on heavy and/or moderate oil and one based on any oil.

Nest fates also were compared with the degree of oiling in the core area using Tukey's HSD multiple comparison test (Zar 1984:186-190) after applying Bartlett's test for homogeneity of group variances. The degree of oiling within each core area was estimated as a weighted mean, giving shoreline segments a weight of 1.0, 0.67, 0.33, and 0.0 for heavy, moderate, light, and no oil, respectively. These weights were multiplied by the length of shoreline in the core area for each class, summed, and divided by the total amount of shoreline in the core area. The values of this "oiling index" ranged from 0.0 for unoiled core areas to 1.0 for core areas where shorelines were entirely coated with heavy oil.

We compared nest occupancy, nest success and nest failure rates between years and between various oiling intensities using a chi-square test. We compared nest fates in 1989 and 1990 using a chi-square test to determine if nest outcome in 1989 influenced the fate of the nest in the following year. We used a t-test to compare the average number of young produced for all nests, for occupied nests and for successful nests between years and for all nests between oiled areas and areas without oil.

RESULTS

We determined the status of 344 nests in 1989 and 1039 nests in 1990; complete data were available for both 1989 and 1990 for 304 nests (Fig. 3-1). The core areas associated with these 304 nests contained an average of 1205 ± 884 m of shoreline (95% confidence interval) with a range of 0 to 3294 m. The core areas for 4 nests contained no shoreline. The nearest shorelines to these nests were either unoiled (n = 1) or not surveyed (n = 3) so these nests were included with other unoiled nests for analysis.

Occupancy Rates

Occupancy rates of the 304 nests were equal between years; eagles occupied 189 sites in 1989 and 184 sites in 1990 (X^2 = 0.173, 1 df, P = 0.678). Nests occupied in 1989 were much more likely to be occupied in 1990 than nests not occupied in 1989 (X^2 = 16.142, 1 df, P < 0.0001). In 1989, nests with any oil in the core area were much less likely to be occupied than nests with no oil in the core area (Table 3-1). Although the occupancy rates for nests in core areas with oil were lower than for nests without oil in 1990, these differences were not statistically significant for any of the oiling regimes.

Nest Success

Eagles successfully raised at least one chick at 58 (19%) of the 304 nests in 1989 whereas 116 nests (38%) were successful in 1990 (X^2 = 27.084, 1 df, p < 0.0001). In 1989, nest success for nests with any oil in the core area was much lower than for nests with no oil in the core area (Table 3-2). Nest success decreased as the degree of oiling in the core area increased. Nest success was independent of oiling intensity in 1990.

Nest Failures

In 1989, 131 of 304 nests (43.1%) failed whereas only 68 (22.4%) failed in 1990 (X^2 = 29.649, 1 df, p < 0.0001). Nest failures at individual nest sites were independent between years. When calculated on the basis of all the nests surveyed (n = 304), differences in nest failure rates among the various oiling intensities in 1989 were not significant, but fewer nests than expected failed in core areas with any oil in 1990 (24 of 147, 16.3%) compared to nests in areas with no oil (44 of 157, 28.0%; X^2 = 5.329, 1 df, P = 0.021). However, when failure rates are calculated based on occupied nests, nest failures in 1989 were highly dependent on the presence of heavy oiling in the core area with more nest failures than expected at nests in core areas with heavy oil (Table 3-3). Failure rates decreased with decreasing oiling intensities. In 1990, although we observed fewer nest failures than expected for nests in core areas with oil, the results were not statistically significant.

Relationship Between 1989 Fate and 1990 Fate

Overall, whether an individual nest was empty, failed or successful in 1990 was highly dependent on the fate of that nest in 1989 (Table 3-4). This relationship was primarily due to nest occupancy; nests empty in 1989 were likely to be empty in 1990 more frequently than expected (X^2 = 16.142, 1 df, P < 0.0001). Nest success in 1990 was likely to reflect nest success in 1989, but the relationship was not significant (X^2 = 3.109, 1 df, P = 0.078).

Oiling Index

The mean "oiling index" for core areas of successful nests ($\bar{x}$ = 0.109, n = 58, SD = 0.229) was less than indices for empty ($\bar{x}$ = 0.258, n = 115, SD = 0.317, P = 0.005) and failed nests ($\bar{x}$ = 0.212, n = 131, SD = 0.299, P = 0.017) in 1989. No significant difference was observed between indices for empty and failed nests in 1989 (P = 0.579). Oiling index means were not significantly different among nest fates in 1990.

Productivity

The number of young in each nest in 1990 was independent of the number of young observed in 1989. Fewer young were produced per nest surveyed, per occupied nest and per successful nest in 1989 than in 1990 (Table 3-5). In 1989, production of young from nests with any degree of oiling in the core area was significantly less than from nests in unoiled core areas (Table 3-6). Production of young decreased with increasing intensities of oiling. In 1990, the number of chicks in a nest was independent of the degree of oiling.

DISCUSSION

In 1989, occupancy rates for nests in oiled core areas were lower than for nests in unoiled core areas. Lower occupancy rates suggest that oil-related impacts had already occurred by the time we initiated helicopter surveys on May 20, nearly two months after the spill occurred.

It is likely that some degree of impact may have occurred at nests in unoiled core areas as well. Although breeding eagles tend to stay in the vicinity of their nests, we occasionally documented movements outside (>2 km) nesting territories, which may have exposed eagles to oil even if their core area was unoiled. A single exposure to fresh crude oil may have been enough to kill an embryo (Hartung 1965, Albers 1978, 1980) or adult.

The lower occupancy rate of nests in oiled core areas could have been due to the death of one or both of the breeding adults, abandonment of the nesting attempt, or early death of the embryo and loss of the egg. The death of the breeding adults seems the most likely explanation. Some nests may have been simply abandoned, but we cannot explain why large scale abandonment would occur and believe it was unlikely. Oil washing up on the beach near a nest did not appear to be an adequate cause by itself for abandonment except in the most extreme cases. Embryo mortality was probably significant, but it seems logical that breeding eagles would not know that an embryo was dead and nests would still have been occupied when we initiated our surveys. We observed that nest failure rates increase sharply in early June near the time of hatching. We believe that this is due primarily to adults abandoning dead embryos and infertile eggs. Our data do not provide insight into the actual mechanism responsible.

The occupancy rate for nests in oiled core areas was lower than the rate for nests in unoiled core areas in 1989, thereby reducing the overall occupancy rate for all nests in 1989. The overall occupancy rate for all nests in 1990 was the same as the rate for all nests in 1989. The overall occupancy rates, 62% in 1989 and 61% in 1990, are 10-30% lower than rates reported for other bald eagle populations in North America (Stalmaster 1987) and lower than the rate for nests in unoiled core areas in 1989. The lack of any increase in occupancy rate in 1990 suggests that the spill related impacts observed in 1989 carried over into the following year, but that these impacts were distributed throughout the sample nests rather than being confined only to nests in oiled core areas.

In 1989, success was lower at nests in oiled core areas than at nests in unoiled core areas and lowest at nests in core areas with the heaviest oiling. In 1990, nest success was independent of oiling intensity. The percentage of total nests that were successful in 1989 was one half of the percentage for 1990, 19% compared to 38%. In 1989, 31% of occupied nests (58 of 189) were successful while in 1990, 63% of occupied (116 of 184) were successful. We suspect that the 1989 rate was actually lower than our data indicate for reasons discussed above and well below the 58% average success rate observed for other populations (Stalmaster 1987), but the 1990 success rate appears to be normal for bald eagle nesting populations.

Nest failures were common in 1989. Nests on heavily oiled beaches failed more frequently than nests on beaches with less oil. Failure rates for nests in core areas with lower concentrations of oil were intermediate between nests in heavily oiled and unoiled core areas, but not significantly different from nests in unoiled core areas. The core areas of empty nests and failed nests had similar degrees of oiling, but some nests likely failed before we initiated surveys in 1989, thereby resulting in misclassification of failed nests as empty nests. Consequently, we probably underestimated failure rates in 1989.

In 1989, few young were produced from nests in oiled core areas. This low productivity was due to a lower than normal occupancy rate, high failure rates, and to smaller broods in nests that were successful. Significantly more young were produced in 1990 than in 1989 based on all 304 nests, on occupied nests, or on successful nests. Eagles in PWS were nearly twice as productive in 1990 than in 1989 even when comparing only nests in unoiled core areas.

Avian mortality due to the ingestion of oil is uncommon (Szaro 1977, Szaro et al. 1978b, Flemming et al. 1982) and therefore was probably not a primary cause of reduced reproductive success. We believe the low nest success, the few young produced by successful nests and the high nest failure rate in 1989 was attributable primarily to embryo mortality as a result of oil contamination. Oil from the *Exxon Valdez* was most toxic when it was first spilled into PWS, about the time when egg laying by eagles began. As volatile compounds evaporate into the atmosphere, the remaining oil becomes less toxic (Szaro et al. 1980). Embryos are particularly susceptible to crude oil contamination from the fouled feathers of the incubating adults and would have been at risk of exposure when the oil was most toxic. We observed that nest failures peaked in early June of both years, when hatching normally occurs. Although the embryo may have been dead for weeks, the incubating adults apparently did not abandon a dead egg until the end of the incubation period.

The close relationship between nest fate and the linear extent and intensity of oiling supports the hypothesis that the observed responses in the eagle population were due to the oil itself and only secondarily to the disturbance created by oil cleanup activities. Although cleanup activities were also correlated with the amount of oiling, the timing of cleanup activities did not necessarily correlate with the timing of failures. Most failures occurred by mid-June whereas cleanup activities occurred throughout the summer. In 1990, buffer zones of 1/2 mile were established around eagle nests in PWS, within which activity (aircraft, boat, human) was restricted. It is possible that the buffer zones, and less intensive cleanup activities, contributed to the observed improvement in reproductive success in 1990, but it was probably the reduction and reduced toxicity of oil that had a greater effect.

We observed a decrease in reproductive success immediately following the spill in 1989, but not in 1990. Long-term consequences for the bald eagle population from the loss of one year's reproduction are probably minimal because survival is more important than reproduction for population stability in a long-lived species such as the bald eagle (Grier 1980). Long term reductions in reproductive success can certainly have negative consequences for the population, but a single poor season by itself is unlikely to influence the number of breeding adults.

CHAPTER 4

BALD EAGLE PRODUCTIVITY OUTSIDE PRINCE WILLIAM SOUND IN 1989 AND 1990 FOLLOWING THE EXXON VALDEZ OIL SPILL

EXECUTIVE SUMMARY

Bald eagle nesting surveys were conducted in 1989 and 1990 in coastal southcentral Alaska to assess the effects of the *Exxon Valdez* oil spill on reproductive success in areas outside PWS, including Kenai Peninsula, Kodiak Archipelago, Katmai National Monument, Alaska Peninsula, and the Copper River Basin and Delta. Reproductive success for this region was difficult to estimate because of biases in survey timing and technique, especially in 1989. Occupancy surveys were conducted after failures had likely occurred, and nonbreeding pairs were often not noted or underestimated. Because of these biases, the lack of pre-spill data, and the potential for wide natural fluctuations in reproductive success, only a substantial reduction in productivity due to the oil spill would have been evident in this study. We could not document decreased reproduction in these areas. This study provides the first estimates of bald eagle productivity for many areas in southcentral Alaska.

INTRODUCTION

On March 24, 1989, the oil tanker *Exxon Valdez* ran aground spilling more than 11 million gallons of crude oil into Prince

William Sound (PWS), Alaska. The oil moved southwest, fouling approximately 1300 km of shoreline in PWS, along the Kenai Peninsula, within the Kodiak Archipelago, and along the Alaska Peninsula (Fig. 1-1). An estimated 8000 bald eagles (Haliaeetus leucocephalus) inhabit these areas and are highly dependent on the nearshore ecosystem for nesting (Hodges et al. 1982, Hodges and Robards 1982) and foraging (Imler and Kalmbach 1955).

Reproductive success of bald eagles typically is evaluated using two surveys. An occupancy survey is conducted to identify all occupied nests and should be timed after all eggs have been laid and before any failures have occurred (Postupalsky 1974, Fraser et al. 1983). A second survey, the productivity survey, is conducted to identify failed nests and to count older young that are likely to fledge. Surveys must by correctly timed to obtain unbiased estimates of reproductive success (Steenhof and Kochert 1982, Fraser et al. 1983).

Estimates of reproductive success for eagles should be based on all occupied nests, including those in which no eggs were laid, because failure to initiate breeding represents one form of reproductive failure (i.e., nonbreeding pairs) (Postupalsky 1974). In southeast Alaska, nonbreeders composed 16-86% of the adult population (Hansen and Hodges 1985), and 6-70% of the adults occuping nests failed to produce eggs (M. Jacobsen, USFWS, Juneau, Ak, pers. comm.). On Kodiak (Hensel and Troyer 1964) and Amchitka (Sherrod et al. 1976) islands, 22-55% and 19% of territorial pairs evidently did not lay eggs, respectively. Because of the potential for a large number of nonbreeding pairs in coastal Alaska, estimates of reproductive success based only on pairs which laid eggs may not be representative of the population as a whole.

Reproductive success of bald eagles varies considerably in western North America. In coastal Alaska, occupied nest success and young per occupied nest ranged from 20%-92% and 0.24-1.5, respectively (Hensel and Troyer 1964, Zweifelhoffer 1992, USFWS unpubl.). In interior Alaska and Canada, occupied nest success and young per occupied nest ranged from 54%-87% and 0.8-1.4, respectively (Ritchie 1982, Blood and Anweiler 1990), but the number of nests and years surveyed was small. In coastal Washington (Grubb et al. 1983) and interior Oregon (Isaacs et al. 1983), occupied nest success and young per occupied nest were 51-79% and 0.72-1.18, respectively. The mechanism controlling the annual variation in reproductive success is unknown.

The objective of this study was to gather, collate, and re-analyze all available data on bald eagle productivity in the region outside PWS affected by the *Exxon Valdez* oil spill during 1989 and 1990 to determine if the spill influenced reproductive success. Because of the large area involved, surveys were conducted separately in each subregion by personnel from the U.S. Fish and Wildlife Service (USFWS), the National Park Service (NPS), and the Bureau of Land Management (BLM). Methods and survey effort varied among subregions, particularly in 1989, due to logistical constraints. Only general and weak conclusions regarding the effects of the oil spill could therefore be made because of the biases and limitations of the data.

Productivity of bald eagles in all areas outside PWS in 1989 and 1990 was generally within the range of natural variation, and, consequently, we could not attribute any decline in bald eagle productivity in 1989 to the oil spill.

METHODS

Study Area

The study area included the southeastern coast of the Kenai Peninsula, the Kodiak Archipelago, and the southern coast of the Alaska Peninsula within the Katmai National Monument and Alaska Peninsula/Becharof National Wildlife Refuge (APBNWR) (Fig. 4-1). Because eagles from interior Alaska were suspected to winter within the spill region, and could therefore have been affected by the spill, the Copper River Basin (CRB) and Copper River Delta (CRD) were also included in the study area.

Survey Methods and Data Analysis

Whenever possible, at least 2 surveys were conducted to assess bald eagle productivity. An occupancy survey was conducted during the incubation period (May to early June), and a productivity survey was conducted after eggs had hatched but before young had fledged (July to early August). Helicopters were used for all surveys unless otherwise noted. Bald eagle nest locations were plotted on USGS 1:63360 topographic maps.

We used terminology and calculated reproductive success based on definitions adapted from Postupalsky (1974) and Fraser et al. (1983) (Table 4-1, Fig. 4-2). Because terminology and criteria used to evaluate reproductive success for raptors are often confusing and different interpretations of data among researchers can result, we included data from a hypothetical study (Fig. 4-2) to clarify for the reader the terminology and calculations used in determination of reproductive success.

Kenai Peninsula.-- Surveys were conducted along the southern coast of the Kenai Peninsula by personnel from Kenai Fjords National Park and the USFWS. No occupancy surveys were flown in 1989. Limited surveys using boats were conducted by personnel from Kenai Fjords National Park and oil spill clean-up crews in June 1989, but locations of nests were often vague or not recorded. In 1989, productivity surveys were flown by USFWS on 27-28 July in a helicopter, and by NPS on 7-8 August in a Supercub.

In 1990, occupancy surveys were conducted on 19-23 May (74% of observations) and 6-7 June (26% of observations), and productivity surveys were flown 4-5 August; all surveys were conducted by USFWS personnel. For some nests, information on status conflicted between field maps and summary reports; we excluded these nests in our analysis. Because there were no occupancy surveys in 1989, we could not calculate nest success or productivity measures other than total young produced. We calculated total young produced for nests which were found on productivity surveys in both 1989 and 1990 to compare productivity between years.

Kodiak Archipelago.-- Zwiefelhofer (1989, 1990) conducted all surveys in the Kodiak Archipelago. Occupancy surveys were flown in a Supercub on 10-12 May 1989 and 7-11 May 1990. A Bell Jet Ranger helicopter was used for occupancy surveys conducted 1-7 June 1989 and 14 May-3 June 1990. The May and June surveys accounted for 64% and 36%, respectively, of the nests surveyed for occupancy in 1989. In 1990, 86% of nests were surveyed for occupancy before 16 May and 99% were surveyed before 25 May. Observers made no distinction between active nests and nests occupied by nonbreeding pairs in 1989. Therefore calculations of

Katmai National Monument.-- Surveys were conducted along the entire Katmai National Monument coastline on the south side of the Alaska Peninsula by Katmai National Monument in 1989 (Yurik 1989) and by the USFWS in 1990. Occupancy surveys were conducted 11 June 1989 and 26-27 May 1990. Productivity surveys were conducted 26 June to 15 August in 1989 and 24-25 July in 1990. The 1989 productivity survey was conducted by boat. Only data summaries were available for 1989 (Yurik 1989) because original survey data were lost, undocumented, or contained discrepancies. Consequently, the only measure of reproductive success in 1989 was total young produced; comparisons between years are based on total young produced.

Alaska Peninsula/Becharof National Wildlife Refuge.-- Surveys were conducted along the south side of the Alaska Peninsula within the APBNWR by Dewhurst (1989, 1990) in 1989 and 1990. Occupancy surveys in 1989 were flown 10 May to 3 June, but most of the nests (89%) were surveyed 1-3 June. Only active nests were noted. Productivity surveys were flown on 24 July and 25 July in a Cessna 206. Additional surveys were conducted on 19-20 June and 4-5 July.

In 1990, 825 miles of coastline was surveyed, but only 375 miles was surveyed for both occupancy and productivity. The 1990 occupancy surveys were conducted 9-11 May and 23-31 May. Productivity surveys were flown 26-28 July with an additional survey 19-21 June. All occupied nests were noted during in 1990.

We could only calculate nest success and productivity for active nests in 1989 because nonbreeding pairs were not identified. To compare productivity between years, we limited our analysis to nests surveyed in both 1989 and 1990.

Copper River Basin.-- Bald eagle nests were surveyed in the Copper River Basin from Tanada Lake and the Gulkana Drainage south to the Million Dollar Bridge by personnel of USFWS, BLM, and NPS. In 1989, occupancy surveys were conducted by fixed-wing aircraft 27 May in the entire CRB, and productivity surveys were conducted by helicopter 30 June-7 July on the Copper River and 25-26 July in the Gulkana Drainage. In 1989, occupancy surveys were conducted by inexperienced observers and relatively few nests were found, especially on the Copper River from Tanada Lakes to Chitina.

In 1990, occupancy surveys were flown 12-16 May and productivity surveys were conducted 26 July-18 August. Fixed-wing aircraft were used on all surveys above the Tiekel River in 1990. Nests occupied by nonbreeding pairs were noted in 1990, but were not noted in 1989. A comparison of productivity between years was based on the total number of young produced for nests found on productivity surveys in both 1989 and 1990.

Copper River Delta.-- The Copper River Delta was not surveyed in 1989 due to logistical constraints. Surveys were conducted by USFWS in 1990 on the western half of the Copper River Delta. Occupancy surveys were flown 12-16 May with a follow-up survey 18-19 June. The initial productivity survey was 26 July with a follow-up survey 15 August. Data were collected on all occupied nests.

RESULTS

Results of bald eagle reproductive surveys for 563 and 869 occupied nests surveyed in 1989 and 1990 respectively are presented in Table 4-2. In all areas and years, reproductive success was similar in 1989 and 1990, and within the range of natural variation for bald eagles in the region. Because of logistical constraints incurred immediately after the oil spill in 1989, occupancy surveys in most areas were often conducted later than optimal or were incomplete. In 1989, many surveyors were unaware of the importance of collecting data on nonbreeding pairs. Survey timing and techniques were improved in 1990, but nonbreeding pairs appear to be underrepresented in the sample for most subregions.

DISCUSSION

Results presented in this study may differ from results presented by refuge biologists or NPS personnel who participated in local bald eagle nesting studies after the spill (Amaral 1989, Zwiefelhofer 1989, 1990, Dewhurst 1989, 1990, Yurik 1989). This is due to differences in interpretation of data. Survey timing, technique, intensity, and extent varied greatly in most areas between 1989 and 1990. Consequently, direct comparisons between years or among areas using all survey data were impossible. We used subsets of data with reduced bias to compare productivity between years. An understanding of the biases involved and their effect on the perceived reproductive rates is essential to enable meaningful interpretations of these data. For year to year comparisons of reproductive success within specific areas, the total number of young produced was perhaps the best measure of an area's productivity if survey intensity, survey area, and observer experience were consistent. Total young produced was less biased by survey timing or by failure to recognize nonbreeding pairs than other commonly used measures such as nest success and young per occupied or active nest. For the following discussion, nest success and young per occupied nest will be referred to collectively as "reproductive rates".

Sources Of Bias

Failure to correctly identify all occupied nests.-- The standard definition of bald eagle productivity is the number of young produced per occupied nest (Postupalsky 1974). Occupied nests include both breeding (active) and nonbreeding pairs (Fig. 4-2). Failure to identify all nonbreeding pairs can seriously overestimate measures of reproductive success based on occupied nests. In this study, some observers were not aware of the importance of noting nests occupied by nonbreeding pairs. Thus we could not accurately measure the actual reproductive success of the breeding population.

Further, identification of all nonbreeding pairs is unlikely even when a concerted effort is made. To meet the definition of occupied, 2 adults must be sighted near or at a nest site. We found that 32% of adult eagles in PWS were missed during aerial population surveys (Chap. 6), and it is even less likely that both adults would be seen attending a nest site during an occupancy survey. This bias would be magnified if occupancy surveys are conducted late because pairs which fail to produce eggs may not be as attentive of the nest later in the season (Postupalsky 1974). In southeast Alaska (Hansen and Hodges 1985, USFWS unpubl.), Katmai National Monument (Troyer 1974, 1975, 1976), Kodiak Archipelago (Hensel and Troyer 1964), and Amchitka Island (Sherrod et al. 1976), 10-70% of territories were occupied by nonbreeding pairs annually. In this study, only 1-11% of pairs occuping nests did not breed. Thus, we believe we overestimated reproductive success based on the number of occupied nests. This bias may have been accentuated if the number of breeding pairs was reduced by the oil spill.

Improperly timed surveys.-- To accurately estimate productivity, occupancy surveys must be conducted before nest failures occur (Fraser et al. 1983, USFWS unpubl.). If occupancy surveys are conducted after some nests have failed, those nests would be incorrectly identified as empty, thereby overestimating nest success. To evaluate the magnitude of this bias, the chronology of nesting events must be known. We knew the nesting chronology for bald eagles only in PWS, and estimated the chronology in other areas based on estimated chick ages and fledging dates reported in other areas. In PWS, the ideal timing was mid-May for occupancy surveys and late July for productivity surveys (USFWS unpubl.). The timing of nesting events on Kodiak Island (Hensel and Troyer 1964) and in the CRB (USFWS unpubl.) is similar to timing in PWS, but nesting along the Alaska Peninsula (Dewhurst 1989, 1990), Katmai National Monument (Troyer 1975) and Kenai Peninsula (NPS, unpubl. data) probably occurs 1-2 weeks earlier than in PWS.

Kenai Peninsula

In 1989, total young produced was the only measure of productivity we could calculate because an occupancy survey was not conducted. Occupancy surveys are also important in accurately estimating total young produced. Nests constructed in conifer trees are often inconspicuous, and active nests are probably more easily found during the incubation period when at least one adult is nearly always at the nest. The white head and tail contrasts with the dark green canopy and helps observers identify nests. One would also expect more nests to be found if both occupancy and productivity surveys are conducted because new nests are found in subsequent surveys. Because survey intensity was lower in 1989, some productive nests were probably overlooked causing the estimate of total young produced to be low.

The between-year comparison of total young produced, based on the subsample of nests found only on productivity surveys, may also be biased. Eagle pairs may use alternate nests some years (Stalmaster 1987), and successful nests are more easily detected than empty nests or failed nests (Steenhof and Kochert 1982). Because only productivity surveys were conducted in 1989, the sample was probably biased towards successful nests. In 1990, both occupancy and productivity surveys were conducted, increasing the likelihood that failed or empty nests were also seen. Consequently, we would have expected the subsample to have more young produced in 1989 than 1990. Because of this bias, and the roughly equal total young produced for the entire area and the subsample, we do not believe there was any difference in productivity between 1989 and 1990.

In 1990, occupancy surveys were conducted 2-5 weeks late, and the percentage of nonbreeding territorial adults was low. Many early failures were probably missed and the percentage of nonbreeding pairs was probably underestimated, causing reproductive rates to be overestimated by 10-30%. The reproductive success of the population may have been low, but was probably within the range of natural fluctuation.

Kodiak Archipelago

Estimates of reproductive success in the Kodiak area in 1989 and 1990 were higher than for any other subregion and above the pre-spill average for Kodiak (Zwiefelhoffer 1990). Reproductive success, however, may have been overestimated in both 1989 and 1990. In 1989, 36% of the occupied nests found were surveyed approximately 3 weeks late. This bias was probably minimal compared to the underestimation of nonbreeding pairs. The percentage of nonbreeding territorial pairs could not be determined in 1989 and was only 3% in 1990 (Table 4-2). However, the number of occupied nests increased from 333 to 412 even though survey area and intensity was the same both years. Although some of the increase may have been due to increased surveyor experience (Zwiefelhoffer 1990), we believe numerous nonbreeding pairs and early failures were missed during the 1989 surveys.

Occupancy surveys were well timed in 1990, but the percentage of nonbreeding territorial pairs was lower than expected. The significance of the bias is difficult to determine because the actual number of territorial pairs is unknown. Because of the high observed reproductive success, there was probably no or minimal decline in productivity in this region due to the oil spill.

Katmai National Monument

Occupancy surveys in 1989 were conducted after most failures had likely occurred. We report only total young produced because of the large potential bias due to survey timing, and because of discrepancies between data summaries and field notes. This estimate of total young produced is a minimal estimate because productivity surveys were conducted by boat and observers were unable to see into all nests or observe nests distant from the shoreline. Even with these biases, more young were produced in 1989 than 1990. Reproductive success was within the range expected for the region.

The observed reproductive success in 1990 was comparable to reproductive success for eagles in other regions of southcentral Alaska. However, the actual reproductive success may have been 10-20% lower in 1990 because occupancy surveys were conducted 2-3 weeks late and numbers of nonbreeding pairs were probably underestimated. Although the actual reproductive success may have been low in 1990, we have no reason to suspect continued effects from the oil spill because productivity in Kodiak and APBNWR apparently increased in 1990.

Alaska Peninsula/Becharof NWR

The observed reproductive success estimates in both years were similar to other subregions and was within the range expected for the region. The reported productivity is probably overestimated, especially in 1989. Occupancy surveys in 1989 were probably conducted 3-4 weeks late, causing reproductive success to be overestimated by 10-30%. No data on nonbreeding pairs were collected in 1989, so the actual reproductive success of the breeding population could not be estimated.

All surveys in 1990 were properly timed, but the low percentage of nonbreeding territorial adults suggests that reproductive success may have been overestimated. There are few data available on breeding rates for territorial pairs in similar habitats, so it difficult to estimate the magnitude of this bias.

Total young produced for the subsample indicates productivity increased in 1990, but the subsample may also be biased. On the Alaska Peninsula, nests are inconspicuous, placed on the ground and are hard to identify unless an eagle is present. Previous knowledge of nest locations increases the chance of finding nests, but this advantage was only possible in 1990. Some nests found first in 1990 were likely overlooked but productive in 1989, accounting for some of the increase in total young seen in 1990. However, productivity was probably higher in 1990, especially considering active nest success was substantially overestimated in 1989.

Although there was an increase in productivity in 1990, reproductive success was probably within the expected range for the region both years. If productivity declined due to the oil spill, it could not be differentiated from natural fluctuation.

Copper River Basin

Reproductive success in the CRB was similar to success in other areas in interior Alaska (Ritchie 1982) and Canada (Blood and Anweiler 1990) in 1989; success was lower in 1990 than in 1989. Occupancy surveys were properly timed both years, but survey intensity was low in 1989. The large increase in number of occupied nests from 1989 to 1990 was not due to more nesting birds, but to nests overlooked in 1989. Productivity surveys were conducted 2-3 weeks early in 1989 and 1-3 weeks late in 1990. We compensated for the early survey in 1989 by eliminating from the data set the few nests with brooding adults where it was impossible to discern if, and how many, young were in the nest. In 1990, chicks had fledged from some nests before the productivity survey, but we believe this bias was insignificant. Despite these biases, productivity was obviously lower in 1990.

Few nesting studies have been conducted in the CRB, so the range of natural fluctuation and rates of nonbreeding are unknown. Nonbreeding pairs were not noted in 1989 and few nonbreeding pairs were seen in 1990. Nonbreeding pairs may be especially difficult to recognize in interior regions of Alaska. Food sources are probably limiting, especially in the spring when ice may cover many feeding areas. Eagles likely travel substantial distances to obtain food, and nesting densities are low. Pairs which fail to lay eggs may not be attentive to their nests because feeding may be more important than territory defense.

The observed decrease in productivity in 1990 is consistent with oil impacts as eagles in the region may not have been exposed until spending the winter of 1989-90 in oiled areas. However, because there was no obvious lingering effect from oil on eagles which nested in areas directly impacted, we believe the observed decrease in productivity was most likely due to natural causes.

Copper River Delta

Reproductive success appeared to be good in 1990, and surveys were properly timed. No comparable data exist for rates of nonbreeding in the area, and no surveys were conducted prior to 1990. We do not believe that reproductive success on the CRD was influenced by the spill.

CONCLUSIONS

We were unable to conclusively demonstrate that the spill impaired bald eagle reproduction outside PWS. However, our ability to detect declines in productivity in areas outside PWS was hampered because of the lack of pre-spill data, and because surveys were not conducted consistently among regions or years. Late occupancy surveys potentially missed numerous early failures, and data on nonbreeding pairs were limited. Estimates of reproductive performance were limited mostly to actively nesting eagles which survived the initial effects of the oil spill. Nesting pairs that were killed due to the spill or failed early in 1989, and did not nest in 1990, would probably not have been detected in this study, resulting in an underestimate of effects of the spill.

This study provides the first estimates of bald eagle reproductive success for many areas of southcentral Alaska. These estimates provide baseline data for future studies, but we emphasize the need to consider the potential biases involved in their determination.

CHAPTER 5

BALD EAGLE POPULATION OF PRINCE WILLIAM SOUND, ALASKA, BEFORE AND AFTER THE EXXON VALDEZ OIL SPILL

EXECUTIVE SUMMARY

We conducted population surveys of bald eagles (Haliaeetus leucocephalus) in Prince William Sound (PWS), Alaska in 1989, 1990, and 1991 to assess the effects of the *Exxon Valdez* oil spill. A 1982 survey provided the only pre-spill data on population size. We calculated a population index based on counts of adult bald eagles from fixed-wing aircraft. We surveyed within stratified random plots each year and completely censused all islands, except Esther I., in PWS in 1989-91. Confidence limits on indices of population size ranged from 13-30%. We could not detect a significant decrease in population size subsequent to the oil spill given these wide confidence intervals. The PWS bald eagle population appeared stable from 1989-91. About 30% of the population was immatures. Using a sample of radiotagged eagles, we estimated that 32% of adult eagles were not seen during population surveys. The adult population index, adjusted for unseen adults and immatures, indicated a spring population in PWS of about 4300 eagles for all age classes during 1989-91.

INTRODUCTION

An estimated 45,000 bald eagles live in Alaska, about 3 times the number of bald eagles living in the rest of the United States (Stalmaster 1987, USFWS, unpubl.). Breeding densities are higher in Alaska than anywhere within the species' range. On 24 March 1989, the oil tanker *Exxon Valdez* ran aground and spilled more than 11 million gallons of crude oil into the waters of Prince William Sound (PWS), Alaska. The oil contaminated extensive shoreline areas used by bald eagles as far west as the Alaska Peninsula (Fig. 1-1). An estimated 900 bald eagles died as a direct result of the oil spill, of which an estimated 247 were killed in PWS (Chapter 2). In 1989, reproductive success was severely reduced in oiled areas within PWS (Chapter 3). This study was conducted from 1989 to 1991 to determine bald eagle numbers in PWS following the spill. A population survey conducted in 1982 served as baseline data for comparison with population data we collected.

Bald eagles are typically censused using aerial surveys (Fuller and Mosher 1987). Adult bald eagles older than 4 years have predominantly white heads and tails and are readily visible. Immature eagles have cryptic plumage and are therefore difficult to see and accurately count during aerial surveys. Consequently, population surveys usually determine an index of the number of adult eagles, which represents the minimum population size. An estimate of the absolute number of eagles may be calculated by correcting the index for unseen adults and immatures. An estimate of total population size was needed to determine the effects of direct mortality and reduced reproduction caused by the *Exxon Valdez* oil spill.

The detectability of animals to airborne observers may be influenced by animal activity, time of day, weather, snow cover, topography, observer experience, type and speed of aircraft, age and sex of animal, season, and habitat (King et al. 1972, Grier 1977, Hodges and King 1982, Leighton et al. 1979, Grier et al. 1981, Kochert 1986, Fuller and Mosher 1987, Pollock and Kendall 1987). No estimates of visibility bias for bald eagles in habitat similar to PWS are available or applicable to the type of population surveys conducted in Alaska (Hodges et al. 1979, Hodges and King 1982). Our concurrent studies using radiotagged adult eagles (Chapter 6) provided an opportunity to assess visibility bias of adult eagles associated with this type of population survey.

We estimated a 1989-91 total PWS population of about 4300 bald eagles by correcting the population index for unseen adults and for immatures not counted during population surveys. The confidence limits on indices were wide and we could not detect a significant decrease in population size due to the *Exxon Valdez* oil spill.

METHODS

Study Area

PWS, located on the southcentral coast of Alaska, encompasses about 39,000 km^2 including 4800 km of shoreline. The coastline is convoluted with many islands, particularly in the western portion. A temperate rainforest dominated by Sitka spruce (Picea sitchensis) and western hemlock (Tsuga heterophylla) covers much of the area to an elevation of about 500 m. Summer temperatures range between 7° and 25° C, winter temperatures rarely fall below -20° C, and more than 500 cm of precipitation falls in some areas annually. The area is sparsely populated by humans with larger communities in Valdez and Cordova and smaller communities in Whittier, New Chenega, and Tatitlek. PWS supports productive commercial fisheries for salmon (Oncorhynchus spp.), herring (Clupea spp.), and various bottom fish. Five hatcheries support the commercial salmon fishing industry. Other industries include clearcut logging and tourism. Since 1978, almost daily oil tanker traffic passes through PWS between the Trans-Alaska Pipeline System terminal at Valdez and west coast refineries.

Survey Methods

We conducted population surveys following techniques used by Hodges et al. (1984) in British Columbia. The survey area was subdivided into 16,828 ha quadrilateral plots. Plot boundaries were parallel to lines of latitude and longitude with 7 minutes (12,964 m) of latitude between plot centers. Plots that consisted entirely of water or entirely of uplands were discarded. Of the remaining 110 plots that contained coastline, 18 were randomly selected and surveyed in 1982. An additional 22 plots were randomly selected and surveyed in 1989-91, as well as the original 18 plots (Fig. 5-1). Plots were stratified to high, medium, or low strata based on the expected density of nesting eagles within the plot (Table 5-1). Although subjective, the stratification was based on our knowledge and experience with nesting bald eagles in these habitats. Plots containing much shoreline and optimal nesting habitat had high expected eagle densities and were assigned to high strata, whereas plots in glaciated fiords with few potential nest sites had low expected eagle densities. Medium density plots were intermediate in the quality of nesting habitat and expected eagle densities. Additionally, we counted bald eagles along the shorelines of all islands in PWS except Esther Island during 1989-91. For 17 surveyed plots that contained *only* island shoreline, the island census data were used instead of the plot survey data. Surveys were flown in late April and early May each year using a turbine DeHavilland Beaver aircraft on amphibious floats. At this time of year, adult eagles are nesting and surveys provide an index to the size of the resident population. We searched shorelines from an altitude of 50-100 m at an airspeed of about 160 km/hr. The pilot and 1-2 observers counted all eagles with predominantly white heads and tails and marked their locations on USGS 1:63360 scale topographic maps. We digitized locations of eagles into a geographic information system database and used ARCINFO (ESRI Inc., Redlands, CA) to determine eagle numbers within plots, on islands, or along oiled segments of shoreline.

Estimation of the Immature Proportion of the Population

To estimate the proportion of immatures in the population, we also recorded the number, locations and ages of all eagles seen flying within surveyed areas. The proportion of flying eagles that did not have white heads was assumed to be an unbiased estimate of the proportion of immature eagles in the population (Hancock 1964, Hodges et al. 1984). Confidence limits on estimates of the percentage of immatures were calculated according to Fowler and Cohen (undated).

Visibility Bias

We radiotagged adult bald eagles for other study objectives; this sample of tagged eagles provided a means to independently measure our likely success at observing adult eagles during population surveys. We used these data to develop a correction for visibility bias applicable to the type of population survey used in this study. We made multiple observations of 35 radiotagged adult eagles in 1990 and 1991 from fixed-wing aircraft during May. Each time we relocated a radiotagged eagle using telemetry, we made a subjective determination of whether we would, would not, or might have seen the eagle on a population survey. For example, an eagle soaring or perched extremely high on a hillside would likely be missed during the population survey, which focused primarily on shoreline habitats at lower elevations.

The accuracy of the estimate for unseen adults could have been influenced by: 1) differences in timing (up to 1 month) between population surveys and visibility experiments, such that a higher proportion of eagles were incubating and presumably less visible during experiments; 2) our sample of radiotagged birds was skewed toward territorial birds, which were more likely to be seen than nonterritorial eagles; and 3) some eagles that we thought "would be seen" would have been missed during population surveys anyway. To compensate for these biases, we assumed that questionable sightings (those that "might have" been seen during surveys) had a likelihood of sighting similar to all definitive observations (rather than an equal ratio). Therefore, we disregarded questionable sightings and calculated the final percentage of radiotagged eagles that would be seen on a typical population survey as a proportion of definitive ("would" or "would not" be seen) sightings only. We assumed a binomial distribution for observations and therefore estimated a confidence interval with standard deviation estimated for a proportion (Fowler and Cohen 1986).

We also recorded general weather when we estimated an eagle's visibility, noting the extent and height of cloud cover, and the presence of fog or rain. The range of weather conditions that occurred during these observations was similar to weather conditions during population surveys.

Data Analysis

Differences in population indices between 1982 and other years were compared using indices derived only from the 18 plots common to surveys in all years, whereas differences among 1989, 1990, and 1991 indices were compared using the island census counts combined with eagle counts from stratified mainland portions of plots. Plots that included both mainland and island areas were re-stratified based on the expected density of eagles within the mainland *only* portion of the plot (Table 5-1). To avoid double-counting for portions of plots that overlapped islands, only the counts for the mainland portion of the plot were included in the estimate. For all between-year comparisons, a t-test was used to test for significant differences ($\alpha = 0.05$) between indices before corrections for visibility bias or proportion of immatures were made.

An estimate of total population size was made by adjusting the adult index for unseen adults and by the proportion of immatures in the population. Confidence limits on corrected estimates were constructed using methods of DeVries (1986).

We determined the number of eagles seen along oiled shorelines of PWS during surveys in 1989-91. Using ARCINFO (ESRI Inc., Redlands, CA), we buffered all eagle locations by 500 m; if oil occurred within the buffer, the eagle was considered to be along an oiled shoreline. Data on shoreline oiling were obtained from the *Exxon Valdez* Oil Spill Damage Assessment Geoprocessing Group (1991). These data were used to compare numbers of eagles seen along oiled shorelines among years.

RESULTS

Population indices for 1982, 1989, 1990, and 1991 were 1565 ± 473, 2089 ± 308, 1941 ± 283, and 2088 ± 273 adult eagles, respectively. Variability in estimates was substantially reduced by increasing the number of plots and censusing islands in 1989-91 (Table 5-2). Although the population index appeared to increase from 1982 to 1989, differences among years or between consecutive years were not significant (Fig. 5-2).

Of 344 eagles seen flying during population surveys in Prince William Sound during the 4 years of surveys, a pooled average of 30.5% ± 4.87% (95% CI) were immatures (27.3%, 28.9%, 30.1%, and 33.0% for the 4 years, respectively).

In 68% ± 7% of 192 observations of radiotagged adults, we believe that we would have seen the eagle during a typical population survey. Accounting for unseen adults and immatures in the population, spring population estimates for PWS were 3325 ±

1228, 4439 ± 981, 4125 ± 860, and 4436 ± 904 bald eagles in 1982, 1989, 1990, and 1991, respectively.

We counted fewer adult eagles along oiled shorelines in 1989 than in 1990 or 1991 along the same shorelines (Table 5-3). Similarly, the proportion of both adults and immatures counted along oiled shorelines increased in 1990-91.

DISCUSSION

The bald eagle population in PWS appeared stable between 1989 and 1991, and we did not observe significant changes in the population after the *Exxon Valdez* oil spill. Because confidence intervals on population indices ranged from 13% to 30%, we could not have detected changes in population index of less than about 300 adult eagles (Table 5-2). The estimated mortality in PWS caused by the oil spill was 247 (range 174-402) eagles of unknown age composition (Chapter 2). This estimated loss was within the confidence interval of the population indices.

The increase in numbers of eagles along oiled segments of shoreline after 1989 (Table 5-3) suggested that eagles were not attracted to oiled areas by an abundance of oiled prey in 1989. The increase could be interpreted 2 ways. First, the fewer eagles seen in 1989 may reflect high mortality before the surveys, and the increase in later years are "replacement" birds. But if we assume that the dates of carcass collection reflect the timing of mortality, 78% of eagles which died due to the spill died after population surveys were conducted in 1989 (Fig. 5-3).

Therefore, we believe that the 1989 population index provides a good estimate of the pre-spill population. Even if a substantial number of eagles died before surveys were conducted, it would not change our conclusion that the population size was not significantly different from 1989 to 1991. The magnitude of the kill was simply not large enough to evoke a statistical difference given the confidence limits on population indices.

A second explanation for the fewer eagles in oiled areas in 1989 could be that eagles avoided areas with high disturbance from cleanup activities. An avoidance of these disturbed areas may explain the low occupancy rates for nests in oiled areas in 1989 (Chapter 3).

More than 128,000 bald eagles were reported killed for bounties in Alaska from 1917 to 1952 (Robards and King 1966), and some persecution likely continued after that time but was not documented (King et al. 1972). A decline in bald eagle populations probably occurred as a result of the bounty system. The stability of the bald eagle population in PWS that we observed during recent years, and the stability of bald eagle populations in other relatively pristine areas of Alaska (Hodges et al. 1979, Hansen and Hodges 1985), suggest that Alaska eagle populations may have returned to or are approaching pre-bounty levels.

Bald eagle populations should be surveyed periodically, perhaps every 3-4 years, to assess population status and provide baseline data. Although the population estimates we calculated had confidence intervals typical of raptor surveys (Kochert 1986), the precision of our estimates was insufficient to document changes of the magnitude caused by the *Exxon Valdez* oil spill. Precision could be improved by increasing the number of plots surveyed or by censusing mainland areas as well as islands. Biologists conducting population surveys in areas with high risk due to oil traffic or other potential hazards should consider increasing the precision of surveys.

CHAPTER 6

SURVIVAL AND POPULATION DYNAMICS OF BALD EAGLES FROM PRINCE WILLIAM SOUND, ALASKA, AFTER THE EXXON VALDEZ OIL SPILL

EXECUTIVE SUMMARY

We calculated age-specific annual survival rates for 159 bald eagles (Haliaeetus leucocephalus) radiotagged in Prince William Sound (PWS), Alaska, from 1989-92 and monitored for up to 3 years. Pooled annual survival rates, calculated using the Kaplan-Meier procedure, were 71% for first-year eagles, 92% for second-year, 100% for third-year and subadult eagles, and 88% for adult bald eagles. Mortality was highest from March to May. We found no indication that survival of bald eagles tagged 4-5 months after the *Exxon Valdez* oil spill in PWS was directly influenced by the spill and concluded that any effect of the spill on survival occurred before eagles were tagged. A deterministic life table model indicated a bald eagle population in 1989 with a finite growth rate of 2% per year. Given the cumulative effects of direct mortality and reduced productivity caused by the oil spill, the bald eagle population will require about 4 years to return to its pre-spill size.

INTRODUCTION

Prince William Sound (PWS), Alaska, provides year-round and seasonal habitat for about 5000 bald eagles (Chapter 5). Bald eagles in PWS are closely associated with shoreline habitats, and nearly all nests occur within 200 m of the beach (Hodges and Robards 1982). Extensive areas of shoreline were contaminated with oil after the oil tanker *Exxon Valdez* ran aground on 24 March 1989, spilling about 11 million gallons of Prudhoe Bay crude oil into PWS. From April to August 1989, an estimated 247 bald eagles were killed in PWS as a direct result of the oil spill (Chapter 2). Concern over the welfare of eagles exposed to oiled areas prompted this study. The objective of this study was to determine if the spill influenced annual survival rates of bald eagles that survived the initial effects of the spill.

Banding data for most raptors are inadequate to estimate survival rates because of small sample sizes, low rates of return, and lack of adult banding (Brownie et al. 1985). Few published estimates of survival rates for bald eagles exist. Sherrod et al. (1976) reported survival of only 10% from hatching to adulthood on Amchitka Island, Alaska. Brown and Amadon (1968) reported a minimum first-year survival of 21%, and survival of only 4% through the first 3 years of life. M. McCollough (pers. comm.) estimated survival of Maine eagles at 77% for first-year eagles, and 91% for older eagles. Gerrard et al. (1978) determined a minimum first-year survival of 37%, 23% for second-year, and 19% for third-year eagles in Saskatchewan. However, these studies used band recovery data or re-observations of marked birds, which are less reliable or accurate for estimating survival rates than use of radiotagged eagles. Buehler et al. (1991) observed 100% survival of radiotagged first-year eagles and 83-92% survival for older age classes in the Chesapeake Bay. Wood (1992) used radiotelemetry to determine minimum annual survival rates of 63%, 84%, and 94% for first-year, second-year, and third-year eagles, respectively.

Young (1968) and Grier (1980), using estimated or hypothetical survival rates and productivity data, illustrated that changes in survival rates have a greater effect on bald eagle populations than changes in reproductive rates, and stressed the need for actual field data on survival and other population variables. This study was the first major study of survival of bald eagles in the relatively pristine coastal habitats of Alaska.

Here, we found no difference in survival rates between eagles tagged in oiled areas and eagles tagged in unoiled areas of PWS. We tagged eagles 4-5 months after the oil spill, however, and were not able to measure survival rates during the period when most eagles were known to have died. We used age-specific survival rates pooled among years to model the bald eagle population in PWS and simulate the cumulative effects of impaired reproduction and direct mortality of eagles caused by the oil spill.

METHODS

Study Area

PWS encompasses about 39,000 km^2 including 4800 km of shoreline. A temperate rainforest of Sitka spruce (Picea sitchensis) and western hemlock (Tsuga heterophylla) covers much of the convoluted coastline and islands of PWS. Summer temperatures range between 7 and 25° C, and winter temperatures seldom drop below -20° C. Annual rainfall exceeds 500 cm in some areas of PWS. PWS supports rich salmon (Oncorhynchus spp.) and herring (Clupea harengus pallasi) fisheries, and salmon populations are augmented by extensive hatchery operations. The nearby Copper River Delta also supports large spawning runs of salmon and eulachon (Thaleichthys pacificus), and tremendous numbers of waterfowl, shorebirds, gulls, and marine mammals.

Radiotagging and Telemetry

We radiotagged 79 adult, 3 subadult, and 69 nestling bald eagles between July and October in 1989-91, and 6 adults and 2 subadults in January 1992. We radiotagged nestling bald eagles in 1989 and 1990 when they were about 8 weeks old. Nestlings were selected based on their age, nest location in relation to shoreline oiling, and the accessibility and climbability of nest trees. Approximately equal numbers of nestlings were tagged in western PWS where most oiling occurred and eastern PWS which was not directly oiled. All nestlings were returned to their nests immediately after tagging.

We also radiotagged approximately equal numbers of adult eagles from oiled and unoiled areas of PWS. We captured adult bald eagles in marine areas using floating, noosed fish (Cain and Hodges 1989). We targeted breeding eagles, although we also tagged a few nonbreeders and subadults. Sex was determined using an index based on bill depth and hallux length (Bortolotti 1984), and eagles with borderline indices (between 0 and 1) were considered unknown sex. All adult and subadult eagles were returned to the same location where they were captured.

Radio transmitters weighed approximately 65 g (Communication Specialists Inc., Orange, Calif.) or 90 g (Advanced Telemetry Systems, Inc, Isanti, Minn.) and were mounted via a backpack harness made of tubular teflon ribbon. Transmitter weights were therefore about 1.2-1.7% of adult body weight. On nestlings, harnesses were left slack to allow for additional growth. Transmitters had a life expectancy of about 3 years and were equipped with mortality sensors that doubled the pulse rate after 5-7 hours without motion.

Aerial radio-tracking flights using a Cessna 180 or 185 aircraft were conducted to relocate birds weekly until March 1991, and monthly until September 1992 using standard telemetry techniques (Gilmer et al. 1981). Reception distance of signals varied from 5-150 km, depending on altitude, local topography, and the strength of individual transmitters. We searched for eagles along the Pacific coast regularly between Homer and Yakutat, Alaska. Twice we also searched south to Seattle, Washington, and west to Kodiak Island, Alaska.

We retrieved dead eagles as soon as possible and recorded the physical characteristics of the recovery location. Carcasses were frozen and shipped to the U.S. Fish and Wildlife Service, National Wildlife Health Research Center, Madison, Wisconsin, for necropsy. Selected tissues were retained for histological examination.

Survival Rates

Annual survival rates were estimated using the Kaplan-Meier procedure modified to allow staggered entry of individuals (Pollock et al. 1989). Hypotheses about differences in survival functions between treatment groups were tested using the log-rank test described in Pollock et al. (1989). We chose these procedures because they allowed for staggered entry and censoring of individuals and did not assume constant survivorship. We estimated survival rates during 3 survival years: a survival year was defined as 1 September to 31 August.

Missing eagles were censored from the risk set the week after they were last known alive during a particular survival year. If a censored bird returned in a subsequent year, it was added when first found and contributed data to the new year's estimate but its status of censored at the end of the last season did not change. Censored birds included birds that emigrated from the study area, birds with lost, weak, or failed transmitters, and birds that died in the study area and were not detected. We assumed that the censoring mechanism was random (not related to the bird's fate) (Pollock et al. 1989). Thus censoring affected only the bounds on the estimate of survival.

We believe that the disappearance of tagged eagles from our study area was due to transmitter failure and not emigration or death. Transmitter failure was usually manifested by a drastic drop in signal strength. We documented transmitter failure (weak signals) for 9 territorial adults while we flew low near perches that these individual eagles used predictably. We could not document this type of transmitter failure for juveniles because they were nomadic and did not perch predictably in the same locations. However, we assumed that transmitters on juveniles failed at the same rate as transmitters on adults, and nearly all missing juveniles could be accounted for by transmitter failure.

Although nestlings were tagged when about 8 weeks old, they were not considered at risk until fledging; we used 1 September as the approximate fledging date. Second-year eagles were eagles tagged as nestlings that survived after 1 September of the year following hatching. Ages of subadult eagles (3-4 years old) were estimated according to illustrations by McCollough (1989). Adult eagles were those with definitive plumage and were assumed to be at least 5 years old (McCollough 1989). We defined a territorial adult eagle as one that showed obvious fidelity to a nest site. Adults and subadults were considered at risk the week after tagging. Non-censored eagles surviving to the end of any given survival year were considered at risk the first week of the next survival year. Therefore, an individual eagle could have contributed to survival estimates for up to 3 survival years.

We compared survival rates among subsets of tagged eagles to determine if their survival might have been influenced by exposure to oil resulting from the *Exxon Valdez* oil spill. We lacked knowledge about the potential exposure to oil for free-flying eagles prior to tagging, so we grouped eagles into oiled or unoiled categories using 3 sets of criteria. First, we simply grouped eagles by tagging region into western PWS or eastern PWS.

Second, we grouped eagles based on oiling at the tagging location. Cumulative shoreline oiling data through August 1989 were provided by the *Exxon Valdez* Oil Spill Damage Assessment Geoprocessing Group (1991). If any shoreline was oiled within a 483 m radius of the capture site, the eagle was grouped into the "oiled" category. This radius represented an area used intensively by nesting eagles, as determined by radio telemetry (Chapter 3).

Finally, we grouped eagles based on their movements and potential exposure to oiled areas after tagging. If more than 50% of the relocations for an eagle were in western PWS, the eagle was considered exposed to oil.

We also compared survival rates for territorial adults tagged in oiled areas and unoiled areas, between years for the same age classes, among age classes, and between sexes (for adults only).

We assumed that the availability and toxicity of oil was negligible by September 1991, the start of the third survival year. We therefore limited all tests of oiled versus unoiled groups to the first 2 survival years.

The assumptions required for the Kaplan-Meier procedure were: 1) birds of each age and sex class were sampled randomly, 2) survival times were independent for individual eagles, 3) survival of eagles was not influenced by capturing or radio-tagging, 4) censoring was not related to an animal's fate, and 5) newly tagged animals had the same survival rates as previously tagged animals (Pollock et al. 1989). We believe that all of these assumptions were reasonably met.

Population Dynamics

We used a deterministic life table (Grier 1980) to model population dynamics of bald eagles in PWS. The model incorporated the maximum number of breeding sites available, the percentage of females that successfully produced young, the average number of young fledged per breeding female, age at first breeding, and survival rates for first-year and for older eagles. A breeding site was a nest territory occupied by a pair of eagles. The model assumes that survival rates are constant after the first year of life. Survival rates were not significantly different for eagle age classes after the first year, and we used a pooled annual survival rate of 0.90 for eagles older than one year.

Reproductive rates for eagles in PWS were greatly reduced in 1989 after the oil spill (Chapter 3). In 1990, reproductive rates rebounded to levels typical of bald eagle populations in other areas of coastal Alaska. Therefore, we used reproductive rates observed in 1990 in PWS -- 57% of females produced young with an average of 1.5 young per successful nest -- to represent baseline conditions.

We estimated the maximum number of breeding sites was 1300 because the current number of occupied breeding sites was an estimated 1200-1300. We assumed this number of sites approached saturation level because nest densities were similar to southeast Alaska where high rates of nonbreeding adults occur (Hansen and Hodges 1985).

We estimated that eagles first bred at 8 years of age for two reasons: 1) delayed breeding is typical for healthy bald eagle populations in near-pristine environments (Hansen and

Hodges 1985, Gerrard and Bortolotti 1988), and 2) we radiotagged 3 eagles as 4-year olds, but none had bred by the end of the study when they were 7 years old. We assumed that there were no unmated eagles ≥8 years old, and that eagles remained reproductively active until death. If eagles bred earlier than 8 years, population growth would be underestimated by the model; population growth would be overestimated if eagles first bred at ages > 8 years.

To evaluate the cumulative effects of the direct mortality and impaired productivity of eagles caused by the *Exxon Valdez* oil spill on the PWS eagle population (Chapter 2), we used Grier's (1980) deterministic population growth model to portray 2 scenarios: one scenario modeled population growth after 1989 in the absence of the oil spill and the second scenario incorporated a reduction of 223 young produced and the deaths of 247 eagles in 1989 (Chapter 2). Because we did not know the age distribution of eagles killed in the spill, we assumed that it mirrored the age class distribution in 1989. The age structure of the population in 1989 was estimated using a spring 1989 population index adjusted for unseen adults and the percentage of immatures in the population (Chapter 5), and survival rates from this study. For purposes of population modeling, we assumed that the oil spill did not directly affect reproduction or cause additional mortality after 1989. Results from other elements of this damage assessment study support this assumption.

RESULTS

Survival of Radiotagged Eagles

Thirty-four of the 159 radiotagged eagles (15 adults, 2 second-year birds, 17 first-year birds) died prior to September 1992. Most mortality occurred in March, April and May (Fig. 6-1). Of 16 carcasses suitable for necropsy (8 adults, 8 fledglings), preliminary diagnoses included trauma (7), emaciation (6), drowning (1), and undetermined (2). At least 4 of the dead adults were suspected to have died as a result of aggressive encounters with other eagles (one each in January, April, June, and October) based on the injuries they sustained and an eyewitness account of the drowning incident.

Survival rates of first-year eagles were lower than for second-year (X^2 = 3.973, P = 0.046) and adult bald eagles (X^2 = 8.565, P = 0.003) (Table 6-1). Survival rates for second-year eagles were not different (X^2 = 0.013, P = 0.909) from survival rates for adults. Differences in survival rates between third-year or subadult eagles and second-year or older eagles (Table 6-1) may be misleading because of small sample sizes and 100% survival in these former 2 age groups. Survival was not different among years for first-year or adult eagles, but was different between years for second-year eagles (due to 100% survival in 1990-91). There was no significant difference in survival rates between adult males and females (X^2 = 0.273, P =

0.60). Estimated survival for radiotagged eagles through the first 4 years of life was 65%.

Influence of the *Exxon Valdez* Oil Spill on Survival

Necropsies of dead radiotagged eagles indicated no specific evidence of oil-caused injuries. No significant differences in survival rates between oiled and unoiled groups, based on capture locations in eastern PWS and western PWS, or on oiling directly at the capture site, were found for any age group during the 2 years following the oil spill (Table 6-2).

Survival between groups based on potential oiling exposure (determined by telemetry relocations) was significantly different only for first-year eagles in 1989 ($X^2 = 6.43$, $P = 0.011$) and in 1990 ($X^2 = 7.859$, $P = 0.005$). In 1989, the "oiled" group had lower survival, but in 1990 the "unoiled" group had lower survival (Table 6-2). These observations may be misleading because of small sample sizes for the oiled category. Necropsies of the 2 first-year eagles that died in oiled areas in 1989 revealed no physical or histological damage indicative of hydrocarbon contamination.

Population Dynamics

The deterministic life-table model indicated a finite population growth rate of about 2% for the bald eagle population had the spill not occurred. This rate of growth is slightly lower than the observed increase in population index between 1982 and 1989 (average about 3.3% per year) in PWS (Chapter 5). By simulating the estimated direct mortality and lost production caused by the oil spill in PWS, we showed that population growth was set back by about 4 years but continued to increase at about the same rate as the simulated population that was not affected by the spill.

We were more confident in the estimated survival rates used in the population model than in reproductive rates, which were based on only one year (1990) that we assumed to be normal. The 2 most uncertain parameters used in our population model were the age at first breeding, and the percentage of females that produced young. To assess the sensitivity of the model to changes in these parameters, we varied values of these parameters in repeated simulations while holding all other parameters constant. Reducing the percentage of females that produced young by 10% (to 47%) resulted in a 1% decrease in the finite rate (R = 1.01) of population growth (Fig. 6-2). By increasing the percentage of females that produced young by 10% (to 67%), the finite rate of population growth increased by 1% (R = 1.03). A difference of ±1 year in the assumed age at first breeding had a similar effect on rate of population growth. A population decrease was noted only with 10% fewer females breeding combined with age at first breeding of 11 years (Fig. 6-2). These observations suggest that only substantial departures from the assumed reproductive rates would contradict our conclusion that the PWS population was slowly increasing before the spill.

DISCUSSION

Effect of the Spill

We used 3 approaches to estimate exposure of eagles to oil because we could not determine each eagle's exposure to oil. Each approach had its limitations. By using only the tagging region or capture site to group eagles, we could not take into account the potential exposure to oiled areas after the bird was tagged. Using radio telemetry relocations to estimate exposure to oiled areas after tagging, we were unable to consider the risk of exposure that could have occurred before we tagged birds.

The most valid comparison of survival between birds from oiled and unoiled areas is most likely that for territorial adults. These birds remained throughout the year in the oiled or nonoiled areas where they were radiotagged and should have served as good samplers of the local environment. There was no difference ($X^2 = 0.4$, $P = 0.525$) in survival rates of territorial adults between oiled and unoiled areas during the 2 years after the spill. This finding suggests that the spill did not adversely affect the eagle population, beyond the immediate effects (Chapter 2).

Population Dynamics

The lack of significant differences in survival relative to the oil spill suggest that the estimated survival rates are suitable for modeling the bald eagle population in PWS.

Cumulative survival rates of bald eagles in PWS through the first 4 years of life was markedly higher than rates reported by Brown and Amadon (1968) and Sherrod et al. (1976), but similar to survival rates for bald eagle populations in Chesapeake Bay (Buehler et al. 1991) and Maine (M. McCollough, pers. comm.). Survival of Maine eagles may have been abnormally high because of a winter-feeding program which enhanced survival.

Both the Chesapeake Bay and Maine populations are likely recovering from depressed levels, and there is apparently little competition for food, nest sites, or favorable winter habitat in these areas (M. McCollough, pers. comm., Buehler et al. 1991). Buehler et al. (1991) predicted a finite population growth rate of between 5.8 and 16.6% per year for the eagle population in Chesapeake Bay. The Maine bald eagle population is expected to increase at 3.1 to 6.3% per year. The PWS population is apparently increasing at a much slower rate than these populations.

Given similar survival rates among these 3 populations, only decreased reproductive output or increased emigration can account for the lower rate of population growth in the PWS population. We estimated that 57% of occupied nests were successful and the number of young produced per occupied nest in PWS in 1990 was

0.86; the 1986-90 average for Chesapeake Bay was 75.2% of occupied nests successful and 1.32 young per occupied nest (Buehler et al. 1991). When the reproductive rates for eagles in Chesapeake Bay are substituted into the PWS model, the resulting population growth rate is 4.8%. This rate of growth is still much higher and suggests that other factors such as delayed age at first breeding may be responsible for the lower rate of population growth in PWS. The PWS population may be limited by density dependent factors. Densities of occupied bald eagle nests (up to 0.6/km of shoreline) in PWS are as high as, or exceed, densities anywhere eagles breed, including southeast Alaska (Robards and Hodges 1977, Hodges 1982, Hodges and Robards 1982), where high rates of nonbreeding eagles occur (Hansen and Hodges 1985). We observed delayed breeding (or nonbreeding) in our small sample of eagles radiotagged as subadults and monitored for 3 years. Our results also suggest a high incidence (50%) of mortality due to aggressive encounters between eagles.

Indices of the adult eagle population in PWS (Fig. 5-2) show that the rate of population growth apparently decreased between the early 1980's and 1989-91, suggesting that density dependent factors may be limiting the rate of population growth. If so, the PWS population will likely stabilize in the near future.

Grier (1980) showed that population dynamics of bald eagles depend more on survival than on reproductive rates and that rates of reproduction may be relatively inconsequential to this species with delayed breeding and long life span. Using the adult survival rate of 0.88 that we estimated, the average life span once eagles reach maturity (5 years) is 19 years (Perrins and Birkhead 1983). Although additional reproductive studies in PWS are required to confirm the accuracy of the reproductive rates used in the model, subtle changes in reproductive rates are unlikely to substantially change the outcome of the model.

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Table 1-1. Estimates (95% confidence interval) of the bald eagle population in Prince William Sound, on the southern shore of the Kenai Peninsula, in the Kodiak archipelago, and on the southern shore of the Alaska Peninsula and potentially at risk due to the *Exxon Valdez* oil spill.

Area	Year	Index to # Adults	Total Adults[a]	Total Population[b]
Prince William Sound	1989	2089(308)	3085(530)	4439(981)
Kenai Peninsula	1989	354(62)	523(96)	752(177)
Kodiak Archipelago	1983	1082(249)	1598(357)	2299(647)
Alaska Peninsula[c]	1983	657(148)	970(208)	1396(378)
Total		4182(767)	6176(1191)	8886(2183)

[a] Adult index adjusted for 32% adults not seen.
[b] Total adults adjusted for 30.5% immatures in the population.
[c] Includes Cape Douglas to Kupreanof Point only.

Table 2-1. Estimated natural mortality of bald eagles in the area affected by the *Exxon Valdez* oil spill, Alaska, between 1 April and 31 August.

	Number of Eagles[a]			Estimated Natural Mortality	
Age class	All spill area	PWS only	Survival rate[b] 1 Apr to 31 Aug	All spill area	PWS only
First year	1011	561	0.8294	172	96
All older	6989	3878	0.9541	321	178
TOTAL				493	274

[a] Population estimates are adjusted for visibility bias (Chapter 1).

[b] Survival rates calculated using Kaplan-Meier procedure (Pollock et al. 1989, Chapter 6).

Table 2-2. Reproductive success for a subset of bald eagle nests in areas affected by the Exxon Valdez oil spill, Alaska, 1989 and 1990.

	Prince William Sound		Kodiak Archipelago		Alaska Peninsula		Katmai Nat. Monument	
	Oiled	Unoiled	Oiled	Unoiled	Oiled	Unoiled	Oiled	Unoiled
Number of Nests with Known Fates in Both Years	169	92	118	297	13	nd[a]	15	9
Number of Young Produced								
1989	32	22	90	194	20	nd	16	4
1990	157	51	70	164	7	nd	7	2
Nest Success (%)[b]								
1989	15	21	44	39	83	nd	73	33
1990	39	38	35	34	38	nd	33	22

[a] no data.

[b] Nest Success is defined here as the number of nests producing at least one young of fledging age / total number of nests with known fates.

Table 3-1. Nest occupancy rates of 304 bald eagle nests in Prince William Sound, Alaska, following the Exxon Valdez oil spill in 1989 and 1990. Rates are compared for no, any, moderate or heavy, or heavy oiling on shorelines within 483 m radius of the nest (core area) (1 df for all tests, based on all nests).

		Oiling Status of Nest Core Area			
		No Oil	Any Oil	Moderate or Heavy Oil	Heavy Oil
n (nests)		157	147	111	76
1989					
	Occupied nests	110	79	59	41
	% Occupied	70.1	53.7	53.2	53.9
	X^2 (vs. No Oil)		7.920	7.273	5.147
	P		0.005	0.007	0.023
1990					
	Occupied nests	101	83	63	41
	% Occupied	64.3	56.5	56.8	53.9
	X^2 (vs. No Oil)		1.652	1.268	1.904
	P		0.199	0.260	0.168

Table 3-2. Nest success rates at 304 bald eagle nests in Prince William Sound, Alaska, following the Exxon Valdez oil spill in 1989 and 1990. Rates are compared for no, any, moderate or heavy, or heavy oiling on shorelines within 483 m radius of the nest (core area) (1 df for all tests, based on all nests).

	Oiling Status of Nest Core Area			
	No Oil	Any Oil	Moderate or Heavy Oil	Heavy Oil
n (nests)	157	147	111	76
1989				
Nests with at least 1 chick	39	19	12	5
% Successful	24.8	12.9	10.8	6.6
X^2 (vs. No Oil)		6.231	7.421	9.989
P		0.013	0.006	0.002
1990				
Nests with at least 1 chick	57	59	44	28
% Successful	36.3	40.1	39.6	36.8
X^2 (vs. No Oil)		0.324	0.182	0.004
P		0.569	0.700	0.948

Table 3-3. Nest failure rate at 304 bald eagle nests in Prince William Sound, Alaska, following the Exxon Valdez oil spill in 1989 and 1990. Rates are compared for no, any, moderate or heavy, or heavy oiling on shorelines within 483 m radius of the nest (core area) (1 df for all tests, based on occupied nests only).

	Oiling Status of Nest Core Area			
	No Oil	Any Oil	Moderate or Heavy Oil	Heavy Oil
1989				
n (nests)	110	79	59	41
Failed nests	71	60	47	36
% Failed	64.5	75.9	79.7	87.8
X^2 (vs. No Oil)		2.301	3.478	6.740
P		0.129	0.062	0.009
1990				
n (nests)	101	83	63	41
Failed nests	44	24	19	13
% Failed	43.6	28.9	30.2	31.7
X^2 (vs. No Oil)		3.591	2.408	1.248
P		0.058	0.121	0.264

Table 3-4. Observed frequency distribution for bald eagle nest fates in 1989 versus nest fates for 1990 in Prince William Sound, Alaska, following the Exxon Valdez oil spill (X^2 = 18.600, 4 df, P = 0.0009, expected values in parentheses).

	Fate in 1990			Total
	Empty	Failed	Successful	
Fate in 1989				
Empty	62 (45)	20 (26)	33 (44)	115
Failed	45 (52)	31 (29)	55 (50)	131
Successful	13 (23)	17 (13)	28 (22)	58
Total	120	68	116	304

Table 3-5. Mean number of bald eagle chicks produced per nest in Prince William Sound, Alaska, 1989-90, following the Exxon Valdez Oil Spill.

	Mean	n	SD
All Nests [a]			
1989	0.240	304	0.531
1990	0.618	304	0.852
Occupied Nests [b]			
1989	0.386	189	0.631
1990	1.022	184	0.887
Successful Nests [c]			
1989	1.259	58	0.442
1990	1.621	116	0.522

[a] $t = 6.795$, $P < 0.0001$

[b] $t = 7.974$, $P < 0.0001$

[c] $t = 4.505$, $P < 0.0001$

Table 3-6. Number of bald eagle nests producing 1, 2, or 3 young in Prince William Sound, Alaska, following the Exxon Valdez oil spill in 1989 and 1990. Rates are compared for no, any, moderate or heavy, or heavy oiling on shorelines within 483 m radius of the nest (core area).

	Oiling Status of Nest Core Area			
	No Oil	Any Oil	Moderate or Heavy Oil	Heavy Oil
n	157	147	111	76
1989				
1 young	31	12	8	3
2 young	8	7	4	2
$\bar{X}$ (young/nest)	0.30	0.18	0.14	0.09
X^2 (vs. No Oil)		8.549	8.887	11.481
P		0.014	0.012	0.003
1990				
1 young	28	18	14	10
2 young	28	40	29	17
3 young	1	1	1	1
$\bar{X}$ (young/nest)	0.55	0.69	0.68	0.62
X^2 (vs. No Oil)[a]		4.732	3.350	1.235
P		0.094	0.187	0.539

[a] The two nests with 3 young were excluded in X^2 analysis to avoid sparsely populated cells (Zar 1984).

Table 4-1. Definitions of terms used in calculations of nest success and productivity for bald eagles (after Postupalsky 1974 and Fraser 1983) as used in this study.

Occupied Nest: Two adults actively defending, near or at a nest. Includes nesting (active) and nonbreeding eagle pairs. The number of occupied nests is an estimate of the territorial pairs in the population.

Active Nest: Any nest with adults in incubation posture, or with eggs or chicks. The number of active nests is an estimate of the segment of the breeding population which produced eggs during the survey year.

Nonbreeding Pair: A pair of eagles associated with a nest but which never produced eggs during the survey year.

Total Young Produced: Number of young produced to an advanced stage of development. Total young produced is the best measure for comparing productivity, year to year, when survey intensity and surveyor experience are consistent.

Young/Occupied Nest: Number of young produced per occupied nest. Includes only occupied nests located on both occupancy and productivity surveys. Young per occupied nest is the standard measure of productivity used by most eagle researchers. However, it is only useful when the number of occupied nests is known.

<u>Young/Active Nest</u> : Number of young per active nest. Includes only active nests located on both occupancy and productivity survey. Young per active nest will always overestimate productivity because it does not account for territorial birds which did not lay eggs or whose nesting attempt failed before the occupancy survey.

<u>Percentage Successful</u>: Percentage of nests in which at least one young was successfully raised to an advanced stage of development. Percentage successful can be based on either occupied or active nests. Includes only nests found on both occupancy and productivity surveys.

<u>Percentage Territorial Pairs Breeding</u>: Percentage of occupied nests in which eggs were laid.

Table 4-2. Nesting success and productivity of bald eagles in southcentral Alaska, 1989 and 1990, following the *Exxon Valdez* oil spill. Numbers in parentheses represent subsets of nests that minimized biases and were used for comparisons between years within a region.

Region[a]	Number Occupied nests found on productivity surveys	# Occupied nests found on occupancy and productivity surveys	Total young produced	Young per occupied nest	Young per active nest	Percentage territorial pairs breeding	Percentage occupied nests successful	Percentage active nests successful
Kenai Pen.[c]								
1989[b]	45(29)	0	52(36)	nd[h]	nd	nd	nd	nd
1990	63(34)	45	58(28)	0.92	1.00	89	51	58
Kodiak Arch.[d]								
1989	333	333	399	1.20	nd	nd	72	nd
1990	412	412	431	1.05	1.07	97	64	66
Katmai NM								
1989[e]	47	0	54	nd	nd	nd	nd	nd
1990	50	43	28	0.56	0.60	93	47	50
APBNWR[f]								
1989	69(69)	62(62)	62(62)	nd	1.00(1.00)	nd	nd	55(55)
1990	114(76)	108(76)	104(77)	0.91	0.96(1.11)	94	56	59(64)
CRB[c,g]								
1989	69(42)	37	81(49)	nd	0.84	nd	nd	51
1990	163(50)	153	105(38)	0.64	0.65	99	40	40
CRD								
1990	67	63	65	0.97	1.03	94	60	64

[a] Katmai National Monument (Katmai NM), Alaska Peninsula/Becharof National Wildlife Refuge (APBNWR), Copper River Basin (CRB), Copper River Delta (CRD).
[b] Kenai Fjords National Park, Seward, Alas., unpubl. data.
[c] Subset(s) includes only nests found on both the 1989 and 1990 productivity surveys.
[d] Zwiefelhofer (1989, 1990)
[e] Yurick (1989)
[f] Dewhurst (1989, 1990). Subset(s) includes nests within the area surveyed in both 1989 and 1990.
[g] Bureau of Land Management, Glennallen, Alas., unpubl. data and National Park Service, Glennallen, Alas., unpubl. data.
[h] no data

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Table 5-1. Stratification of plots used to count bald eagles after the Exxon Valdez oil spill in Prince William Sound, Alaska, 1989.

Plot #[a]	Years Surveyed	Stratum[b] based on all shoreline *within plot*	Stratum[b] based only on mainland *shoreline in plot*
-51 +28	82, 89-91	L	L
-52 +26	82, 89-91	L	NA
-52 +28	82, 89-91	L	L
-53 +26	82, 89-91	M	NA
-54 +27	82, 89-91	L	NA
-55 +31	82, 89-91	L	L
-55 +32	82, 89-91	L	L
-56 +26	82, 89-91	H	NA
-57 +29	82, 89-91	L	NA
-58 +22	82, 89-91	L	L
-58 +24	82, 89-91	L	NA
-58 +29	82, 89-91	M	NA
-58 +33	82, 89-91	L	L
-59 +27	82, 89-91	M	M
-59 +29	82, 89-91	M	NA
-60 +22	82, 89-91	L	NA
-60 +24	82, 89-91	H	M
-62 +27	82, 89-91	L	L
-49 +29	89-91	L	L
-50 +27	89-91	L	L
-51 +26	89-91	L	NA
-51 +32	89-91	L	L
-51 +33	89-91	L	L
-52 +29	89-91	H	H
-53 +30	89-91	H	M
-53 +32	89-91	L	L
-55 +25	89-91	M	NA
-55 +26	89-91	M	NA
-56 +24	89-91	L	NA
-56 +30	89-91	L	L
-57 +33	89-91	L	L
-57 +34	89-91	L	L
-58 +27	89-91	H	NA
-58 +30	89-91	M	M
-58 +31	89-91	L	L
-59 +21	89-91	L	NA
-59 +24	89-91	L	NA
-60 +26	89-91	L	L
-61 +24	89-91	L	L
-61 +29	89-91	L	L

[a] coordinates of plot centerpoint (i-j) can be computed as: latitude in degrees = lat(j) = 57.325° + 0.1167j and longitude in degrees = 134° - i(0.1167/cos(lat[j])).

[b] L = Low eagle density, M = Medium eagle density, H = High eagle density, NA = plot entirely on island

Table 5-2. Estimates of adult bald eagles in randomly selected stratified survey plots and on islands, and population indices in Prince William Sound, Alaska, during spring of 1982 and 1989-91.

Year	Eagle Density Strata Low	Eagle Density Strata Medium	Eagle Density Strata High	Island Census	Adult Index (±95% CI)	Estimated Total Eagle Population(95%CI)[a]
1982	680	552	333	NA[b]	1565(473)	3325(1228)
1989	525	396	100	1068	2089(308)	4439(981)
1990	421	312	29	1179	1941(283)	4125(860)
1991	493	301	46	1248	2088(273)	4436(904)

[a] corrected for unseen adults and immatures.
[b] Islands not censused in 1982.

Table 5-3. Numbers of bald eagles along oiled and unoiled shorelines surveyed in Prince William Sound, Alaska, 1989-91.

	Number of Eagles				Percentage of annual total on oiled shoreline	
	Oiled shoreline		Unoiled shoreline			
Year	Adults	Immatures	Adults	Immatures	Adults	Immatures
1989	292	16	1196	82	19.6	16.3
1990	364	32	1103	75	24.8	29.9
1991	371	27	1209	72	23.5	27.3

Table 6-1. Annual survival rates, by age class, for 159 bald eagles radiotagged in Prince William Sound, Alaska, 1989-92.

Age Class	# eagle-years[a]	Annual Survival Rate ± 95% CI[b]
First-Year	68	0.71 ±0.14 A[c]
Second-Year	36	0.92 ±0.12 B
Third-Year	10	1.00 C
4th and 5th Years	5	1.00 C
Adults > 5 years old	142	0.88 ±0.06 B
males	63	0.86 ±0.09[d]
females	63	0.90 ±0.09

[a] an eagle-year equals one eagle that contributed to the survival rate for a particular year (e.g., one eagle monitored for all or part of 3 different survival years contributes 3 eagle-years).

[b] confidence intervals were not calculated if no mortality occurred for a year class.

[c] survival rates with same letter are not different.

[d] survival rates of males and females were not different.

Table 6-2. Effects of the Exxon Valdez oil spill on annual survival rates[a] for radiotagged bald eagles in Prince William Sound (PWS), Alaska, based on tagging region, oiling at capture site, and movements after tagging. Survival rates are given ±95% CI. Numbers in parentheses indicate the number of eagles contributing to the survival estimate for that particular subset.

		Tagging region		Oiling at capture site		Movements after tagging	
Age	Year	Western PWS	Eastern PWS	Oiled Shoreline within 483m	No oil within 483m	High potential for exposure	Low or no potential for exposure
First-Year	89	0.79±0.24 (15)	0.76±0.30 (15)	0.83±0.22 (13)	0.73±0.30 (17)	0.33±0.53 (3) *[b]	0.83±0.18 (27)
First-Year	90	0.52±0.32 (19)	0.70±0.27 (19)	0.47±0.33 (15)	0.74±0.32 (23)	1.00[c] (5) **[d]	0.62±0.21 (33)
Adult[e]	89	0.94±0.14 (17)	0.85±0.19 (15)	0.92±0.17 (13)	0.88±0.16 (19)	0.92±0.17 (13)	0.88±0.16 (19)
Adult[e]	90	0.84±0.17 (20)	0.77±0.23 (14)	0.77±0.26 (14)	0.84±0.16 (20)	0.80±0.22 (16)	0.83±0.18 (18)

[a] Survival rates calculated from 1 September to 31 August using Kaplan-Meier procedure (Pollock et al. 1989).

[b] Different (P = 0.011) between subsets with high and low potential for exposure.

[c] Survival was 1.0 up to mid-April, when the last of the 5 birds in the subset was censored. Thereafter, survival was unknown. Confidence interval was not computed.

[d] Different (P = 0.005) between subsets with high and low potential for exposure.

[e] Three 3-4 year-olds were included in adults category in 1989, one in 1990.

Figure 1-1. Cumulative extent of oiling from the *Exxon Valdez* oil spill, Alaska, 1989.

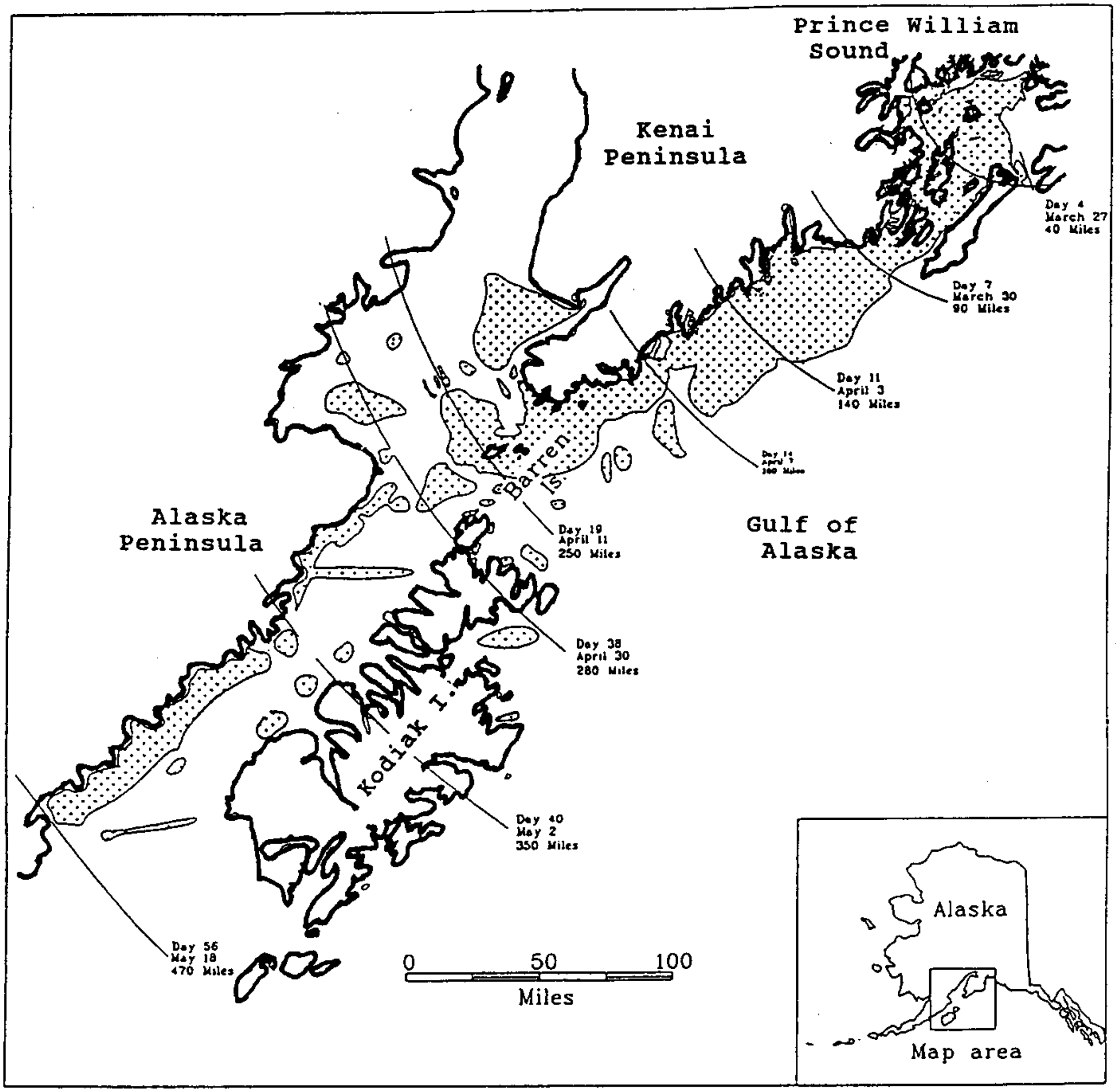

Prince William Sound
Kenai Peninsula
Day 4
March 27
40 Miles
Day 7
March 30
90 Miles
Day 11
April 3
140 Miles
Barren Is.
Alaska Peninsula
Gulf of Alaska
Day 19
April 11
250 Miles
Day 38
April 30
280 Miles
Kodiak I.
Day 40
May 2
350 Miles
Day 56
May 18
470 Miles
0
50
100
Miles
Alaska
Map area

Figure 1-2. Location of geographic areas included in the estimate of the bald eagle population potentially at risk due to the *Exxon Valdez* oil spill.

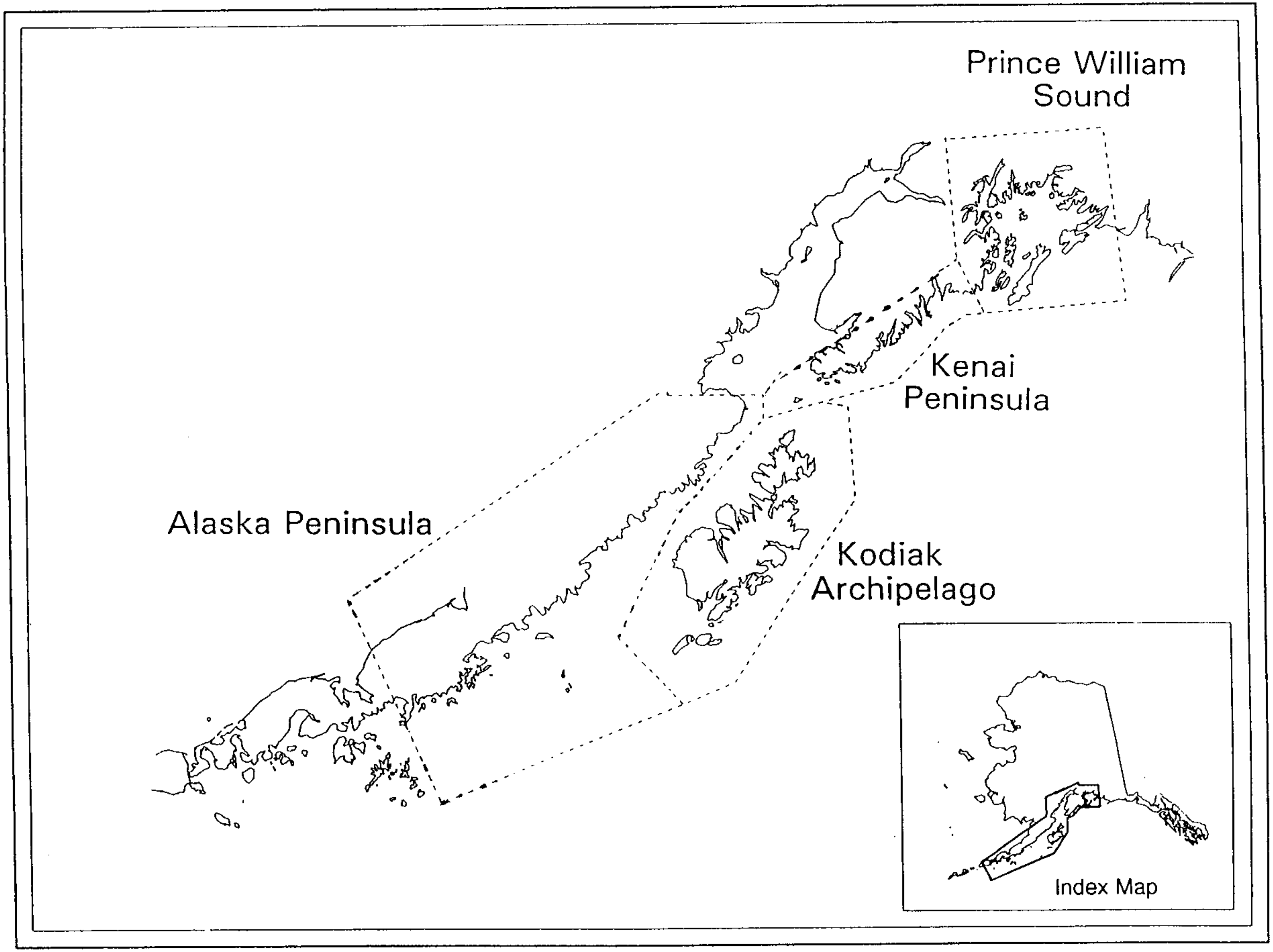

Prince William Sound
Kenai Peninsula
Alaska Peninsula
Kodiak Archipelago
Index Map

Figure 2-1. *Sources of estimates for total mortality of bald eagles due to Exxon Valdez oil spill.*

NUMBER OF CARCASSES FOUND	151
	+
BEACHED CARCASSES MISSED ON SEARCHED BEACHES	38
	+
BEACHED CARCASSES ON UNSEARCHED BEACHES	63
	+
CARCASSES IN WOODS, NOT FOUND	717
	-
EXPECTED NATURAL MORTALITY ON OILED SHORELINES	67
	=
MORTALITY DUE TO OIL SPILL	902

Figure 3-1. Bald eagle nest sites surveyed in 1989 and 1990 to evaluate the impact of the *Exxon Valdez* oil spill on reproductive success in Prince William Sound, Alaska.

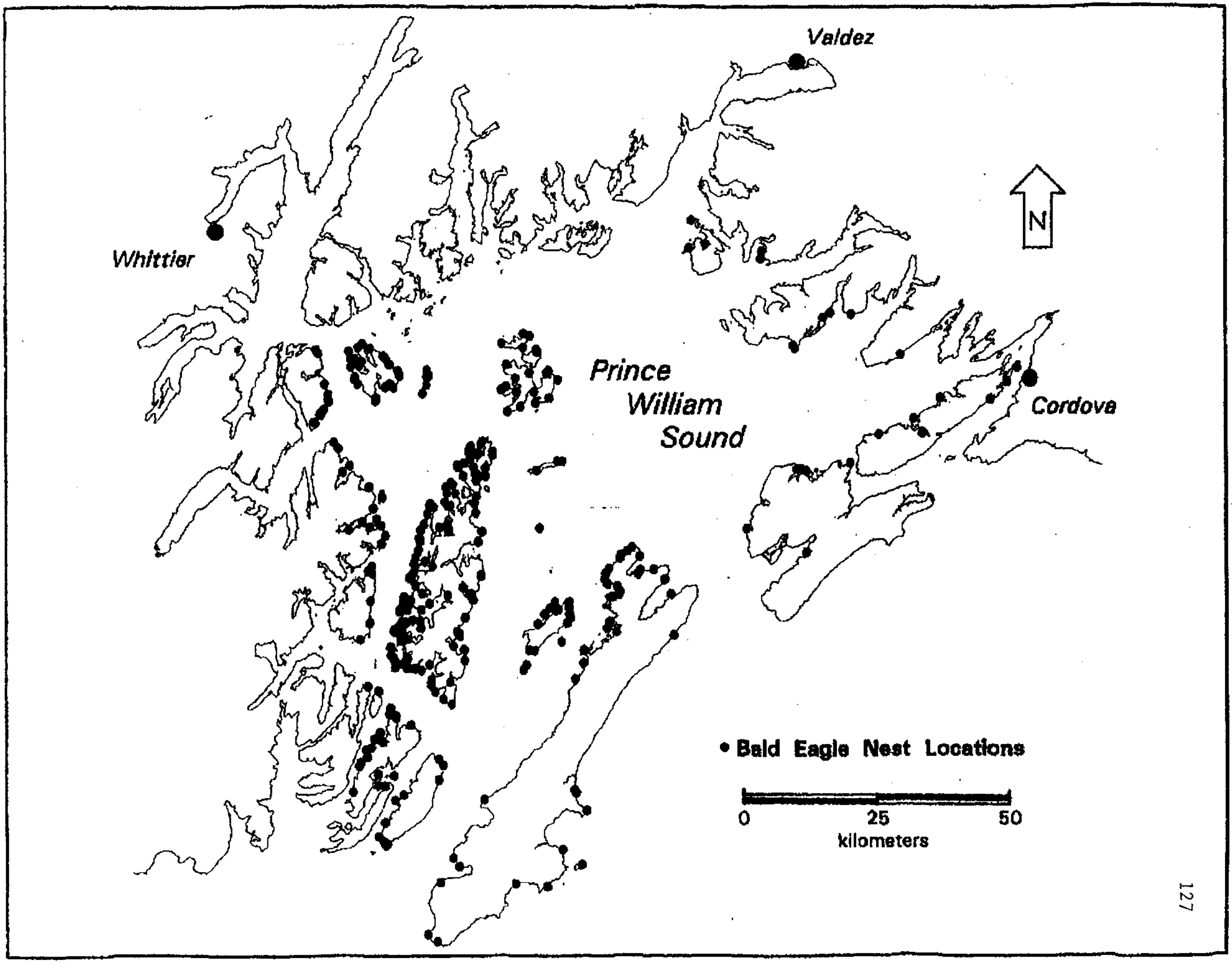
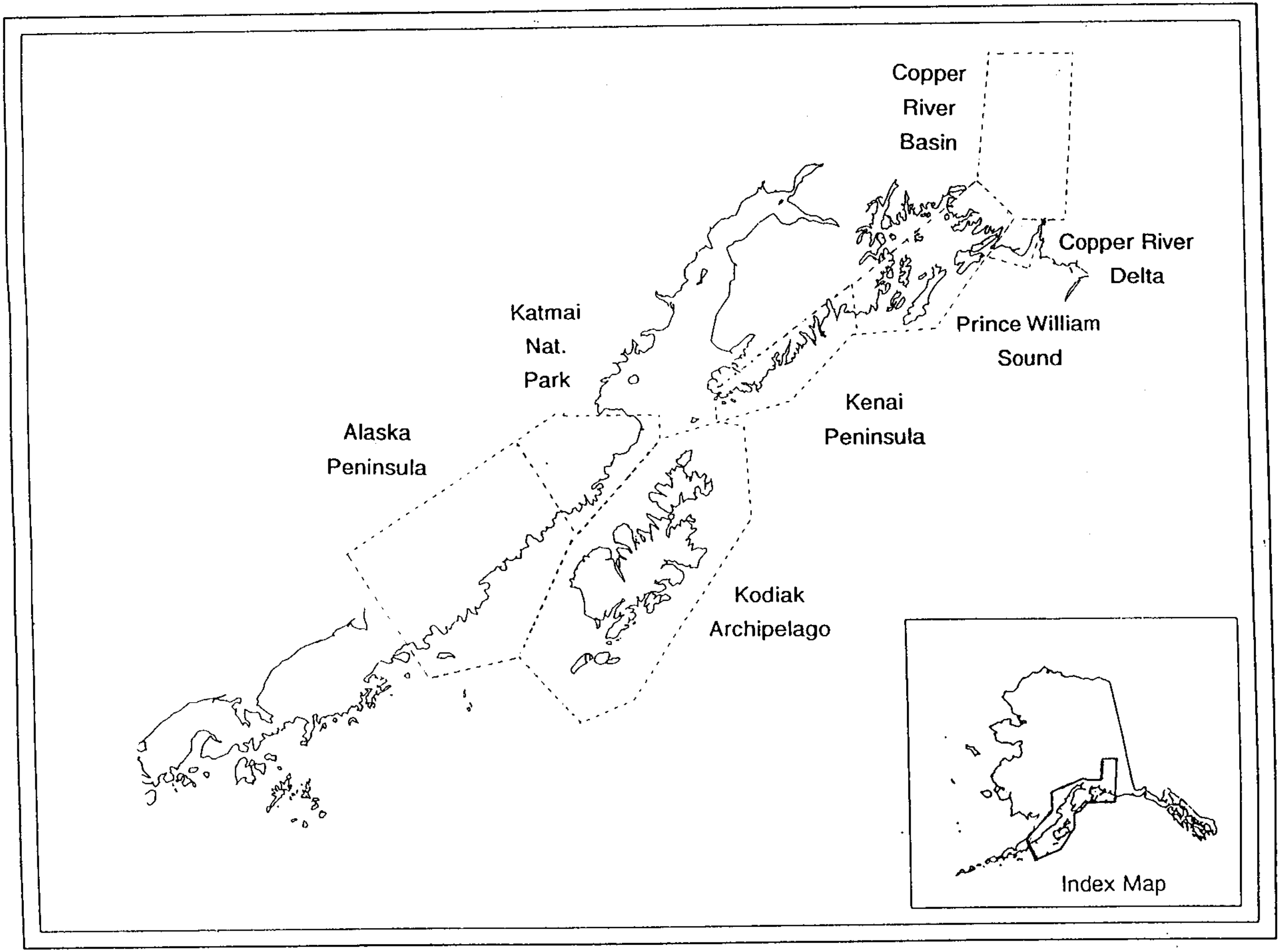

Valdez
Whittier
N
Prince
William
Sound
Cordova
• Bald Eagle Nest Locations
0
25
50
kilometers

Figure 4-1. Areas surveyed for bald eagle productivity in southcentral Alaska, 1989 and 1990, following the *Exxon Valdez* oil spill.



Copper
River
Basin
Copper River
Delta
Prince William
Sound
Katmai
Nat.
Park
Kenai
Peninsula
Alaska
Peninsula
Kodiak
Archipelago
Index Map

Figure 4-2. Terminology used in reporting the reproductive patterns of nesting bald eagles. Information gathered during surveys is in unshaded blocks, which allowed calculations of statistics (shaded blocks). The values presented are hypothetical.

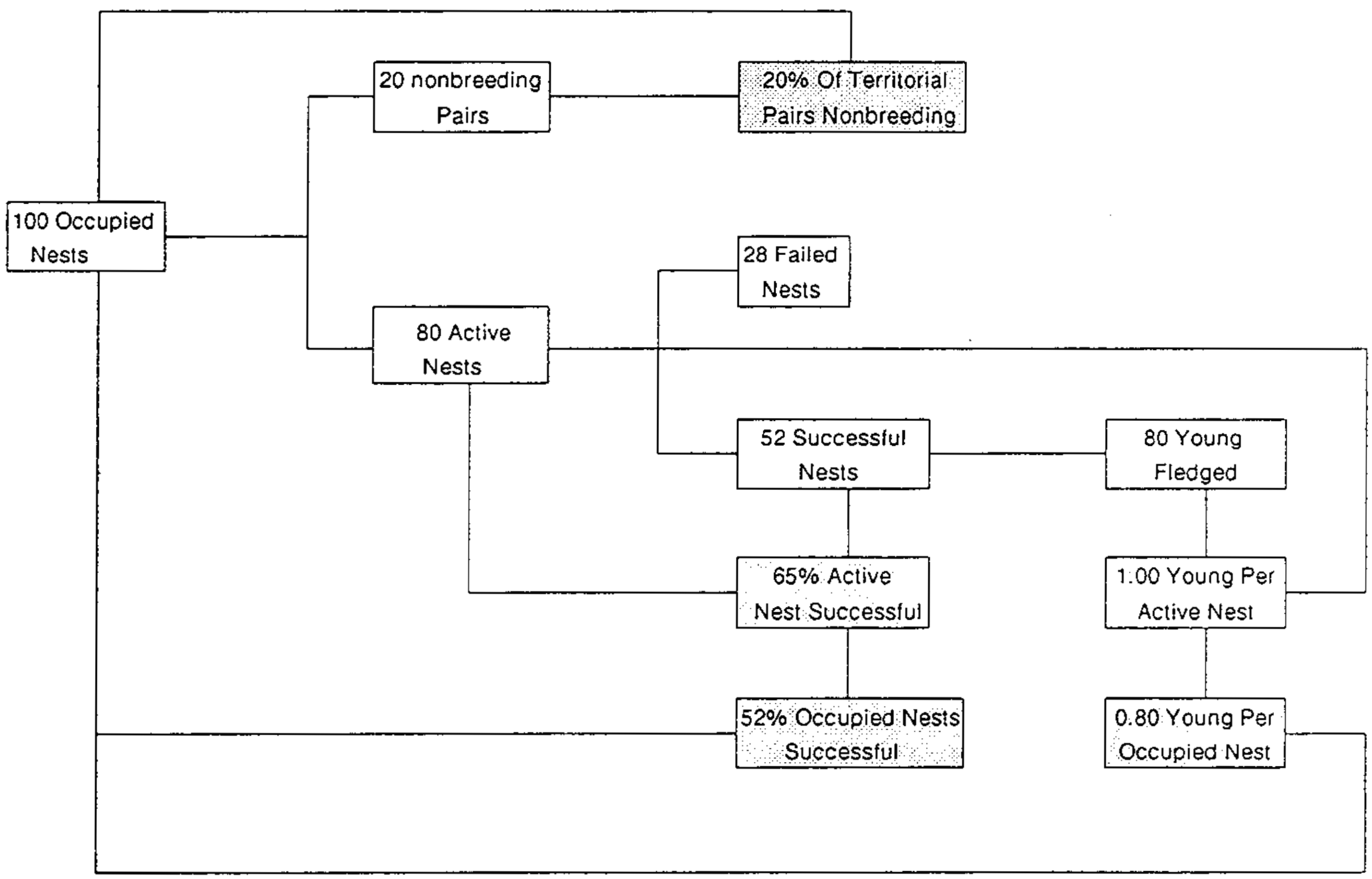

20 nonbreeding Pairs
20% Of Territorial Pairs Nonbreeding
100 Occupied Nests
28 Failed Nests
80 Active Nests
52 Successful Nests
80 Young Fledged
65% Active Nest Successful
1.00 Young Per Active Nest
52% Occupied Nests Successful
0.80 Young Per Occupied Nest

Figure 5-1. Location of 40 randomly selected plots surveyed for bald eagles within Prince William Sound, Alaska, 1982 and 1989-91. Plots with dashed borders were surveyed only in 1989-91. In addition to these plots, all islands (except Esther I.) were surveyed in 1989-91.

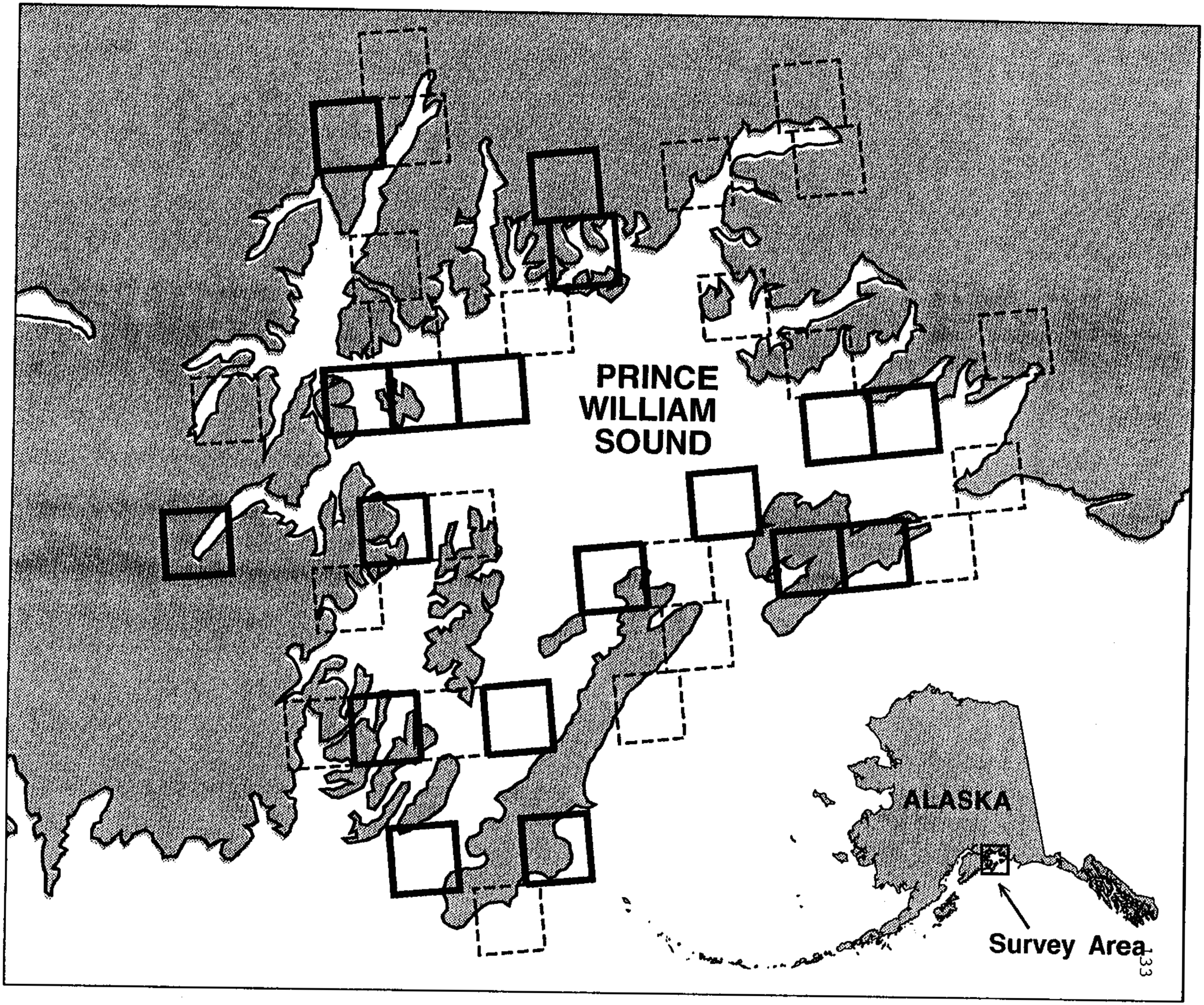

PRINCE
WILLIAM
SOUND
ALASKA
Survey Area

Figure 5-2. Population indices for adult bald eagles in Prince William Sound, Alaska, 1982 and 1989-91.

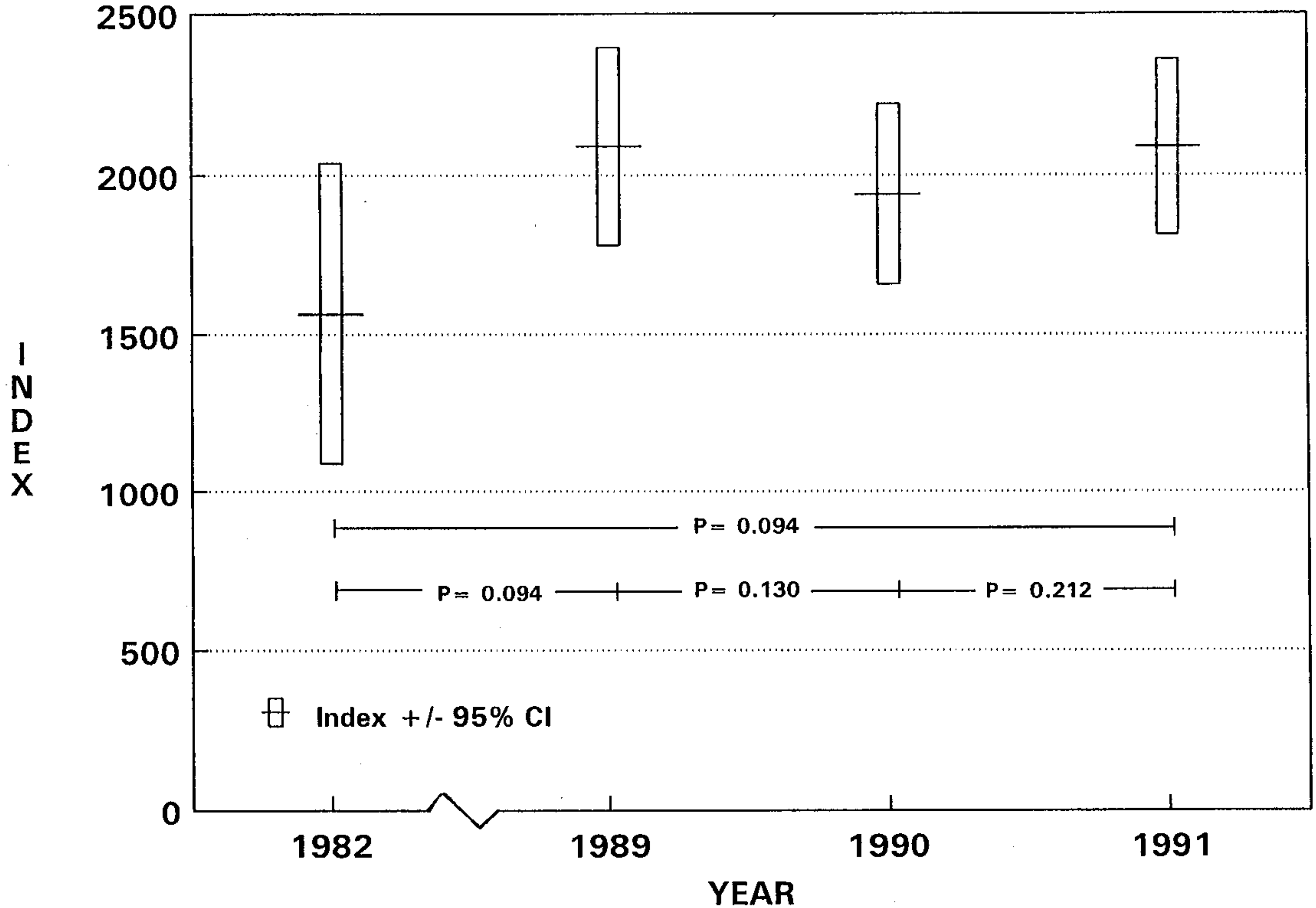
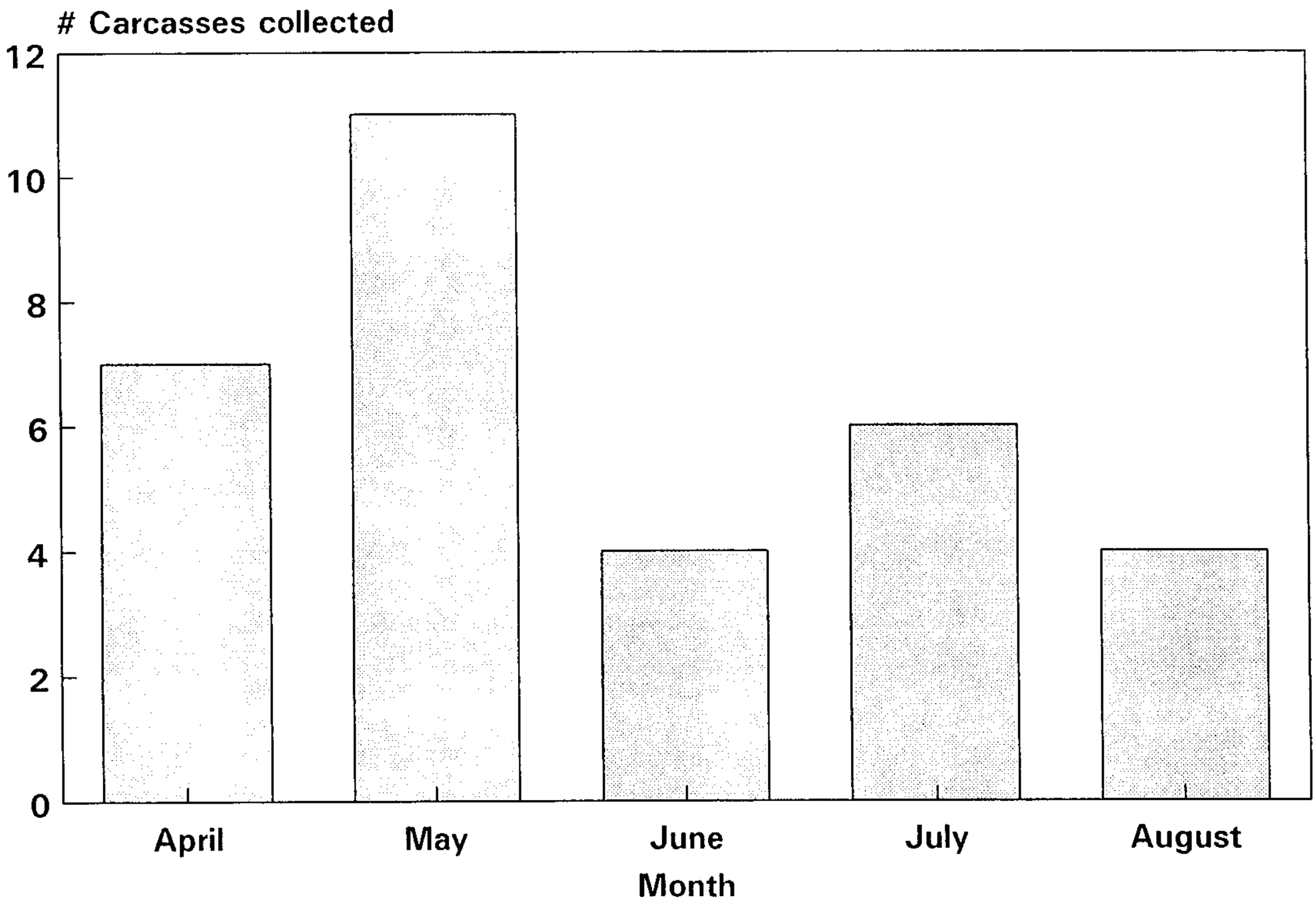

2500
2000
1500
1000
500
0
INDEX
P= 0.094
P= 0.094
P= 0.130
P= 0.212
Index +/- 95% CI
1982
1989
1990
1991
YEAR

Figure 5-3. Dates when bald eagle carcasses were collected in Prince William Sound, 1989.



Carcasses collected
12
10
8
6
4
2
0
April
May
June
July
August
Month

Figure 6-1. Numbers of radiotagged adult (>5 years old) and juvenile (<2 years old) bald eagles dying by month in Prince William Sound, Alaska, 1989-92.

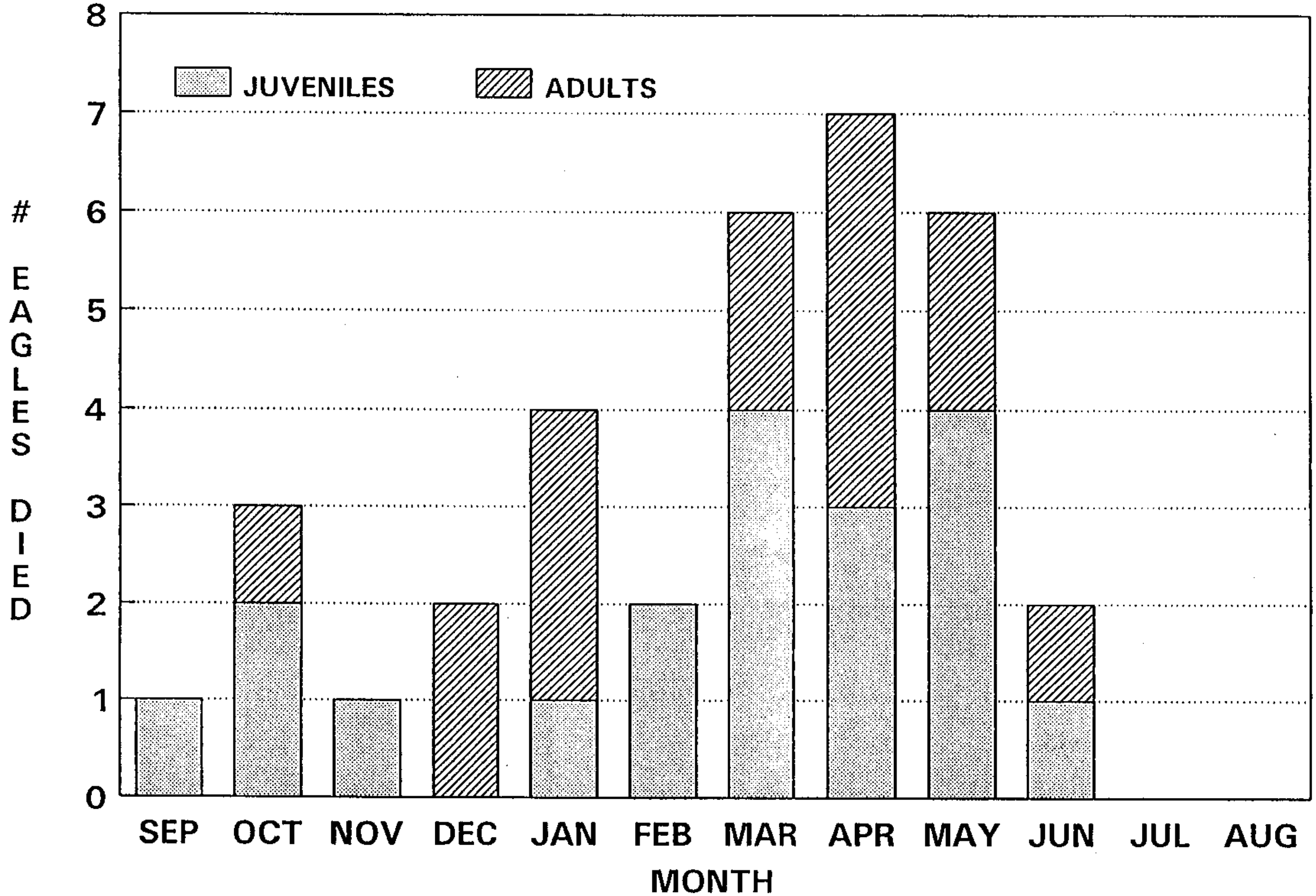
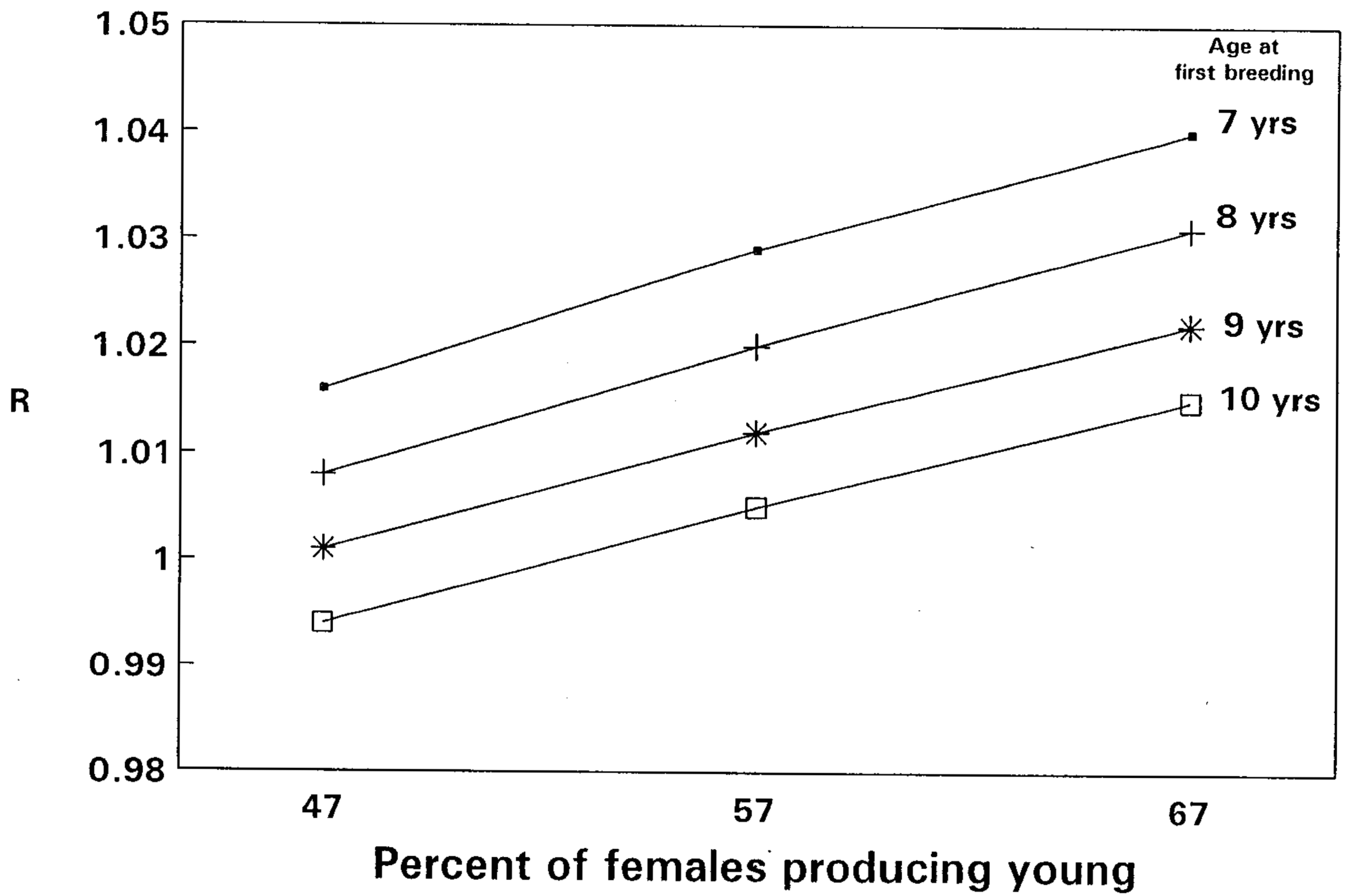

JUVENILES
ADULTS
EAGLES DIED
8
7
6
5
4
3
2
1
0
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
MONTH

Figure 6-2. Effect of varying age at first breeding and percentage of females that produced young on hypothetical rates of finite population growth for bald eagles in Prince William Sound, Alaska.


1.05
1.04
1.03
1.02
1.01
1
0.99
0.98
R
Age at
first breeding
7 yrs
8 yrs
9 yrs
10 yrs
47
57
67
Percent of females producing young