# HARBOR SEAL INVESTIGATIONS IN ALASKA
# ANNUAL REPORT
# NOAA GRANT NA57FX0367

Photo by Lauri Jemison

## *CONTRIBUTORS*

J. Baker, P. Becker, P. Boveng, K. Frost, S. Iverson, L. Jemison,
B. Kelly, J. Lewis, L. Lowry, E. Mathews, G. O'Corry-Crowe,
R. Papa, G. Pendleton, K. Pitcher, G. Sheffield, R. Small,
U. Swain, R. Westlake, K. Wynne, R. Zarnke

ARLIS

Alaska Department of Fish and Game
Division of Wildlife Conservation
333 Raspberry Road
Anchorage, Alaska 99518

QL
737
.P64
H27
1997

October 1997

ARLIS
3 3755 000 09642 0

# HARBOR SEAL INVESTIGATIONS IN ALASKA
## ANNUAL REPORT
## NOAA GRANT NA57FX0367

*Contributors*

J. Baker, P. Becker, P. Boveng, K. Frost, S. Iverson, L. Jemison, B. Kelly,
J. Lewis, L. Lowry, E. Mathews, G. O'Corry-Crowe, R. Papa,
G. Pendleton, K. Pitcher, G. Sheffield, R. Small, U. Swain,
R. Westlake, K. Wynne, R. Zarnke

*Principal Investigator*

Robert J. Small
Alaska Department of Fish and Game
Division of Wildlife Conservation
333 Raspberry Road
Anchorage, Alaska 99518

State of Alaska
Tony Knowles
Governor

Department of Fish and Game
Frank Rue
Commissioner

Division of Wildlife Conservation
Wayne Regelin

October 1997

ARLIS
Alaska Resources
Library & Information Services
3150 C Street, Suite 100
Anchorage, Alaska 99503

QL
737
.P64
H27
1997

# ABSTRACT

In response to a severe decline in the numbers of harbor seals in the Gulf of Alaska, the National Marine Fisheries Service has provided annual grants to the Alaska Department of Fish and Game to investigate causes of the decline and to monitor population trends. The conceptual approach to this research has been to compare various population parameters between the declining Gulf of Alaska population (experimental population) and the increasing or stable Southeast Alaska population (control population).

Linear and quadratic models that incorporated environmental covariates and replicate counts of seals from established trend routes were used to estimate population trends in the Ketchikan and Sitka areas of Southeast Alaska and the Kodiak area of the Gulf of Alaska. The estimated trend for the Ketchikan area was +9.3%/yr (1983-1996), whereas in Sitka the annual trend was estimated at +3.0% (1983-1996). Baseline counts were obtained from haulouts in the northeastern Gulf of Alaska for potential future trend analyses. The estimated trend of harbor seals on haulouts along the Kodiak trend route was +7.2%/yr (1993-1996). Numbers of harbor seals on southwest Tugidak during the molting period appeared stable from 1992-1996 after a long period of decline.

Long-term and recent trends in harbor seal numbers in Glacier Bay were estimated based on data from 1975-1978, 1983-1984, and 1992-1996. The trend in numbers of seals at Johns Hopkins Inlet, the primary glacial ice haulout, was positive since 1975, with a steep rate of growth (+30.7%) between 1975 and 1978. The recent (1992-1996) trend in Johns Hopkins Inlet was also positive, but lower: June trend 7%, August trend 13%. Combined trends from both terrestrial and glacial ice haulouts indicate that overall numbers in Glacier Bay are stable or have increased from 1992 to 1996. However, a negative trend of -8.6% was estimated for the terrestrial sites. Whether the decline among terrestrial sites is the result of a shift in distribution to the glacial site, a decrease in birth rate, or an increase in mortality is unknown.

The number of seals coming ashore at Tugidak Island in the western Gulf of Alaska declined 72% - 85% between 1976 and 1988 and stabilized during the 1990s. A comparison of pupping phenology and demography between declining and stable years found that the onset and peak of pupping occurred 7-18 days later in the 1970s than in the 1990s. Pup abandonment was highest during the 1970s. The percentage of adult males on shore increased in the 1990s. Indices of productivity and first year survival were confounded by haulout behavior and are biased measures. Between the 1970s and 1990s, the ratio of seals ashore during pupping to the number ashore during molting increased from 0.3 to 1.1, perhaps reflecting changes in demography. Changes in demography and pupping phenology were discussed relative to possible changes in food availability between the 1970s and the 1990s.

A feasibility study was conducted to evaluate the potential of using tooth fine structures to obtain data on individual reproductive histories and growth for harbor seals. Decalcified and stained longitudinal tooth sections from 30 harbor seals were examined to determine if "transition zones", apparently indicative of sexual maturity, were present in tooth cementum. Ages were also estimated based on the number of cementum annuli. Transition zones were identified in most older animals and appeared indicative of sexual maturity in most cases. Independent estimates of age were quite similar. It was

concluded that tooth fine structures have potential for estimating age of sexual maturation. Technique development for tooth preparation is needed, particularly if indices of growth are to be obtained.

Literature was reviewed and laboratory testing done to evaluate techniques for pregnancy determination of captured harbor seals and Steller sea lions. Ultrasound has been used successfully to determine pregnancy status several weeks after blastocyst implantation for harbor seals. Progesterone levels have been reported to provide reliable pregnancy determinations during mid to late gestation for harbor seals although we had two females that were known to be pregnant during late gestation but were reported to have low progesterone levels. Chorionic gonadotrophin levels may have potential for determining pregnancy status during early gestation. An assay for bovine pregnancy specific protein B elicited a response in serum of both harbor seals and Steller sea lions. Additional research is needed to determine if this reaction is to a pregnancy specific substance in harbor seals and Steller sea lions.

Satellite-linked depth recorders (SDRs) were attached to 21 harbor seals in Southeast Alaska and the Kodiak Island region during the spring and fall to monitor their movements patterns, and haulout and diving behaviors. Seals were tracked for up to 263 days. All 21 seals exhibited a strong fidelity to their capture area, although movements varied considerably by individual. The ten adults stayed within the same general area of their capture, with a round-trip of 150-200 km by a male the only extensive movement recorded for adults. Subadults made more extensive movements than adults, often undertaking repeated movements exceeding 100 km and spending considerable time away from their capture sites. Seals used a wide variety of habitats including open water habitats, heads of bays, and glacial fjords. The diving behavior of the 21 seals is characterized by relatively short (<4 min) and shallow dives (< 50 m). Seals rarely dove deeper than 150 m, with only 1% of all dives being to greater depths. Seals in Southeast Alaska generally dove deeper than seals in the Kodiak region, reflecting the deeper bathymetry of the area. Dive depths, however, appeared notably lower for 1995 seals in both areas compared to seals tagged in 1993 and 1994. Seals in Southeast Alaska and the Kodiak region showed considerable individual variation and strong seasonal and diurnal patterns in diving. Dives were more common at night, and dive depths decreased markedly during the late spring and summer while deeper dives were more prevalent during the fall and winter. Although some size-based physiological constraints were evident, the diving abilities of subadults were similar to that of adults. The foraging behavior of subadults was characterized by a greater diversity in diving patterns and movements.

Sera from 352 harbors seals, obtained from 1978-1997, were tested to determine antibody presence for eight disease agents; canine distemper virus, phocine distemper virus, phocid herpesvirus, *Toxoplasma gondi*, influenza A, *Brucella* spp., *Chlamydia pssittaci*, and calciviruses. Positive responses occurred for all agents except canine distemper virus and influenza A. Symptoms of these diseases have not been observed in Alaskan harbor seals nor were there obvious differences in prevalence for animals in Southeast Alaska and in other areas of Alaska. Therefore, the hypothesis that disease has been an important factor in the decline in seal numbers in some areas of Alaska is not supported.

The presence of contaminants in harbor seals and Steller sea lions has been suggested as one possible cause of the declines of these species in some areas of Alaska. A project with the following objectives has been developed to assist in evaluating this hypothesis: (1) Compile and review information available on contaminants in harbor seals with emphasis on Alaska; (2) Evaluate the available information to determine whether it is sufficient to assess the likely impacts of contaminants on harbor seals in Alaska; and (3) Determine what additional sampling and analysis should be done. Anticipated products of this project are a synthesis report and a computerized annotated bibliography.

Alaskan harbor seal stock structure was investigated using mitochondrial DNA. Mitochondrial DNA differentiation throughout Alaska is clinal, along a coastal continuum from Southeast to Bristol Bay. On a large geographic scale, a significant substructure division was found at Cook Inlet. No differences in the genetic composition of seals sampled from the Gulf of Alaska between the 1970s and the 1990s (after a large-scale decline) were detected.

Eight DNA microsatellite loci were screened with the ultimate goal of examining the consequences of population decline on spatial and temporal patterns of genetic variation. The wide range of variability found in the seven amplifiable loci may reflect differing ages and rates of evolution. These differing levels of polymorphism may suggest that a range of population and behavioral genetic questions can be addressed using these markers. Future studies will integrate ecological and behavioral data and how they relate to gene flow in Alaskan harbor seals. The microsatellite project will be expanded to assess stock identification.

Prey were identified from 262 harbor seal scats from northern Bristol Bay, the Kodiak Island area and Southeast Alaska. Prey were also identified from stomach contents of eight seals taken by Alaska Native subsistence hunters from Southeast Alaska. Notable geographic differences were detected in top-ranked prey species, based on frequency of occurrence; i.e., the percentage of total scats that a particular prey was found. In northern Bristol Bay, flounders, sandlance, tomcod, and smelts were top-ranked prey, whereas pollock, arrowtooth flounder, and herring were top-ranked prey in the Kodiak area and Southeast Alaska.

Fatty acid signatures found in samples of blubber from harbor seals were used to compare relative diets of animals from the Kodiak area, Yakutat Bay, and Southeast Alaska. There were differences among locations and between adults and subadults. Seal diets from Prince William Sound, while different from the other geographic areas, were most similar to those from Kodiak and Yakutat. There also appeared to be smaller scale geographic differences and possibly interannual differences.

## TABLE OF CONTENTS

Page

# INTRODUCTION

Dramatic declines of harbor seal (*Phoca vitulina richardsi*) populations have been documented near Kodiak Island and in Prince William Sound (PWS), Alaska. Specifically, the number of seals decreased by approximately 90% between 1976 and 1995 on Tugidak Island (Pitcher 1990, Lewis *et al*. 1996), located southwest of Kodiak Island, and in PWS numbers decreased by 62% between 1984 and 1996 (Frost *et al*. 1997). A research program to investigate the possible cause(s) of the population decline in Alaska was initiated in 1993 by the Alaska Department of Fish and Game (ADF&G) through funds allocated by the U.S. Congress. This research program has continued with annual grants awarded to ADF&G and administered by the National Marine Fisheries Service (NMFS), Alaska Region, of the National Oceanic and Atmospheric Administration (NOAA). This report represents the progress of the investigation of harbor seals in Alaska achieved during the 1996 performance period (1 July 1996 – 30 June 1997), fulfilling the reporting requirements under NOAA grant number NA57FX0367.

Overall, the status and trend of harbor seal populations in Alaska was poorly understood when ADF&G began their research investigations in 1993. Trend routes had been established in PWS, and the Sitka and Ketchikan areas of Southeast Alaska (SE) in 1983 as a means to collect population data in a standardized, repetitive manner to document population trends. These trend routes were surveyed again in 1984, but none were flown again until 1988 when the PWS and Ketchikan routes were surveyed. Annual surveys of the PWS route have been conducted since the *Exxon Valdez* oil spill in 1989. With the start of the NOAA-funded harbor seal research program in 1993, trend route surveys were re-initiated in SE and the Kodiak Island area. An estimate of the number of harbor seals in Alaska was not available until NMFS began the first statewide population survey in 1991. Population surveys were conducted in Bristol Bay, along north side of the Alaska Peninsula, and in PWS in 1991; the remaining areas of the Gulf of Alaska, including the Copper River Delta, were completed in 1992. NMFS then surveyed SE in 1993 and the Aleutian Islands in 1994. NMFS also conducted research projects during 1994 in SE and during 1996 near Cordova to estimate 'correction factors' that can be used to extrapolate counts of the number of seals hauled out during aerial surveys to an estimate of the total population size. ADF&G researchers funded by this NOAA contract have assisted NMFS in their research projects on harbor seals in Alaska.

An understanding of harbor seal population dynamics, ecology, and behavior is necessary to determine what proximate and ultimate factors may cause their populations to decrease. In addition, an understanding of the genetic structure of Alaskan harbor seals is required to properly delineate distinct population stocks for which conservation and management strategies can be effectively implemented. Such knowledge was also limited or did not exist in 1993. Recognizing this lack of necessary information, a diverse research program was initiated to increase our general understanding of harbor seal biology, and to address specific hypotheses related to the population decline.

The decline of harbor seal populations must be considered within the context of the Gulf of Alaska and Bering Sea ecosystems. Declines in other marine mammal populations have occurred, most notably the western stock of the Steller sea lion

(*Eumetopias jubatus*) which was classified as endangered in May 1997. The northern fur seal (*Callorhinus ursinus*), whose numbers decreased by over a million animals (>50%) between 1950 and 1983, was given depleted status by NMFS in 1988. Significant population decreases of several seabird species have also been documented. Changes in fish species composition have been recorded, with substantial increases in some species, such as walleye pollock (*Theragra chalcogramma*), and decreases in others. Whether such population fluctuations are inherent to the dynamic nature of the ecosystems or are the result of specific perturbations, perhaps anthropogenic, is unknown. Regardless, because harbor seals are predators near the top of the trophic structure, knowledge of population status and trends of species interacting with seals, particularly prey species, should be integrated into hypotheses aimed to determine the cause of seal declines.

Work undertaken during 1996 marks the completion of four years for the NOAA-funded harbor seal research program. Considerable progress has been made since 1993. A new trend route was established, and the amount of data collected from trend site surveys is sufficient to determine significant population trends in all three areas. Three years of demographic studies on Tugidak Island have been completed and compared to data collected in the 1970s. Forty-eight seals have been monitored with satellite-linked depth recorders to describe foraging behavior, seal movements, and haulout patterns. A summary of the prevalence of infectious diseases has been completed and a review of environmental contaminants is nearly complete. A genetic study to delineate management stocks of Alaskan harbor seals is complete, and the initial results of studies examining seal diet are available. However, much work remains. Results and progress made in each of the first four years must be synthesized and integrated for a more thorough understanding of the results, which can then be used to determine the most effective and efficient means to provide further knowledge of Alaskan harbor seals.

As stated in the project proposal, the focus of the 1996 research program was fourfold:

1. Complete statistical analysis and reporting of existing data.

2. Monitor the trend in harbor seal numbers in selected areas.

3. Investigate factors that may be affecting harbor seals in those areas.

4. Provide information to NMFS that can be used for designing a conservation and management program for harbor seals.

The specific objectives to meet these overall research goals were as follows:

***Objective 1.*** Determine and monitor the number and trend in number of harbor seals at selected sites in the Ketchikan, Sitka, Kodiak, and the northeastern Gulf of Alaska areas.

***Objective 2.*** Determine reproductive rate, age and sex composition, and level of human disturbance at Tugidak Island during pupping and molting periods and compare results to similar data collected in the 1970s.

***Objective 3.*** Describe the distribution and use of harbor seal haulouts in the Southeast Alaska and the Kodiak Archipelago, including temporal and spatial patterns of haulout use.

***Objective 4.*** Describe the areas and depths used for feeding by harbor seals in Southeast Alaska and the Kodiak Archipelago.

***Objective 5.*** Compare indices of health status and the prevalence of some infectious diseases of harbor seals in Southeast Alaska and the Kodiak Archipelago.

***Objective 6.*** Determine genetic structure of harbor seals in Alaska.

***Objective 7.*** Develop methods for estimating vital life history parameters of harbor seals, such as growth rates, age at sexual maturity, reproductive interval, and pregnancy rate.

***Objective 8.*** Provide support to studies by other investigators that will examine the nutritional status, energetic requirements, and food habits of harbor seals.

A supplemental proposal described 3 additional objectives:

***Objective 9*:** Compile information on contaminants in Alaskan harbor seals, evaluate adequacy of current information and make recommendations for future contaminants work.

***Objective 10*:** Determine prey utilization of harbor seals through identification of fatty acids in blubber samples.

***Objective 11*:** Determine prey utilization of harbor seals through analyses of scats and stomach contents.

These 11 objectives were addressed by a diverse group of research scientists from several state and federal agencies and universities working cooperatively with ADF&G. In this annual report, the results of these research efforts are presented in separate chapters prepared by the individual scientists.

(NOTE: The literature cited in this introduction and the summary are presented at the end of the report.)

## ACKNOWLEDGEMENTS

Financial support for this project was provided by the annual Congressional appropriations in the Department of Commerce budget that were passed on to the Alaska Department of Fish and Game (ADF&G) through the National Oceanic and Atmospheric Administration.

The 1996 Alaskan harbor seal research project was a joint effort by many individuals associated with several agencies and academic institutions. Foremost was Jon Lewis, as the project's principal investigator from 1993 until the spring of 1996. Jon's efforts to establish the foundation of a diverse and extensive research project are greatly appreciated. In addition, contributions from the individuals listed below were instrumental to the success of the project.

From ADF&G: Rob Delong for development of software to manage and analyze satellite tag data; Kathy Frost for assistance in the analysis of satellite tag data, fatty acid research, and pregnancy determination research; Lloyd Lowry for oversight of the project, and satellite data analysis and diet analysis; Dennis McAllister for field research and technical assistance; Grey Pendleton for statistical analysis; Ken Pitcher for data analysis and report preparation; Gay Sheffield for disease and diet analyses; Una Swain for field research, analysis of dive data, trend count survey efforts, and administrative assistance; Dave Van den Bosch for logistical support and equipment preparation; Vicki Vanek for the collection of specimens from Alaska Native subsistence hunters, and Randy Zarnke for disease analysis. Administrative support within ADF&G was provided by Jean Fults, Diana Ground, and Lauri Ritter.

From the National Marine Fisheries Service: Alaska Regional Office, Kaja Brix as the project's technical monitor and Peter Jones as program officer; National Marine Mammal Laboratory, Jason Baker and Peter Boveng for tooth structure research and Thomas Loughlin for project oversight; Southwest Fisheries Science Center, Greg O'Corry-Crowe and Robin Westlake for genetic research. From the University of Alaska, Lauri Jemison for her continued studies on Tugidak Island and diet analysis; Steve Trumble and Brian Fadley for collecting physiological specimens and data; and Kate Wynne for field research assistance, collection of specimens from Alaska Native subsistence hunters, and conducting trend counts in the Kodiak region. From Dalhousie University, Sara Iverson for fatty acid research. From the National Institute of Standards and Technology, Paul Becker and Rebecca Papa for initiating the contaminant review. Thanks to Don Bowen for serum and data for Sable Island harbor seals.

Thanks are also due to Monica Riedel and the Alaska Native Harbor Seal Commission for their efforts to help organize the collection of specimens from Alaska Native subsistence hunters, and for insight on how traditional knowledge can be incorporated into the management of harbor seals in Alaska.

# CHAPTER ONE

# DEMOGRAPHICS OF ALASKAN HARBOR SEAL POPULATIONS

## OBJECTIVE 1

Determine and monitor the number and trend in number of harbor seals at selected sites in the Ketchikan, Sitka, Kodiak, and the northeastern Gulf of Alaska areas

## OBJECTIVE 2

Determine reproductive rate, age and sex composition, and levels of human disturbance at Tugidak Island during pupping and molting periods and compare results to similar data collected in the 1970s

## OBJECTIVE 7

Develop methods for estimating vital life history parameters of harbor seals, such as growth rates, age at sexual maturity, reproductive interval, and pregnancy rate

# HARBOR SEAL POPULATION TRENDS IN THE KETCHIKAN, SITKA, AND KODIAK ISLAND AREAS OF ALASKA

Robert J. Small[1], Grey W. Pendleton[2], and Kate M. Wynne[3]

[1]Alaska Department of Fish and Game, Division of Wildlife Conservation
333 Raspberry Road, Anchorage, Alaska 99518

[2]Alaska Department of Fish and Game, Division of Wildlife Conservation
P.O. Box 240020, Douglas, Alaska 99824

[3]Alaska Sea Grant College Program, Fishery Industrial Technical Center,
900 Trident Way, Kodiak, Alaska 99615

## INTRODUCTION

In the Gulf of Alaska and Prince William Sound regions of Alaska, harbor seal (*Phoca vitulina*) numbers declined substantially from the late 1970s through the early 1990s (Pitcher 1990, Hoover-Miller 1994, Frost et. al. 1997). A sympatric species of pinniped, the Steller sea lion (*Eumetopias jubatus*) also declined greatly in the Gulf of Alaska and Aleutian Islands during this period and was classified as "endangered" under the Endangered Species Act in May 1997. In Southeast Alaska (SE), harbor seal numbers appeared to be increasing or stable in recent years and are thought to be relatively abundant (Lewis *et al.* 1996). Likewise, populations of the Steller sea lion appear stable in SE (Calkins *et al.* 1997).

In 1993, concerns about declining pinniped populations led to an expanded program of monitoring harbor seal numbers to estimate population trends. Two geographic areas were chosen: the Kodiak area in the Gulf of Alaska where populations had declined, and SE where populations appeared stable or increasing. Population data were also collected from Tugidak Island, southwest of Kodiak Island, where the first major decline of harbor seals in Alaska was documented (Pitcher 1990). Trend data were collected concurrently with studies of growth, physiological condition, disease, pollutants, movements, diving behavior, habitat use, food habits, and genetic relationships in an attempt to gain insight into the cause(s) of the decline.

## METHODS

### Survey Methods

The Alaska Department of Fish and Game (ADF&G) established trend routes in the Ketchikan and Sitka areas of SE (Figures 1 & 2) in 1983 to monitor harbor seal populations (Calkins and Pitcher 1984). ADF&G surveyed both trend routes again in 1984 (Pitcher 1986), but then neither route was surveyed until the Ketchikan route was flown in 1988 (Pitcher 1989). In 1993, the National Marine Fisheries Service (NMFS) surveyed the entire SE region as part of their first statewide survey (Loughlin 1994), including the areas where both the Ketchikan and Sitka trend routes are located. ADF&G then surveyed the Ketchikan route in 1994 (Lewis 1995), and both the Ketchikan and Sitka routes in 1995 (Lewis *et al.* 1996). NMFS surveyed the Kodiak Island area in 1992, also as part of their first statewide survey (Loughlin 1993), from which a trend count route was established by ADF&G in 1993. The Kodiak trend route was subsequently surveyed by ADF&G in 1994 (Lewis 1995) and 1995 (Lewis *et al.* 1996). In 1996, ADF&G again surveyed the Ketchikan, Sitka, and Kodiak trend routes. Previously, the data from the NMFS surveys (1992 Kodiak, 1993 Ketchikan and Sitka) have been included in population trend analyses (Lewis *et al.* 1996). Our current trend analysis does not include these data because they were collected using a different format than that used by ADF&G, and the number of annual trend counts conducted by ADF&G is sufficient to perform the analysis.

Trend routes were surveyed with single engine, float equipped aircraft during the molting period in late August and early September 1996. Surveys were flown 2 hours before and 2 hours after low tide, at an altitude of 800 feet unless weather conditions required slightly lower altitudes. After locating hauled out harbor seals, the aircraft circled and the observer counted all seals (including those in the water near haulouts), using 7 or 8 power binoculars when necessary, and then took 35mm photographs (ASA 400) with an 80-200mm zoom lens for groups of more than 10-15 seals. Weather conditions (e.g., wind speed, air temperature, cloud conditions) were recorded at each haulout. We attempted to obtain at least five replicate surveys for each route. Seal numbers were later counted from color slide images projected on paper screens. Count data from each trend site within the three survey routes for 1996 are summarized in Appendices I-III; Lewis *et al.* (1996) presented count data from all previous years.

At the southwestern Tugidak Island haulout site (Figure 3, site # 23), counts of seals were made from atop 30 m bluffs during the molting period in late August and early September, 1996, as conducted previously in 1976-79, biennially from 1982-1994, and in 1995 (Lewis *et al.* 1996). Counts were conducted within one hour of daytime low tide. The 1996 count data are summarized in Appendix IV, and were analyzed separately from aerial trend route counts; Lewis *et al.* (1996) presented Tugidak counts from all previous years.

## Model Selection

An estimate of population trend based on trend counts must account for the variation in those counts that results from both real changes in population abundance and factors that affect the proportion of the population visible during surveys. Rather than assume that a constant proportion of seals were visible, and thus observed during each survey, we modeled counts as a function of environmental covariates; e.g., height of low tide, time of day. We then estimated the population trend for a series of annual counts using overdispersed multinomial models (Link and Sauer 1997). With this type of model, counts ($Y_{ij}$ , i indicates site and j indicates replicate) are assumed to be overdispersed Poisson random variables (i.e., negative binomial) with expected values ($m_i$) that have the relationship $\ln(m_i) = h(i) * g_i(\underline{x}) * f_i(t)$. In this equation, h(i) represents site effects, which are treated as a multiplicative nuisance parameter, $g_i(\underline{x})$ is a loglinear function of the environmental covariates ($\underline{x}$) that are unrelated to population change, and $f_i(t)$ is the population trajectory with t indicating year.

The population trajectory can be thought of as a smoothed curve proportional to the actual population sizes across years. Because trajectories were not always linear (i.e., the rate of change varies through time) on the log scale, we defined trend as the geometric mean rate of change over the interval of interest. Trend is therefore a single-number summary of the average change in the trajectory. Because the actual population sizes are unknown, the height of the trend on the y-axis was arbitrarily chosen such that it passed through the mean count in approximately the middle of the survey period for each area.

The environmental covariates used in our analysis included *date*, *time of day*, *tide height* at the nearest (in time) low tide, *time relative to low tide*, and *time relative to sunrise*. These main effect covariates are the same as those investigated by Frost *et al.* (1997); however, we structured all covariates as continuous whereas they used categorical versions of these variables. In addition to the linear form of covariates, we also included *date* and *time* as quadratic covariates (i.e., $date^2$ and $time^2$), and the following 3 two-way interaction covariates: *date*tide*, *time*tide height*, and *time*time relative to low tide*. These quadratic and interaction covariates were chosen because of known or suspected patterns in seal haulout behavior. The total number of covariates we considered was constrained by the number of counts and limitations on computing resources. Models with both linear and quadratic population trajectories (i.e., change in population size across years on the log scale) were tested.

The combination of covariates and degree of polynomial used to produce the trajectory, and subsequent trend estimate, was determined by first starting with a model containing all covariates and a quadratic trajectory. Covariates were then eliminated one at a time based on the likelihood ratio tests until all remaining covariates were significant ($P<0.05$) or were a component of a higher order term (i.e., quadratic or interaction) that was significant. For example, *date* was retained in the final model for Ketchikan with a *P*-value of 0.59 because it was contained in the $date^2$ covariate that was significant ($P<0.0001$). The final model was then used to estimate a single composite trajectory, and subsequently an associated trend estimate, for all sites within a route; this process assumes that the covariate functions were the same for each site. Overall, the advantages of this modeling approach are that counts are adjusted for the effects of the environmental covariates simultaneously with the estimation of the population trajectory, and that variability not accounted for by the covariates can differ among sites.

We calculated an adjusted index to population size for each year a route was surveyed using the residual method of Sauer and Geissler (1990). For each count at every survey site, residuals were computed as the observed count minus the count predicted by the model. The average residuals for each year were summed across sites. These combined residuals were then displayed with the estimated trend line to indicate residual variation in the counts after the model had been fit. These adjusted indices indicate whether observed counts in a specific year were generally above or below the population size predicted by the final model.

The population trend for the southwest beach site on Tugidak Island was estimated by linear regression of the natural logs of mean annual land-based counts during 1982-1996, and the most recent 5 year period of 1992-1996.

## RESULTS

The mean count for the Ketchikan trend route was 2,708 in 1996, an increase of 3.8% from the 1995 count of 2,604 (Table 1). The mean count for the Sitka route decreased 21.5% from the 1995 count of 2,041 to 1,602 in 1996. A similar decrease of 20.1% was observed along the Kodiak trend route, with a 1996 mean count of 2,541 compared to 3,180 in 1995.

A significantly ($P<0.001$) increasing annual trend of 9.3% was estimated for the Ketchikan route from 1983-1996, with 95% confidence intervals (CI) from 7.5 to 11.0% (Table 2, Figure 4). Although mean counts in 1996 for both the Sitka and Kodiak routes decreased by about 20%, trend estimates based on modeling these counts and environmental covariates resulted in significantly increasing annual trends for both areas. For Sitka, the annual trend estimate from 1983-1996 was 3.0% ($P<0.001$), with a tight 95% CI of 2.1 to 3.9% (Table 2, Figure 5). For Kodiak, the annual trend estimate was 7.2% ($P<0.001$) for the last 4 years, 1993-1996, with a 95% CI of 3.5 to 10.8%.

For the Ketchikan route, the difference between the adjusted population index and the estimated trend line was positive in 1983, 1984, and 1988, and negative for counts in the 1990s. The difference alternated between positive and negative for Sitka, and for Kodiak was positive in 1993 and 1996, and negative in 1994 and 1995 (Table 1).

Based on final model selections, a large number of environmental covariates significantly influenced the number of seals hauled out in the Ketchikan route, but fewer covariates appear to influence the number of seals hauled out in Kodiak (Table 3). For Sitka, the time of surveys was not available for the 1983 and 1984 surveys, thus *date* was the only covariate available, which was not significant. The following results pertain only to the Ketchikan and Kodiak routes.

$Date^2$ had a significant negative effect in Ketchikan; i.e., counts decreased during the survey period. *Time of day* had a significant positive influence on both routes; i.e., counts increased later in the day. The negative effect of *tide height* was significant for both routes, indicating that higher tides decreased counts. *Time relative to low tide* was significant only for Ketchikan, indicating that counts decline as surveys are conducted farther from low tide. Time relative to sunrise may have had a negative effect ($P$=0.09) for Kodiak; i.e., counts decreased as the amount of time after sunrise increased. For the Kodiak route, neither the quadratic forms of *date* ($date^2$) and *time* ($time^2$) nor the three interaction covariates (e.g., *date * tide height*) were significant. For Ketchikan, $date^2$ and $time^2$ were both significant with an opposite direction of influence (i.e., negative) than the linear forms; the *time * tide time* interaction was also significant.

The mean number of seals counted on the southwest beach site of Tugidak Island during the molting period of August and early September 1996 was 711, up 17.1% from the 1995 count of 607. Linear regression on the natural log of the mean annual counts from 1982-1996 found a significant ($P<0.001$) decreasing trend of –7.0% (Figure 7).

However, an increasing trend of 4.4% was estimated for the 1992-1996 period, but this trend was not significantly different from zero (*P*=0.25).

## DISCUSSION

The inclusion of the 1996 aerial counts into our trend analysis strengthens the inference that harbor seal populations are increasing in SE. In Ketchikan, the annual trend of 9.3% from 1983-1996 represents a slight increase from the 8.0% estimate through 1995 (Lewis *et al.* 1996). Our current trend analysis includes a 1996 count that was 3.8% higher than the 1995 count, but does not include the 1993 count from the NMFS state-wide survey, which was substantially (54.1 to 69.2%) lower than any other count between 1988-1996. In Sitka, the 3.0% increasing annual trend was 4.5% greater than that (–1.5%) reported through 1995, and also represents the first statistically significant increasing trend reported for the route. Considering that the Sitka count in 1996 was 21.5% lower than in 1995, the large increase in the trend estimate is likely due to the exclusion of the 1993 NMFS count, for two possible reasons. First, the 1993 count was also substantially lower (25.1 to 57.1%) than all other Sitka counts. Second, and perhaps more importantly, the 1993 count was one of only 5 available counts, and excluding it would have a relatively higher impact on the trend estimate than the Ketchikan route with 7 available counts. When our results from the Ketchikan and Sitka areas are combined with those of Mathews and Pendleton (1997, Chapter 1) that demonstrate an overall increasing population trend in Glacier Bay from 1992-1996, they provide a strong indication that seal populations in SE have been increasing since at least 1983. Populations of harbor seals in British Columbia, to the south of SE, increased at 12.5% annually between 1973 and 1990 (Olesiuk *et al.* 1990), but since then the growth rate appears slower (Olesiuk pers. comm.).

The final selected model for the Kodiak area indicated a significant increasing trend of 7.2% over the last 4 years (1993-1996). Yet, the 1996 mean count (2,541) was nearly identical to the 1993 count (2,522), and about 650 less than both the 1994 and 1995 counts (Table 1). Thus, this increasing trend demonstrates the influence of environmental covariates on the interpretation of aerial trend counts. Comparable data are not available prior to the 1992 count (1,563), precluding a long term analysis of population trend for the Kodiak region. Certainly, the best available data indicate an increasing trend for the Kodiak population over the last 4-5 years; yet, population numbers remain severely reduced from those reported in the 1970s. This inference is supported by the stable numbers from the 1992-1996 land based counts from the southwest beach site of Tugidak. However, these counts have not yet been analyzed for the possible influence of time of day and tide, and thus are not directly comparable.

The primary use of a model that incorporates environmental covariates is to more precisely estimate population trend. Such models have been employed for the analysis of trend count data from PWS (Frost *et al.* 1997) and elsewhere in Alaska (Lewis *et al.* 1996). A secondary purpose of such models is to provide, indirectly, insight on how the number of seals hauled out during aerial surveys is affected by environmental factors; e.g., time of day, tide height, etc. However, the statistical interpretation of these effects is equivocal (see 'Covariate Analysis' below), and thus the subsequent biological inference is complicated and subjective. For example, our current analysis does not provide an indication of the relative significance among covariates, nor a distinction of which covariate had "the most significant" effect on counts. We will therefore address only a few of the more prominent results relative to the effect of covariates on trend counts, and the following discussion should be considered speculative.

The influence of tide on the number of seals hauled out was significant in two ways: counts were lower on days with a higher mean low tide, and counts were higher when conducted closer to peak low tide. The model used by Frost *et al.* (1997) indicated that tide height did not significantly affect counts, but that time relative to low tide did, with highest counts between 1.0 hour before to 1.5 hours after low tide. In our analysis, counts increased with surveys later in the day; time of day was the most significant covariate in the PWS model. Counts may have decreased during the survey period for Ketchikan, but date of survey did not appear to influence Kodiak counts. If the survey date has a negative influence on counts, larger numbers of seals would haul out at the beginning of the survey window. This result would also suggest that higher counts could possibly be observed prior to the current survey window, as was predicted by the PWS model. Land-based studies conducted throughout the molt period at trend sites in the different survey areas would address the question of when peak haul out numbers occur. If indeed slightly higher counts could be obtained, the relative increased precision in trend estimation is currently unknown.

### Modeling with Covariates

Survey counts can be represented as $C = N*P$, where C is the count, N is the actual population size and P is the probability of including an animal that is part of N in C (sighting probability). In trend analyses, we want to determine if and how N changes through time; i.e., the population trend. With count data alone, we cannot estimate P directly, but rather model it as a function of environmental covariates. The objective of modeling is to produce a model complex enough to mimic the underlying phenomenon, in this case sighting probability, using as few parameters as possible. Models that are too simple (e.g., trend models without covariates when the covariates actually have an effect on counts) can produce biased estimates of other parameters, and hence biased estimates of trend (Burnham and Anderson 1992). Models that are too complex (e.g., contain unnecessary parameters) reduce precision (i.e., have larger estimated variances).

Another factor that complicates trend estimation is the potential confounding of population trend with the effects of environmental covariates on numbers of animals counted. Covariates that have a systematic pattern over the duration of surveys used to produce trends are confounded with time, making distinction between the effects of the covariate and true population changes over time (i.e., trend) difficult to separate. For example, if counts in early years are conducted late in the survey period and those in later years are conducted earlier in the survey period, changes in counts could not be distinguished between an actual change in population size versus a change in sighting probability. The covariates used in our analysis change over a short time interval (date, time of survey, tide). This, along with replicate within-year counts, reduces the problems of confounding.

The true functional relationship of these continuous covariates with the number of seals counted is unknown, and changes in the functions can result in large changes in trend estimates. Because there is no obvious "correct" functional form for the covariates, we modeled covariates in a manner similar to that used to model time change; i.e., linear on the natural log scale. However, we also allowed quadratic terms for some covariates and interactions for some combinations. This allowed a "wider array of choices" of covariate forms for the model selection procedure to "choose" from. However, this did not guarantee that the range of functional forms includes one that mimics the true relationship.

Lurking variables cause changes in sighting probability that are not associated with changes in population size (Barker and Sauer 1992). The covariates we used, if not included in the model but actually influencing sighting probability, would be lurking variables and their effect could be mistaken for a change in population size. In addition, because measurements of all potential covariates are not available and sample size restraints would preclude inclusion of extremely large pools of covariates, lurking variables may exist that were not considered in our modeling process. One common symptom of lurking variables is the selection of very complex models, especially those involving interactions. Our model building and selection procedures account for the exclusion of important variables by using complex functions of the variables that are included.

The issues discussed above necessitate caution in interpreting the effects of covariates on counts. The covariates selected by the likelihood ratio tests are highly dependent on which covariates are available and the choices of functional forms.

## Future directions in trend analysis

Although we do not anticipate changes in the basic structure of the trend analyses (i.e., Poisson regression including the use of environmental covariates), several modifications to the established procedure will be investigated. These modifications include refinement of the covariates used in the analyses, investigation of new model selection procedures, and the use of site-specific trajectories.

The main effect covariates used in analysis of harbor seal trends are the same as those used by Frost *et al.* (1997), although we use a continuous structure and they use a discrete structure. We have added quadratic effects (date, time-of-day) and interactions (e.g., date*tide height). We will investigate the forms of the variables to determine if other structures or interactions might be more appropriate. For example, using tide height at the survey time rather than tide height at the peak low tide, and the time difference between the survey and peak low tide, and their interaction.

In our most recent previous analysis of harbor seal population trends (Lewis *et al.* 1996), we used AIC to select the appropriate model. For this report, we used likelihood ratio tests for model selection. We will investigate the use of AICc (Hurvich and Tsai 1989, Burnham *et al.* 1995) as an alternative selection procedure. AICc has the advantages of AIC but has improved properties when the sample size is small relative to the number of parameters estimated.

Currently, a single composite trajectory is estimated for all seal survey sites on a trend route. In contrast, in analyzing Steller sea lion trends we have used site-specific trajectories (Calkins *et al.* 1997), which are then combined through an empirical Bayes approach to get a composite trend estimate. A preliminary analysis of the harbor seal data through 1995 yielded very similar results with both approaches. The Poisson regression can be parameterized to allow site-specific trajectories while still producing a composite trend estimate. We will investigate the feasibility of changing our programs to accommodate this approach. In conjunction with this, we will assess the feasibility of using a commercially available statistics package (i.e., SAS) to perform the analyses, which will facilitate transfer of our procedures to other biologists with similar analysis requirements.

## ACKNOWLEDEMENTS

We thank the individuals who conducted aerial surveys from which the data used in this report were generated, particularly Jon Lewis, Dennis McAllister, Ken Pitcher, and Una Swain. Numerous pilots not only flew their aircraft for extended periods, often in adverse conditions, but also assisted us in locating seals; their efforts are greatly appreciated.

## LITERATURE CITED

Barker, R. J., and J. R. Sauer. 1992. Modeling population change from time series data. Pages 182-194, *in*, D. R. McCullough and R. H. Barrett, eds. Wildlife 2001: populations. Elsevier, London, England. 1163 pages.

Burnham, K. P., and D. R. Anderson. 1992. Data-based selection of an appropriate model: the key to modern data analysis. Pages 16-30 *in* D. R. McCullough and R. H. Barrett, eds., Wildlife 2001: Populations. Elsevier Applied Science, London, England.

Burnham, K. P., G. C. White, and D. R. Anderson. 1995. Model selection strategy in the analysis of capture-recapture data. Biometrics 51:888-898.

Calkins, D. and K. Pitcher. 1984. Pinniped investigations in southern Alaska, 1983-84. Contract Report to NMFS. 19 pp.

Calkins, D., D. C. McAllister, K. W. Pitcher, and G. W. Pendleton. 1997. Steller sea lion status and trend in southeast Alaska. Pages 5-33, *in* Steller sea lion recovery investigations in Alaska, 1995-1996, K. W. Pitcher editor; Alaska Department of Fish and Game Final Report for NOAA Award NA57FX0256, 125 pages.

Frost, K. J., L. F. Lowry, J. M. Ver Hoef, and S. J. Iverson. 1997. Monitoring, habitat use, and trophic interactions of harbor seals in Prince William Sound, Alaska. *Exxon Valdez* Oil Spill Restoration Project Annual Report (Restoration Project

96064), Alaska Department of Fish and Game, Division of Wildlife Conservation, Fairbanks, Alaska.

Hoover-Miller, A. A. 1994. Harbor seal (*Phoca vitulina*) biology and management in Alaska. Report to U.S. Marine Mammal Commission, Contract Number T75134749. 45 pp.

Hurvich, C. M., and C. Tsai. 1989. Regression and time series model selection in small samples. Biometrika 76:297-307.

Lewis, J. P., G. W. Pendleton, K. W. Pitcher, and K. M. Wynne. 1996. Harbor seal population trends in Southeast Alaska and the Gulf of Alaska. Pages 8-57 *in* Annual report of harbor seal investigations in Alaska. Alaska Department of Fish and Game Final Report for NOAA Award NA57FX0367, 203 pages.

Link, W. A., and J. R. Sauer. 1997. Estimation of population trajectories from count data. Biometrics 53:488-497.

Loughlin, T. R. 1993. Abundance and distribution of harbor seals (*Phoca vitulina richardsi*) in the Gulf of Alaska and Prince William Sound in 1992. Annual Report to the MMPA Assessment Program, Office of Protected Resources, NMFS, NOAA, 1335 East-West Highway, Silver Spring, MD 20910.

Loughlin, T. R. 1994. Abundance and distribution of harbor seals (*Phoca vitulina richardsi*) in Southeastern Alaska during 1993. Annual Report to the MMPA Assessment Program, Office of Protected Resources, NMFS, NOAA, 1335 East-West Highway, Silver Spring, MD 20910.

Mathews, E. A., and G. W. Pendleton. 1997. Estimation of trends in abundance of harbor seals (*Phoca vitulina richardsi*) at terrestrial and glacial ice haulouts in Glacier Bay National Park, Southeast Alaska, 1975-1996. Pages ??, *in* Harbor Seal Investigations in Alaska, 1996-1997. Alaska Department of Fish and Game Final Report for NOAA Award NA57FX0367, ?? pages.

Olesiuk, P. F., M. A. Bigg and G. M. Ellis. 1990. Recent trends in the abundance of harbor seals , *Phoca vitulina*, in British Columbia. Canadian Journal of Fisheries and Aquatic Science 47:992-1003.

Pitcher, K. W. 1986. Harbor seal trend count surveys in southern Alaska: 1984. Report to the NMFS, Alaska Region, contract 81-ABC-00280, 10p, Available from the Alaska Department of Fish and Game, 333 Raspberry Road, Anchorage, AK 99518.

Pitcher, K. W. 1989. Harbor seal trend count surveys in southern Alaska, 1988. Final Report Contract MM4465852-1 submitted to U.S. Marine Mammal Commission. Washington DC. 15pp.

Pitcher, K. W. 1990. Major decline in number of harbor seals, *Phoca vitulina richardsi*, on Tugidak Island, Gulf of Alaska. Marine Mammal Science 6:121-134.

Sauer, J. R., and P. H. Geissler. 1990. Estimation of annual indices from roadside counts. Pages 58-62 in J. R. Sauer and S. Droege, eds. Survey design and statistical methods for the estimation of avian population trends. U.S. Fish and Wildlife Service Biological Report 90(1). 166pp.

Table 1. Annual mean total counts of harbor seals from population trend routes in the Ketchikan, Sitka, and Kodiak areas of Alaska, 1983-1996. An indication of whether these counts were generally above or below the predicted population size is given by the difference between the adjusted index[1] and the estimated population trend line.

| | Ketchikan | | Sitka | | Kodiak | |
|---|---|---|---|---|---|---|
| Year | Mean Count | Adjusted Index - Trend | Mean Count | Adjusted Index – Trend | Mean Count | Adjusted Index – Trend |
| 1983 | 1059 | 71 | 1168 | 38 | -- | -- |
| 1984 | 1554 | 329 | 1273 | -66 | -- | -- |
| 1988 | 1821 | 219 | -- | -- | -- | -- |
| 1992 | -- | -- | -- | -- | 1563[2] | -- |
| 1993 | 835[2] | -- | 875[2] | -- | 2522 | 75 |
| 1994 | 2228 | -313 | -- | -- | 3184 | -165 |
| 1995 | 2604 | -201 | 2041 | 186 | 3180 | -244 |
| 1996 | 2708 | -250 | 1602 | -61 | 2541 | -174 |

[1] The adjusted index is described in the methods section.

[2] Reported from the NMFS state-wide survey and was not included in the trend analysis.

Table 2. Annual harbor seal population trend (%change/year) estimates based on trend counts in the Ketchikan, Sitka, and Kodiak areas in Alaska.

| Area | Years | n | Trend (se) | 95% Confidence Limits | t (df) | *P* |
|---|---|---|---|---|---|---|
| Ketchikan | 1983-96 | 6 | 9.3 (0.87) | 7.5 – 11.0 | 10.64 (577) | <0.001 |
| Sitka | 1983-96 | 4 | 3.0 (0.45) | 2.1 - 3.9 | 6.75 (562) | <0.001 |
| Kodiak | 1993-96 | 4 | 7.2 (1.87) | 3.5 - 10.8 | 3.82 (495) | <0.001 |

Table 3. Levels of probability (*P*)[1] for environmental covariates that significantly influenced the number of harbor seals hauled out in the Ketchikan, Sitka, and Kodiak areas of Alaska, for the time periods listed. *P*-values are listed for those covariates that were retained in the final model selection to determine population trend, along with their respective direction of influence (+ increasing; - decreasing) on the number of seals hauled out; remaining covariates were either not available for consideration (NA) or not significant (NS).

| | Ketchikan 1983-96 | | Sitka 1983-96 | | Kodiak 1993-96 | |
|---|---|---|---|---|---|---|
| Covariate | *P*[1] | +/- | *P*[1] | +/- | *P*[1] | +/- |
| Year | <0.001 | + | <0.001 | + | <0.001 | + |
| Year * Year | NS | | 0.007 | + | <0.001 | - |
| Date | 0.593 | + | NS | | NS | |
| Time of day (Time) | <0.001 | + | NA | | 0.080 | + |
| Tide height at nearest low tide | 0.053 | - | NA | | 0.231 | - |
| Time relative to low tide | <0.001 | - | NA | | NS | |
| Time relative to sunrise | NS | | NA | | 0.091 | - |
| Date * Date | <0.001 | - | NS | | NS | |
| Time * Time | <0.001 | - | NA | | NS | |
| Date * Tide height | NS | | NA | | NS | |
| Time * Tide height | NS | | NA | | NS | |
| Time * Tide time | <0.001 | + | NA | | NS | |

[1] Individual probabilities are based on the Wald statistics from the final model, and likely differ from the probabilities of the likelihood ratio statistics used in testing the significance of each covariate in the model selection process.

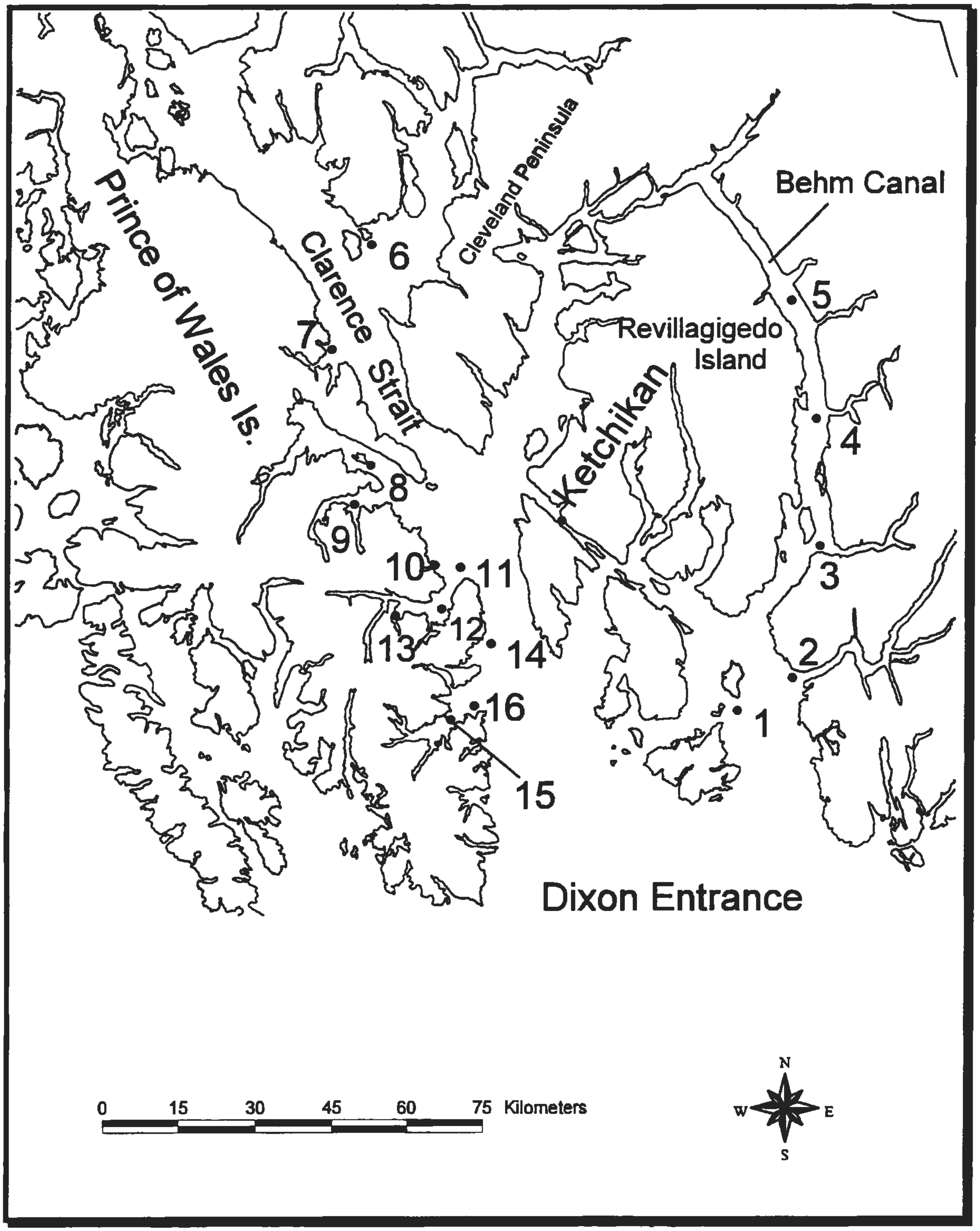


Figure 1. Trend count sites in the Ketchikan area of southeast Alaska.
1. Whale Rock
2. White Reef
3. Carp Island
4. New Eddystone
5. Channel Island
6. Eagle Island
7. Tolstoi Island
8. Daisy Island
9. McKenzie Island
10. Clover Bay
11. Skin Island
12. Lancaster Cove
13. East Dora Bay
14. Wedge Island
15. Moria Sound
16. Whiterock Island

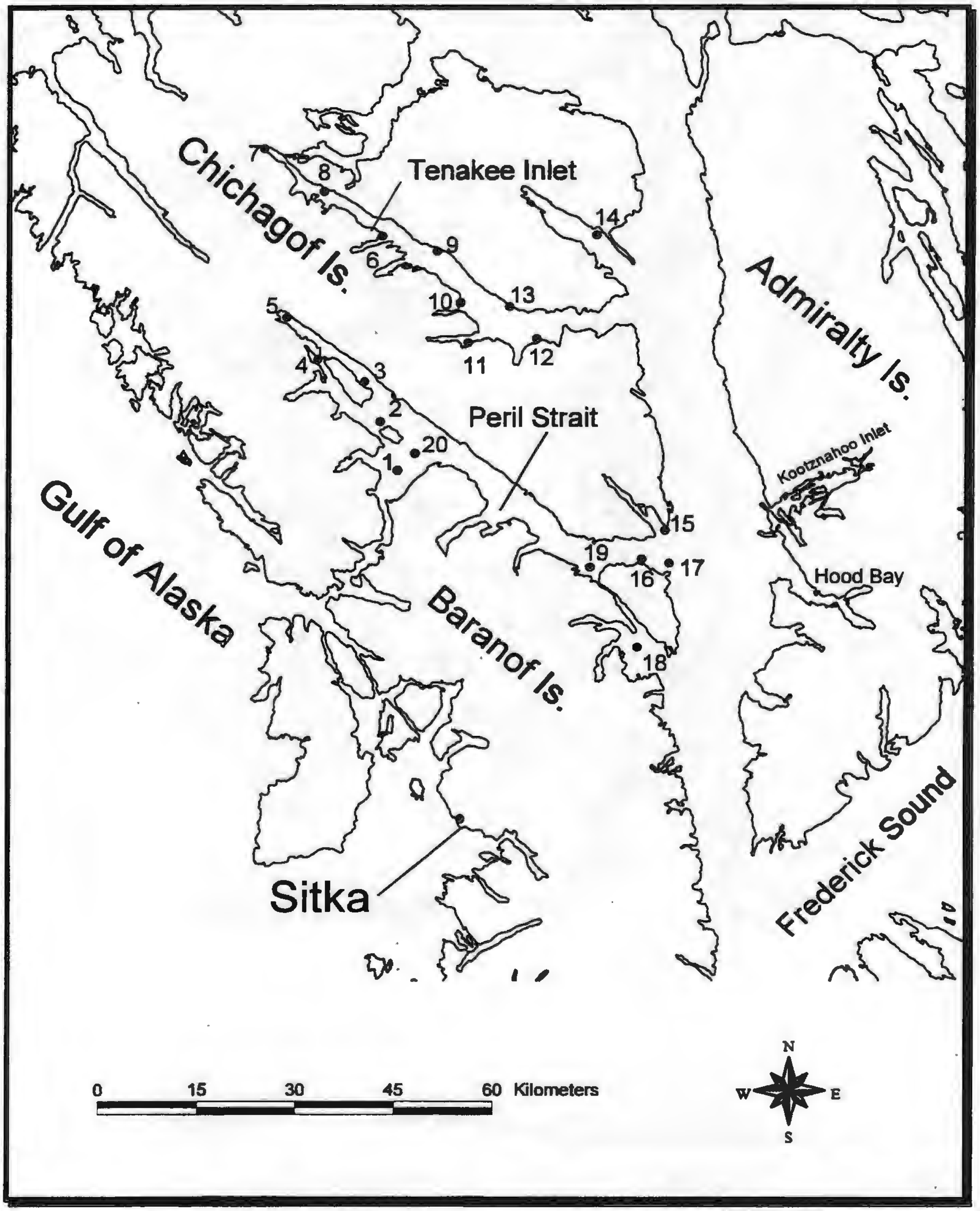


Figure 2. Trend count sites in the Sitka area of southeast Alaska.

1. Hogatt Reef
2. Vixen Island
3. Moser Island N.
4. Southarm
5. Northarm
6. Long Bay
7. Head of Tenakee
8. Grassy Island
9. Mid Island Shoal
10. Saltry Bay
11. Crab Bay
12. Strawberry Rock
13. Tenakee Rock
14. Appletree
15. Point Hayes
16. Traders
17. Midway Reef
18. Plover
19. Point Moses
20. Krugloi Island

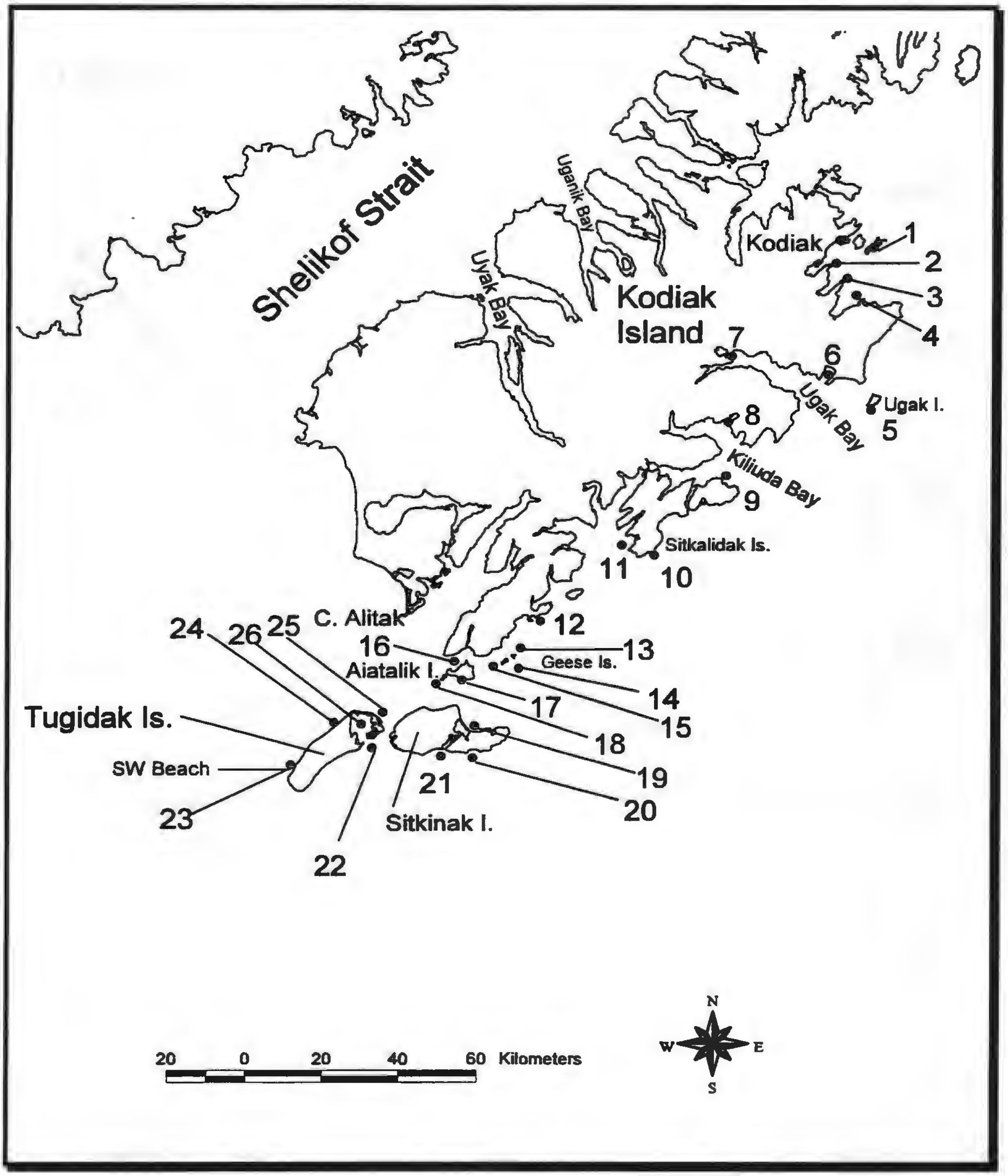


Figure 3. Trend Count Sites in the Kodiak Island area of Alaska

1. Long Island
2. Cliff Point
3. Broad Point
4. Kalsin Bay
5. Ugak Island
6. West Pasagshak
7. Upper Ugak Bay
8. Shearwater Bay
9. Barnabas Rocks
10. Black Point
11. Rolling Bay
12. Outer Kaguyak
13. Geese Island N
14. Geese Island SE
15. Geese Island SW
16. Aiaktalik Ledges
17. Aiaktalik Island
18. Sunstrom Island
19. Sitkinak Lag. N
20. Sitkinak SE
21. Sitkinak Lag. S
22. Tugidak Bars
23. SW Tugidak
24. Tugidak N
25. Tugidak NNE
26. Tugidak Lagoon (Inside)

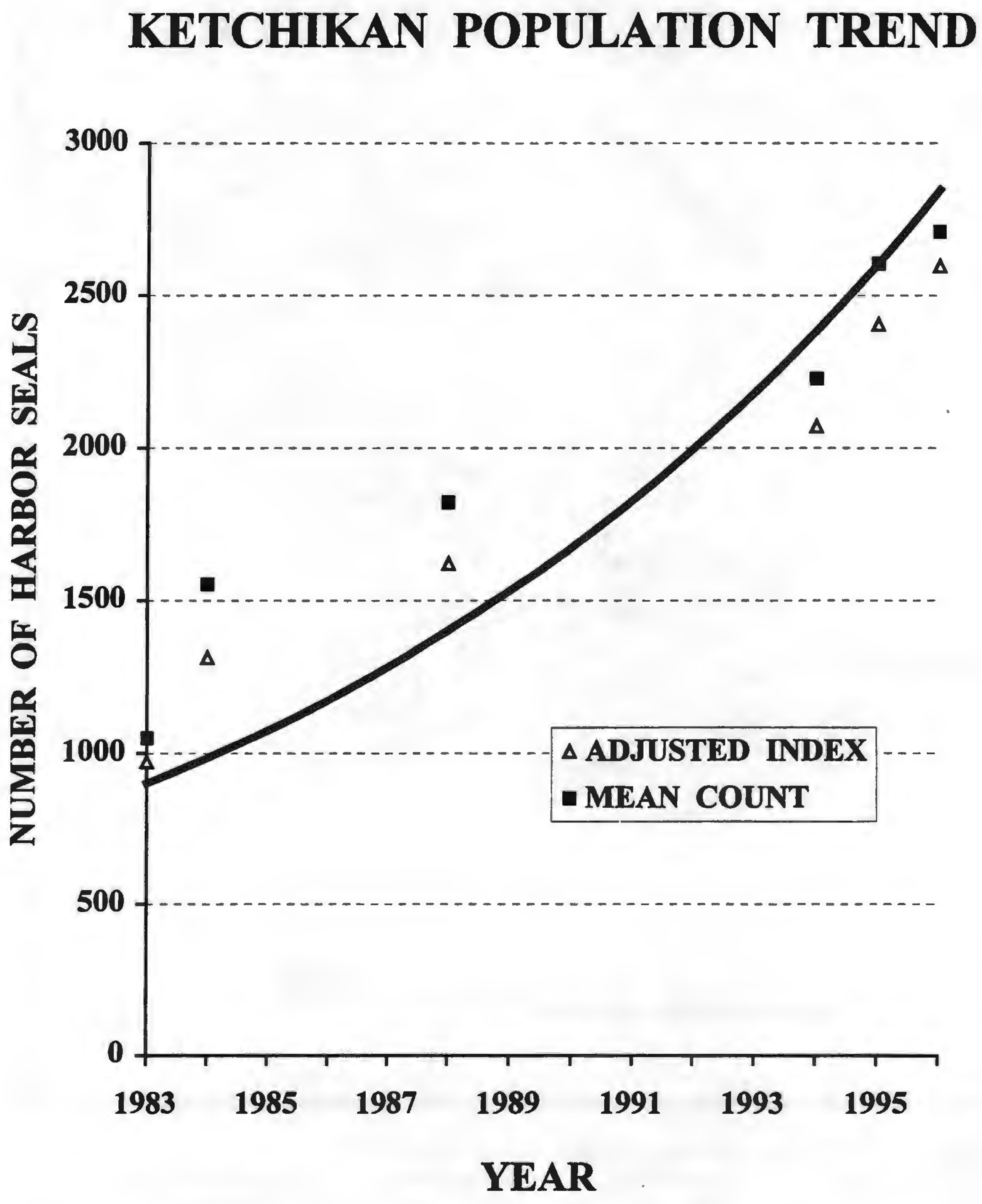


Figure 4. Estimated annual population trend of 9.3% for harbor seals in the Ketchikan area of Alaska, 1993-1996. See text for description of adjusted index.

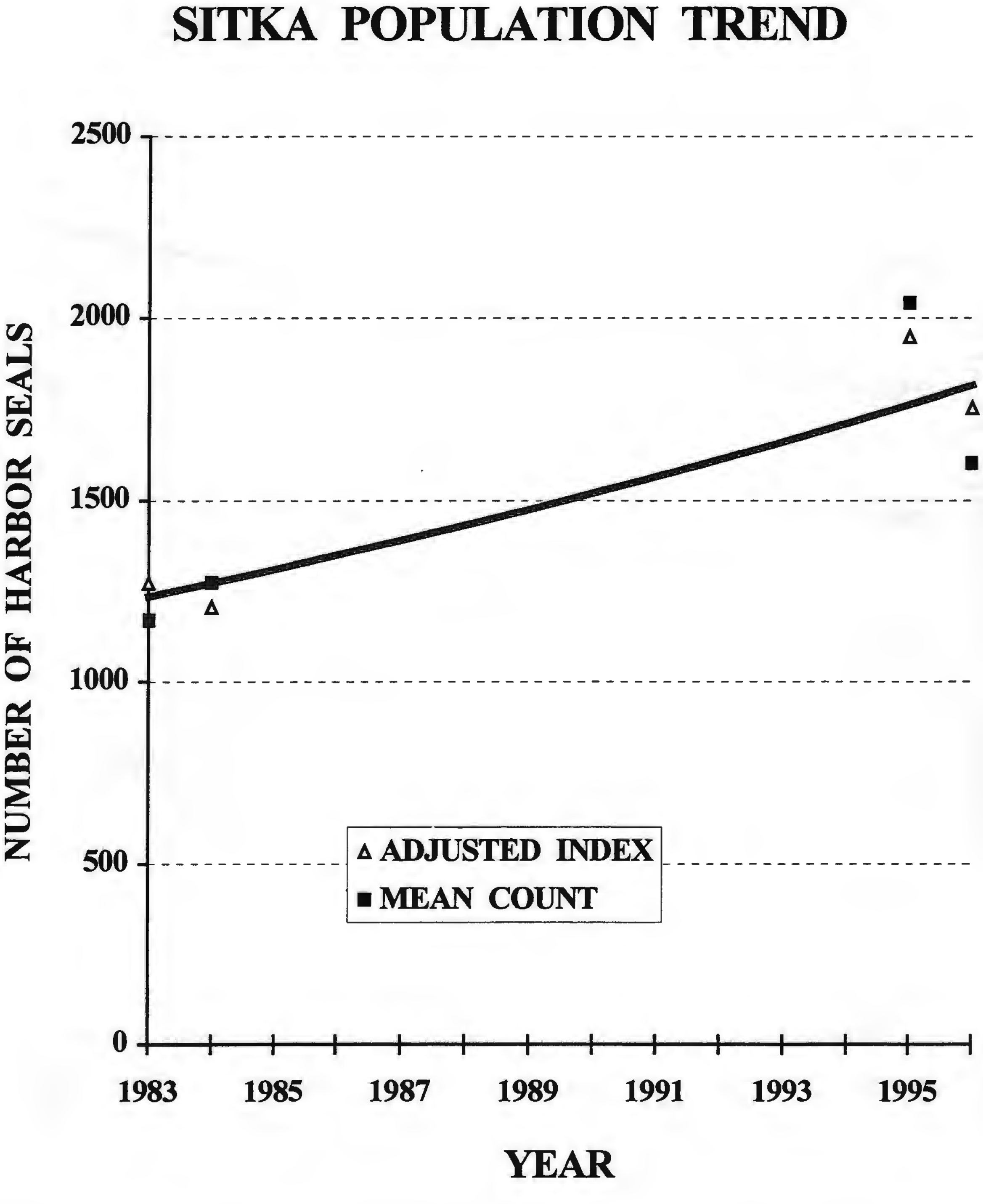


Figure 5. Estimated annual population trend of 3.0% for harbor seals in the Sitka area of Alaska, 1993-1996. See text for description of adjusted index.

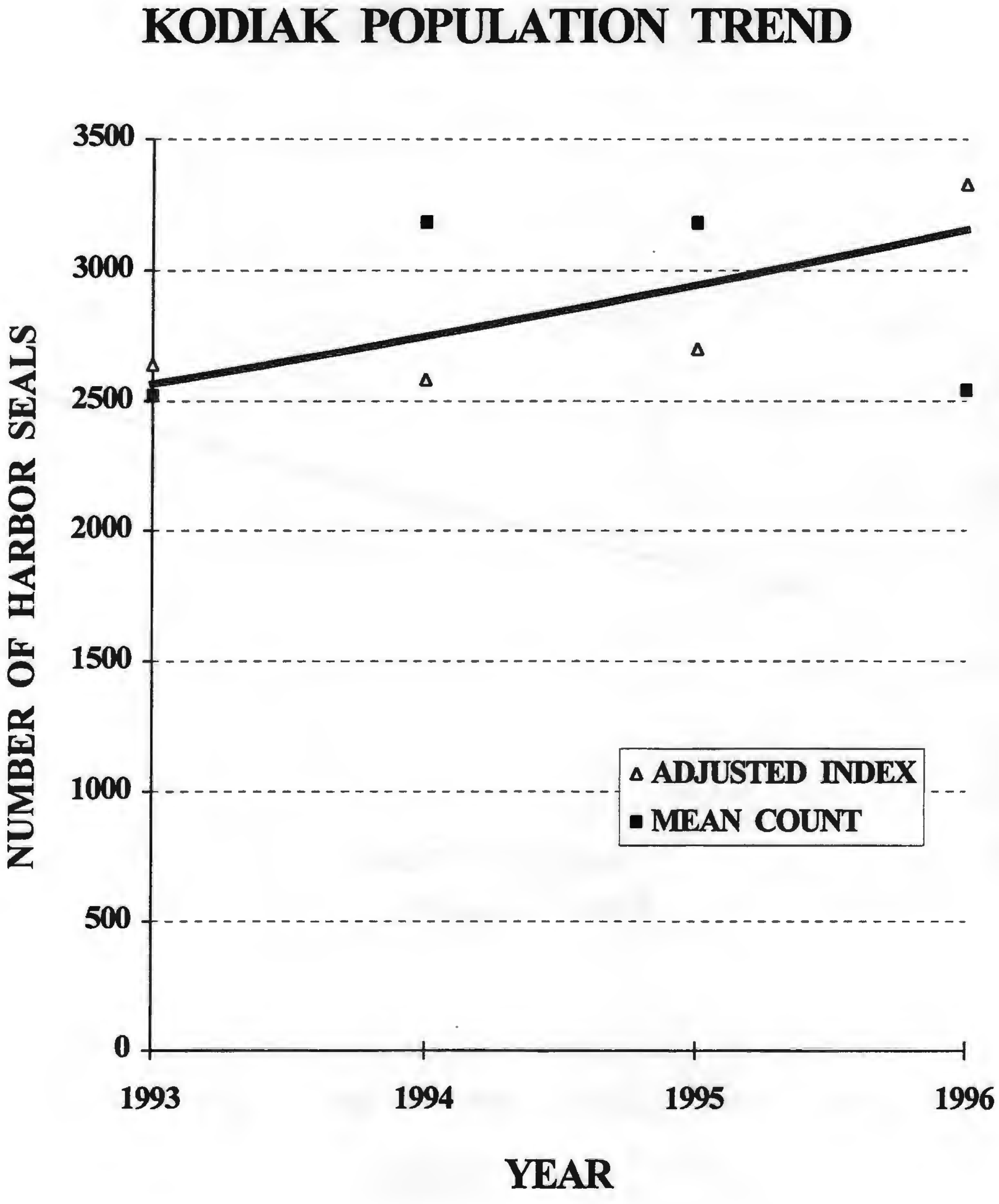


Figure 6. Estimated annual population trend of 7.2% for harbor seals in the Kodiak Island area of Alaska, 1993-1996. See text for description of adjusted index.

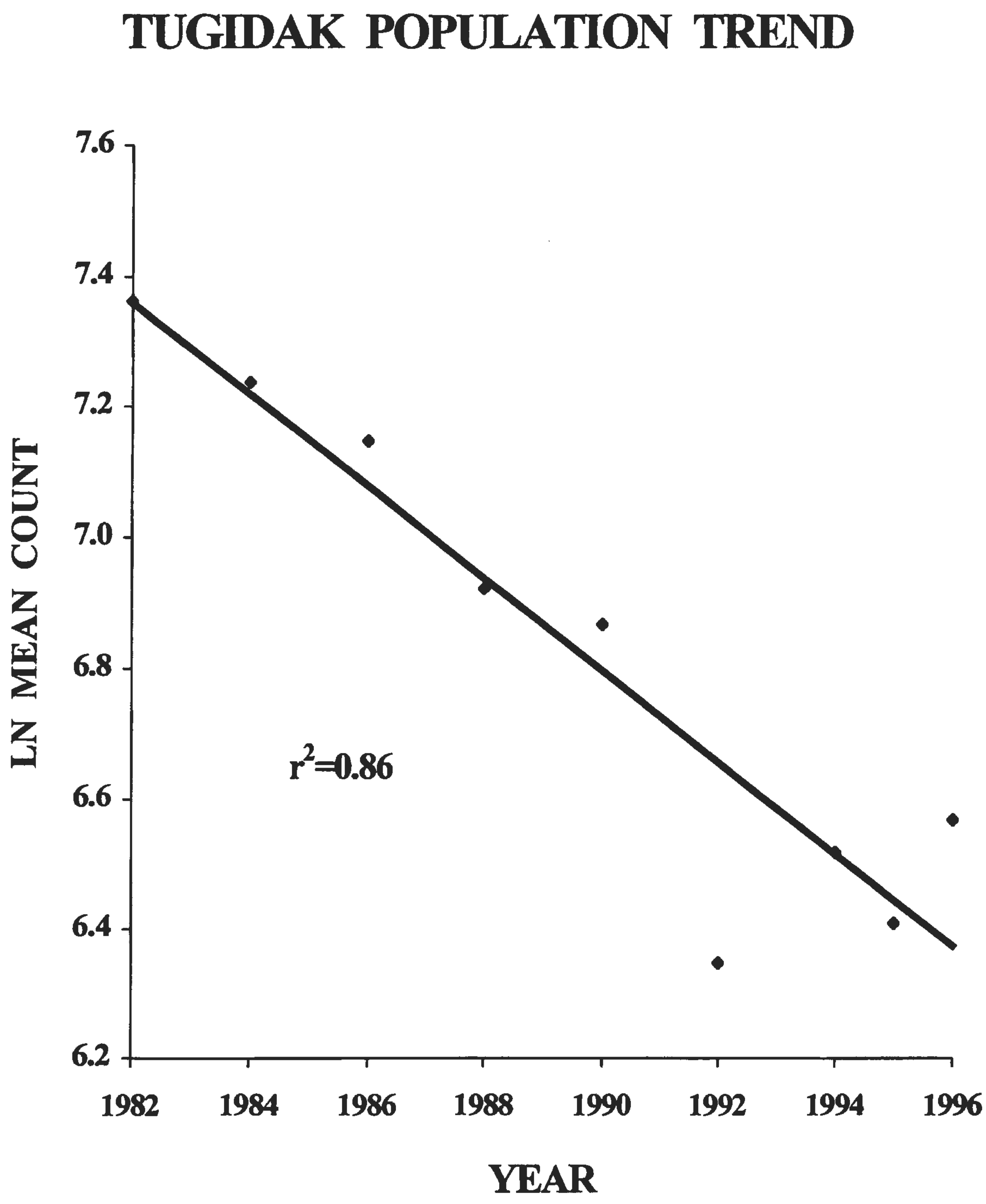


Figure 7. Linear regression of annual mean counts of harbor seals from 1982-1996 during the molting period on southwest beach of Tugidak Island, Gulf of Alaska.

**Appendix I. 1996 harbor seal aerial survey data from the Ketchikan area trend count route.**

| SITE # | SITE NAME | DATE | # SEALS |
|---|---|---|---|
| 1 | Whale R | 8/27/96 | 147 |
| 1 | Whale R | 8/29/96 | 5 |
| 1 | Whale R | 9/1/96 | 126 |
| 1 | Whale R | 9/2/96 | 69 |
| 1 | Whale R | 9/3/96 | 108 |
| 1 | Whale R | 9/5/96 | 118 |
| 2 | White R | 8/27/96 | 804 |
| 2 | White R | 8/29/96 | 33 |
| 2 | White R | 8/31/96 | 652 |
| 2 | White R | 9/1/96 | 710 |
| 2 | White R | 9/2/96 | 474 |
| 2 | White R | 9/3/96 | 731 |
| 2 | White R | 9/5/96 | 536 |
| 3 | Carp I | 8/27/96 | 0 |
| 3 | Carp I | 8/29/96 | 0 |
| 3 | Carp I | 8/31/96 | 0 |
| 3 | Carp I | 9/1/96 | 0 |
| 3 | Carp I | 9/2/96 | 0 |
| 3 | Carp I | 9/3/96 | 0 |
| 3 | Carp I | 9/5/96 | 0 |
| 4 | N Eddystone Rk | 8/27/96 | 359 |
| 4 | N Eddystone Rk | 8/29/96 | 197 |
| 4 | N Eddystone Rk | 8/31/96 | 332 |
| 4 | N Eddystone Rk | 9/1/96 | 367 |
| 4 | N Eddystone Rk | 9/2/96 | 297 |
| 4 | N Eddystone Rk | 9/3/96 | 212 |
| 4 | N Eddystone Rk | 9/5/96 | 287 |
| 5 | Channel I | 8/27/96 | 337 |
| 5 | Channel I | 8/29/96 | 173 |
| 5 | Channel I | 8/31/96 | 250 |
| 5 | Channel I | 9/1/96 | 270 |
| 5 | Channel I | 9/2/96 | 188 |
| 5 | Channel I | 9/3/96 | 196 |
| 5 | Channel I | 9/5/96 | 43 |
| 6 | Eagle I | 8/27/96 | 595 |
| 6 | Eagle I | 8/29/96 | 485 |
| 6 | Eagle I | 8/31/96 | 539 |
| 6 | Eagle I | 9/1/96 | 495 |
| 6 | Eagle I | 9/3/96 | 455 |
| 6 | Eagle I | 9/5/96 | 471 |
| 7 | Tolstoi I | 8/27/96 | 90 |
| 7 | Tolstoi I | 8/29/96 | 97 |
| 7 | Tolstoi I | 8/31/96 | 115 |
| 7 | Tolstoi I | 9/1/96 | 120 |
| 7 | Tolstoi I | 9/3/96 | 100 |
| 7 | Tolstoi I | 9/5/96 | 89 |
| 8 | Daisy I | 8/27/96 | 98 |
| 8 | Daisy I | 8/29/96 | 70 |
| 8 | Daisy I | 8/31/96 | 147 |
| 8 | Daisy I | 9/1/96 | 150 |
| 8 | Daisy I | 9/2/96 | 61 |
| 8 | Daisy I | 9/3/96 | 86 |
| 8 | Daisy I | 9/5/96 | 148 |
| 9 | McKenzie I | 8/27/96 | 171 |
| 9 | McKenzie I | 8/29/96 | 183 |
| 9 | McKenzie I | 8/31/96 | 79 |
| 9 | McKenzie I | 9/1/96 | 237 |
| 9 | McKenzie I | 9/2/96 | 181 |
| 9 | McKenzie I | 9/3/96 | 6 |
| 9 | McKenzie I | 9/5/96 | 23 |
| 10 | Clover Bay | 8/27/96 | 25 |
| 10 | Clover Bay | 8/29/96 | 45 |
| 10 | Clover Bay | 8/31/96 | 42 |
| 10 | Clover Bay | 9/1/96 | 63 |
| 10 | Clover Bay | 9/2/96 | 62 |
| 10 | Clover Bay | 9/3/96 | 0 |
| 10 | Clover Bay | 9/5/96 | 61 |
| 11 | Skin I | 8/28/96 | 6 |
| 11 | Skin I | 8/29/96 | 11 |
| 11 | Skin I | 8/31/96 | 3 |
| 11 | Skin I | 9/1/96 | 36 |
| 11 | Skin I | 9/2/96 | 16 |
| 11 | Skin I | 9/3/96 | 8 |
| 11 | Skin I | 9/5/96 | 19 |
| 12 | Lancaster C | 8/28/96 | 22 |
| 12 | Lancaster C | 8/29/96 | 33 |
| 12 | Lancaster C | 8/31/96 | 27 |
| 12 | Lancaster C | 9/1/96 | 29 |
| 12 | Lancaster C | 9/2/96 | 37 |
| 12 | Lancaster C | 9/3/96 | 17 |
| 12 | Lancaster C | 9/5/96 | 22 |
| 13 | E Dora Bay | 8/28/96 | 82 |
| 13 | E Dora Bay | 8/29/96 | 39 |
| 13 | E Dora Bay | 8/31/96 | 37 |
| 13 | E Dora Bay | 9/1/96 | 159 |
| 13 | E Dora Bay | 9/2/96 | 64 |
| 13 | E Dora Bay | 9/3/96 | 69 |
| 13 | E Dora Bay | 9/5/96 | 71 |
| 14 | Wedge I | 8/29/96 | 205 |
| 14 | Wedge I | 8/31/96 | 121 |
| 14 | Wedge I | 9/1/96 | 297 |
| 14 | Wedge I | 9/2/96 | 256 |
| 14 | Wedge I | 9/3/96 | 215 |
| 14 | Wedge I | 9/5/96 | 196 |
| 15 | Moria Sound | 8/29/96 | 262 |
| 15 | Moria Sound | 8/31/96 | 142 |

| SITE # | SITE NAME | DATE | # SEALS |
|---|---|---|---|
| 15 | Moria Sound | 9/1/96 | 297 |
| 15 | Moria Sound | 9/2/96 | 84 |
| 15 | Moria Sound | 9/3/96 | 245 |
| 15 | Moria Sound | 9/5/96 | 257 |
| 16 | Wh. Rock I | 8/28/96 | 99 |
| 16 | Wh. Rock I | 8/29/96 | 116 |

| SITE # | SITE NAME | DATE | # SEALS |
|---|---|---|---|
| 16 | Wh. Rock I | 8/30/96 | 131 |
| 16 | Wh. Rock I | 8/31/96 | 105 |
| 16 | Wh. Rock I | 9/1/96 | 113 |
| 16 | Wh. Rock I | 9/2/96 | 112 |
| 16 | Wh. Rock I | 9/3/96 | 133 |
| 16 | Wh. Rock I | 9/5/96 | 140 |

**Appendix II. 1996 harbor seal aerial survey data from the Sitka area trend count route.**

| SITE # | SITE NAME | DATE | # SEALS |
|---|---|---|---|
| 1 | Hoggatt | 8/26/96 | 6 |
| 1 | Hoggatt | 8/27/96 | 57 |
| 1 | Hoggatt | 8/28/96 | 69 |
| 1 | Hoggatt | 8/29/96 | 54 |
| 1 | Hogatt | 9/1/96 | 141 |
| 1 | Hogatt | 9/2/96 | 47 |
| 1 | Hogatt | 9/3/96 | 97 |
| 2 | Vixen | 8/26/96 | 267 |
| 2 | Vixen | 8/27/96 | 232 |
| 2 | Vixen | 8/28/96 | 278 |
| 2 | Vixen | 8/29/96 | 293 |
| 2 | Vixen | 9/1/96 | 263 |
| 2 | Vixen | 9/2/96 | 188 |
| 3 | Moser I N | 8/26/96 | 15 |
| 3 | Moser I N | 8/27/96 | 6 |
| 3 | Moser I N | 8/28/96 | 9 |
| 3 | Moser I N | 8/29/96 | 8 |
| 3 | Moser I N | 9/1/96 | 5 |
| 3 | Moser I N | 9/2/96 | 0 |
| 3 | Moser I N | 9/3/96 | 0 |
| 4 | Southarm | 8/26/96 | 17 |
| 4 | Southarm | 8/27/96 | 0 |
| 4 | Southarm | 8/28/96 | 0 |
| 4 | Southarm | 8/29/96 | 0 |
| 4 | Southarm | 9/1/96 | 0 |
| 4 | Southarm | 9/2/96 | 5 |
| 4 | Southarm | 9/3/96 | 2 |
| 5 | Northarm | 8/26/96 | 47 |
| 5 | Northarm | 8/27/96 | 0 |
| 5 | Northarm | 8/28/96 | 1 |
| 5 | Northarm | 8/29/96 | 0 |
| 5 | Northarm | 9/1/96 | 18 |
| 5 | Northarm | 9/2/96 | 0 |
| 5 | Northarm | 9/3/96 | 1 |
| 6 | Long Bay | 8/26/96 | 110 |
| 6 | Long Bay | 8/27/96 | 158 |
| 6 | Long Bay | 8/28/96 | 162 |
| 6 | Long Bay | 8/29/96 | 216 |
| 6 | Long Bay | 9/1/96 | 109 |
| 6 | Long Bay | 9/2/96 | 117 |
| 7 | Head of Tenakee | 8/26/96 | 43 |
| 7 | Head of Tenakee | 8/27/96 | 27 |
| 7 | Head of Tenakee | 8/28/96 | 58 |
| 7 | Head of Tenakee | 9/1/96 | 89 |
| 7 | Head of Tenakee | 9/2/96 | 143 |
| 7 | Head of Tenakee | 9/3/96 | 151 |
| 8 | Grassy | 8/26/96 | 110 |
| 8 | Grassy | 8/27/96 | 6 |
| 8 | Grassy | 8/28/96 | 0 |
| 8 | Grassy | 9/1/96 | 99 |
| 8 | Grassy | 9/2/96 | 0 |
| 8 | Grassy | 9/3/96 | 0 |
| 9 | Mid I. S. | 8/26/96 | 32 |
| 9 | Mid I. S. | 8/27/96 | 29 |
| 9 | Mid I. S. | 8/28/96 | 40 |
| 9 | Mid I. S. | 8/29/96 | 42 |
| 9 | Mid I. S. | 9/1/96 | 38 |
| 9 | Mid I. S. | 9/2/96 | 35 |
| 9 | Mid I. S. | 9/3/96 | 29 |
| 10 | Saltry Bay | 8/26/96 | 0 |
| 10 | Saltry Bay | 8/27/96 | 0 |
| 10 | Saltry Bay | 8/28/96 | 0 |
| 10 | Saltry Bay | 8/29/96 | 0 |
| 10 | Saltry Bay | 9/1/96 | 0 |
| 10 | Saltry Bay | 9/2/96 | 0 |
| 10 | Saltry Bay | 9/3/96 | 0 |
| 11 | Crab Bay | 8/26/96 | 213 |
| 11 | Crab Bay | 8/27/96 | 205 |
| 11 | Crab Bay | 8/28/96 | 282 |
| 11 | Crab Bay | 8/29/96 | 248 |
| 11 | Crab Bay | 9/1/96 | 239 |
| 11 | Crab Bay | 9/2/96 | 214 |
| 11 | Crab Bay | 9/3/96 | 83 |
| 12 | Strawberry Rk | 8/26/96 | 23 |
| 12 | Strawberry Rk | 8/27/96 | 66 |
| 12 | Strawberry Rk | 8/28/96 | 59 |
| 12 | Strawberry Rk | 8/29/96 | 61 |
| 12 | Strawberry Rk | 9/1/96 | 31 |
| 12 | Strawberry Rk | 9/2/96 | 38 |
| 12 | Strawberry Rk | 9/3/96 | 3 |
| 13 | Tenakee Rk | 8/26/96 | 109 |
| 13 | Tenakee Rk | 8/27/96 | 133 |
| 13 | Tenakee Rk | 8/28/96 | 197 |
| 13 | Tenakee Rk | 9/1/96 | 229 |
| 13 | Tenakee Rk | 9/2/96 | 185 |
| 13 | Tenakee Rk | 9/3/96 | 181 |
| 14 | Appletree | 8/26/96 | 131 |
| 14 | Appletree | 8/28/96 | 198 |
| 14 | Appletree | 9/1/96 | 266 |
| 14 | Appletree | 9/3/96 | 155 |
| 15 | Pt Hayes | 8/26/96 | 29 |
| 15 | Pt Hayes | 8/27/96 | 66 |
| 15 | Pt Hayes | 8/28/96 | 30 |
| 15 | Pt Hayes | 9/1/96 | 78 |
| 15 | Pt Hayes | 9/2/96 | 66 |
| 15 | Pt Hayes | 9/3/96 | 11 |

| SITE # | SITE NAME | DATE | # SEALS |
|---|---|---|---|
| 16 | Traders | 8/26/96 | 19 |
| 16 | Traders | 8/27/96 | 39 |
| 16 | Traders | 8/28/96 | 76 |
| 16 | Traders | 9/1/96 | 21 |
| 16 | Traders | 9/2/96 | 37 |
| 16 | Traders | 9/3/96 | 20 |
| 17 | Midway | 8/26/96 | 8 |
| 17 | Midway | 8/27/96 | 27 |
| 17 | Midway | 8/28/96 | 30 |
| 17 | Midway | 9/1/96 | 41 |
| 17 | Midway | 9/2/96 | 9 |
| 17 | Midway | 9/3/96 | 37 |
| 18 | Plover | 8/26/96 | 46 |
| 18 | Plover | 8/27/96 | 105 |
| 18 | Plover | 8/28/96 | 147 |

| SITE # | SITE NAME | DATE | # SEALS |
|---|---|---|---|
| 18 | Plover | 9/1/96 | 75 |
| 18 | Plover | 9/2/96 | 32 |
| 18 | Plover | 9/3/96 | 91 |
| 19 | Pt. Moses | 8/26/96 | 59 |
| 19 | Pt. Moses | 8/27/96 | 76 |
| 19 | Pt. Moses | 8/28/96 | 67 |
| 19 | Pt. Moses | 9/1/96 | 102 |
| 19 | Pt. Moses | 9/2/96 | 7 |
| 19 | Pt. Moses | 9/3/96 | 77 |
| 20 | Krugloi | 8/26/96 | 0 |
| 20 | Krugloi | 8/27/96 | 81 |
| 20 | Krugloi | 8/28/96 | 139 |
| 20 | Krugloi | 9/1/96 | 145 |
| 20 | Krugloi | 9/2/96 | 101 |
| 20 | Krugloi | 9/3/96 | 101 |

**Appendix III. 1996 harbor seal aerial survey data from the Kodiak area trend count route.**

| SITE # | SITE NAME | DATE | # SEALS |
|---|---|---|---|
| 1 | Long I | 8/28/96 | 51 |
| 1 | Long I | 8/29/96 | 43 |
| 1 | Long I | 8/30/96 | 42 |
| 1 | Long I | 8/31/96 | 31 |
| 1 | Long I | 9/1/96 | 25 |
| 1 | Long I | 9/2/96 | 28 |
| 1 | Long I | 9/3/96 | 29 |
| 2 | Cliff Pt | 8/28/96 | 2 |
| 2 | Cliff Pt | 8/29/96 | 0 |
| 2 | Cliff Pt | 8/30/96 | 0 |
| 2 | Cliff Pt | 8/31/96 | 0 |
| 2 | Cliff Pt | 9/1/96 | 1 |
| 2 | Cliff Pt | 9/2/96 | 4 |
| 2 | Cliff Pt | 9/3/96 | 4 |
| 3 | Broad Pt | 8/28/96 | 0 |
| 3 | Broad Pt | 8/29/96 | 0 |
| 3 | Broad Pt | 8/30/96 | 2 |
| 3 | Broad Pt | 8/31/96 | 0 |
| 3 | Broad Pt | 9/1/96 | 0 |
| 3 | Broad Pt | 9/3/96 | 0 |
| 4 | Kalsin B | 8/28/96 | 107 |
| 4 | Kalsin B | 8/29/96 | 113 |
| 4 | Kalsin B | 8/30/96 | 71 |
| 4 | Kalsin B | 8/31/96 | 116 |
| 4 | Kalsin B | 9/1/96 | 90 |
| 4 | Kalsin B | 9/2/96 | 105 |
| 4 | Kalsin B | 9/3/96 | 133 |
| 5 | Ugak I | 8/28/96 | 270 |
| 5 | Ugak I | 8/29/96 | 244 |
| 5 | Ugak I | 8/30/96 | 236 |
| 5 | Ugak I | 8/31/96 | 240 |
| 5 | Ugak I | 9/1/96 | 304 |
| 5 | Ugak I | 9/2/96 | 247 |
| 5 | Ugak I | 9/3/96 | 0 |
| 6 | W. Pasagshak | 8/28/96 | 62 |
| 6 | W. Pasagshak | 8/29/96 | 93 |
| 6 | W. Pasagshak | 8/30/96 | 76 |
| 6 | W. Pasagshak | 8/31/96 | 81 |
| 6 | W. Pasagshak | 9/1/96 | 42 |
| 6 | W. Pasagshak | 9/3/96 | 114 |
| 7 | Upper Ugak B. | 8/28/96 | 0 |
| 7 | Upper Ugak B. | 8/29/96 | 0 |
| 7 | Upper Ugak B. | 8/30/96 | 14 |
| 7 | Upper Ugak B. | 8/31/96 | 20 |
| 7 | Upper Ugak B. | 9/1/96 | 36 |
| 7 | Upper Ugak B. | 9/2/96 | 29 |
| 7 | Upper Ugak B. | 9/3/96 | 0 |
| 8 | Shearwater B | 8/28/96 | 62 |
| 8 | Shearwater B | 8/29/96 | 77 |
| 8 | Shearwater B | 8/30/96 | 91 |
| 8 | Shearwater B | 8/31/96 | 84 |
| 8 | Shearwater B | 9/1/96 | 54 |
| 8 | Shearwater B | 9/2/96 | 76 |
| 8 | Shearwater B | 9/3/96 | 83 |
| 9 | Barnabas Rks | 8/28/96 | 27 |
| 9 | Barnabas Rks | 8/29/96 | 16 |
| 9 | Barnabas Rks | 8/31/96 | 36 |
| 9 | Barnabas Rks | 9/2/96 | 0 |
| 10 | Black Pt | 8/29/96 | 96 |
| 10 | Black Pt | 8/31/96 | 116 |
| 10 | Black Pt | 9/1/96 | 32 |
| 10 | Black Pt | 9/2/96 | 95 |
| 11 | Rolling B | 8/28/96 | 25 |
| 11 | Rolling B | 8/29/96 | 51 |
| 11 | Rolling B | 8/30/96 | 50 |
| 11 | Rolling B | 8/31/96 | 49 |
| 11 | Rolling B | 9/1/96 | 56 |
| 11 | Rolling B | 9/2/96 | 51 |
| 11 | Rolling B | 9/3/96 | 53 |
| 12 | O. Kaguyak | 8/28/96 | 0 |
| 12 | O. Kaguyak | 8/29/96 | 0 |
| 12 | O. Kaguyak | 8/30/96 | 0 |
| 12 | O. Kaguyak | 8/31/96 | 0 |
| 12 | O. Kaguyak | 9/1/96 | 0 |
| 12 | O. Kaguyak | 9/2/96 | 5 |
| 12 | O. Kaguyak | 9/3/96 | 3 |
| 13 | Geese I N | 8/29/96 | 116 |
| 13 | Geese I N | 8/30/96 | 173 |
| 13 | Geese I N | 8/31/96 | 165 |
| 13 | Geese I N | 9/1/96 | 156 |
| 13 | Geese I N | 9/2/96 | 154 |
| 14 | Geese I SE | 8/28/96 | 4 |
| 14 | Geese I SE | 8/29/96 | 9 |
| 14 | Geese I SE | 8/30/96 | 18 |
| 14 | Geese I SE | 8/31/96 | 10 |
| 14 | Geese I SE | 9/1/96 | 27 |

| SITE # | SITE NAME | DATE | # SEALS |
|---|---|---|---|
| 14 | Geese I SE | 9/2/96 | 17 |
| 15 | Geese I SW | 8/28/96 | 0 |
| 15 | Geese I SW | 8/29/96 | 4 |
| 15 | Geese I SW | 8/30/96 | 5 |
| 15 | Geese I SW | 8/31/96 | 5 |
| 15 | Geese I SW | 9/1/96 | 0 |
| 15 | Geese I SW | 9/2/96 | 10 |
| 16 | Aiaktalik L | 8/28/96 | 0 |
| 16 | Aiaktalik L | 8/29/96 | 20 |
| 16 | Aiaktalik L | 8/30/96 | 25 |
| 16 | Aiaktalik L | 8/31/96 | 30 |
| 16 | Aiaktalik L | 9/1/96 | 24 |
| 16 | Aiaktalik L | 9/2/96 | 18 |
| 17 | Aiaktalik Is | 8/28/96 | 69 |
| 17 | Aiaktalik Is | 8/29/96 | 66 |
| 17 | Aiaktalik Is | 8/30/96 | 75 |
| 17 | Aiaktalik Is | 8/31/96 | 72 |
| 17 | Aiaktalik Is | 9/1/96 | 44 |
| 17 | Aiaktalik Is | 9/2/96 | 71 |
| 18 | Sunstrom I | 8/28/96 | 0 |
| 18 | Sunstrom I | 8/29/96 | 2 |
| 18 | Sunstrom I | 8/30/96 | 2 |
| 18 | Sunstrom I | 8/31/96 | 3 |
| 18 | Sunstrom I | 9/1/96 | 3 |
| 18 | Sunstrom I | 9/2/96 | 3 |
| 19 | N. Sitkinak Lgn | 8/28/96 | 61 |
| 19 | N. Sitkinak Lgn | 8/29/96 | 83 |
| 19 | N. Sitkinak Lgn | 8/30/96 | 32 |
| 19 | N. Sitkinak Lgn | 8/31/96 | 62 |
| 19 | N. Sitkinak Lgn | 9/1/96 | 82 |
| 19 | N. Sitkinak Lgn | 9/2/96 | 75 |
| 20 | Sitkinak I SE | 8/28/96 | 174 |
| 20 | Sitkinak I SE | 8/29/96 | 146 |
| 20 | Sitkinak I SE | 8/30/96 | 149 |
| 20 | Sitkinak I SE | 8/31/96 | 187 |
| 20 | Sitkinak I SE | 9/1/96 | 163 |
| 20 | Sitkinak I SE | 9/2/96 | 113 |
| 22 | SE Tugidak Bars | 8/28/96 | 154 |
| 22 | SE Tugidak Bars | 8/29/96 | 179 |
| 22 | SE Tugidak Bars | 8/30/96 | 191 |
| 22 | SE Tugidak Bars | 8/31/96 | 149 |
| 22 | SE Tugidak Bars | 9/1/96 | 202 |

| SITE # | SITE NAME | DATE | # SEALS |
|---|---|---|---|
| 23 | SW Tugidak | 8/28/96 | 568 |
| 23 | SW Tugidak | 8/29/96 | 308 |
| 23 | SW Tugidak | 8/30/96 | 796 |
| 23 | SW Tugidak | 8/31/96 | 840 |
| 23 | SW Tugidak | 9/2/96 | 979 |
| 24 | N. Tugidak (out) | 8/28/96 | 0 |
| 24 | N. Tugidak (out) | 8/29/96 | 0 |
| 24 | N. Tugidak (out) | 8/30/96 | 128 |
| 24 | N. Tugidak (out) | 8/31/96 | 201 |
| 24 | N. Tugidak (out) | 9/1/96 | 0 |
| 24 | N. Tugidak (out) | 9/2/96 | 142 |
| 25 | NE Tugidak (out) | 8/28/96 | 418 |
| 25 | NE Tugidak (out) | 8/29/96 | 286 |
| 25 | NE Tugidak (out) | 8/30/96 | 307 |
| 25 | NE Tugidak (out) | 8/31/96 | 205 |
| 25 | NE Tugidak (out) | 9/1/96 | 392 |
| 25 | NE Tugidak (out) | 9/2/96 | 329 |
| 26 | Tugidak Lag in | 8/28/96 | 114 |
| 26 | Tugidak Lag in | 8/29/96 | 90 |
| 26 | Tugidak Lag in | 8/30/96 | 101 |
| 26 | Tugidak Lag in | 8/31/96 | 121 |
| 26 | Tugidak Lag in | 9/1/96 | 60 |
| 26 | Tugidak Lag in | 9/2/96 | 130 |
| 27 | NNE Tugidak (out) | 8/28/96 | 0 |
| 27 | NNE Tugidak (out) | 8/29/96 | 0 |
| 27 | NNE Tugidak (out) | 8/30/96 | 0 |
| 27 | NNE Tugidak (out) | 8/31/96 | 0 |
| 27 | NNE Tugidak (out) | 9/1/96 | 0 |
| 27 | NNE Tugidak (out) | 9/2/96 | 0 |
| 28 | Upper Kiliuda | 8/28/96 | 0 |
| 28 | Upper Kiliuda | 8/29/96 | 0 |
| 28 | Upper Kiliuda | 8/31/96 | 0 |
| 29 | Womens Bay marker | 9/1/96 | 39 |
| 29 | Womens Bay marker | 9/3/96 | 47 |
| 30 | Chiniak marker | 8/28/96 | 0 |
| 30 | Chiniak marker | 8/29/96 | 0 |
| 30 | Chiniak marker | 8/30/96 | 0 |
| 30 | Chiniak marker | 8/31/96 | 0 |
| 30 | Chiniak marker | 9/1/96 | 0 |
| 30 | Chiniak marker | 9/2/96 | 0 |
| 30 | Chiniak marker | 9/3/96 | 0 |

## Appendix IV. 1996 land based counts of harbor seals on southwestern Tugidak Island.

| YEAR | MONTH | DAY | NO_SEALS |
|---|---|---|---|
| 1996 | 8 | 3 | 776 |
| 1996 | 8 | 5 | 733 |
| 1996 | 8 | 6 | 824 |
| 1996 | 8 | 7 | 786 |
| 1996 | 8 | 8 | 905 |
| 1996 | 8 | 9 | 999 |
| 1996 | 8 | 10 | 276 |
| 1996 | 8 | 11 | 883 |
| 1996 | 8 | 12 | 754 |
| 1996 | 8 | 15 | 887 |
| 1996 | 8 | 16 | 640 |
| 1996 | 8 | 17 | 641 |
| 1996 | 8 | 18 | 693 |
| 1996 | 8 | 19 | 744 |
| 1996 | 8 | 20 | 762 |
| 1996 | 8 | 21 | 799 |
| 1996 | 8 | 22 | 836 |
| 1996 | 8 | 23 | 786 |
| 1996 | 8 | 24 | 714 |
| 1996 | 8 | 25 | 722 |
| 1996 | 8 | 26 | 669 |
| 1996 | 8 | 27 | 583 |
| 1996 | 8 | 28 | 829 |
| 1996 | 8 | 29 | 684 |
| 1996 | 8 | 30 | 865 |
| 1996 | 8 | 31 | 673 |
| 1996 | 9 | 1 | 588 |
| 1996 | 9 | 2 | 681 |
| 1996 | 9 | 3 | 553 |
| 1996 | 9 | 4 | 742 |

# ABUNDANCE AND DISTRIBUTION OF HARBOR SEALS FROM ICY BAY TO ICY STRAIT, SOUTHEAST ALASKA DURING AUGUST 1996, WITH RECOMMENDATIONS FOR A POPULATION TREND ROUTE

Elizabeth A. Mathews[1,2] and Jamie N. Womble[3]

[1]Glacier Bay National Park, Resource Management Division
P.O. Box 140, Gustavus, Alaska 99826

[2]University of Alaska Southeast, Biology Department, ELAS
11120 Glacier Highway, Juneau, Alaska 99801

[3]P.O. Box 211382, Auke Bay, AK 99821

## INTRODUCTION

Harbor seal *(Phoca vitulina richardsi)* numbers on Tugidak Island in the Gulf of Alaska declined by as much as 86% between the mid-1970s and the late 1980s (Hoover-Miller 1994, Pitcher 1990). Declines in harbor seal numbers have also been reported in Prince William Sound (Frost *et al.* 1995), in Bristol Bay, and along the Alaskan Peninsula (Withrow and Loughlin 1996). In contrast, harbor seal numbers in Southeast Alaska appear to be stable, or possibly increasing (Mathews 1995, Lewis *et al.* 1996). The causes of declines in harbor seal, as well as Steller sea lion *(Eumetopias jubatus)* and sea bird, populations are not fully understood, although they appear to involve changes in prey distribution, abundance, or age class structure (Loughlin and Merrick 1988; Merrick 1995, Springer 1993). Trends in numbers of harbor seals in Southeast Alaska are of interest both for their comparative value, as well as to ensure that a significant change in abundance can be detected early, should one occur.

In 1995, a multi-agency meeting sponsored by the National Marine Fisheries Service (NMFS) and the Alaska Department of Fish and Game (ADF&G) was held in Fairbanks to discuss the status of, and monitoring methods for, harbor seals in Alaska (Small 1995). A primary goal of the meeting was to evaluate and standardize monitoring methods to ensure that appropriate and comparable data are collected across regions, years, and investigators. A topic of discussion at the meeting was whether or not additional aerial survey routes for estimating trends in harbor seal abundance should be established. Currently, four areas in Southeast Alaska have been surveyed regularly enough to be considered as trend routes (Table 1). These include three aerial survey routes of terrestrial haulouts near Ketchikan and Sitka and in Glacier Bay, and a fourth site in Johns Hopkins Inlet (a tidewater glacial fjord in Glacier Bay) where seals haul out on glacial ice. If trends in seal abundance from annual surveys of a subset of selected areas are closely correlated with trends in abundance throughout a region, they can be used to reduce the frequency (and cost) of region-wide surveys.

The 800 km or so of coastline from Icy Bay in the northeast Gulf of Alaska to Icy Strait in Southeast Alaska (Figure 1) is of particular interest as a potential trend route, not only because it is adjacent to the eastern edge of the region where declines have been documented (Pitcher 1990), but also because it includes several large tidewater glacial fjords (i.e., Icy and Disenchantment bays), productive river drainages (i.e., the Alsek and Dangerous rivers), and protected bays (i.e., Lituya Bay), as well as long stretches of exposed coastline. Although drifting icebergs from active tidewater glaciers appear to be preferred habitat during pupping and molting (Calambokidis *et al.* 1987, Mathews 1995), Johns Hopkins Inlet is currently the only tidewater glacier system where seal abundance has been regularly monitored in Alaska (Table 1). The inclusion of other glacially driven systems, such as Icy and Disenchantment bays, in a trend route should be considered in light of their use by large aggregations of seals. Changes in the trend in numbers of seals observed in the northeast Gulf might also provide an early indicator if the decline begins to move eastward.

**Table 1.** Areas in Southeast Alaska which have been surveyed for harbor seals during the late summer molt and which may be useful for monitoring trends in abundance. Shaded boxes represent years when a survey was flown, and the letters within the boxes correspond to the principal investigators' initials (see references below).

| | **Haulout Substrates** | | **Survey Years** | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Area** | terrestrial | glacial ice | 75 | 76 | 77 | 78 | ... | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 |
| 1) Ketchikan | yes | | | | | | | [illegible] | [illegible] | | | | P2 | | | | | [illegible] | [illegible] | [illegible] | [illegible] |
| 2) Sitka | yes | | | | | | | [illegible] | [illegible] | | | | | | | | | [illegible] | | [illegible] | [illegible] |
| 3) Johns Hopkins In | | yes | [illegible] | [illegible] | [illegible] | [illegible] | | [illegible] | [illegible] | | | | | | | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 4) Glacier Bay (excl. JHI) | yes | | | | | | | | | | | | | | | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 5) Icy Bay to Icy St | yes | yes | | | | | | | | | | | | | | | | [illegible] | | | [illegible] |

**References**
1) Calkins & Pitcher 1984 (CP); Pitcher 1986 (P1); Pitcher 1989 (P2); Loughlin 1994 (Lo);
2) Lewis 1996 (Le)
2) Calkins & Pitcher 1984; Pitcher 1986; Loughlin 1994; Lewis 1996
3) Streveler 1979 (S); Calambokidis *et al.* 1987 (C); Loughlin 1994; Mathews 1995 (M), 1996 & 1997
4) Mathews 1995 & Mathews & Pendleton 1997
5) Loughlin 1994; Mathews & Womble 1997 (MW)

The first region-wide aerial survey for harbor seals in Southeast Alaska, including Icy Bay to Icy Strait, was conducted in 1993 by the NMFS, National Marine Mammal Lab (NMML) (Loughlin 1994a). This survey was part of a large effort to obtain minimum population estimates for harbor seals throughout Alaska. Our August 1996 survey covered one of the seven areas included in the NMFS 1993 survey (Figure 1). The NMML surveys have been flown, or are scheduled to occur, every three to four years in each of four regions in the state (Withrow and Loughlin 1996). A second survey of Southeast Alaska occurred in 1997.

On six days in August 1996 we conducted aerial surveys of all or portions of the coast between Icy Bay and Icy Strait, south of Glacier Bay. The objectives of this aerial photographic survey were: 1) to establish a minimum population estimate (MPE) for the area, 2) to determine if all or a portion of the Icy Bay to Icy Strait route flown by the NMML in 1993 (Loughlin 1994a) might be a practical, trend route for monitoring seals at haulouts, and 3) to compare the distribution and abundance of seals from this August survey to that from the earlier survey of the same area in September 1993. In this report we present the results of the 1996 survey and compare the distribution of seals to that observed in September 1993. We also provide recommendations for a specific trend route within the study area.

## METHODS

### Study Area

The northeast Gulf of Alaska from Icy Bay to Icy Strait includes at least 35 harbor seal haulouts on substrates ranging from glacial ice to rocky shores, sand reefs, and tidally-exposed rocks. From 18-27 August 1996, we conducted surveys between Icy Bay (59° 53'N, 141° 28'W) and Cape Spencer (58° 15'N, 137° 40'W) and in Cross Sound and Icy Strait, west of Mud Bay (136° W) (Figure 1). Surveys of the outer coast to Cape Spencer were conducted by Womble and originated in Yakutat. All but one of the surveys of the Icy Strait/Cross Sound area was conducted by Mathews from Gustavus as part of a survey of haulouts in Glacier Bay. Results from the Glacier Bay survey are included in a separate report (Mathews and Pendleton 1997).

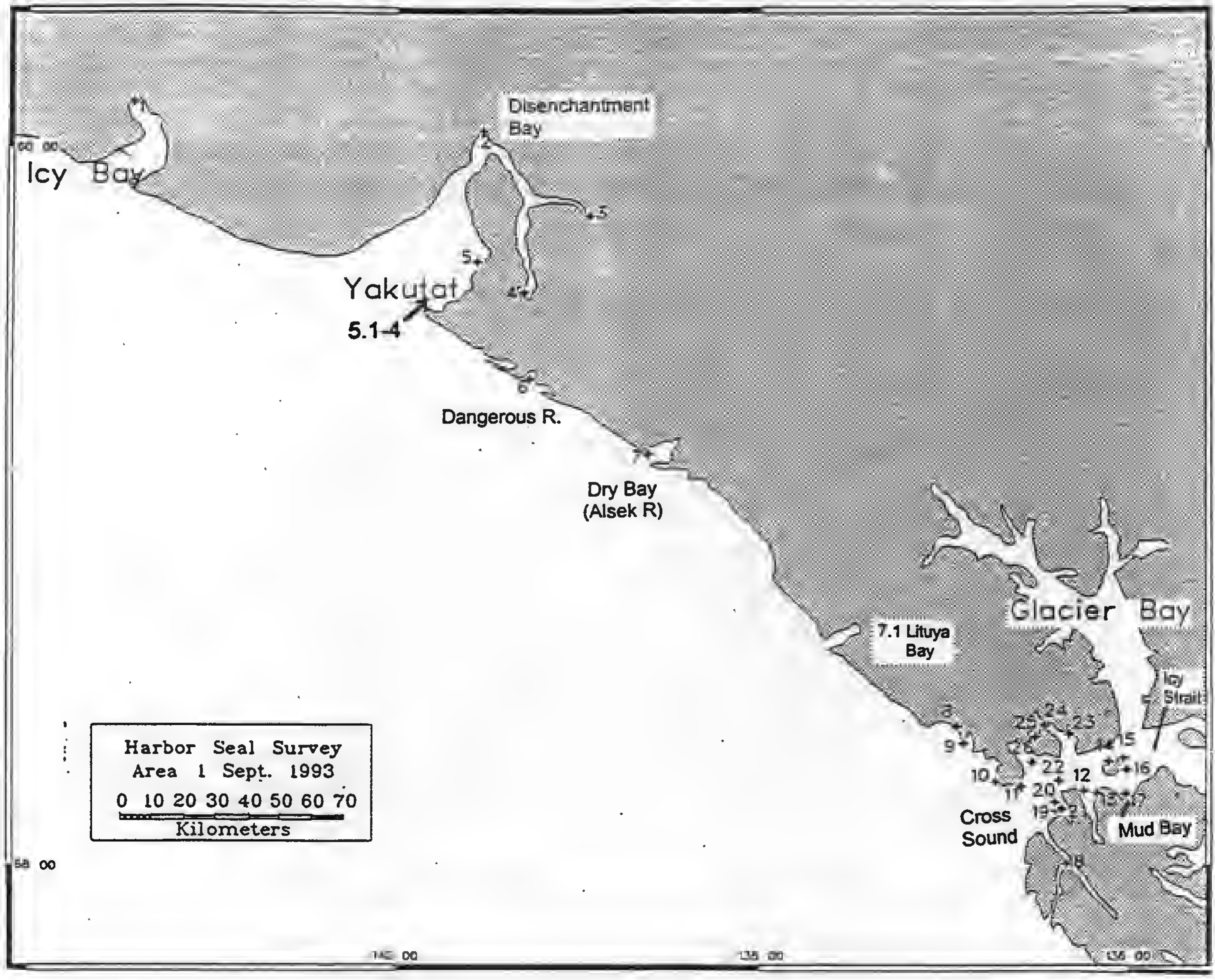
Due to the large geographic area included between Icy Bay and Icy Strait, we could not reach all haulouts within two hours of low tide on a single flight nor without refueling. Consequently, we divided the route into three general areas (Figure 1):

a) glacial ice haulouts in Icy Bay and Disenchantment Bay (encompasses Hubbard and Turner glaciers[1]), and terrestrial haulouts in Yakutat Bay, and Russell and Nunatak Fjords (sites 1-5.4),
b) the outer coast from the Dangerous River to Cape Spencer (sites 6-11; 23-26), and
c) the Icy Strait/Cross Sound area east to Mud Bay (sites 12-22).

At tidally influenced terrestrial haulouts, seal numbers are typically highest during ebb or low tides (Calambokidis *et al.* 1987, Frost *et al.* 1996b, Pitcher and Calkins 1979). Surveys of areas b and c, predominately comprised of terrestrial haulouts, were accordingly scheduled to depart from the airport 2.5-3 hours before low tide. Weather conditions and early morning tides, however, did not always allow us to exactly follow these preferred protocols for tidally influenced haulouts. In Muir Inlet, a previously active tidewater glacier in Glacier Bay, the numbers of seals hauled out on glacial ice were relatively stable from mid morning (9:00) to late evening (21:00) during August

---

[1] **We considered Hubbard and Turner Glaciers as separate haulout areas, since discreet groups of seals on ice were seen in front of both glaciers. In the Loughlin 1994 report, the 'Hubbard Glacier' counts appear to have included seals in front of Turner Glacier.**



| Site # and Name | Site # and Name | Site # and Name | Site # and Name | Site # and Name |
|---|---|---|---|---|
| 1 Icy Bay | 5.1 Otmeloi Island | 8 Boussole Bay | 13 Gull Cove | 20.1 George Is |
| 2 Hubbard Glacier | 5.2 Foxy Reef | 9 Astrolabe Rocks | 14 Is. N of Lemesurier | 21 Althorp Rocks |
| 2.1 Turner Glacier | 5.3 Knight Island (rk) | 9.1 Graves Rocks | 15 Lemesurier NE | 22 Inian Islands |
| 3 Nunatak Fjord | 5.4 Redfield Cove | 9.2 Dixon Harbor Rks | 16 Lemesurier SE | 23 Dundas River D. |
| 4 Russell Fjord | 6 Dangerous River | 10 Polka Pen Rocks | 17 Quartz Point | 24 Dundas Bay Fork |
| 5 Krutoi Island | 7 Dry Bay (Alsek R) | 11 Cape Spencer | 18 Miner I (rocks) | 25 Dundas Bay Is. |
|  | 7.1 Lituya Bay | 12 Shaw Island | 19 Three Hill Island | 26 Taylor Bay |
|  |  | 12.1 Elfin Cove Rocks | 20 Gaff Rock |  |

**Figure 1.** Area of survey coverage with haulout location numbers. (This map is a modified copy of Figure 2 from Loughlin 1994; with permission.) Haulouts denoted with whole numbers are from Loughlin 1994; sites denoted by a number with a decimal were occupied during surveys in 1996, but not during the surveys in 1993. (Location names are given in Table 3.)

**Table 2.** Time of surveys with optimal survey times for five areas from Icy Bay to Icy Strait during 1996. Optimal times for surveying seals at terrestrial haulouts are at low tides +/- two hours; for glacial haulouts counts may remain high from 9:00 – 21:00 (Calambokidis *et al.* 1983). The times for areas with several haulouts are from the middle of the survey section, and exact times are in Appendix I. (*: glacial ice haulout; *ns:* not surveyed due to bad weather conditions.)

| Date | Location | Time of Survey | Optimal Time | Within Optimal |
|---|---|---|---|---|
| **Aug 18** | a) Icy Bay* | 9:00 | 9:00 - 21:00 | yes |
| | a) Hubbard Glacier* | 9:51 | 9:00 - 21:00 | yes |
| | b) Dangerous Rvr | 11:25 | 8:04 - 12:04 | yes |
| | b) DryBay/Alsek Rvr | 11:40 | 8:04 - 12:04 | yes |
| | b) Cape Spencer Area | 12:37 | 8:04 - 12:04 | |
| | c) Icy St/Cross Snd | *ns* | | |
| **Aug 19** | a) Icy Bay* | 15:00 | 9:00 - 21:00 | yes |
| | a) Hubbard Glacier* | 14:15 | 9:00 - 21:00 | yes |
| | b) Dangerous Rvr | 9:03 | 8:36 - 12:36 | yes |
| | b) DryBay/Alsek Rvr | 9:23 | 8:36 - 12:36 | yes |
| | b) Cape Spencer Area | 10:20 | 8:36 - 12:36 | yes |
| | c) Icy St/Cross Snd | *ns* | | |
| **Aug 20** | *(other areas not surveyed due to bad weather)* | | | |
| | c) Icy St/Cross Snd | 12:32 | 9:13 - 13:13 | yes |
| **Aug 21** | *(other areas not surveyed due to bad weather)* | | | |
| | c) Icy St/Cross Snd | 12:11 | 9:58 - 13:58 | yes |
| **Aug 22** | a) Icy Bay* | 17:25 | 9:00 - 21:00 | yes |
| | a) Hubbard Glacier* | 16:30 | 9:00 - 21:00 | yes |
| | b) Dangerous Rvr | 10:54 | 10:58 - 14:58 | |
| | b) DryBay/Alsek Rvr | 11:15 | 10:58 - 14:58 | yes |
| | b) Cape Spencer Area | 12:20 | 10:58 - 14:58 | yes |
| | c) Icy St/Cross Snd | *ns* | | |
| **Aug 23** | *(other areas not surveyed due to bad weather)* | | | |
| | a) Hubbard Glacier* | 9:31 | 9:00 - 21:00 | yes |
| **Aug 24** | a) Icy Bay* | *ns* | | |
| | a) Hubbard Glacier* | 10:59 | 9:00 - 21:00 | yes |
| | b) Dangerous Rvr | 14:17 | 13:41 - 17:41 | yes |
| | b) DryBay/Alsek Rvr | 14:35 | 13:41 - 17:41 | yes |
| | b) Cape Spencer Area | 15:38 | 13:41 - 17:41 | yes |
| | c) Icy St/Cross Snd | *ns* | | |
| **Aug 25** | a) Icy Bay | *ns* | | |
| | a) Hubbard Glacier | 13:20 | 9:00 - 21:00 | yes |
| | b) Dangerous Rvr | 15:24 | 14:54 - 18:54 | yes |
| | b) DryBay/Alsek Rvr | 15:38 | 14:54 - 18:54 | yes |
| | b) Cape Spencer Area | 16:25 | 14:54 - 18:54 | yes |
| | c) Icy St/Cross Snd | *ns* | | |
| **Aug 27** | a) Icy Bay* | 12:24 | 9:00 - 21:00 | yes |
| | a) Hubbard Glacier* | 9:45 | 9:00 - 21:00 | yes |
| | b) Dangerous Rvr | 6:52 | 4:38 - 8:38 | yes |
| | b) DryBay/Alsek Rvr | 7:08 | 4:38 - 8:38 | yes |
| | b) Cape Spencer Area | *ns* | | |
| | c) Icy St/Cross Snd | *ns* | | |

counts (Calambokidis *et al.* 1983). We, thus, assumed that there was considerable latitude in the timing of daily flights over Icy and Disenchantment bays. Table 2 summarizes the actual and optimal times of flights for five broadly categorized survey areas along the route flown in 1996. Appendix I includes the specific survey times for each haulout.

## Aerial Survey Methods

The surveys were flown in three different single engine Cessna 185 airplanes. On all but the last two of the survey days an observer assisted the photographer and pilot in looking for seals and recording data. While looking for haulouts we typically flew at about 303 m (1000 ft) at cruising speeds of 100-130 knots. When an occupied haulout was located, we reduced our altitude and speed from a distance to avoid disturbing seals. Photographs of haulouts were typically taken at an altitude of about 212 m (700 ft) and an air speed of about 80 knots. We avoided flying directly over a haulout as this is more likely to startle the seals. Some seals were startled into the water on August 24 when a different, louder plane was flown by the same pilot.

Seals on haulouts, or visible in the water near a haulout, were photographed through an open window using a 35 mm camera (Nikon 6006 or Nikon 8008) with either an 80-200 mm zoom lens or a 300 mm auto-focus lens. We used color slide film (400 ASA) shot at shutter speeds of 1/250 seconds or, preferably, faster. The date, time, location, altitude, frame numbers, and shutter speeds were recorded for each surveyed haulout, and the recorder included a general description of weather conditions (precipitation and cloud cover). In addition, we noted if haulouts were unoccupied (a ‘0’ in the database). We also noted if we were not able to check a haulout because of inclement weather (a ‘null’ value in the database).

We photographed all terrestrial haulouts that were occupied, even if there were only a few seals present. Numbers of seals and sea lions tend to be under-estimated by observers (Withrow 1982, J. Lewis pers. comm., pers. obser.), and there can be variation with some over- and under-estimation among even experienced observers (Withrow 1982). An additional advantage of photographs is that they can be verified and archived for future use. We did, however, visually estimate numbers of seals at haulouts as a backup in the event of camera failure or film loss.

Groups of seals were usually small enough to fit into one field of view in the camera, although this was not the case at the glacial ice haulouts where 100s of seals were widely dispersed on icebergs. On most days, we took a series of overlapping photographs of seals on glacial ice that could then be matched edge to edge during assessment, but the degree of coverage of these photographs is not known and we believe that counts from them may underestimate total numbers. During the fourth and last flight over Icy Bay and Hubbard and Turner glaciers on August 27, seals were visually counted, rather than photographed. In Icy Bay, this approach was possible on this day because seals were distributed in a long narrow strip that could be counted in one continuous pass. That is, there were few enough seals along the long strip width that an observer could make a direct count.

During each survey, we checked all previously identified haulouts (Loughlin 1994) which could be approached except Miner Island (site 18) in Lisianski Inlet. Miner Island was excluded in order to keep our flight times within two hours of low tide, and because checking this one haulout would have required an additional 20-30 minutes of flight time ( no other haulouts were identified along the route to Miner Island during the 1993 surveys). The photographer, observer, and pilot searched for unidentified haulouts along the route. On several days, when conditions and timing allowed, we surveyed and photographed seals at some of the haulouts along the outer coast (i.e., Dry Bay/Alsek River, Dangerous River, Dixon Harbor) twice in one day, once during the outbound leg of the survey and again on the return flight. The difference in time between these repeat surveys ranged from 1.5 to 3.75 hours (Appendix I).

### Photographic Slide Analysis

We projected the sharpest slide (or slide series) with the clearest view of seals for each haulout onto sheets of mounted white paper and counted individual seals by marking their images on the paper. To count seals from slide series of the large haulouts, we used two projectors to determine where adjacent slides overlapped. Each slide was counted twice for verification, although verification counts of entire slide series were not done. The majority of verification counts were identical, but a few with more than 100 seals differed by 1-4 seals. In these cases the average of the two numbers was used. Labeled slides will be stored in archival boxes at Glacier Bay National Park.

### Data Storage and Analysis

We entered the results of the slide counts as well as related information (date, time, location, air temperature, weather conditions, tide information, and comments) into a *Microsoft Access* database. *Microsoft Excel* files designed to meet analysis specifications of the ADF&G (Grey Pendleton, pers. comm.) were generated from the original database. A copy of the data will be submitted to ADF&G (Anchorage) on disk with the final report, and the data will also be archived at Glacier Bay National Park in Gustavus. Summary statistics for tables and graphs were generated using *Microsoft Access*, *Excel,* and *Deltagraph (DeltaPoint)* software.

## RESULTS

### Aerial Survey Results: Minimum Population Estimate

Daily counts of seals at each haulout are summarized in Table 3. The minimum estimate for August 1996 along this route was 4,342 harbor seals, the highest number of seals observed at haulouts during a single survey day (Table 3). We were not able to survey all haulouts on any one day, so this high count is clearly a conservative estimate for the area. The sums of the maximum and mean numbers of seals observed at each haulout were 5,279 and 3,079 (Table 3). Between day variance at several haulouts, particularly the glacial fjords, was quite high and generally higher than those observed during the September 1993 surveys (Table 3, Appendix II).

**Table 3.** Harbor seals counted at haulouts during aerial surveys in August 1996. Whole-number locations follow those presented by Loughlin (1994); haulout sites with a decimal extension had seals on them during surveys in 1996 but not in 1993.

| | August 1996 Survey Days | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Site Number and Name** | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **27** | **Max** | **Mean** | **SD** | **N** |
| 1 Icy Bay | 125 | 1053 | | | 219 | 1220 | | | 1350 | 1350 | 793 | 577.90 | 5 |
| 2 Hubbard Glacier | 305 | 1232 | | | 493 | 430 | 229 | 770 | 351 | 1232 | 544 | 349.67 | 7 |
| 2.1 Turner Glacier | | 122 | | | | | | | 6 | 122 | 64 | 82.02 | 2 |
| 3 Nunatak Fjord | 28 | | | | 126 | 47 | 26 | 30 | 40 | 126 | 50 | 38.32 | 6 |
| 4 Russell Fjord | 95 | 6 | | | 202 | 3 | 72 | 72 | 183 | 202 | 90 | 77.98 | 7 |
| 5 Krutoi Island | 0 | 0 | | | 0 | 0 | 0 | 0 | | 0 | 0 | | 6 |
| 5.1 Otmeloi Island | | | | | 6 | 1 | 0 | 2 | | 6 | 2 | 2.63 | 4 |
| 5.2 Foxy Reef | | | | | 27 | 12 | 6 | 4 | | 27 | 12 | 10.40 | 4 |
| 5.3 Knight Island (rk) | | | | | | 25 | 0 | 5 | | 25 | 10 | 13.23 | 3 |
| 5.4 Redfield Cove | | | | | 5 | 0 | 0 | 0 | | 5 | 1 | 2.50 | 4 |
| 6 Dangerous River | 33 | 56 | | | 41 | | 44 | 19 | 67 | 67 | 43 | 16.88 | 6 |
| 7 Dry Bay (Alsek) | 801 | 938 | | | 739 | | 163 | 847 | 967 | 967 | 743 | 296.24 | 6 |
| 7.1 Lituya Bay | 22 | 56 | | | 0 | | 7 | | 22 | 56 | 21 | 21.58 | 5 |
| 8 Boussole Bay | 0 | 0 | | | 0 | | 0 | | | 0 | 0 | | 4 |
| 9 Astrolabe Rocks | 59 | 84 | | | 0 | | 57 | 32 | | 84 | 46 | 31.80 | 5 |
| 9.1 Graves Rocks | 27 | 18 | | | 0 | | 42 | 25 | | 42 | 22 | 15.27 | 5 |
| 9.2 Dixon Harbor Rks | | | | | | | 18 | 4 | | 18 | 11 | 9.90 | 2 |
| 10 Polka Pen Rocks | 0 | 0 | | | | | 0 | | | 0 | 0 | | 3 |
| 11 Cape Spencer | 0 | 93 | | | | | 54 | 70 | | 93 | 54 | 39.55 | 4 |
| 12 Shaw Island | | 15 | | 0 | | | | | | 15 | 8 | 10.61 | 2 |
| 12.1 Elfin Cove Rocks | | | | 20 | | | | | | 20 | 20 | | 1 |
| 13 Gull Cove | | 0 | | 0 | | | | | | 0 | 0 | | 2 |
| 14 Is. N of Lemesurier | | 123 | 215 | 171 | | | | | | 215 | 170 | 46.01 | 3 |
| 15 Lemesurier NE | | 88 | 74 | 37 | | | | | | 88 | 66 | 26.35 | 3 |
| 16 Lemesurier SE | | 31 | 0 | 17 | | | | | | 31 | 16 | 15.52 | 3 |
| 17 Quartz Point | | 138 | 30 | 72 | | | | | | 138 | 80 | 54.44 | 3 |
| 18 Miner I (rocks) | (not included in 1996 survey) | | | | | | | | | | | | 0 |
| 19 Three Hill Island | | 0 | | 0 | | | | | | 0 | 0 | | 2 |
| 20 Gaff Rock | | 43 | | 9 | | | | 25 | | 43 | 26 | 17.01 | 3 |
| 20.1 George Is | | | | 24 | | | | | | 24 | 24 | | 1 |
| 21 Althorp Rocks | | 44 | | 45 | | | | | | 45 | 45 | 0.71 | 2 |
| 22 Inian Islands | | 40 | | 45 | | | | 70 | | 70 | 52 | 16.07 | 3 |
| 23 Dundas River D. | 0 | 0 | | | | | 0 | 0 | | 0 | 0 | | 4 |
| 24 Dundas Bay Fork | 0 | 26 | | | | | 26 | 10 | | 26 | 16 | 12.79 | 4 |
| 25 Dundas Bay Is. | 0 | 26 | | | | | 32 | 30 | | 32 | 22 | 14.88 | 4 |
| 26 Taylor Bay | 0 | 110 | | | | | 0 | 0 | | 110 | 28 | 55.00 | 4 |
| **Totals =** | 1495 | **4342** | 319 | 440 | 1858 | 1738 | 776 | 2015 | **2986** | 5279 | 3079 | | |

Comparison of Counts from 1996 and 1993

The maximum number of seals counted on a single day (Table 3, Appendix II) and the sum of the daily maximum counts and means for each haulout (Table 4, Figure 2) were all higher during the August 1996 survey compared to the September 1993 survey. Because the high counts for each haulout occurred on different days, the sum of maximum counts overestimates the number of seals resting on haulouts on any given day during the survey period. The highest number of seals observed during a single survey day in August 1996 was 4,342 (Figure 2, Table 3), whereas the highest count in September 1993 was 3,124 (Figure 2, Appendix II). The highest count from the September 1993 survey was quite close to the second highest count from a single day during the August 1996 survey (3,234 vs. 2,986) (Table3, Appendix I).

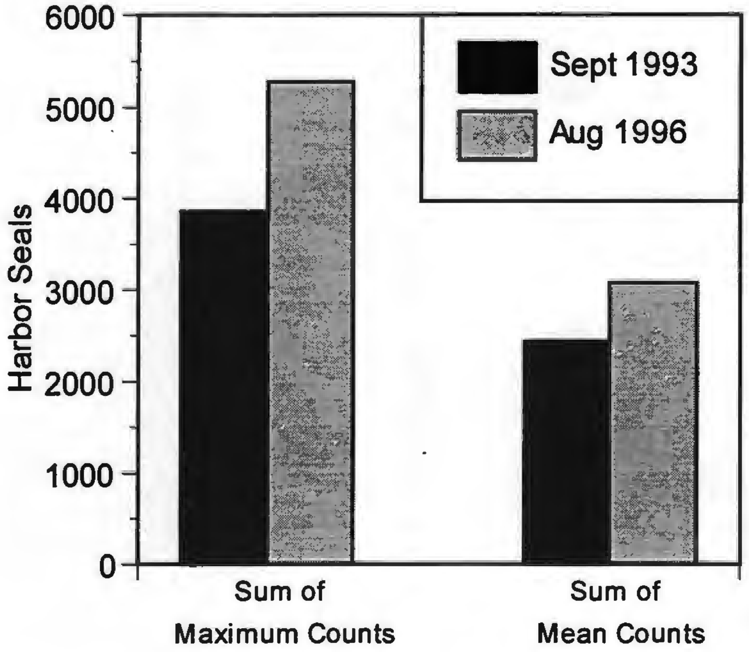
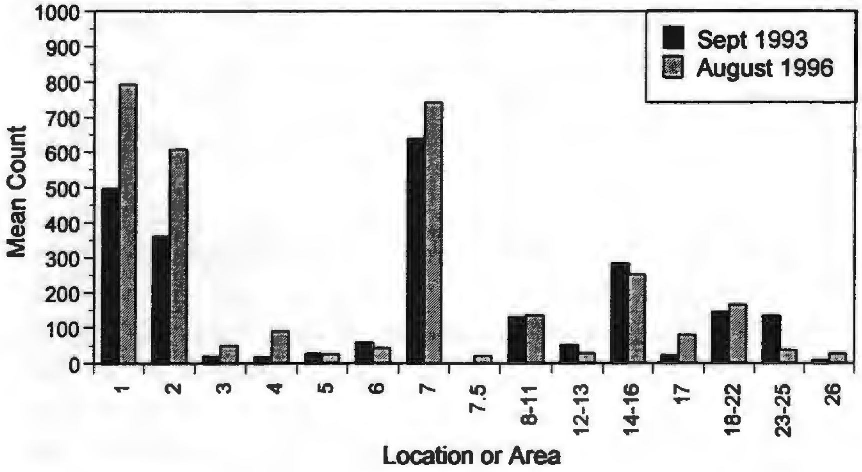


**Figure 2.** Sum of maximum and mean counts for each haulout from surveys in September 1993 (Loughlin, 1994) and August 1996. These figures do not include corrections for differences in survey timing or tide height.

**Table 4.** Summary of maximum and mean counts for each haulout surveyed in September 1993 (Loughlin 1994) and August 1996. (The sum of means from 1993 is lower in this table than in Loughlin 1994 due to the inclusion of '0' seals vs. no data reported at Gull Cove and Quartz Point on Sept. 16 in an updated database.)

| Site | | September 1993 | | | | August 1996 | | | |
|---|---|---|---|---|---|---|---|---|---|
| No. | Site Name | Max | Mean | SD | N | Max | Mean | SD | N |
| 1 | Icy Bay (ice) | 907 | 496 | 323 | 4 | 1350 | 793 | 578 | 5 |
| 2 | Hubbard Glacier (ice) | 747 | 361 | 260 | 5 | 1232 | 544 | 350 | 7 |
| 2.1 | Turner Gl. (ice) | | | | | 122 | 64 | 82 | 2 |
| 3 | Nunatak Fiord | 29 | 19 | 12 | 5 | 126 | 50 | 38 | 6 |
| 4 | Russel Fiord (ice) | 67 | 17 | 27 | 6 | 202 | 90 | 78 | 7 |
| 5 | Krutoi Is. | 53 | 27 | 18 | 4 | 0 | 0 | | 6 |
| 5.1 | Otmeloi Is. | | | | | 6 | 2 | 3 | 4 |
| 5.2 | Foxy Reef | | | | | 27 | 12 | 10 | 4 |
| 5.3 | Knight Is. | | | | | 25 | 10 | 13 | 3 |
| 5.4 | Redfield Cove | | | | | 5 | 1 | 3 | 4 |
| 6 | Dangerous River | 75 | 59 | 20 | 5 | 67 | 43 | 17 | 6 |
| 7 | Dry Bay (Alsek) | 879 | 748 | 231 | 5 | 967 | 743 | 296 | 6 |
| 7.5 | Lituya Bay (ice) | | | | | 56 | 21 | 22 | 5 |
| 8 | Boussole Bay | 17 | 8 | 9 | 4 | 0 | 0 | | 4 |
| 9 | Astrolabe Rocks | 72 | 39 | 30 | 4 | 84 | 46 | 32 | 5 |
| 9.1 | Graves Rks | | | | | 42 | 22 | 15 | 5 |
| 9.2 | Dixon Harbor | | | | | 18 | 11 | 10 | 2 |
| 10 | Polka Pen rocks | 30 | 15 | 12 | 4 | 0 | 0 | | 3 |
| 11 | Cape Spencer | 120 | 68 | 34 | 5 | 93 | 54 | 40 | 4 |
| 12 | Shaw Is. | 58 | 38 | 15 | 4 | 15 | 8 | 11 | 2 |
| 12.5 | Elfin Cove Rk | | | | | 20 | 20 | | 1 |
| 13 | Gull Cove | 31 | 14 | 13 | 4 | 0 | 0 | | 2 |
| 14 | Lemesurier, Is to N | 194 | 140 | 49 | 4 | 215 | 170 | 46 | 3 |
| 15 | Lemesurier, Is to NE | 236 | 110 | 88 | 4 | 88 | 66 | 26 | 3 |
| 16 | Lemesurier, Is to SE | 67 | 34 | 25 | 4 | 31 | 16 | 16 | 3 |
| 17 | Quartz Point | 49 | 22 | 20 | 4 | 138 | 80 | 54 | 3 |
| 18 | Miner Is (not surveyed in 1996, so excluded) | | | | | | | | 0 |
| 19 | Three Hill Is. | 10 | 9 | | 2 | 0 | 0 | | 2 |
| 20 | Gaff Rock | 36 | 25 | | 2 | 43 | 26 | 17 | 3 |
| 20.5 | George Is. | | | | | 24 | 24 | | 1 |
| 21 | Althorp Rocks | 26 | 24 | | 2 | 45 | 45 | 1 | 2 |
| 22 | Inian Island | 31 | 23 | | 2 | 70 | 52 | 16 | 3 |
| 23 | Dundas River D. | 49 | 44 | | 2 | 0 | 0 | | 4 |
| 24 | Dundas Bay, fork | 33 | 33 | | 2 | 26 | 16 | 13 | 4 |
| 25 | Dundas Bay, Is | 52 | 27 | | 2 | 32 | 22 | 15 | 4 |
| 26 | Taylor Bay, Is. S. | 36 | 23 | | 2 | 110 | 28 | 55 | 4 |
| | Sums = | 3904 | 2422 | | | 5279 | 3079 | | |

Out of 15 haulouts or haulout areas counted in both years, nine had higher mean counts and 10 had higher maximum counts during the August 1996 compared to the September 1993 survey. Fewer seals were observed in August 1996 than in September 1993 at the other sites or areas (Figures 3a and 3b). None of these comparisons include corrections for differences in survey timing or tide height. Six haulouts that had been used during the September 1993 survey were not used during the August 1996 survey (Table 4). Ten additional haulouts, including four small haulouts in Yakutat Bay which were only exposed at low tides (sites 5.1 - 5.4), were occupied during the August 1996 survey but not during the September survey (Appendix II).



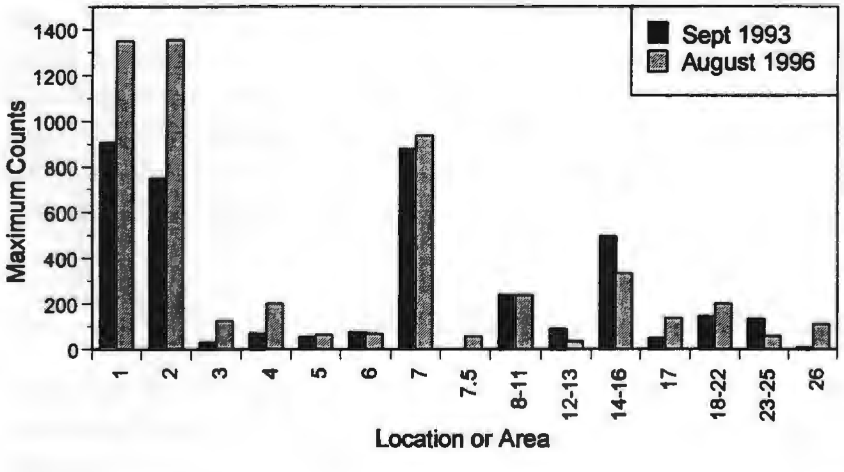


**Figure 3. 3a)** Comparison of mean and **3b)** maximum counts of harbor seals at 14 different haulouts or haulout areas from surveys in September 1993 and August 1996. Location numbers correspond to haulouts listed in Table 3, and the survey sites are ordered by location, from northwest to southeast (left to right).

## DISCUSSION

### Minimum Population Estimate and Count Variance, August 1996

Without corrections for incomplete coverage or differences in tide height at the time of surveys, the most conservative estimate for the minimum number of seals at haulouts along the route is 4,342 seals, the high count from a single day (August 19, 1996). This is 1,218 seals higher than the high count for September 1993 (3,124 seals, Appendix II), however this should not be construed as an increasing trend since no corrections have been made for differences in the dates of the surveys or environmental factors (i.e., tide height or time). Because of the differences in survey timing (13-20 September, 1993 vs. 18-27, August 1996) and the three year interval between annual surveys, we did not feel that it was appropriate to conduct an analysis for trends in seal numbers at this time. In addition, our high count was 1,356 seals higher than our next highest count on August 27, 1996. If we had not been able to survey on August 19, 1996, our maximum and mean counts would have been more similar to those obtained by NMFS in September 1993.

The high day to day variance in seals observed on glacial ice in Icy Bay may be due to rapid changes in substrate availability. Such extreme (five-fold) fluctuations are rare in Johns Hopkins Inlet in Glacier Bay during mid August surveys, although two-fold changes are occasionally observed (Mathews 1995). Icy Bay is more open and may be subject to greater extremes in currents as well as a more erratic production of ice than near the face of Johns Hopkins glacier. On August 22, when only 219 seals were observed in Icy Bay, there was less ice than on other days surveyed, but this survey was also the latest one (17:25) flown during the month. The relative stability in numbers of seals resting on ice observed by Calambokidis *et al.* (1983) off Muir Glacier may not apply in Icy Bay. In Aialik Bay, Kenai Fiords National Park, Hoover (1983) observed more seals on glacial ice in the two days following a storm. The August 22 low count followed a day of bad weather (rain, fog), yet this does not appear to have had the effect observed in Ailek Bay, perhaps because the weather we experienced was not specifically a storm. In summary, we are not certain of the cause for the extreme variability from day to day in Icy Bay, but we suspect that it is largely driven by patterns of ice production and movement. Such high variance will presumably decrease the sensitivity of detecting changes in trends in this area.

### Proposed Trend Route: Options for the Northeast Gulf of Alaska

The primary goal of this work was to determine if a subsection of the route between Icy Bay and Icy Strait might serve as a practical, informative trend route for monitoring harbor seal abundance and distribution. If a section of this coast is to become a trend route, we recommend that the route include the haulouts from Icy Bay to either Dry Bay and the Alsek River or to Cape Spencer (sites 1-7 or 1-11, Figure 1), depending upon the survey plane's cruising speed, survey route, and budget considerations. We minimized coverage of haulouts in Cross Sound and western Icy Strait because full coverage of this area would make the route too long to bracket low tides during a single day in most single engine aircraft. These sites also encompass habitat more similar to that found in the lower portions of Glacier Bay and in the Ketchikan and Sitka routes. If desired, the haulouts in the Icy Strait/Cross Sound area not included in our proposed route could be efficiently surveyed from Gustavus, but this would require a second survey team in order for surveys to bracket low tide cycles.

The route includes the three areas (Icy Bay, Hubbard and Turner glaciers, and the Dry Bay/Alsek River) with the largest aggregations of seals observed both in 1996 and in 1993 (Table 4). On August 19, 1996 more the 50% of the 4,342 seals observed were in Icy and Disenchantment bays, with an additional 22% observed on sandbars in or near Dry Bay and the Alsek River. Similarly, more than 50% of the 3,124 seals observed on September 19, 1993 were observed in these same glacial fjords, with about 77% in the fjords and at the Dry Bay/Alsek areas combined (Loughlin 1994, Appendix II)

The proposed trend route encompasses important habitat including tidewater glacial fjords where logging activities and cruise ship and tour boat traffic are increasing, and where oil drilling is proposed (Kozie *et al.* 1996). The route includes substantial river drainages (i.e., the Dry Bay/Alsek River) with eulachon *(Thaleichthys pacificus)* and commercially and subsistence harvested salmon *(Oncorhynchus spp.)* runs that attract large numbers of seals (M. Sharp pers. comm.). It also includes haulouts separated by open coast habitat not represented in the four other trend routes in Southeast Alaska, and a large proportion of the coastline bordering Glacier Bay National Preserve – a section of the national park in which commercial and subsistence fishing and hunting are legislatively permitted.

In order for a survey route to serve as a practical trend route, it needs to be possible to reach all tidally influenced haulouts along the route within about a four hour period, bracketing the low tide cycle by about two hours. With Yakutat airport as the starting point, eight terrestrial haulouts (sites 4-6 and 8-11) and Lituya Bay (site 7, a relatively small glacial ice haulout along the route) and possibly a few representative sites in Cross Sound and western Icy Strait could be surveyed within this time (in a single engine Cessna 185 or comparable fixed wing aircraft). Additional time would be needed for the straight-line flight back to the airport (Appendix III. Tables A-1 and A-2). The average flight time during our August 1996 surveys (excluding time to land and refuel) was about 5.5 hrs with a maximum of 6.5 hrs, however we were never able to survey all sites due to bad weather so these are minimum estimates.

The route could be flown one of two general ways:

1) Fly the terrestrial sites from Yakutat to Gustavus on the first day, with an overnight in Gustavus. Repeat the terrestrial sites on the next day from Gustavus to Yakutat and survey the glacial sites after refueling in Yakutat. This model assumes that the low tides are in the morning, but it could be modified to accommodate later tides by picking up the glacial haulouts before flying from Yakutat to Gustavus. In this case, the three glacial sites (Icy Bay, Hubbard and Turner glaciers) would be surveyed every other survey day, at most.

2) With possibly fewer sites covered in Cross Sound and Icy Strait or a faster plane, the glacial sites could be surveyed each day with a stop to refuel in Yakutat in between the terrestrial haulout sites and the glacial ice sites.

As mentioned, if haulout patterns in Icy Bay and other tide-water glacial fjords are similar to those observed by Calambokidis *et al.* (1983) in Muir Inlet (Glacier Bay), then high counts should be obtained during surveys conducted between 9:00 a.m. and early evening, either before or after the terrestrial haulouts, depending upon whether the low tide is in the morning or afternoon. This flexibility in survey timing for Icy Bay (and Disenchantment Bay) can be used to allow for refueling, as well as a crew break, in between areas. However, there is some suggestion that seal numbers may not remain stable in Icy Bay as they did in Muir Inlet, so this assumption needs to be tested.

## Comments on the Reliability of Aerial Surveys of Seals on Glacial Ice

Although systematic counts from an elevated observation site can be used to reliably count several thousand seals in glacial fjords (Streveler 1979, Calambokidis *et al.* 1987, Mathews 1995), there is not currently a reliable or confirmed aerial method for surveying large numbers of seals that are widely dispersed on shifting glacial ice. Kozie, *et al.* (1996) describe a stratified sampling method for estimating seal abundance from aerial surveys in Icy and Disenchantment bays, but the accuracy and precision of this technique remain to be tested.

We found that seals in Icy and Disenchantment bays (Hubbard and Turner glaciers) could be counted visually (with an unknown level of accuracy) or photographed for later counting in some circumstances, depending upon how many there were and on their distribution on the ice. If there were only a few hundred animals hauled out in a fjord or area, direct or photographic counts, or a combination of the two methods, are possible. Reliable counts from the air are less feasible when there are large (i.e. >1,000) numbers of seals widely distributed across a fjord. However, if seals happen to be distributed along a band of ice narrow enough to fit into one field of view and parallel to a safe flight route, a series of overlapping photographs can be used to obtain a direct, verifiable count of all visible seals. One of us (Womble) experimented with this technique in Icy Bay on August 19 when 1,053 seals were photographed, however we suspect that this count may be an underestimate. This method does require that the seals be (fortuitously) distributed in a long, narrow band. On August 27, a visual count of 1,350 seals was made in Icy Bay, but such a count cannot be confirmed (as compared to the slide series).

Fjords fed by active tidewater glaciers appear to be preferred habitat for breeding and molting (Streveler 1979, Calambokidis *et al.* 1987, Mathews 1995), so they need to be included where population trend routes encompass them. We recommend that in addition to testing the reliability of stratified sampling estimates (Kozie *et al.* 1996), experiments with higher altitude, medium or large format cameras and sensitive film be explored as a method to improve the reliability and accuracy of seal counts in tidewater glacial fjords. One such experiment was conducted in Johns Hopkins Inlet in July 1997.

The results from this work were very promising; a report comparing the results and costs of aerial photographs to those of land-based counts will be available at a later date.

Because Icy and Disenchantment bays are used by a majority of seals in the area for pupping and molting, we recommend that they be included as part of the route, despite the current use of opportunistic and experimental counting methods. If these glacial ice haulouts are not monitored and a decline (or increase) in seal abundance of up to 50% in adjacent waters is observed, it would not be possible to distinguish whether the change was due to an area-wide decline, or caused by an influx of seals into (or exodus from) Icy or Disenchantment bays. In addition, the large daily variance observed in the numbers of seals in Icy Bay (Table 3) makes this an important area to monitor, since numbers in glacial fjords could be inversely correlated with those at nearby land haulouts. Clearly, improved aerial photography or other methods are needed for monitoring tidewater glacial haulouts.

## Timing of the Proposed Aerial Survey Route

During the annual molt, harbor seals spend more time resting (Johnson and Johnson 1979), so counts tend to be higher during active stages of molt (Bishop 1967). Determining the optimal period of time during late summer for flying the northeast Gulf of Alaska route remains to be fine-tuned, although the results from this report and from other areas in Southeast Alaska (Calambokidis *et al.* 1987, Mathews and Kelly 1996, Streveler 1979) suggest that more seals are likely to be observed at haulouts during August low tide cycles than in September. While our results support this observation, they are potentially confounded by the three year interval between the two surveys.

If the goal is to count a higher proportion of the seals present, as is the case for a minimum population estimate, then we need to know when the peak in the molt cycle occurs. Very little work on harbor seals has been done along the northeast Gulf coast, so the timing of the molt cycle is not specifically known. In Glacier Bay, higher numbers at land and ice haulouts have typically been observed in August compared to September (Mathews and Kelly 1996), and it is assumed that the timing of the molt cycle for seals in this adjacent area would be similar. To verify this assumption, it would be valuable to regularly survey the selected trend route (or possibly a representative portion of it) in one year from August through September, perhaps every two or three days.

## Comparison of Counts from 1996 and 1993

The single-day high count and the sums of the mean and maximum counts for each haulout were all higher during the August 1996 survey compared to the September 1993 survey (Figure 2, Tables 3 and 4). However, none of the survey days in either year included coverage of all of the haulouts, and no corrections have been made for partial coverage or differences in survey timing or tide height. Some of the difference in seal numbers observed between the two survey years may be due to the later date (month) of the 1993 survey. In other parts of Southeast Alaska, the numbers of seals observed at haulouts during mid-September have been up to 85% lower than observed in late August (Mathews and Kelly 1996). Similarly, Withrow and Loughlin (1995) found that 67%

(CV=4.7%) of harbor seals equipped with radio tags near Cordova, Alaska in 1995 were hauled out during mid August compared to 39% (CV=14%) during early September surveys.

## CONCLUSIONS

The results from several years of surveys of the coast between Icy Bay and Dry Bay or Cape Spencer that are conducted at the same time of year using comparable methods should increase our ability to monitor trends in abundance of harbor seals in the northeast Gulf of Alaska, although improved methods of counting seals on glacial ice are needed. Statistical models designed to reduce the variance between daily counts of seals by controlling for differences in survey timing, tide height and time, as well as other environmental or observer differences have been developed (Frost *et al.* 1996a, Lewis *et al.* 1996) and could be applied to improve the sensitivity of trend data for detecting changes in numbers of harbor seals at haulouts between Icy Bay and Icy Strait.

## ACKNOWLEDGMENTS

We are especially grateful to Amy Hawkins-Bowman, Pavia Wald, and Teresa Ferrell for volunteering their time to record data and look for seals during aerial surveys. We thank our skilled pilots, Steve Wilson, Chuck Shrath (Air Excursions), and Shane Stephenson (Gulf Air) for their flying and seal-spotting expertise. Mary Porter (GBNP) provided friendly logistic support in Yakutat. We are grateful to Jon Lewis, Lloyd Lowry and the Alaska Department of Fish and Game for initiating and supporting the project and to Glacier Bay National Park for providing logistical support and OAS flight safety training. A draft of the manuscript was improved by comments from Tom Loughlin, Lloyd Lowry, Dave Withrow, and Bob Small.

## LITERATURE CITED

Bishop, R.H. (1967). "Reproduction, age determination and behavior of the harbor seal, *Phoca vitulina* L., in the Gulf of Alaska." M.S. Thesis, University of Alaska, College.

Brown, R. F., and Mate, B. R. (1983). "Abundance, movements, and feeding habits of Harbor Seals (*Phoca vitulina*) at Netarts and Tillamook Bays, Oregon." *Fishery Bulletin*, 81, 291-301.

Calambokidis, J., Steiger, G. T., and Healey, L. E. (1983) "Behavior of harbor seals and their reaction to vessels in Muir Inlet, Glacier Bay, Alaska." *5th Biennial Conference on the Biology of Marine Mammals*, Boston, MA, 10 p.

Calambokidis, J., Taylor, B. L., Carter, S. D., Steiger, G. H., Dawson, P. K., and Antrim, L. D. (1987). "Distribution and haul-out behavior of harbor seals in Glacier Bay, Alaska." *Canadian Journal of Zoology*, 65, 1391-1396.

Frost, K. J., Lowry, L. F., Hoef, J. M. V., and Gerodette, T. (1996a). "Using Poisson regression and power analysis to monitor harbor seals in Prince William Sound, Alaska." , ALaska Department of Fish and Game, Fairbanks, AK.

Frost, K. J., Lowry, L. F., Small, R. J., and Iverson, S. J. (1996b). "Monitoring, habitat use, and trophic interactions of harbor seals in Prince William Sound, Alaska." *Study Number 95064*, Alaska Department of Fish and Game, Wildlife Conservation, Douglas, AK.

Frost, K. J., Lowry, L. F., and Ver Hoef, J. (1995). "*Exxon Valdez* oil spill restoration project annual report: habitat use, behavior, and monitoring of harbor seals in Prince William Sound, Alaska." *Restoration Projects 94064 and 94320-F*, Alaska Department of Fish & Game.

Hill, P. S., DeMaster, D. P., and Small, R. J. (1996). "Draft Alaska Marine Mammal Stock Assessments 1996." , NMFS, NMML, Seattle.

Hoover, A. (1983). Behavior and ecology of harbor seals *Phoca vitulina richardsi* inhabiting glacial ice in Aialik Bay, Alaska. M.S. Thesis, Uinv. Alaska., Fairbanks, AK. 133 pp.

Hoover-Miller, A. (1994). "The harbor seal in Alaska." Revised marine mammals of Alaska: species accounts with research and management recommendations, J. W. Lentfer, ed., Marine Mammal Commission, Washington, D.C.

Lewis, J. P., Pendleton, G. W., Pitcher, K. W., and Wynne, K. M. (1996). "Harbor seal population trends in Southeast Alaska and the Gulf of Alaska." *NA57FX0367*, Alaska Department of Fish and Game, Douglas, AK.

Loughlin, T. R. (1992). "Abundance and distribution of harbor seals *(Phoca vitulina richardsi)* in Bristol Bay, Prince William Sound, and Copper River Delta during 1991." , U.S. National Marine Fisheries Service, National Marine Mammal Laboratory.

Loughlin, T. R. (1994). "Abundance and distribution of harbor seals *(Phoca vitulina richardsi)* in Southeastern Alaska during 1993." , U.S. National Marine Fisheries Service, National Marine Mammal Laboratory.

Loughlin, T. R., and Merrick, R. L. (1988). "Comparison of commercial harvest of walleye pollock and northern sea lion abundance in the Bering Sea and Gulf of

Alaska." *Proceedings of the International Symposium on the Biology and Management of Walleye Pollock*, Anchorage, Alaska.

Mathews, E. A. "Longterm trends in abundance of harbor seals (*Phoca vitulina richardsi*) and development of monitoring methods in Glacier Bay National Park, Southeast Alaska." *Third Glacier Bay Science Symposium*, Glacier Bay National Park & Preserve, AK, 254-263.

Mathews, E. A., and Kelly, B. P. (1996). "Extreme temporal variation in harbor seal *(Phoca vitulina richardsi)* numbers in Glacier Bay, a glacial fjord in Southeast Alaska." *Mar. Mamm. Sci.*, 12(3), 483-488.

Merrick, R. L. (1995). "The relationship of the foraging ecology of Steller sea lions *(Eumetopias jubatus)* to their population decline in Alaska," Ph.D, University of Washington, Seattle, WA.

Pitcher, K. W. (1990). "Major decline in the number of harbor seals *(Phoca vitulina)* on Tugidak Island, Gulf of Alaska." *Marine Mammal Science*, 121-134.

Pitcher, K. W., and Calkins, D. G. (1979). "Biology of the harbor seal *(Phoca vitulina richardsii)* in the Gulf of Alaska." *Ru 229, Contract Number 03-5-002-69*, Outer Continental Shelf Environmental Assessment Program.

Pitcher, K. W., and McAllister, D. C. (1981). "Movements and haulout behavior of radio-tagged harbor seals *(Phoca vitulina)*." *Canadian Field-Naturalist*, 95(3), 292-297.

Small, R. J. (1995). "Population assessment of harbor seals in Alaska.", NMML, NMFS, Seattle, WA, Fairbanks, AK.

Springer, A. M. (1993). "Report of the seabird working group. *In:* Is it food? Addressing marine mammal and seabird declines." *93-01*, University of Alaska, Fairbanks.

Streveler, G. P. (1979). "Distribution, population ecology, and impact susceptibility of the harbor seal in Glacier Bay, Alaska." , U.S. National Park Service, Glacier Bay National Park and Preserve.

Thompson, P. M., Kovacs, K. M., and McConnel, B. J. (1994). "Natal dispersal of harbour seals (*Phoca vitulina*) from breeding sites in Orkney, Scotland." *J. Zool., Lond.*, 234, 668-673.

Withrow, D. E. (1982). "Using aerial surveys, ground truth methodology, and haul out behavior to census Steller sea lions, *Eumetopias jubatus*," Ph.D., University of Washington, Seattle, WA.

Withrow, D.E. and Loughlin, T.R. (1995). "Haulout behavior and a correction factor estimate for the proportion of harbor seals missed during molt census surveys near Cordova, Alaska." Annual Report, Marine Mammal Protection Act and Endangered Species Act Implementation Program 1995, NMFS, Silver Spring, MD. Pp. 89-116.

## Appendix I. Data from aerial surveys in August 1996

| Site # | Site | Date | Time | # Seals | Site # | Site | Date | Time | # Seals |
|---|---|---|---|---|---|---|---|---|---|
| 101 | Icy Bay | 8/18/96 | 9:00 | 125 | 105.3 | Knight Island (rk) | 8/23/96 | 12:37 | 25 |
| 101 | Icy Bay | 8/19/96 | 15:00 | 1053 | 105.3 | Knight Island (rk) | 8/24/96 | 11:18 | 0 |
| 101 | Icy Bay | 8/22/96 | 17:25 | 219 | 105.3 | Knight Island (rk) | 8/25/96 | 13:47 | 5 |
| 101 | Icy Bay | 8/23/96 | 10:03 | 1220 | 105.4 | Redfield Cove | 8/22/96 | 14:00 | 5 |
| 101 | Icy Bay | 8/27/96 | 12:24 | 1350 | 105.4 | Redfield Cove | 8/23/96 | 12:41 | 0 |
| 102 | Hubbard Gl | 8/18/96 | 9:51 | 305 | 105.4 | Redfield Cove | 8/24/96 | 11:22 | 0 |
| 102 | Hubbard Gl | 8/19/96 | 14:15 | 1232 | 105.4 | Redfield Cove | 8/25/96 | 13:53 | 0 |
| 102 | Hubbard Gl | 8/22/96 | 16:30 | 493 | 106 | Dangerous R | 8/18/96 | 11:25 | 33 |
| 102 | Hubbard Gl | 8/23/96 | 9:31 | 430 | 106 | Dangerous R | 8/19/96 | 9:03 | 56 |
| 102 | Hubbard Gl | 8/24/96 | 10:59 | 229 | 106 | Dangerous R | 8/22/96 | 10:54 | 0 |
| 102 | Hubbard Gl | 8/25/96 | 13:20 | 770 | 106 | Dangerous R | 8/22/96 | 13:20 | 41 |
| 102 | Hubbard Gl | 8/27/96 | 9:45 | 351 | 106 | Dangerous R | 8/24/96 | 14:17 | 44 |
| 102.1 | Turner Glacier | 8/19/96 | 14:22 | 122 | 106 | Dangerous R | 8/24/96 | 18:01 | 42 |
| 102.1 | Turner Glacier | 8/27/96 | 9:48 | 6 | 106 | Dangerous R | 8/25/96 | 15:24 | 13 |
| 103 | Nunatak Fjord | 8/18/96 | 10:12 | 28 | 106 | Dangerous R | 8/25/96 | 18:25 | 19 |
| 103 | Nunatak Fjord | 8/22/96 | 16:12 | 126 | 106 | Dangerous R | 8/27/96 | 6:52 | 44 |
| 103 | Nunatak Fjord | 8/23/96 | 9:17 | 47 | 106 | Dangerous R | 8/27/96 | 9:06 | 67 |
| 103 | Nunatak Fjord | 8/24/96 | 10:48 | 26 | 107 | Dry Bay (Alsek) | 8/18/96 | 11:40 | 801 |
| 103 | Nunatak Fjord | 8/25/96 | 13:07 | 30 | 107 | Dry Bay (Alsek) | 8/18/96 | 14:38 | 642 |
| 103 | Nunatak Fjord | 8/27/96 | 9:32 | 40 | 107 | Dry Bay (Alsek) | 8/19/96 | 9:23 | 938 |
| 104 | Russell Fjord | 8/18/96 | 10:29 | 95 | 107 | Dry Bay (Alsek) | 8/22/96 | 11:15 | 739 |
| 104 | Russell Fjord | 8/19/96 | 13:55 | 6 | 107 | Dry Bay (Alsek) | 8/24/96 | 14:35 | 163 |
| 104 | Russell Fjord | 8/22/96 | 13:38 | 202 | 107 | Dry Bay (Alsek) | 8/24/96 | 17:50 | 38 |
| 104 | Russell Fjord | 8/23/96 | 9:01 | 3 | 107 | Dry Bay (Alsek) | 8/25/96 | 15:38 | 847 |
| 104 | Russell Fjord | 8/24/96 | 10:32 | 10 | 107 | Dry Bay (Alsek) | 8/25/96 | 18:13 | 391 |
| 104 | Russell Fjord | 8/24/96 | 11:31 | 72 | 107 | Dry Bay (Alsek) | 8/27/96 | 7:08 | 823 |
| 104 | Russell Fjord | 8/25/96 | 12:53 | 72 | 107 | Dry Bay (Alsek) | 8/27/96 | 8:34 | 867 |
| 104 | Russell Fjord | 8/27/96 | 9:15 | 183 | 107.1 | Lituya Bay | 8/18/96 | 12:14 | 22 |
| 105 | Krutoi Island | 8/18/96 | 10:35 | 0 | 107.1 | Lituya Bay | 8/19/96 | 9:58 | 56 |
| 105 | Krutoi Island | 8/19/96 | 14:30 | 0 | 107.1 | Lituya Bay | 8/22/96 | 12:43 | 0 |
| 105 | Krutoi Island | 8/22/96 | 13:50 | 0 | 107.1 | Lituya Bay | 8/24/96 | 15:07 | 7 |
| 105 | Krutoi Island | 8/23/96 | 12:27 | 0 | 107.1 | Lituya Bay | 8/27/96 | 7:36 | 22 |
| 105 | Krutoi Island | 8/24/96 | 11:18 | 0 | 108 | Boussole Bay | 8/18/96 | 12:30 | 0 |
| 105 | Krutoi Island | 8/25/96 | 13:53 | 0 | 108 | Boussole Bay | 8/19/96 | 10:05 | 0 |
| 105.1 | Otmeloi Island | 8/22/96 | 13:52 | 6 | 108 | Boussole Bay | 8/22/96 | 12:16 | 0 |
| 105.1 | Otmeloi Island | 8/23/96 | 12:28 | 1 | 108 | Boussole Bay | 8/24/96 | 15:35 | 0 |
| 105.1 | Otmeloi Island | 8/24/96 | 11:19 | 0 | 109 | Astrolabe Rcks | 8/18/96 | 12:37 | 59 |
| 105.1 | Otmeloi Island | 8/25/96 | 13:55 | 2 | 109 | Astrolabe Rcks | 8/19/96 | 10:20 | 84 |
| 105.2 | Foxy Reef | 8/22/96 | 13:55 | 27 | 109 | Astrolabe Rcks | 8/22/96 | 12:20 | 0 |
| 105.2 | Foxy Reef | 8/23/96 | 12:25 | 12 | 109 | Astrolabe Rcks | 8/24/96 | 15:38 | 57 |
| 105.2 | Foxy Reef | 8/24/96 | 11:20 | 6 | 109 | Astrolabe Rcks | 8/25/96 | 16:25 | 32 |
| 105.2 | Foxy Reef | 8/25/96 | 13:52 | 4 |  |  |  |  |  |

## Appendix I. Data from aerial surveys in August 1996 (cont.)

| Site # | Site | Date | Time | # Seals |
|---|---|---|---|---|
| 109.1 | Graves Rocks | 8/18/96 | 13:00 | 27 |
| 109.1 | Graves Rocks | 8/19/96 | 10:37 | 18 |
| 109.1 | Graves Rocks | 8/22/96 | 12:25 | 0 |
| 109.1 | Graves Rocks | 8/24/96 | 16:14 | 42 |
| 109.1 | Graves Rocks | 8/25/96 | 16:43 | 25 |
| 109.2 | Dixon Harbor Rks | 8/24/96 | 15:47 | 18 |
| 109.2 | Dixon Harbor Rks | 8/24/96 | 17:12 | 13 |
| 109.2 | Dixon Harbor Rks | 8/25/96 | 16:30 | 4 |
| 110 | Polka Pen Rocks | 8/18/96 | 13:12 | 0 |
| 110 | Polka Pen Rocks | 8/19/96 | 10:49 | 0 |
| 110 | Polka Pen Rocks | 8/24/96 | 16:20 | 0 |
| 111 | Cape Spencer | 8/18/96 | 13:15 | 0 |
| 111 | Cape Spencer | 8/19/96 | 11:38 | 93 |
| 111 | Cape Spencer | 8/24/96 | 16:22 | 54 |
| 111 | Cape Spencer | 8/25/96 | 16:50 | 70 |
| 112 | Shaw Island | 8/19/96 | 11:49 | 15 |
| 112 | Shaw Island | 8/21/96 | 11:40 | 0 |
| 113 | Gull Cove | 8/19/96 | 11:47 | 0 |
| 113 | Gull Cove | 8/21/96 | 11:38 | 0 |
| 114 | Is N of Lemesurier | 8/19/96 | 12:29 | 123 |
| 114 | Is N of Lemesurier | 8/20/96 | 12:32 | 215 |
| 114 | Is N of Lemesurier | 8/21/96 | 12:11 | 171 |
| 115 | Lemesurier NE | 8/19/96 | 11:22 | 88 |
| 115 | Lemesurier NE | 8/20/96 | 12:17 | 74 |
| 115 | Lemesurier NE | 8/21/96 | 11:28 | 37 |
| 116 | Lemesurier SE | 8/19/96 | 11:31 | 31 |
| 116 | Lemesurier SE | 8/20/96 | 12:19 | 0 |
| 116 | Lemesurier SE | 8/21/96 | 11:31 | 17 |
| 117 | Quartz Point | 8/19/96 | 11:36 | 138 |
| 117 | Quartz Point | 8/20/96 | 12:23 | 30 |
| 117 | Quartz Point | 8/21/96 | 11:35 | 72 |
| 119 | Three Hill Island | 8/19/96 | 12:09 | 0 |
| 119 | Three Hill Island | 8/21/96 | 11:53 | 0 |
| 120 | Gaff Rock | 8/19/96 | 12:13 | 43 |
| 120 | Gaff Rock | 8/21/96 | 11:45 | 9 |
| 120 | Gaff Rock | 8/25/96 | 17:23 | 25 |
| 120.1 | George Is | 8/21/96 | 11:48 | 24 |
| 121 | Althorp Rocks | 8/19/96 | 12:05 | 44 |
| 121 | Althorp Rocks | 8/21/96 | 11:54 | 45 |
| 121.1 | Elfin Cove Rocks | 8/21/96 | 11:59 | 20 |
| 122 | Inian Islands | 8/19/96 | 11:56 | 40 |
| 122 | Inian Islands | 8/21/96 | 12:02 | 45 |
| 122 | Inian Islands | 8/25/96 | 17:20 | 70 |
| 123 | Dundas River D. | 8/18/96 | 13:22 | 0 |
| 123 | Dundas River D. | 8/19/96 | 11:18 | 0 |
| 123 | Dundas River D. | 8/24/96 | 16:50 | 0 |
| 123 | Dundas River D. | 8/25/96 | 17:14 | 0 |
| 124 | Dundas Bay Fork | 8/18/96 | 13:20 | 0 |
| 124 | Dundas Bay Fork | 8/19/96 | 11:09 | 26 |
| 124 | Dundas Bay Fork | 8/24/96 | 16:35 | 26 |
| 124 | Dundas Bay Fork | 8/25/96 | 17:05 | 10 |
| 125 | Dundas Bay Is. | 8/18/96 | 13:23 | 0 |
| 125 | Dundas Bay Is. | 8/19/96 | 11:03 | 26 |
| 125 | Dundas Bay Is. | 8/24/96 | 16:44 | 32 |
| 125 | Dundas Bay Is. | 8/25/96 | 17:09 | 30 |
| 126 | Taylor Bay | 8/18/96 | 13:12 | 0 |
| 126 | Taylor Bay | 8/19/96 | 10:52 | 110 |
| 126 | Taylor Bay | 8/24/96 | 16:30 | 0 |
| 126 | Taylor Bay | 8/25/96 | 17:03 | 0 |

## Appendix II. Harbor seal survey results from September 1993

Harbor seals counted at haulouts during aerial surveys in September 1993. Data are from Loughlin (1994), but include some differences (shaded numbers) from a more recent database than that in the 1994 report.

| | **1993 Survey Dates** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Location** | 9/13 | 9/14 | 9/15 | 9/16 | 9/17 | 9/18 | 9/19 | 9/20 | **Max** | **Mean** | **SD** |
| 1 Icy bay (ice) | | | 159 | | 340 | | 907 | 578 | 907 | 496 | 323.29 |
| 2 Hubbard Glacier | 116 | | 299 | | 155 | | 747 | 488 | 747 | 361 | 260.49 |
| 3 Nunatak Fjord | 26 | | 29 | | 16 | | 24 | 0 | 29 | 19 | 11.66 |
| 4 Russell Fjord, Is | 67 | | 0 | | 0 | 30 | 0 | 3 | 67 | 17 | 27.32 |
| 5 Krutoi Is, E reef | | | 18 | 16 | 20 | | 53 | | 53 | 27 | 17.58 |
| 6 Dangerous River | | 75 | 71 | 26 | | 68 | 56 | | 75 | 59 | 19.87 |
| 7 Dry Bay (Alsek) | | 879 | 530 | 708 | | 846 | 778 | | 879 | 748 | 138.55 |
| 8 Boussole Bay | | | 14 | 17 | | 0 | 0 | | 17 | 8 | 9.03 |
| 9 Astrolabe Rocks | | | 72 | 49 | | 0 | 35 | | 72 | 39 | 30.14 |
| 10 Polka Pen rocks | | | 15 | 30 | | 0 | 16 | | 30 | 15 | 12.26 |
| 11 Cape Spencer | | 75 | 69 | 28 | | 49 | 120 | | 120 | 68 | 34.33 |
| 12 Shaw Island | | 26 | | 42 | | 27 | 58 | | 58 | 38 | 15.06 |
| 13 Gull Cove | | 11 | | 0 | | 31 | 13 | | 31 | 14 | 12.84 |
| 14 Lemesurier N | | 86 | | 113 | | 194 | 165 | | 194 | 140 | 48.94 |
| 15 Lemesurier NE | | 73 | | 35 | | 236 | 97 | | 236 | 110 | 87.63 |
| 16 Lemesurier SE | | 15 | | 15 | | 67 | 37 | | 67 | 34 | 24.62 |
| 17 Quartz Point | | 22 | | 0 | | 49 | 18 | | 49 | 22 | 20.24 |
| 18 Miner Is. (area not surveyed in 1996, so counts of 64 and 32 not included in this summary) | | | | | | | | | | | |
| 19 Three Hill I. | | 10 | | 8 | | | | | 10 | 9 | 1.41 |
| 20 Gaff Rocks (GI) | | 14 | | 36 | | | | | 36 | 25 | 15.56 |
| 21 Althorp Rocks | | 26 | | 22 | | | | | 26 | 24 | 2.83 |
| 22 Inian Island | | 31 | | 15 | | | | | 31 | 23 | 11.31 |
| 23 Dundas River D. | | 49 | | 38 | | | | | 49 | 44 | 7.78 |
| 24 Dundas B. forks | | 33 | | 33 | | | | | 33 | 33 | 0.00 |
| 25 Dundas B island | | 52 | | 2 | | | | | 52 | 27 | 35.36 |
| 26 Taylor Bay | | 9 | | 36 | | | | | 36 | 23 | 19.09 |
| **Totals:** | 209 | 1486 | 1276 | 1269 | 531 | 1597 | 3124 | 1069 | 3904 | 2422 | |

## Appendix III. Durations of Aerial Survey Routes

The durations of each survey flown in August 1996 are summarized in Table A-1 below. All of the surveys summarized in this table started in Yakutat. On each day the survey team stopped at the Yakutat Airport to refuel, or to wait for improved weather conditions. Approximate flight times between the airport and four haulout areas are provided in Table A-2 for assessing the timing feasibility of survey routes with different boundaries.

**Table A-1.** Summary of aerial survey durations and haulout areas covered, August 1996.

| | Time | | | | | |
|---|---|---|---|---|---|---|
| **Date** | **Depart** | **Return** | **Subtotal** | **Total** | **Areas Surveyed** | **Comments** |
| 8/18/96 | 8:18 | 10:50 | 2:32 | | I - 5 | Majority of area between Icy Bay |
| | 11:15 | 14:50 | 3:35 | 6:07 | 6-II, 22-26 | and Cape Spencer surveyed |
| 8/19/96 | 8:48 | 12:43 | 3:55 | | 6-II, 22-26 | Majority of area between Icy Bay |
| | 13:17 | 15:52 | 2:35 | 6:30 | 5, 2, 1 | and Cape Spencer surveyed |
| 8/20/96 | no survey | | | | | below minimums for flying |
| 8/21/96 | no survey | | | | | below minimums for flying |
| 8/22/96 | 10:45 | 14:00 | 3:15 | | 6 - 9.2, 4, 5 | Majority of area between Icy Bay |
| | 15:45 | 18:20 | 2:35 | 5:50 | 2, 3, 1 | and Cape Spencer surveyed |
| 8/23/96 | 8:48 | 12:48 | 4:00 | | 4, 3, 2, 1, 5 | |
| | 14:18 | 14:31 | 0:13 | 4:13 | | took off, but ceiling to East too low |
| 8/24/96 | 10:19 | 11:33 | 1:14 | | 4, 3, 2, 5 | used a different (louder) Cessna |
| | 14:01 | 18:06 | 4:05 | 5:19 | 6-11, 23-26 | 185; some haulouts flushed |
| 8/25/96 | 12:41 | 13:55 | 1:14 | | 4, 3, 2, 5 | |
| | 15:15 | 18:32 | 3:17 | 4:31 | 6, 7, 8-11, 20, 22-26 | could not fly into Lituya Bay |
| 8/26/96 | no survey | | | | | below minimums for flying |
| 8/27/96 | 6:43 | 10:08 | 3:25 | | 6, 7, 7.5, 4, 3, 2, 5 | |
| | 11:09 | 12:50 | 1:41 | 5:06 | 1 | visual count in Icy Bay |
| | **Mean Survey Duration =** | | | 5:22 | | |
| | **Maximum Survey Duration =** | | | 6:30 | | |

**Table A-2.** Approximate straight-line flight times (one way) for a Cessna 185 (180 Km/hr) between the Yakutat Airport and four haulout areas.

| | Distance (Km) | Time |
|---|---|---|
| Yak Airport - Icy Bay | 130 | 0:43 |
| Dry Bay - Airport | 70 | 0:23 |
| Lituya Bay - Airport | 150 | 0:50 |
| Cape Spencer - Airport | 230 | 1:17 |

# ESTIMATION OF TRENDS IN ABUNDANCE OF HARBOR SEALS AT TERRESTRIAL AND GLACIAL ICE HAULOUTS IN GLACIER BAY NATIONAL PARK, SOUTHEAST ALASKA, 1975-1996

Elizabeth A. Mathews[1,2] and Grey W. Pendleton[3]

[1]Glacier Bay National Park, Resource Management Division
P.O. Box 140, Gustavus, Alaska 99826

[2]University of Alaska Southeast, Biology Department, ELAS
11120 Glacier Highway, Juneau, Alaska 99801

[3]Alaska Department of Fish and Game, Division of Wildlife Conservation
P.O. Box 240020, Douglas, Alaska 99824

## INTRODUCTION

Johns Hopkins Inlet, a tide-water glacial fjord in Glacier Bay National Park in Southeast Alaska, is used by approximately 3,000-4,000 harbor seals *(Phoca vitulina richardsi)* during pupping and molting, and it currently comprises the largest documented breeding aggregation of harbor seals remaining in Alaska due to declines in other parts of the state (Calambokidis *et al.* 1987, Hoover-Miller 1994, Mathews 1995). Approximately 70-80% of the seals in Glacier Bay rest, give birth, nurse, or molt on drifting icebergs in Johns Hopkins Inlet. In addition, roughly 1,000-1,500 (20-30%) seals rest and pup at 20-30 terrestrial haulouts in other parts of the bay (Mathews 1995). Park-wide counts of seals that rest on these two different substrates were initiated in 1992 through a collaboration between the National Park Service (NPS) and the National Marine Mammal Lab of NMFS (Mathews 1992, Mathews 1995).

Harbor seal numbers in parts of the Gulf of Alaska declined by as much as 85% between the mid-1970s and 1988 (Pitcher 1990), and declines at terrestrial haulouts in Prince William Sound have also been detected (Frost *et al.* 1996). Declines have not previously been detected in Southeast Alaska where harbor seal numbers have appeared to be stable or increasing (Lewis *et al.* 1996, Mathews 1995). Although declines in harbor seals as well as sea lions and sea birds have been linked to changes in prey abundance or availability, the specific causes of these declines in the Gulf of Alaska, Aleutian Islands, and the Bering Sea have not been fully elucidated (Loughlin and Merrick 1988, Merrick 1995, Springer 1993).

The status of harbor seals in Glacier Bay is of local as well as regional interest, because at least three factors that could influence population trends are unique to the Park as compared to other parts of Alaska. Glacier Bay National Park is the only place where subsistence hunting of harbor seals is prohibited in Alaska. A second potential factor is that NPS regulations prohibit all vessels from entering Johns Hopkins from June 1 to July 31, during the peak of pupping and the 3-6 week lactation period (Bigg 1969). Finally, surveys of harbor seals in Johns Hopkins Inlet – the only glacial ice haulout for harbor seals that has been monitored for more than a few years – span more than two decades and provide a valuable opportunity to evaluate long-term trends in seal numbers at this important breeding site (Calambokidis *et al.* 1987, Streveler 1979, unpublished NPS reports).

To assess long-term and recent trends in harbor seal numbers in Glacier Bay, we analyzed data from 1975-1978 (Streveler 1979), 1983 (Sharman and Babcock unpublished NPS data), 1984 (Calambokidis unpublished data), and 1992-1996. We used continuous covariates to improve the sensitivity of the surveys to detect changes in numbers of seals; this type of analysis reduces the variation in counts resulting from factors not related to real changes in population abundance. Improved sensitivity to changes in the numbers of seals at glacial ice and terrestrial haulouts in Glacier Bay is desirable both because harbor seal numbers have declined significantly in other parts of the State, and because national parks are mandated to monitor and preserve their natural resources.

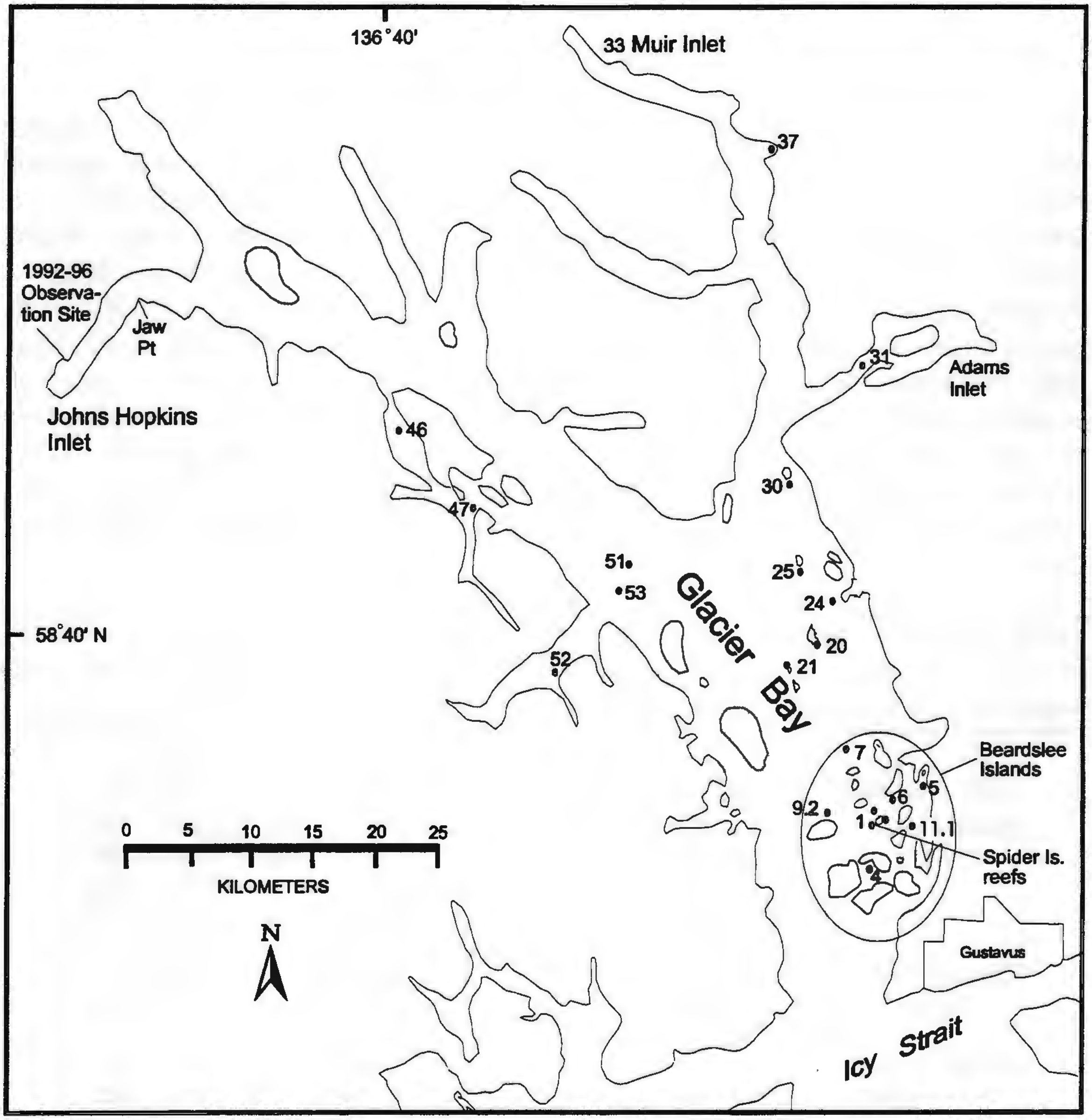
In this report we present the results of an analysis of recent surveys of both the glacial ice and terrestrial habitats used by harbor seals in Glacier Bay, and we compare recent counts from Johns Hopkins Inlet to survey data spanning more than two decades.

## METHODS

### Study Area

Johns Hopkins Inlet is located in the northwest arm of Glacier Bay (58°N, 138°30'W) (Figure 1). It is used by approximately 70% of the seals in Glacier Bay during pupping, breeding, and molting periods from spring to early fall (Mathews 1995). Glacial ice bergs in the upper reaches of Muir Inlet (Figure 1) were used by up to 1,000 seals during pupping and molting from the mid-1970s (Streveler 1979) to as recently as 1984. (Calambokidis *et al.* 1987). But, by 1992 the tide-water glacier at the head of the inlet had grounded and no seals have been observed on icebergs at this site since then (Mathews 1995)

In addition to Johns Hopkins Inlet, there are 20-30 regularly used terrestrial haulouts throughout the bay that have been identified in the last two decades (Lentfer and Maier 1989, Mathews 1992, NPS unpublished data); however, only about 20 of these have been occupied during the August surveys described in this report (Figure 1). More than half of the seals observed at terrestrial haulouts during the August surveys have been found on the reefs and low islands to the west of Spider Island, in the Beardslee Island Wilderness area (Site 1, Figure 1).



1) Spider Island reefs
4) Secret Bay
5) Hutchins Bay
6) Link Is, reef to SE
7) Flapjack Island
9.2) Sita Reef
11) Kidney Stone Islet
20) Leland Island
21) N. Marble Island
24) Sandy Cove Rock
25) Sturgess Island
30) Garforth Island
31) Adams Inlet
33) Muir Inlet (ice)
37) McBride Glacier (ice)
46) Skidmore Inlet
47) Hugh Miller Inlet
51) Lone Island
52) Tyndall Rock
53) Geikie Rocks

**Figure 1.** Map of Glacier Bay with the main terrestrial haulout sites used during August surveys between 1992 and 1996. Johns Hopkins and Muir Inlets are tidewater glacial fjords where seals currently (Johns Hopkins Inlet) or historically (Muir Inlet) have congregated in large numbers during spring and summer.

## Shore-based Counts of Seals on Glacial Ice, 1975-78 and 1983-84

Each year from 1975 through 1978, Streveler (1979) counted harbor seal pups and non-pups (adults, juveniles, and yearlings) using a 30 power tripod-mounted spotting scope from three different elevated observation sites in Johns Hopkins Inlet for two to four days in mid-June (Table 1). Because seals were widely distributed in the Inlet and beyond Jaw Point (Figure 1), each count required one or two relocations to a different overlook. Thus, there was only enough time for one count in the morning and a second in the afternoon. G. Streveler conducted all of the counts, while an assistant recorded the data (Streveler pers. comm.). Prior to these counts, Streveler had several years of experience from counting and observing seals in Muir Inlet and elsewhere in Glacier Bay. We felt that these counts were reliable for evaluating long-term trends for several reasons: (1) all counts were by one experienced individual; (2) the daily variance of the counts was relatively low (Table 1); and (3) there were written methods available describing the work.

**Table 1.** Dates, methods, haulout substrate, and sources of harbor seal survey data included in this analysis. For the counts of seals in Johns Hopkins Inlet (JHI), n = sum of daily counts; for the aerial surveys, n = number of survey days.

| Substrate (method) | Year | Month | Days of Mo. | n | Mean | St Dev | 95% Conf Int |
|---|---|---|---|---|---|---|---|
| **1) Glacial Ice, JHI**<br>(shore-based counts) | 1975 | June | 19-20 | 2 | 1442 | 19 | 1403 - 1480 |
| | 1976 | June | 19-22 | 7 | 1923 | 183 | 1556 - 2289 |
| | 1977 | June | 15-18 | 4 | 2330 | 211 | 1908 - 2751 |
| | 1978 | June | 18-20 | 3 | 3305 | 128 | 3050 - 3560 |
| **2, 3) Glacial Ice, JHI**<br>(shore-based counts) | 1983 | August | 10-13 | 12 | 2750 | 621 | 1508 - 3993 |
| | 1984 | August | 7-16 | 10 | 3464 | 1150 | 1165 - 5764 |
| **4) Glacial Ice, JHI**<br>(shore-based counts) | 1992 | June | 17-18 | 3 | 2565 | 13 | 2538 - 2565 |
| | 1993 | June | 14-17 | 6 | 3260 | 1025 | 1209 - 3260 |
| | 1994 | June | 16-20 | 18 | 2497 | 273 | 1951 - 2497 |
| | 1995 | June | 14-17 | 14 | 2280 | 394 | 1492 - 2280 |
| | 1996 | June | 13-18 | 13 | 2975 | 501 | 1974 - 2975 |
| **5) Glacial Ice, JHI**<br>(shore-based counts) | 1992 | August | 20-23 | 14 | 3833 | 983 | 1868 - 5799 |
| | 1993 | August | 23-24 | 3 | 3361 | 1032 | 1297 - 5425 |
| | 1994 | August | 10-16, 29-30 | 28 | 3065 | 549 | 1966 - 4163 |
| | 1995 | August | 9-21 | 40 | 3170 | 552 | 2065 - 4275 |
| | 1996 | August | 13-20, 21-26 | 32 | 3430 | 531 | 2367 - 4493 |
| **6) Terrestrial Haulouts in Glacier Bay**<br>(aerial surveys) | 1992 | August | 27, 28 | 2 | 1705 | 164 | 1377 - 2033 |
| | 1993 | (no survey) | | | | | |
| | 1994 | August | 10-12 | 4 | 2095 | 296 | 1503 - 2688 |
| | 1995 | August | 1,8,10 | 3 | 2169 | 260 | 1649 - 2689 |
| | 1996 | August | 11,19-21,29,31 | 6 | 902 | 668 | 0 - 2239 |

**References:** 1) Streveler 1979, 2) 1983: Sharman and Babcock, NPS unpublished data, 3) 1984: Calambokidis, 4-6) Mathews

In 1983 from August 10-13, L. Sharman and E. Babcock (described in Dudgeon and Swartbeck 1988, unpublished report) counted seals in Johns Hopkins Inlet following methods similar to those described by Streveler (1979), although they were able to count from the same single elevated site used in recent surveys rather than having to move from one site to another. The two observers took turns counting and recording, so no simultaneous paired counts were made. We included these data in our trend analysis because one of the observers (Sharman) had previously conducted counts of seals in Johns Hopkins Inlet, and there were clear descriptions of their methods, which were similar to those used by Streveler (Sharman and Brown 1983 and Dudgeon and Swartbeck, 1988, NPS unpublished reports).

In 1984, J. Calambokidis led a team of students in a multifaceted study of harbor seals in Glacier Bay, including daily counts of seals in Johns Hopkins Inlet from August 7 to 16 (Calambokidis *et al.* 1997). One to three counts per day were made by an individual using binoculars or spotting scopes from several elevated sites on shore between 07:00 and 22:00.(Calambokidis *et al.* 1987). Only the daily high counts were used in this analysis, and we did not have the time of each count as we did for other data sets (Calambokidis, unpublished data). We included these data in our trend analysis because: 1) Calambokidis and his assistants had also conducted studies of seals in Muir Inlet prior to 1984, 2) observers were trained by these experienced observers, and 3) the methods and results from this work have been published. The mean value and 95% confidence intervals from these daily high counts are summarized in Table 1.

### Shore-based Counts of Seals on Glacial Ice, 1992-1996

From 1992 to 1996, we conducted shore-based counts of harbor seals in Johns Hopkins Inlet and aerial surveys for seals at terrestrial haulouts throughout Glacier Bay; results from some of this work have been reported elsewhere (Mathews 1992, Mathews 1995, Mathews and Kelly 1996). Since 1992, aerial surveys and shore-based counts in Johns Hopkins Inlet have been conducted in August, during the annual molt when seals spend a higher proportion of time at haulouts (Calambokidis *et al.* 1983, Johnson 1979). We also conducted shore-based counts of seals in Johns Hopkins Inlet in mid-June, after most pups are born, from 1992-1996.

From mid-June and mid-August of 1992 through 1996, a team of observers has counted seals in Johns Hopkins Inlet from an elevated (ca 20 m above sea level) land site located about 2.5 km from the face of the glacier (Figure 1). Two observers simultaneously count seals from this elevated site. Typically two to four paired counts were made each day with at least one paired count between 10:00 and 14:00, because Calambokidis *et al.* (1987) found that seal numbers in Muir and Johns Hopkins Inlet peaked around midday during summer months. For the June counts, seals were categorized as adults or pups in all years except 1993 when only adults were counted. In August, no age class distinction was made, because older weaned pups are difficult to distinguish from adults at a distance.

In Johns Hopkins Inlet, seals are typically dispersed over an area of more than two to three square miles, making systematic coverage of the long fjord with a narrow-field spotting scope or hand-held binoculars extremely difficult. To reduce errors associated with losing one's place during a count, we mounted either monocular spotting scopes (1992 and 1993) or 20 X 60 Ziess binoculars (1994-1996) on tripods and also divided our field of view into four subsections for more systematic counting. The 20 X 60 binoculars are optically superior to the spotting scopes. Details of the methods used during these counts are provided by Mathews (1995).

### Aerial Photographic Counts of Seals at Terrestrial Sites, 1992-96

In 1992 and from 1994-1996 aerial surveys of the terrestrial haulouts in Glacier Bay were flown during monthly low tide cycles during the molt in August. Aerial surveys of terrestrial haulouts were scheduled to occur while there was a field crew in Johns Hopkins Inlet, although in 1992 the surveys occurred four days after the counts in Johns Hopkins Inlet (Table 1).

During aerial surveys we attempted to check all known haulouts and to search for undocumented or new haulouts; however, weather conditions occasionally prevented complete surveys of the bay. Surveys were flown at about 303 m (1000 ft), and observers scanned each haulout, often with binoculars, for seals. When seals were located, we reduced our altitude to about 212 m (700 ft) with the haulout at about a 45 degree angle from the photographer's side of the plane. Photographs were taken through an open window with an SLR camera equipped with a motor drive and either an 80-200 mm zoom lens, or a 300 mm fixed lens. We used 200-400 ASA slide film, and most photographs were taken at 1/250 second or faster.

For each haulout we recorded the location, time, film frame numbers, and made a visual estimate of the number of seals. For known haulouts, we also noted if seals were not present (a '0' in the database), or if we were unable to survey a haulout due to bad weather (a null value). We also made general comments about weather conditions, and beginning in 1995 we recorded outside air temperatures periodically during surveys.

Groups of seals at all haulouts were small enough to fit in one frame, except at the Spider Island reefs where we took a series of overlapping photographs to include all seals on the haulouts. The sharpest slide or slide series was selected for counting seals. We counted seals by projecting slide images onto white paper so that each animal could be marked. Verification counts were made for each haulout until two identical counts were obtained or, for haulouts with >100 seals, until at least two counts differed by no more than four seals. We found that counting accuracy of the larger haulouts is improved by using a handheld digital counter.

Because the earlier counts (1975-1978) were conducted in June, whereas those from 1983, 1984 and 1992-1996 were made in August, not all time periods could be compared to others. The time periods included in the trend analysis are summarized in Table 2.

**Table 2.** Time periods, month, and age groups counted during surveys for harbor seals in Glacier Bay by haulout substrate, survey method used, and location (JHI: Johns Hopkins Inlet, Muir: Muir Inlet, and GB: Glacier Bay, excluding Johns Hopkins Inlet).

**Glacial Ice (shore-based counts):**

| Loc | Years | Month | Groups Counted |
|---|---|---|---|
| JHI | 1975-1978 | June | non-pups and pups |
| JHI | 1983-1996 | Aug | all seals |
| JHI | 1992-1996 | Aug | all seals |
| JHI | 1992-1996 | June | non-pups only |
| Muir | 1973-1978 | June | non-pups and pups |

**Terrestrial Haulouts (aerial surveys)**

| Loc | Years | Month | Groups Counted |
|---|---|---|---|
| GB | 1992, 1994-96 | Aug | all seals |

## Estimation of Trends in Seal Numbers

During all surveys, some harbor seals are in the water and unavailable for counting. Consequently, aerial and shore-based surveys of seals at their haulouts measure only a proportion of the population. If survey methods and timing are standardized and the proportion of animals counted remains fairly constant, such surveys can be used as reliable indices of population trends. Yet, pinniped surveys are inherently fraught with the potential for high variance between days and years, due to environmental and behavioral factors that influence the number of seals at haulouts. In addition, harbor seals respond to environmental variables differently depending upon the haulout substrate. For example, seal numbers at glacial ice haulouts, unlike most terrestrial sites, do not fluctuate with tide height; instead, they tend to peak around midday (Calambokidis *et al.* 1987) or they may remain relatively high from mid-morning to evening (Calambokidis *et al.* 1983). Thus, we considered a different set of potential environmental and observer-related covariates for surveys of seals resting on these two substrates. In addition, the two methods used to survey seals in Glacier Bay, aerial photography at the terrestrial sites and shore-based counts at the primary glacial haulout, present different potential sources of variation.

An estimate of population trend based on aerial or shore-based surveys must account for the variation in those counts which results both from real changes in population abundance as well as factors that affect the proportion of the population visible during surveys. Rather than assume a constant proportion of seals was visible, and thus observed during each survey, we modeled counts as a function of environmental (e.g., height of low tide, time of day) and other (e.g., optical equipment used during shore-based counts, observer skill level, and count quality) variables. The environmental covariates used in our analysis of the data from aerial surveys of terrestrial haulouts from 1992 –1996 included date, time of day, tide height at the nearest (in time) low tide, time relative to low tide, and time relative to sunrise. These are the same covariates investigated by Frost *et al.* (unpublished), however we structured all covariates as continuous whereas they used categorical versions of these variables.

We considered an overlapping, but different suite of covariates in the analysis of seal count data from shore-based surveys of glacial ice haulouts in Johns Hopkins Inlet. These were: date, time of day, observer experience, count quality, and two categories of optical equipment.

Observer levels in most cases changed with time, and they were categorized in all years as follows:

*Level 1:* experienced harbor seal observer or an individual who had conducted at least four counts and whose results were within at least 20% of those of a more experienced observer on at least two recent counts.

*Level 2*: moderately experienced observers who had completed at least two counts and whose previous counts were within at least 20% of those of a more experienced observer or within 20% of a same-day count; any observer who had counted seals in more than one season.

*Level 3:* beginning observers are individuals who had not yet counted more than twice, or individuals whose counts had not been within 20% of a more experienced observer's counts for at least two recent counts. Counts by Level 3 observers were not used in this analysis.

Count quality was a subjective rating used by Level 1 and 2 observers only during counts from 1992 to 1996 to assess the quality of their counts. This variable encompassed environmental conditions (i.e., lighting, heat waves), subtle distractions, and known disruptions during a count. Ratings ranged from 1 for excellent to 7 for very poor. Count quality ratings less than 4 were not used in this analysis. The two categories of optical equipment for all shore-based surveys were 1) monocular spotting scopes on tripods or hand-held binoculars, and 2) high-powered binoculars mounted on tripods (used from 1994-1996).

In addition to the linear form of covariates, we included date and time as quadratic covariates (i.e., date squared and time squared), and the three following two-way interaction covariates for counts from aerial surveys: 1) date * tide, 2) time * tide height, and 3) time * time relative to low tide. These quadratic and interaction covariates were chosen because of known or suspected patterns in seal haulout behavior. The total number of covariates we considered was constrained by the number of counts and limitations on computing resources. Models with both linear and quadratic population trajectories (i.e., change in population across years on the log scale) were tested.

Using the two different sets of covariates, we then estimated the population trend for a series of annual counts using overdispersed multinomial models (Link and Sauer 1997). With this type of model, counts ($Y_{ij}$, i indicates site and j indicates replicate) are assumed to be overdispersed Poisson random variables (i.e., negative binomial) with expected values ($m_i$) that have the relationship $\ln(m_i) = h(i) * g_i(\underline{x}) * f_i(t)$. In this equation, h(i) represents site effects, which are treated as a multiplicative 'nuisance' parameter, $g_i(\underline{x})$ is a loglinear function of the covariates ($\underline{x}$) that are unrelated to population change, and $f_i(t)$ is the population trajectory with t indicating year.

Each population trajectory can be thought of as a smoothed version of the actual population size across years. Because trajectories were not always linear (i.e., the rate of change varies through time) on the log scale, we defined trend as the geometric mean rate of change over the interval of interest. Trend is therefore a single-number summary of the average change in the trajectory for a selected period of time. Because the actual population sizes are unknown, the height of the trend on the y-axis was arbitrarily chosen such that it passed through the mean count in approximately the middle of the survey period for each area or time period. Overall, the advantages of this modeling approach are that counts are adjusted for the effects of environmental and other covariates simultaneously with the estimation of the population trajectory, and that variability not accounted for by the covariates can differ among sites.

The combination of covariates and degree of polynomial used to produce each trajectory, and subsequent trend estimate, was determined by first starting with a model containing all appropriate (by survey method) covariates and a quadratic trajectory. Covariates were then eliminated one at a time based on the likelihood ratio tests until all remaining covariates were significant ($P<0.05$) or were a component of a higher order term (i.e., quadratic or interaction) that was significant. For example, time was retained in the final model for 1992-1996 August aerial counts because $\text{time}^2$ was significant. Final models for each of the seven time periods/areas were used to estimate a trajectory and associated trend estimate for each time period and study area.

## RESULTS

Counts of harbor seals in Johns Hopkins Inlet during both June and August surveys showed a positive annual trend for all of the time periods tested (Table 3). Most of the increase since 1975 appears to have occurred within the first four years, when an annual trend of 30.7% was observed (Figure 2). The trend in numbers at Johns Hopkins Inlet, the primary glacial ice haulout area during August was positive (7.1%) between 1992 and 1996, whereas the trend at the terrestrial haulouts during the same month and time period was negative (-8.6%) (Table 3, Figure 3). For the 1992-1996 period when data collection methods were nearly identical each year, June counts of non-pups increased at a steeper rate (13.1% vs. 7.1%) than counts of all seals during the August molt (Table 3, Figure 4).

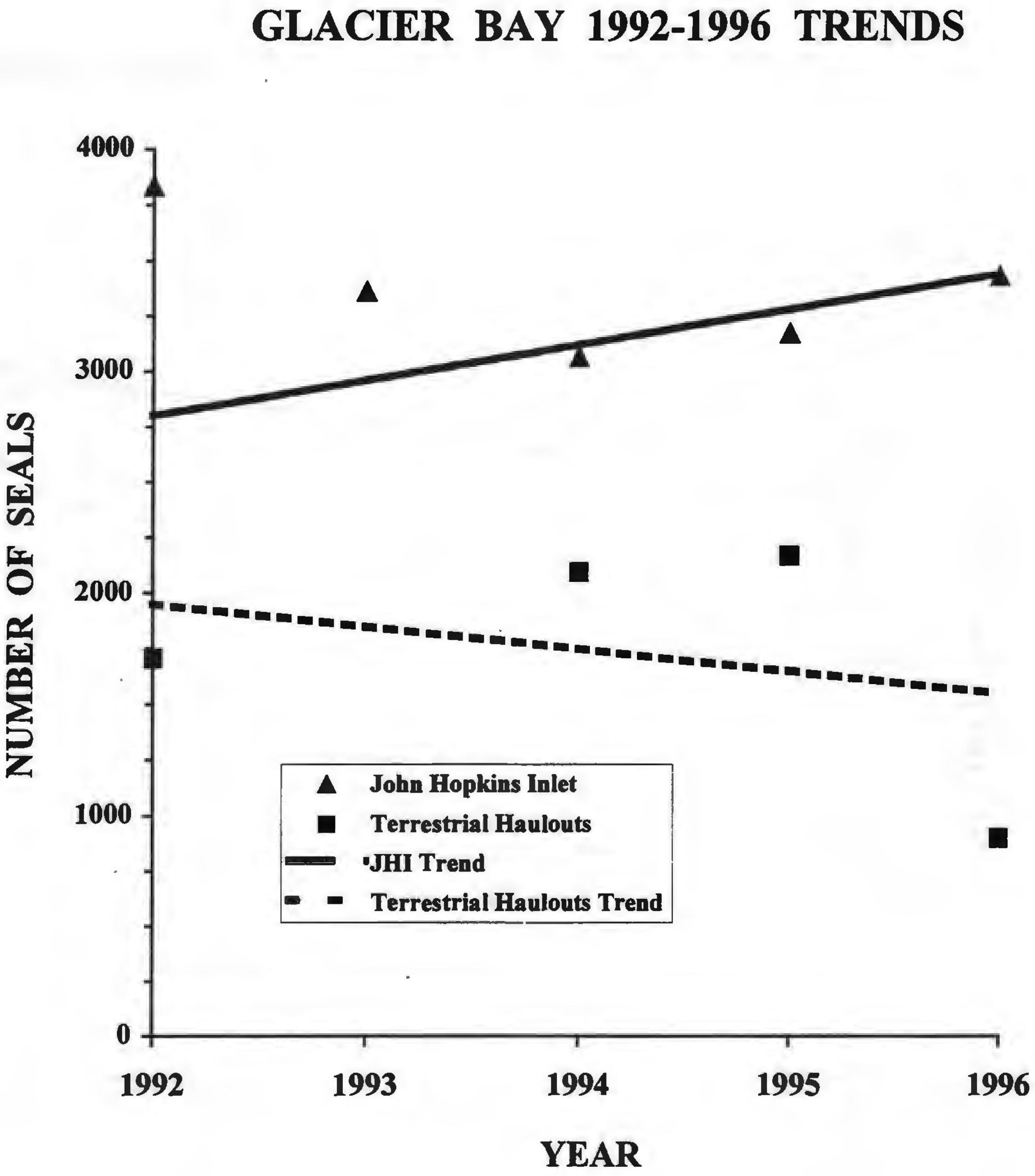
**Table 3.** Estimates of trends in numbers of seals at glacial ice haulouts (Johns Hopkins Inlet, JHI and Muir Inlet) and terrestrial haulouts (Gl Bay) during different periods of time. The environmental (1-4) and other (10-12) covariates selected for harbor seal trend models from land-based counts in Johns Hopkins Inlet (JHI) and Muir Inlet and from aerial photographic surveys of terrestrial haulout sites in Glacier Bay (Gl Bay) are listed for each survey area and time period. A list of all potential covariates tested is provided below.

| Location | Years | Month | Age Category | Trend (% / yr) | 95% Conf. Interval | *p* | *DF* | *t, crit* | Linear/ Quad | Covariates Selected by Models | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | 1 | 2 | 3 | 4 | 5 | 10 | 11 | 12 |
| JHI | 1975-96 | June | All Seals | + 3.9 | 2.4 - 5.3 | < 0.001 | 83 | 5.377 | Q | | | X | | | X | X | |
| JHI | 1975-78 | June | All Seals | + 30.7 | 24.3 - 37 | <0.001 | 13 | 10.457 | L | | | | | | | | |
| JHI | 1983-96 | August | All Seals | + 2.6 | 1.18 - 4.12 | <0.001 | 136 | 3.566 | L | | | | | | X | | |
| JHI | 1992-96 | June | Non Pups | + 13.1 | 8 - 18.3 | <0.001 | 42 | 5.118 | L | X | | X | | | X | | |
| JHI | 1992-96 | August | All Seals | + 7.1 | 1.7 - 12.4 | <0.01 | 112 | 2.635 | L | | | | | | X | | X |
| Gl Bay* | 1992-96 | August | All Seals | - 8.62 | (-11.7) - (-5.6) | <0,001 | 141 | -5.57 | L | X | X | X | X | | | | |
| Muir In | 1973-78 | June | All Seals | - 5.8 | (-12.6) - (0.9) | | | | L | | | | | | | | |
| Muir In | 1973-94 | Jun/Aug | All Seals | - 9.4 | (-12.6) - (-6.3) | <0.001 | 52 | -6.001 | L | X | | | | | | | |

* Mainly terrestrial haulouts; all others are from glacial ice.

**Covariates considered in the models:**

1) date of survey relative to the mean survey date of counts on that route,
2) relative survey date squared,
3) time-of-day of survey relative to the mean time-of-day for all surveys,
4) relative time-of-day squared,
5) tide height at the low tide closest in time to the survey,
6) survey time relative to the time of the closest low tide,
7) survey time in relation to sunrise,
8) time-of-day/tide height interaction, and
9) time relative to low tid/tide height interaction
10) optical equipment used during land-based counts (applies to Johns Hopkins Inlet only)
11) observer's level of experience at counting harbor seals on glacial ice (applies to JH Inlet only)
12) subjective ranking of count quality by observers; used from 1992-1996.



---

**Figure 2.** Trends in harbor seal numbers at glacial ice (Johns Hopkins Inlet, triangles) and terrestrial haulouts (circles) throughout Glacier Bay from August surveys, 1992-1996. Symbols are mean values from shore-based counts (glacial ice substrate) and aerial surveys (terrestrial haulouts); mean values are not corrected for incomplete coverage or environmental factors.

---

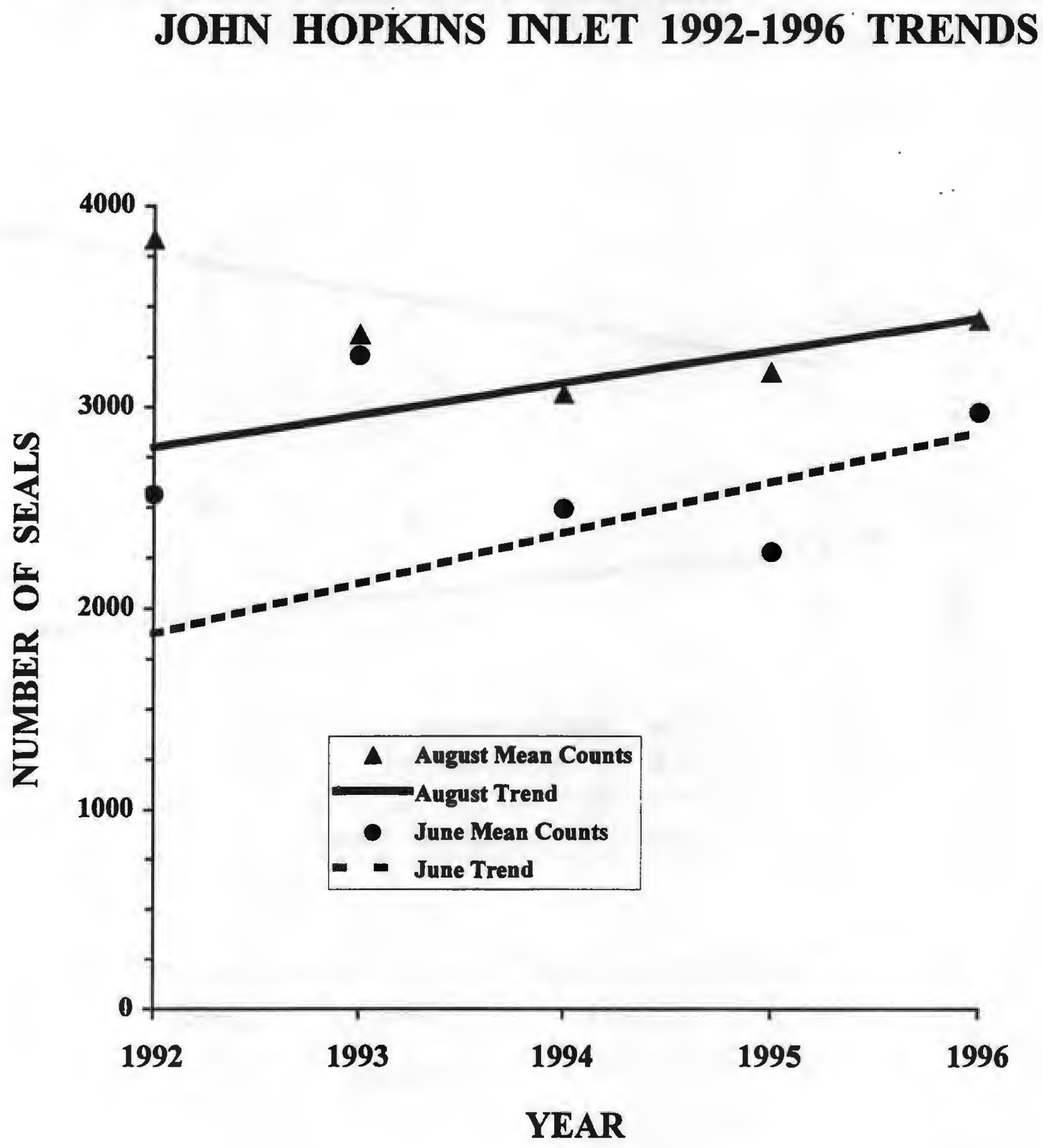


**Figure 3.** Trends in harbor seal numbers in June and August 1992-1996 at Johns Hopkins Inlet, the primary glacial ice haulout in Glacier Bay. Symbols are mean values from shore-based counts of non-pups in June (circles) and of all seals in August (triangles); mean values are not corrected for incomplete coverage or environmental factors.

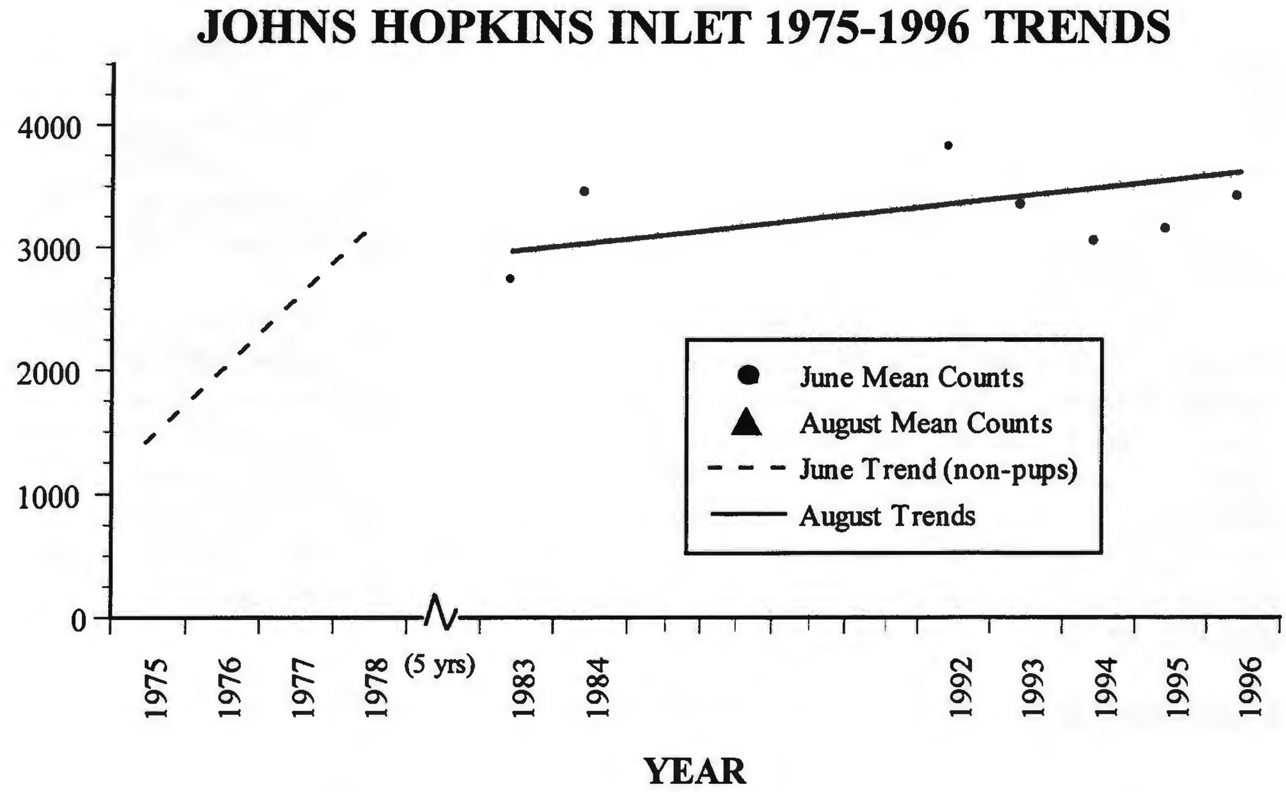


**Figure 4.** Long-term trends in numbers of harbor seals in Johns Hopkins Inlet, the primary haulout area in Glacier Bay. Symbols are mean values from shore-based counts that are not corrected for incomplete coverage or environmental factors. Data are from Streveler (1979), Sharman and Babcock (1983), Calambokidis (1984, unpublished data), and Mathews (1995 and current report).

## DISCUSSION

### Recent Trends, 1992-1996: Use of Glacial Ice and Terrestrial Haulouts

Between 1992 and 1996 harbor seal numbers at terrestrial sites in Glacier Bay exhibited a negative trend (-8.6%), whereas in Johns Hopkins Inlet the trend was positive (+7%) during this same time period and month (Table 3, Figure 2). This suggests that seal distribution may have shifted from terrestrial to glacial ice haulouts, although there are other potential explanations for the divergent trends noted at the two different substrates. Survival and/or site fidelity may be higher for seals in Johns Hopkins Inlet, and/or immigration to Johns Hopkins Inlet from areas outside of Glacier Bay, as well as from within the Park, may have occurred. Another potential factor that may have contributed to the negative trend at terrestrial sites is that the primary terrestrial haulout (Spider Island reefs, Figure 1) appears to have been exposed to increasing levels of human disturbance in 1996 (and 1997) (Mathews 1997b). In addition, survey coverage of the terrestrial sites in August was incomplete on all days in 1996. If, on the other hand, some of the increase in Johns Hopkins Inlet can be attributed to changes in distribution from terrestrial to glacial haulouts, the degree of the decline at the terrestrial sites (8.6% of 1,000-2,000 seals, or approximately 86-170 seals/year) does not fully explain the increase observed at the glacial ice site (7% of 3,000-4,000 seals, or approximately 210-280 seals/year) (Table 1).

The combined effect of the negative trend at terrestrial haulouts and the positive trend in Johns Hopkins Inlet is that numbers in Glacier Bay overall appear to be stable or possibly increasing. The negative trend rates for harbor seals in areas of the Gulf of Alaska where declines are considered serious ranged from 7 to 7.7% between 1976 and 1988 (Tugidak Island: Pitcher, 1990) and between 1984 and 1992 (Prince William Sound: Frost and Lowry 1993, Pitcher 1989, overall trend cited in Hill *et al.* 1996). If we had not conducted surveys of harbor seals in the ice habitat, we would have concluded that harbor seals in Glacier Bay had declined between 1992 and 1996 at annual rates higher than those observed in the Gulf of Alaska.

### Recent Trends, 1992-1996: June versus August Counts, Johns Hopkins Inlet

The trend in seal numbers in Johns Hopkins Inlet for both the June (pupping) and August (molting) counts was positive, although the rate of increase was almost twice as high (13%/yr vs 7%/yr) for the June surveys, which did not include pups due to the higher error in counting them. On average, 29% (SD=6%) of the animals in Johns Hopkins Inlet during our mid-June surveys were females with dependent pups. Thus, close to half of the seals considered in the trend estimate (which excludes pups) for June were parturient females. In Glacier Bay, glacial ice habitat is used by significantly more females with pups than are terrestrial sites (Streveler 1979, Calambokidis *et al.* 1987, Mathews 1997a), and some females may be immigrating into the Inlet to give birth.

### Long-term Trends, 1975-1996: Johns Hopkins Inlet

Harbor seal numbers in Johns Hopkins Inlet increased steeply (30.7%/yr) between 1975 and 1978, and then the rate of increase slowed to an estimated average of 2.6%/year for the period 1983-1996. Recent trends (+2.6% for 1983-1996 and +7% for 1992-1996, Table 3) are well within observed and theoretical net growth rates for harbor seal populations, although Johns Hopkins Inlet is clearly not a closed population.

The steep annual rate of increase observed between 1975 and 1978 in Johns Hopkins Inlet may be a result of one or more of the following factors: 1) increased birth rates, 2) decreased mortality, and/or 3) immigration into the Inlet. In the sections that follow we consider each of these potential contributors to the rapid expansion observed in Johns Hopkins Inlet, and we suggest that at least two factors, decreased mortality and immigration, were involved.

There is no evidence for increased birth rates in Johns Hopkins Inlet between 1975 and 1978; the proportion of females with pups in this glacial fjord was consistently high (28%) during all 4 survey years (Mathews 1995).

The observed annual rate of increase does not appear to be due to decreased mortality alone, although it is a probable co-factor. Streveler (1979) counted an average of 28% (SD = 2.2%; data summarized in Mathews, 1995) pups during his June surveys in these four years, so the observed 30% annual increase would suggest that there had been close to 100% survival of pups born in this Inlet in four consecutive years – a very unlikely prospect given that the maximum theoretical net productivity rate for pinnipeds is estimated to be 12% (Wade and Angliss 1996). In addition, one of the highest documented population growth rates (12.5%) for harbor seals was observed in British Columbia between 1973 and 1987, and it occurred after management culling and commercial hunting of seals was ended in 1970 (Olesiuk *et al.* 1990). The authors attributed this high rate of growth to population recovery from harvest. The rate of increase in Johns Hopkins from 1975 to 1978 was more than two times that observed in British Columbia; thus, the observed increase in seal numbers in Johns Hopkins Inlet is likely to have involved more than just a decrease in mortality.

We might assume that seals, particularly mature females, accustomed to using glacial ice would tend to relocate to another glacial fjord if ice habitat in one location declined, as it did in Muir Inlet in the late 1970s and mid 1980s (Streveler 1979, Calambokidis *et al.* 1987). By 1992 no more than 200 seals were observed in Muir Inlet, and by 1994 the receding glacier had grounded and no seals have been observed on icebergs in this area since then (Mathews 1992, and pers. observ.). While some seals that could no longer find adequate ice substrate in Muir Inlet may have moved to Johns Hopkins Inlet to breed, the increase in Johns Hopkins from 1975 to 1978 cannot be explained solely by emigration from Muir Inlet, although it may have contributed slightly. The annual rate of decrease in Muir Inlet was estimated to be 5.8% (95% CI = -12.6 to –0.9%/yr) between 1973 and 1978 (Table 3), and only about a 1,000 seals were observed during June counts in the mid-1970s (Streveler 1979). Thus, if all of the seals that left Muir were detected in Johns Hopkins Inlet, this would account for only about 2-4% (5.8% x 1,000/3,300 to 5.8% x 1,000/1,440; Table 1) of the 30%/yr increase observed in Johns Hopkin Inlet.

Immigration from areas other than Muir Inlet remains a likely co-factor (with decreased mortality) in the observed rapid increase in Johns Hopkins Inlet between 1975 and 1978. Because there were no surveys of terrestrial haulouts before 1992, we cannot determine if there were shifts in seal distribution between glacial ice and terrestrial haulouts in Glacier Bay between 1975 and 1978, as may have occurred between 1992 and 1996 (Figure 4). Close to 70% of the seals in Glacier Bay, and at least 50% of seals in the northeast Gulf of Alaska (Mathews and Womble 1997, this volume) select glacial ice habitat when it is accessible. Thus, an understanding of seal use of glacial ice habitat is essential if trend surveys are to be conducted in nearby waters. If glacial ice haulouts are not monitored, large changes in numbers at terrestrial haulouts may be misinterpreted as population growth or decline, rather than shifts in distribution between habitats.

Several factors may have contributed to the recent and long-term trends in numbers of harbor seals in Glacier Bay. The cessation of subsistence hunting in Glacier Bay began in 1973 and may have contributed to the steep increase in seal numbers observed in Johns Hopkins Inlet between 1975 and 1978, but it is unlikely that it was the only factor involved. Immigration from Muir Inlet and from terrestrial sites are likely contributors to the 30%/year trend. Since 1988, Johns Hopkins Inlet has been closed to all vessel traffic during pupping and early stages of nursing. The extent to which reduced disturbance of females with dependent young might increase the survival or overall fitness of pups is not known, but it is likely to have a positive energetic effect and this might explain some of the continued positive trend in seal numbers in Johns Hopkins Inlet. NPS regulations currently limit vessel approaches to ¼ mile from the primary terrestrial haulout (Spider Island reefs) in Glacier Bay during pupping and molting. Yet, this regulation may not be preventing frequent disturbance of seals at these reefs. Recent increases in human disturbance (Mathews 1997b) may have contributed to the negative trend in seal numbers at terrestrial sites and possibly to the increases observed in Johns Hopkins Inlet through displacement of seals; however, the long-term effects of human activities on haulout patterns and site fidelity remain to be elucidated in Glacier Bay. In addition to immigration and emigration, changes in mortality, and human disturbance, shifts in prey distribution or availability may have influenced the diverging trends in seal numbers at terrestrial and glacial ice haulouts between 1992 and 1996.

## CONCLUSIONS

The analysis of harbor seal survey data from both terrestrial and glacial ice haulouts in Glacier Bay indicates that since 1992 overall numbers have been stable or may be increasing slightly, and that there was a high rate of growth at the primary glacial haulout from 1975-1978. However, the negative trend at terrestrial sites between 1992-1996 should be closely monitored, since it is not known if the decline is the result of a shift in distribution, a decrease in birth rate, an increase in mortality, or a result of increased human disturbance. Trend routes adjacent to active tidewater glacial fjords used by significant numbers of seals need to include surveys of seals on glacial ice to avoid misinterpreting a shift in distribution as a decline or increase in overall population abundance.

## ACKNOWLEDGEMENTS

We thank Lara Dzinich for her devotion to the project and her significant contributions to data collection and slide analysis. We are indebted to several hard-working field crews comprised of University of Alaska students, volunteers, and NPS staff who assisted with the counts in Johns Hopkins Inlet. These vital contributors include B. Kunibe, J. Driscoll, R. Morris, C. Coyle, S. LeGros, C. Pohl, N. Ratner, A. Knuth, C. Knight, J. Danner, H. Dedeitus, and L. Wolstenholme. E. Hooge, K. Wilson, D. Williams, A. Maselko, P. Wald, T. Farrell, J. Doherty, and A. vanDusen assisted with aerial surveys and we thank them for their generous help. Crucial logistic support was provided by NPS staff (T. Gage, J. Williams, R. Yerxa, C. Young, M. Goodro). We thank our pilots (M. Sharp, S. Wilson, and C. Shroth) for their assistance with spotting seals and for returning us home safely. Drafts of this report were improved by

constructive comments from Chris Gabriele, Elizabeth Hooge, Lauri Jemison, Mary Kralovec, Bob Small, Una Swain, and Jim Taggart,.

## LITERATURE CITED

Allen-Miller, S. (1988). "Movement and activity patterns of harbor seals at the Point Reyes peninsula, California," M.S., University of California, Berkeley, CA.

Bigg, M. A. (1969). *The harbor seal in British Columbia*, Queen's Printer for Canada, Ottawa.

Bigg, M. A. (1981). "Harbour seal, *Phoca vitulina* Linnaeus, 1758 and *Phoca largha* Pallas, 1811." Handbook of marine mammals, S. H. Ridgeway and R. J. Harrison, eds., Academic Press, London, 1-27.

Brown, R. F., and Mate, B. R. (1983). "Abundance, movements, and feeding habits of Harbor Seals (*Phoca vitulina*) at Netarts and Tillamook Bays, Oregon." *Fishery Bulletin*, 81, 291-301.

Calambokidis, J., Steiger, G. T., and Healey, L. E. (1983). "Behavior of harbor seals and their reaction to vessels in Muir Inlet, Glacier Bay, Alaska." *5th Biennial Conference on the Biology of Marine Mammals*, Boston, MA, 10 p.

Calambokidis, J., Taylor, B. L., Carter, S. D., Steiger, G. H., Dawson, P. K., and Antrim, L. D. (1987). "Distribution and haul-out behavior of harbor seals in Glacier Bay, Alaska." *Canadian Journal of Zoology*, 65, 1391-1396.

Divinyi, C. A. (1971). "Growth and movements of a known-age harbor seal." *Journal of Mammology*, 52(4), 824.

Frost, K. F., and Lowry, L. F. (1993). "Assessment of injury to harbor seals in Prince William Sound, Alaska, and adjacent areas following the Exxon Valdez oil spill." *Study No. 5*, State-Federal Natural Resources Damage Assessment, Marine Mammals.

Frost, K. J., Lowry, L. F., Small, R. J., and Iverson, S. J. (1996). "Monitoring, habitat use, and trophic interactions of harbor seals in Prince William Sound, Alaska." *Study Number 95064*, Alaska Department of Fish and Game, Wildlife Conservation, Douglas, AK.

Hill, P. S., DeMaster, D. P., and Small, R. J. (1996). "Draft Alaska Marine Mammal Stock Assessments 1996." , NMFS, NMML, Seattle.

Hoover-Miller, A. (1994). "The harbor seal in Alaska." Revised marine mammals of Alaska: species accounts with research and management recommendations, J. W. Lentfer, ed., Marine Mammal Commission, Washington, D.C.

Johnson, B. W. a. P. A. J. (1979). "Population peaks during the molt in harbor seals." *Abstracts from Presentations at the Thrid Biennial Conference on the Biology of Marine Mammals*, Seattle, WA, 31.

Lentfer, H., and Maier, A. (1989). "Wildlife and vessel observations in the Beardslee Islands in the early summer." , U.S. National Park Service, Glacier Bay National Park and Preserve.

Lewis, J. P., Pendleton, G. W., Pitcher, K. W., and Wynne, K. M. (1996). "Harbor seal population trends in Southeast Alaska and the Gulf of Alaska." *NA57FX0367*, Alaska Department of Fish and Game, Douglas, AK.

Link, W. A., and Sauer, J. R. (1997). "Estimation of population trajectories from count data." *Biometrics*, 53, 488-497.

Loughlin, T. R., and Merrick, R. L. (1987). "Comparison of commercial harvest of walleye pollock and northern sea lion abundance in the Bering Sea and Gulf of Alaska." *Proceedings of the International Symposium on the Biology and Management of Walleye Pollock*, Anchorage, Alaska.

Mathews, E. A. (1992). "Harbor seal *(Phoca vitulina)* censuses in Glacier Bay National Park and Preserve: a comparison of land-based and aerial censusing." , NMFS, NMML and U.S. National Park Service, Glacier Bay National Park and Preserve, Seattle, WA.

Mathews, E. A. (1995). "Longterm trends in abundance of harbor seals (*Phoca vitulina richardsi*) and development of monitoring methods in Glacier Bay National Park, Southeast Alaska." *Third Glacier Bay Science Symposium*, Glacier Bay National Park & Preserve, AK, 254-263.

Mathews, E. A. (1997a). "Habitat selection and distribution of harbor seal females with pups in Glacier Bay National Park, Alaska." , Glacier Bay National Park Service, Gustavus, AK.

Mathews, E. A. (1997b). "Preliminary assessment of haulout behavior of harbor seals *(Phoca vitulina)* and sources of disturbance at the Spider Island reefs, Glacier Bay National Park." , Glacier Bay National Park, Gustavus, AK.

Mathews, E. A., and Kelly, B. P. (1996). "Extreme temporal variation in harbor seal *(Phoca vitulina richardsi)* numbers in Glacier Bay, a glacial fjord in Southeast Alaska." *Mar. Mamm. Sci.*, 12(3), 483-488.

Merrick, R. L. (1995). "The relationship of the foraging ecology of Steller sea lions *(Eumetopias jubatus)* to their population decline in Alaska," Ph.D, University of Washington, Seattle, WA.

Olesiuk, P. F., Bigg, M. A., and Ellis, G. M. (1990). "Recent trends in the abundance of harbor seals, *Phoca vitulina*, in British Columbia." *Can. J. Fish. Aquat. Sci.*, 47, 992-1003.

Pitcher, K. W. (1989). "Harbor seal trend count surveys in southern Alaska, 1988." , Alaska Department of Fish and Game.

Pitcher, K. W. (1990). "Major decline in the number of harbor seals *(Phoca vitulina)* on Tugidak Island, Gulf of Alaska." *Marine Mammal Science*, 121-134.

Pitcher, K. W., and Calkins, D. G. (1979). "Biology of the harbor seal *(Phoca vitulina richardsii)* in the Gulf of Alaska." *Ru 229, Contract Number 03-5-002-69*, Outer Continental Shelf Environmental Assessment Program.

Springer, A. M. (1993). "Report of the seabird working group. *In:* Is it food? Addressing marine mammal and seabird declines." *93-01*, University of Alaska, Fairbanks.

Streveler, G. P. (1979). "Distribution, population ecology, and impact susceptibility of the harbor seal in Glacier Bay, Alaska." , U.S. National Park Service, Glacier Bay National Park and Preserve.

Swain, U., Lewis, J., Pendleton, G., and Pitcher, K. (1996). "Movements, haulout, and diving behavior of harbor seals in Southeast Alaska and Kodiak Island." *NA57FX0367*, Alaska Department of Fish and Game Division of Wildlife Conservation, Douglas, Alaska.

Wade, P. R., and Angliss, R. P. (1996). "Guidelines for assessing Marine Mammal stocks: Report of the GAMMS Workshop." *NMFS-OPR-12*, NOAA, Seattle, WA.

# PUPPING PHENOLOGY AND DEMOGRAPHY OF HARBOR SEALS ON TUGIDAK ISLAND, ALASKA

Lauri A. Jemison and Brendan P. Kelly

Institute of Marine Science, School of Fisheries and Ocean Science
University of Alaska Fairbanks, P.O. Box 757200
Fairbanks, Alaska 99775

## INTRODUCTION

Tugidak Island, located 40 kilometers south of Kodiak Island in the western Gulf of Alaska (Figure 1), was a haulout site for an estimated 15,000 - 20,000 harbor seals (*Phoca vitulina richardsi*) during the late 1950s through the mid 1960s (Mathisen and Lopp 1963, Pitcher 1990). A commercial harvest during the 1960s through 1972 removed an estimated 18,000 seals from the island, about 90% of which were pups. The harvests likely were responsible for a decline in the number of seals through 1972. A simulation model of the effects of the harvest suggested that the population would stabilize by the mid 1970s and then slowly begin to increase (Pitcher 1990). Biennial counts conducted from 1976 through 1988, however, detected a 72% - 85% decline in the number of harbor seals using the island (Pitcher 1990). Numbers may have stabilized during the early to mid 1990s (Lewis *et al.* 1996); the maximal count in 1995 was just under 2,000 seals (Alaska Department of Fish and Game (ADFG) unpublished data).

The harbor seal decline was not an isolated event, as Steller sea lions (*Eumetopias jubatus*), northern fur seals (*Callorhinus ursinus*), and several species of piscivorous seabirds also have declined in the Gulf of Alaska and the Bering Sea (Braham *et al.* 1980, Fowler 1982, Merrick *et al.* 1987, York and Kozloff 1987, Loughlin *et al.* 1992, Springer 1993). While counts of overall numbers of harbor seals have been essential in identifying the population decline, a better understanding of the decline may be gained by examining pupping phenology and demography of seals on shore during the decline and later years. A shift in pupping phenology may indicate changes in prey abundance or availability or changes in the demographic structure of the population. Differences in the demographic structure of the seals on shore may reflect changes in behavior, survival rates, or the sex/age structure of the population.

We recorded pupping phenology and demography of the population on Tugidak Island to determine whether timing of pupping, indices of productivity, abandonment, first year survival, and the proportion of older males ashore differed during declining and stable years.

## METHODS

### Study area & timing

Harbor seals on the southern and western shores of Tugidak Island (56°30'N, 154°40'W) were surveyed during the pupping period in June 1976 - 1979 and May and June in 1994 - 1996; additional surveys were conducted during the molting period in August and September of 1976, 1978, 1979, and 1996.

During the 1970s, seals along the southwestern shore (SW Beach) were surveyed. Small numbers of seals hauled out sporadically on the central portion of the western shore (Middle Beach), but they constituted only a small fraction of the total number of seals on SW Beach, and were not included in counts. During the pupping period in the mid 1990s, SW and Middle Beach haulouts were of similar size and all seals in both areas were included in the surveys (Figure 2).

### Synopsis of data collected

Three types of data were collected and used in our analyses: pupping phenology (date of onset and maximal pup count), counts (total number of pups and non pups on shore during pupping, total number of seals on shore during molting), and demography (seals recorded according to sex/age class during pupping). Not all types of data were collected every year; as a result, not all sample years were suitable for the various comparisons (Table 1).

### Data collection

Observations were made using a spotting scope (20x) and binoculars (10 x 25) from atop 30 meter cliffs overlooking haulout beaches; a Polaroid camera was used to aid counting in some years. Whenever possible, surveys were conducted within 2 hours of afternoon low tide, when typically the greatest number of seals were on shore. Low tide surveys were not always possible, however, due to poor weather or the timing of the low tide. Seals on shore were easily counted during low and mid tides, when views of seals were unobstructed; during high tide, haulout space was limited to a narrow band of beach adjacent to the cliffs, making observations difficult. When more than one observer was available, each observer counted seals on about half of the beach area.

We categorized seals according to sex and age class during the pupping period in June. Sex was determined by the location of genitalia when the ventrum was visible or by association of a mother and pup. When sex could not be ascertained, the sex was recorded as unknown. We classified seals as either pups, yearlings, or older. Pups were easy to identify by their small size, newly molted pelage, and association with their mother. Unattended pups that were either starvelings or appeared too young to be weaned were recorded as lone pups. Yearlings were defined as the smallest size class of seal excluding pups and typically had a muddy or bleached pelage which lacked obvious spots and rings, as they were in the pre-molt stage. Any seal larger than a yearling was recorded as older; this category included both immature and mature animals.

### Comparable time periods

We compared count and demographic data between years during a standardized peak pupping period. We defined the peak pupping period as a nine day period centered around the maximal pup count. To compare counts of all seals on shore during August - September, the adult molting period, we used counts during a nine day period centered around the maximal count.

### Analyses

Demographic data from 1978, 1994, 1995, and 1996 were summarized and compared by forming indices of productivity, abandonment, first year survival, and the proportion of older males. The following ratio estimators (Scheaffer *et al*. 1990) were used as indices:

| | |
|---|---|
| *Index of productivity* | Pups / Older females |
| *Index of abandonment* | Lone pups / Pups |
| *Index of first year survival* | Yearlings / Non pups |
| *Older males* | Older males / Older seals |

Our index of productivity may be low, since the older female category included some immature females; however, this measure considers only females on the beach and thus may be biased high if non-pregnant females remained at sea rather than hauling out.

For each index, a single ratio estimate was calculated for each year by using the series of counts within the peak pupping period as a cluster (summing over time in numerator and denominator), which reduces the impact of daily time dependence. A Student's t - test was used to compare whether there were significant differences between two years; we used $\alpha = 0.05$ as our significance level.

We used the Kruskal-Wallis one way analysis of variance test to determine whether there was a significant difference between 1976 and 1979 in the number of pups and the number of non pups (Daniel 1978). Each of the nine days centered around the maximal pupping date were treated as independent observations. Additionally, we used the Kruskal-

Wallis test to determine whether there was an overall significant difference in the number of seals on shore during the 1990s. A Bonferroni multiple-comparison procedure with $\alpha = 0.05$ was used to identify significant differences between years. The Kruskal-Wallis test and Bonferroni procedure were also used to identify changes in the number of seals within each sex/age category during the 1990s.

Maximal and mean counts of seals in each sex/age category were compiled to determine the percent change within each category between 1994, 1995, and 1996.

Typically, we were able to determine the sex of 65% - 80% of the older seals during each survey. Therefore, in order to determine the total number of each sex in the older age category, we estimated the number of females and the number of males in the unknown/older category. We used the ratio of older males to older females without pups to estimate the number of males and females in the unknown/older category. The estimated number of each sex was then added to the observed number of each sex as an estimate of the total number of older females and older males. During 1995 and 1996, seals tended to separate into three haulout areas, two of which were skewed toward either males or females. We estimated the number of seals in the unknown category for each haulout individually during those years.

To see if there were differences in the number of seals hauled out during the peak pupping and molting periods in 1976, 1978, 1979, and 1996, we formed the following ratio.

*Pupping : Molting* mean # seals during pupping : mean # seals during molting

An estimated variance was calculated using a Taylor series approximation (Rice 1995). We assumed that counts conducted during the pupping and molting periods were independent of each other and thus set the covariance term to zero. Individual ninety-five percent confidence intervals were calculated. When comparing pairs of years using these confidence intervals, the overall confidence level was 90%.

## RESULTS

### Timing of pupping

A mother-pup pair or single lone pup was occasionally observed during May surveys in 1976, but not until 1 June was more than one attended pup seen on SW Beach (Johnson 1976a); the onset of pupping in 1977 and 1978 was similar to 1976 (Table 2). In 1994 and 1995, the onset of pupping was not observed, but pups were present during the first day of observations (25 May), and approximately 75 pups were on shore by 1 June. In 1996, two newborn pups were observed on 13 May, and by the first of June 182 pups were on shore. Bishop (1967) reported that pupping on Tugidak Island in 1964 began in early May. Pups born before mid May retained some or all of their lanugo which is normally shed *in utero* before birth; the majority of these pups were eventually deserted. Most pups born in the later half of May had shed their lanugo *in utero* and were attended by their mothers.

In 1964, the greatest number of pups on shore was observed about 13 June (Bishop 1967). Timing of the maximal pup count was very similar between years in the 1970s, occurring from 20 to 22 June in 1976, 1978, and 1979. The maximal number of seals ashore in 1977 probably occurred during the same time period; however, disturbances caused seals to leave the beach and interrupted the counts. During 1994, 1995, and 1996, timing of the maximal pup counts was similar to 1964. Thus, peak pupping occurred 7 - 11 days earlier in 1964 and the mid-1990s than in the mid to late 1970s. Whether the shift in the onset and peak of pupping was gradual, occurring over several years, or abrupt is unknown.

During the 1970s, the length of time from the onset of pupping to the peak pup count was about 21 days. The length of time from the onset of pupping to the maximal pup count was similar in 1964 and 1996 (about 30 days, assuming pupping began 15 May in 1964, when females began attending their pups).

### Trends in June count data: 1970s

Pitcher (1990) reported a 72% decline between 1976 and 1986 in counts of harbor seals during the pupping period (which he defined as 1 - 30 June) on Tugidak Island. To further investigate that decline, we tested whether there was a decline in the number of pups and the number of non pups in those years. Both the number of pups and the number of non pups declined significantly between 1976 and 1979 (Kruskal-Wallis statistic for both = 6.0000, $p = 0.0143$). The mean number of pups on shore declined an average of 18% per year; similarly, the mean number of non-pups on shore declined an average of 16% per year (Table 3).

### Trends in June count data: 1990s

The number of seals on shore during the peak pupping period varied between 1994, 1995, and 1996 (Kruskal-Wallis statistic = 10.7978, $p = 0.0045$). The number of seals in 1994 was significantly lower than in 1995 ($p < 0.05$) or 1996 ($p < 0.05$). The number of seals in 1995 and 1996 was similar to each other ($p > 0.20$). The maximal and mean numbers of seals increased 53% and 55%, respectively, between 1994 and 1995 (Table 4).

The number of pups increased similarly between 1994 - 1995 and 1995 - 1996 (mean counts increased 14% and 12%, respectively), although the number of pups was only significantly different between 1994 and 1996 ($p < 0.05$). Between 1994 and 1995, there was a 78% increase in the mean number of non pups on shore ($p< 0.05$); however, non pup counts did not differ between 1995 and 1996 ($p > 0.20$).

Among non pups, the number of seals in each demographic class increased from 1994 to 1995, however, they did not increase at the same rate. The mean counts of yearlings, older males, and older females increased 236%, 154%, and 45%, respectively. Changes in the number of seals in each demographic class were smaller between 1995 and 1996 (Table 5).

### Index of productivity

The ratio of pups to older females was 0.75 (1978), 0.76 (1994), 0.60 (1995), and 0.70 (1996); the ratio in 1995 was significantly lower than in 1994 ($p < 0.05$) and significantly lower than in 1978 at $\alpha = 0.10$. Small sample size in 1978, $n = 4$, may have limited power to detect a significant difference. There were no significant differences between any other two years (Table 6).

The index of productivity was lowest in 1995. Between 1994 and 1995 there was a significant increase in both the number of yearlings and the number of older females. If the increase in older females resulted mainly from an increase in non-mature females (as suggested by the increase in yearling seals), the ratio of pups to older females would be reduced.

### Index of abandonment

The ratio of lone pups to total pups on shore in 1978 (0.10) was significantly greater ($p<0.05$) than in 1995 (0.04) and 1996 (0.04).

### Index of first year survival

In 1994, the ratio of yearlings to non pups was lowest and significantly different from every other year ($p < 0.01$), while this ratio was significantly greater in 1978 than every other year ($p < 0.05$). The ratio was similar between 1995 and 1996 ($p > 0.10$).

### Older males

The ratio of older males to older seals was significantly lower ($p < 0.05$) in 1978 than in 1995 and 1996; the ratio was also significantly lower in 1994 than in 1996 ($p < 0.05$). The number of older males on shore differed between 1994, 1995, and 1996 (Kruskal-Wallis statistic = 11.5968, $p = 0.0030$); the number of older males was significantly less in 1994 than in 1995 and 1996 ($p < 0.05$).

### Older females

The number of older females on shore also differed between 1994, 1995, and 1996 (Kruskal-Wallis statistic = 9.1031, $p = 0.0106$); the difference was significantly less in 1994 than 1995 or 1996 ($p < 0.05$).

Changes in haulout patterns during molting

The longest series of daily counts during the molting period were conducted in 1976 and 1996, when seals were surveyed from early August through early to mid September. In 1976, the number of seals increased from 2,526 on 1 August to 9,300 on 30 August; thereafter the number of seals declined. The trend in seal numbers in 1996 was quite different, with no steady increase in the number of seals ashore throughout the month (Figure 3).

Pupping period (June) : Molting period (August) ratios

During the mid-late 1970s, many more seals hauled out during the molting period than during the pupping period. The ratio formed by dividing the mean number of seals during the peak pupping period by the mean number during the peak molting period was 0.36 in 1976, 0.23 in 1978, and 0.30 in 1979. In 1996, the mean number of seals during the peak pupping period was greater than the mean number of seals during the peak molting period (ratio = 1.15). The confidence intervals for 1996 and 1979 did not overlap, but all other pairs of comparisons between years overlapped. Ratios calculated using maximal pupping and molting counts (1976= 0.38, 1978 = 0.24, 1979= 0.34, and 1996=1.05) were similar to those calculated using means.

## DISCUSSION

The 85% decline in the number of harbor seals in the Gulf of Alaska described by Pitcher (1990) suggests that conditions in the western Gulf of Alaska were not conducive to a stable or growing population of harbor seals during the mid to late 1970s through the early 1990s. Reduced food availability may have played a role in the decline of other marine mammal and seabird species during the past 30 years in the Gulf of Alaska and the Bering Sea (*e.g.*, Merrick *et al.* 1987, Trites 1992, Springer 1993) and limited food resources may have contributed to the harbor seal decline on Tugidak Island. Changes in the harbor seal population on Tugidak Island have been tracked by repetitive counts of seals ashore during the pupping and molting periods. While these counts have been essential in identifying the decline, additional understanding of the decline is gained by examining pupping phenology and the dynamics of sex and age structure of seals on shore.

Shift in the timing of pupping

The onset and peak of pupping occurred earlier in 1964 and in the mid 1990s than in the mid to late 1970s; additionally during the 1970s, the length of time from the onset to the peak of pupping was shorter. The later pupping period during the 1970s is unusual, as timing of birth of most pinnipeds in temperate or higher latitudes varies little between years (Bartholomew and Hoel 1953, Boyd and Campbell 1971, Boulva 1975, LeBoeuf and Briggs 1977, Coulson 1981, Stein 1989, Duck 1990, Boyd 1991). Changes in pupping phenology may be related to the age structure of the population, a change in the time when food is available, or a reduction in available food.

Changes in the age structure of the harbor seal population on Tugidak Island could influence the timing of pupping. Older female northern elephant seals (*Mirounga angustirostris*) and possibly Antarctic fur seals tend to give birth earlier than younger females (Reiter *et al.* 1981, Lunn and Boyd 1993, Lunn *et al.* 1994, Boyd 1996). If older female harbor seals give birth earlier, the later date of pupping in the 1970s might suggest a population skewed toward young females. Due to the commercial harvests that continued through 1972, however, we suspect that the population was skewed toward older females during the mid 1970s. It appears that during years when the population was large (1964) or potentially increasing (1990s), pupping occurred earlier and was of longer duration.

Temporal changes in food availability could alter parturition dates. Temte (1994) proposed that the timing of pupping in Alaska is likely constrained by temperature, prey availability, and ice conditions. Boyd (1984) found that female gray seals (*Halichoerus grypus*) whose body condition increased earliest in spring had the earliest implantation dates. Stewart *et al.* (1989) proposed that implantation in Atlantic harp seals (*Phoca groenlandicus*) occurred after females attained a certain level of body fat. If important prey resources became available to females later in the summer during the 1970s, females may have been delayed in attaining a level of body fat necessary for the reproductive cycle to continue, which in turn delayed parturition. Whether a delay in the reproductive cycle influences the implantation stage or the length of gestation is unclear. While both the onset and peak of pupping were earlier in the 1990s than the 1970s, the timing of pupping within the 1970s and within the 1990s was very consistent. The consistency in timing of pupping suggests that the forces influencing timing were effecting all females similarly.

The observed shift in pupping on Tugidak Island suggests that harbor seal females may have had difficulty obtaining adequate food, as female body condition and/or food availability has been correlated with timing of reproduction in other mammals. Antarctic fur seal (*Arctocephalus gazella*) females returned to the breeding beaches later, gave birth later, were less likely to give birth and successfully wean their pups, and had longer pregnancies, in years of reduced food availability (Duck 1990, Lunn and Boyd 1993, Lunn *et al.* 1994, Boyd 1996). Studies of terrestrial mammals have linked food availability and/or female body condition with changes in timing of reproduction in white-tailed deer (*Odocoileus virginiamus*) (Ruthven *et al.* 1994), Southern mule deer (*Odocoileus hemionus fuliginatus*) (Bowyer 1991), reindeer (*Rangifer tarandus tarandus*) (Skogland 1984), Dall's sheep (*Ovis dalli*) (Rachlow and Bowyer 1991), marbled polecats (*Vormela peregusna syriaca*) (M. Ben-David, University of Alaska Fairbanks, Fairbanks, AK) and mink (*Mustela vison*) (Ben-David 1997).

Based on data from 1964 and the 1970s, it appears that the age of first ovulation was later in the 1970s. In 1964, Bishop (1967) examined 11 harbor seal females aged three to five years old and determined that all 11 were mature by four years of age. In contrast, Pitcher and Calkins (1979) examined 26 three and four year-old females and found that only seven were mature by four years of age. The age of first reproduction may have been later in the 1970s as a result of reduced food availability. Density dependent factors were likely not the cause of the later age of maturity during the 1970s as the population apparently was an order of magnitude larger during the 1960s. Additionally, ages of first ovulation and initial pregnancy were significantly higher for seals in the Gulf of Alaska during the mid 1970s than for seals in British Columbia and Prince William Sound (Pitcher and Calkins 1979).

The mean number of pups and non pups on shore declined an average of 18% and 16% per year, respectively, during the 1970s. If we assume a constant sex/age structure to the population from 1976 to 1979, then the non pup decline reflects an overall change in the population, including a decline in mature females, which in turn represents a decline in the number of pups born. The similarity of the pup and non pup declines suggests that a large change in productivity did not occur. Pitcher and Calkins (1979) found pregnancy rates of females eight years and older in the Gulf of Alaska during the mid 1970s to be high (92%) and not significantly different from pregnancy rates of seals in British Columbia (97%), suggesting that productivity did not decline.

The higher ratio of lone pups to total pups in 1978 may be further evidence that females had difficulty obtaining food during the mid to late 1970s. Reduced food availability resulted in female Antarctic fur seals increasing their time at sea (Boyd *et al.* 1994) and in having less success in raising their pups (Lunn *et al.* 1994); if harbor seals respond similarly, the result may be an increase in abandoned pups. Alternately, frequent disturbances in the 1970s may have contributed to high rates of abandonment.

Between the mid 1970s and the 1990s, harbor seals also declined elsewhere in Alaska including Nanvak Bay in northern Bristol Bay (Johnson 1976b; Wilson and Jemison 1994; Wilson 1995; Moran and Wilson 1996), Otter Island in the Pribilof Islands (Johnson 1976b, Kelly 1978, Jemison 1996), the north side of the Alaska Peninsula (Withrow and Loughlin 1996), Aialik Bay (Hoover 1983, Hoover-Miller 1994), and Prince William Sound (Frost and Lowry 1994). Opportunistic surveys of harbor seals in the Kodiak area during the 1970s and 1980s indicated that a major area-wide decline occurred (Lewis *et al.* 1996), suggesting that seals on Tugidak Island did not simply move to nearby haulout sites. In Southeast Alaska, populations appear to be stable or increasing (Lewis *et al.* 1996), and seals in British Columbia have been increasing about 12.5% per year since 1973 (Olesiuk *et al.* 1990).

## Potential causes of food limitations

Factors that may have influenced food availability for marine mammals and birds include a change in oceanic and atmospheric conditions, the impacts of commercial fisheries, or a combination of these. A significant climatic change in the north Pacific region from about 1976 to 1988 was characterized in Alaska by a shift from cooler to warmer ocean and atmospheric conditions (Trenberth 1990, Trenberth and Hurrell 1994). On Gertrude Island, Washington, harbor seal births peaked in mid August in the mid 1970s and in late September in 1991 (Moss 1992). The shift to a later pupping period in Washington occurred during the same years as the shift to an earlier pupping period on Tugidak Island; the opposite shift may be related to the out of phase fluctuations of the Alaska and California currents (Chelton and Davis 1982). During years when there are stronger circulation and cooler sea surface temperatures in the Gulf of Alaska, sea surface temperatures off the Washington coast are warmer and California current flow is weaker (Hollowed and Wooster 1992). Those differences in oceanic conditions have been related to differences in production and abundance of zooplankton and fish (Wickett 1967).

Coincident with the climate shift was a dramatic change in the community structure in the western and central Gulf of Alaska from a crustacean/forage fish dominated community to a pleuronectid/gadid dominated community (Piatt and Anderson 1996). The abundance of capelin (*Mallotus villosus*), a top-ranked prey item of harbor seals in the Gulf of Alaska (Pitcher 1980), has fluctuated in recent decades. Bottom trawls in Pavlov Bay were dominated by capelin and shrimp between 1972 and 1978. After 1978, capelin and shrimp abundance greatly declined coincident with large increases in pollock, cod, and flatfishes. The abrupt change in species composition was seen in all trawl surveys conducted in the western and central Gulf of Alaska, including a long time series of trawls conducted off the southern end of Kodiak Island (Piatt and Anderson 1996).

Spawning capelin may be an especially important food source for pups and lactating harbor seals. Capelin come inshore to spawn from June through August in the Kodiak area (P. Anderson, National Marine Fisheries Service, Kodiak, AK), coinciding with harbor seal lactation and the first month or two of foraging by newly weaned pups. During and after spawning, capelin are weakened or die, and are potentially easy prey for harbor seals. Although sample sizes were too small for statistical comparisons, pups (n = 13) appeared to eat a higher proportion of capelin than did older animals (Pitcher and Calkins 1979). Weaned pups likely have a narrower diet and are restricted to smaller fish and invertebrate prey than are older seals. Thus, they may be more susceptible to changes in prey abundance and availability than are adults. In the Gulf of Alaska, prey in 13 weaned pup stomachs, sampled in the mid to late 1970s, were small in length (<15 cm) and included shrimp, capelin, Pacific tomcod (*Micrlandus proximus*), walleye pollock (*Theragra chalcogramma*), and Pacific sandlance (*Ammodytes hexapterus*) (Pitcher 1980). Documented declines in capelin and shrimp, which occurred at the same time as the harbor seal decline, may have influenced the survival of newly weaned pups.

Pollock was another top-ranked prey of harbor seals collected from 1973 through 1978 in the Gulf of Alaska (Pitcher 1980). Warmer water temperatures and increases in zooplankton throughout the North Pacific have been associated with increases in abundance, catch, or strong year-classes of several commercially important fish species including pollock, salmon (*Onchorhynchus* spp.), and sablefish (*Anoplopoma fimbria*) (Alverson 1992, Brodeur and Ware 1992, McFarlane and Beamish 1992, Francis and Hare 1994). Despite the regional increase in pollock abundance, there was evidence of changes in pollock distribution and the abundance of smaller age classes coincident with the regime shift that may have made pollock less available to harbor seals in the Kodiak area. After 1977, the center of pollock abundance may have shifted from the Kodiak area westward to the Shumagin Islands (Alton *et al.* 1987). Hollowed and Megrey (1989) described an 80% decline between the late 1970s and the mid 1980s in 3-year old pollock, an age-class that is an important prey size for harbor seals (Frost and Lowry 1986).

Pollock were clearly important in marine mammal diets during the 1970s (Pitcher 1980, 1981). Alverson (1992) presumed that pollock abundance in the Gulf of Alaska was low during the early 1960s, coinciding with high Steller sea lion populations, leading him to question whether pollock were an important part of the Steller sea lion diet at that time. Alverson suggested that small forage fishes and squids were likely much more important in the diet of both Steller sea lions and northern fur seals in the early 1960s and that the importance of pollock increased greatly during the 1970s and 1980s. It is reasonable to speculate that similar shifts in prey importance in harbor seal diets occurred. The first and highest population estimates for harbor seals in the Gulf of Alaska came from the late 1950s/early 1960s (Mathisen and Lopp 1963, Bishop 1967) when pollock abundance may have been low.

It is unclear how commercial fisheries have influenced the availability of important prey resources of marine birds and mammals. Since the mid 1950s, fisheries off the coast of Alaska have grown at a tremendous rate. Large removals of certain fish and invertebrate species have likely altered predator-prey relationships, influencing community structure and confounding interpretations of environmentally influenced changes. As Alverson (1992) points out, the uncertainties are too numerous to separate the effects of environmental changes and commercial fisheries on the ecosystem; however, it is clear that the community structure in the Gulf of Alaska during the early 1960s differed dramatically from the early 1990s. Based on the evidence that important prey resources were less abundant or available during the late 1970s through the 1980s, we consider these to be "poor" food years.

### Increasing population trend during the 1990s

Our data suggest that the harbor seal population using the southern and western shores of Tugidak Island was increasing during the 1990s, particularly after 1994. Between 1994 and 1995, the total number of seals on shore increased more than 50%, which may indicate that the population was growing. This increase, however, was greater than what was biologically possible in a closed population, suggesting that seals moved to Tugidak from other areas or that environmental conditions were conducive to more seals coming ashore. Although the total number of seals on shore was only slightly higher in 1996 than in 1995 (and not significantly different), we suspect that the population was still increasing because the number of pups born increased at a similar rate between 1994 - 1995 and 1995 - 1996. Other studies in the Gulf of Alaska provide support for these observations. Surveys of several sites in the Kodiak Island area from 1992 - 1995 indicated a stable or increasing harbor seal population (Lewis *et al.* 1996). Investigations of the health status and body condition of harbor seals from 1993 - 1995 did not find indications of diseased or unhealthy animals (Fadely and Castellini 1996). The Kodiak and Aleutian Islands regions had the highest harvest of juvenile harbor seals throughout the state between 1992 and 1995 (Wolfe and Mishler 1996). In the Kodiak area, 32% to 40% of the total harvest consisted of juveniles from 1992 - 1994 and increased to 52% in 1995. Capelin were an important prey item of halibut and several species of seabirds in the waters north of Kodiak Island in the mid 1990s (Roseneau *et al.* 1996, Roseneau and Byrd 1997) suggesting that their abundance may be increasing; however, there is no evidence from on-going, long term trawl surveys in the western Gulf of Alaska that capelin abundance has increased since the early 1980s (P. Anderson, National Marine Fisheries Service, Kodiak, AK). Based on the observations that the harbor seal population stabilized in the 1990s and possibly began increasing after 1994, we considered the years after 1994 to be "better" food years than the period from the late 1970s through the 1980s.

### Food availability and demographic structure of haulout

We suggest that during years when seals have difficulty obtaining enough food, they will spend less time on shore resting (or possibly nursing) and more time at sea foraging, a strategy employed by Antarctic fur seals (Boyd *et al.* 1994). Thompson *et al.* (1994) suggested that the degree to which harbor seal females fed during lactation was related to body size. Smaller females increased their time away from haulout areas, presumably on foraging trips, sooner after parturition than larger females, which probably have greater energy reserves. We hypothesize that during poor food years, seals with the strongest ties to land will make up a larger portion of the seals on shore than during years when food resources are not as limited. During the pupping period, reproductive females likely have the greatest need to haul out as they come ashore to give birth and nurse their pups. Younger animals, such as yearlings, may also have strong ties to land as they are beginning to molt during the pupping period. Seals haul out more frequently and for longer periods during the period of new hair growth (Stewart and Yochem 1984, Calambokidis *et al.* 1987, Thompson *et al.* 1989, Watts 1996) presumably because warmer temperatures on land allow skin temperatures to be elevated, expediting hair growth (Feltz and Fay 1966). Adult males may have the least need to come ashore during the peak pupping period, as new hair growth has not yet begun and few females are in estrus.

The demographic data support the idea that the sex/age structure of seals on shore is influenced by environmental conditions, such as food availability. The ratios of older males to older seals on shore were highest during 1995 and 1996, as we would expect during better food years when males could "afford" to spend more time on shore resting. The ratio of yearlings to non pups on shore was highest in 1978 and lowest during the 1990s. We expected a higher ratio of yearlings to non pups during the pupping season in poor years, since yearlings are beginning to molt then. The high ratio in 1978 is consistent with the idea that during poor food years, seals with strong ties to land will make up a larger proportion of the seals on shore. We would also expect, however, that other factors may confound the ratio of yearlings to non pups. During years when food is limited, young seals may have the greatest difficulty obtaining sufficient food and thus might increase their time at sea foraging and/or have increased mortality rates. The ratio of pups to older females was high in 1978 and lowest in 1995, suggesting that, during poor food years, non reproductive females were less likely to haul out. While our indices of productivity and first year survival are reflective of changes in environmental conditions, they are confounded by changes in haulout behavior and so are not accurate measures of production and survival.

Overall, 1994 stands out as an unusual year in most of the comparisons, not fitting the pattern of 1970s (declining numbers, poor food availability) vs. the 1990s (stable or increasing numbers, possibly better food availability). We wonder if 1994 was perhaps a transition year in the Tugidak area from a period of poor food availability to one of better food availability. Preliminary analyses from 1997 suggest that the sex/age structure of seals on shore is similar to 1995 and 1996.

### Pupping : molting relationship

During the 1970s on Tugidak Island, 2 - 4 times as many seals hauled out during the molting period as during the pupping period. The ratio changed dramatically by the mid-1990s, however, when more seals came ashore during the pupping period. Additionally, there was no large increase in the number of seals on shore during August of 1996, as there had been in August during the 1970s. The change in the relationship of pupping and molting numbers may be related to changes in the demographic structure of the population, combined with the differential timing of the molt in different sex/age classes. Harbor seal pups molt first (*in utero*), followed by yearlings, then by older females, and finally by older males (Bishop 1967, Johnson 1976a, Thompson and Rothery 1987). Thus, a population skewed toward younger seals would probably exhibit an earlier increase in numbers associated with molting than a population skewed toward older animals. Additionally, changes in haulout behavior could influence the relationship of pupping to molting numbers; as suggested earlier, during poor food years older males may be less likely to haul out during the pupping period, which would lower the pupping to molting ratio. In most regions of Alaska, the relationship of pupping to molting numbers is not well known.

### Relevance to population monitoring

In Alaska, aerial surveys to estimate populations and determine population trends have been timed to correspond with the adult molting period, except along the north side of the Alaska Peninsula, where counts have been conducted during pupping and molting periods (Everitt and Braham 1980, Loughlin 1992). The precise timing of molting, however, is unknown in many regions of Alaska. Surveys not conducted at a similar stage of the molt within and between regions may make population estimates and elucidation of population trends difficult. Studies during the 1960s suggested that molting in Southeast Alaska began three weeks later than in the Prince William Sound - Kodiak region (Jemison 1997), yet this was never confirmed. Additionally, the timing of molting varies between sex and age classes and is not necessarily stable from year to year. Counts conducted during the peak molting period are likely biased toward certain sex and age classes, and changes in the demographic structure of the population or in the timing of pupping may change the timing of the peak molting period, further confounding interannual comparisons. For example, if surveys are conducted during the peak of the adult molting period, detection of a decline in juvenile survival may be delayed. Conversely, when a population begins to increase, this increase may not be evident for several years based on molt surveys, but instead may be more visible during the pupping period, as may currently be the case on Tugidak Island.

The abrupt increase in the number of seals between 1994 and 1995 on Tugidak Island was similar to an increase observed on the Alaska Peninsula. From the mid 1960s to 1975, counts at the major haulout sites along the north side of the Alaska Peninsula ranged from 5,000 to 15,000 seals during pupping. Counts of those sites in 1976 recorded over 23,000 seals, while counts from 1977 through 1991 ranged from 10,000 to 12,600 seals (Hoover-Miller 1994). The 1976 counts have made it difficult to determine whether the population along the Alaska Peninsula had declined, and those counts were at times deleted from the analyses to make comparisons easier. We suggest that the exceptional count in 1976 may reflect an increase in time ashore by many or all sex/age classes as a result of good foraging conditions, similar to what may have happened on Tugidak Island in 1995. The large increases in the number of seals on shore in consecutive years at Tugidak Island and along the north shore of the Alaska Peninsula suggest that aerial and ground surveys of hauled out seals may not accurately reflect population size. Other methods should be employed to help track population changes and to help interpret the results of aerial surveys. Long-term monitoring of pupping phenology and the timing of the molt at representative sites throughout the state will allow aerial surveys to be timed so that they are comparable between years. Counts of the number of pups on shore during the peak pupping period may be an additional way to track population trends. Changes in pupping phenology and the sex/age structure of seals on shore, particularly the proportion of older males to older seals, may reflect important environmental changes. Comparisons with other long term studies of climate and ecosystem change may greatly enhance interpretation of these changes. Using a standard time period, such as the peak pupping period, to compare demographic and count data will insure that between year comparisons are conducted during the same biological time period.

## ACKNOWLEDGMENTS

We were lucky to have excellent assistance and good company in the field from Jen Donnel, Jeff Jemison, Joel Kafka, Eileen Kelly, Robin Lynn, Gay Sheffield, Mike Simpkins, and Carol Wilson. Unpublished data were provided by Brian Johnson, Pattie Johnson, Dennis McAllister, and Ken Pitcher. We thank Mike Castellini, Alan Springer and Dana Thomas for their comments and suggestions on this project.

We thank Jon Lewis for his initial interest in and continued support for this project; Lori Quakenbush for valuable ideas and editorial comments; Dave Prokopowich for adding yet another camp to his morning radio schedule; Kate Wynne and Dave VanDenBosch for help with logistics; Norma Haubenstock for graphics expertise; and John and Midge Garber for their generous hospitality on Tugidak Island.

This effort has greatly benefited from helpful discussions with students, faculty, and staff at the University of Alaska Fairbanks and the Alaska Department of Fish and Game.

Thanks to Brian and Pattie Johnson for many thought-provoking discussions. Special thanks are due to Ken Pitcher. Ken began the monitoring program on Tugidak Island, and it was through his foresight and persistence that work continued through the 1990s. Ken also provided valuable insight into harbor seal biology and haulout behavior.

## LITERATURE CITED

Alton, M., M. O. Nelson, and B. A. Megrey. 1987. Changes in the abundance and distribution of walleye pollock (*Theragra chalcogramma*) in the western Gulf of Alaska (1961-1984). Fisheries Research 5:185-197.

Alverson, D. L. 1992. A review of commercial fisheries and the Steller sea lion (*Eumetopias jubatus*): the conflict arena. Reviews in Aquatic Sciences 6:203-256.

Bartholomew, G. A., and P. G. Hoel. 1953. Reproductive behavior of the Alaska fur seal, *Callorhinus ursinus*. Journal of Mammalogy 34:417-436.

Ben-David, M. 1997. Timing of reproduction in wild-mink: the influence of spawning Pacific salmon. Canadian Journal of Zoology 75:376-382.

Bishop, R. H. 1967. Reproduction, age determination, and behavior of the harbor seal, *Phoca vitulina* L., in the Gulf of Alaska. M.S. Thesis. University of Alaska, College. 121pp.

Boulva, J. 1975. Temporal variations in birth period and characteristics of newborn harbour seals. Rapports et Proces-Verbaux des Reunions 169:405-408.

Bowyer, R. T. 1991. Timing of parturition and lactation in southern mule deer. Mammalia 72:138-145.

Boyd, I. L. 1984. The relationship between body condition and the timing of implantation in pregnant grey seals *Halichoerus grypus*. Journal of Zoology, London 203:113-123.

---. 1991. Environmental and physiological factors controlling the reproductive cycles of pinnipeds. Canadian Journal of Zoology 69:1135-1148.

---. 1996. Individual variation in the duration of pregnancy and birth date in Antarctic fur seals: the role of environment, age, and sex of fetus. Journal of Mammalogy 77:124-133.

Boyd, I. L., J. P. Y. Arnould, T. Barton, and J. P. Croxall. 1994. Foraging behavior of Antarctic fur seals during periods of contrasting prey abundance. Journal of Animal Ecology 63:703-713.

Boyd, J. M., and R. N. Campbell. 1971. The Grey seal *Halichoerus grypus* at North Rona, 1959 to 1968. Journal of Zoology, London 164:469-512.

Braham, H. W., R. D. Everitt, and D. J. Rugh. 1980. Northern sea lion population decline in the eastern Aleutian Islands. Journal of Wildlife Management 44:25-33.

Brodeur, R. D., and D. M. Ware. 1992. Long-term variability in zooplankton biomass in the subarctic Pacific Ocean. Fisheries Oceanography 1:32-38.

Calambokidis, J., B. Taylor, S. Carter, G. Steiger, P. Dawson, and L. Antrim. 1987. Distribution and haul out behavior of harbor seals in Glacier Bay, Alaska. Canadian Journal of Zoology 65:1391-1396.

Calkins, D. G., and E. Goodwin. 1988. Investigation of the declining sea lion population in the

Gulf of Alaska. Unpublished rept., Alaska Dept. Fish and Game, Anchorage, AK. 76pp.

Chelton, D. B., and R. E. Davis. 1982. Monthly mean sea level variability along the western coast of North America. Journal of Physical Oceanography 12:757-784.

Coulson, J. C. 1981. A study of the factors influencing the timing of breeding in the grey seal *Halichoerus grypus*. Journal of Zoology, London 194:553-571.

Daniel, W. W. 1978. Applied Nonparametric Statistics. Boston, Houghton Mifflin Company. 503pp.

Duck, C. D. 1990. Annual variation in the timing of reproduction in Antarctic fur seals, *Arctocephalus gazella*, at Bird Island, South Georgia. Journal of Zoology, London 222:103-116.

Everitt, R. D., and H. W. Braham. 1980. Aerial survey of Pacific harbor seals in the southeastern Bering Sea. Northwest Science 54:281-288.

Fadely, B. S., and M. A. Castellini. 1996. Hematology and plasma chemistry values for Gulf of Alaska harbor seals, and preliminary regional comparisons 1993-95. Annual report: harbor seal investigations in Alaska. NOAA Grant NA57FX0367. Alaska Dept. Fish and Game, Douglas, AK. 203pp.

Feltz, E. T., and F. H. Fay. 1966. Thermal requirements in vitro of epidermal cells from seals. Cryobiology 3:261-264.

Fowler, C. W. 1982. Interactions of northern fur seals and commercial fisheries. Transactions of the North American Wildlife Conference 47:278-292.

Francis, R., C, and S. Hare R. 1994. Decadal-scale regime shifts in the large marine ecosystems of the North-east: a case for historical science. Fisheries Oceanography 3:279-291.

Frost, K., and L. Lowry. 1986. Sizes of walleye pollock, *Theragra Chalcogramma*, consumed by marine mammals in the Bering Sea. Fishery Bulletin 84:192-197.

Frost, K. J., and L. F. Lowry. 1994. Habitat use, behavior, and monitoring of harbor seals in Prince William Sound, Alaska. *Exxon Valdez* Oil Spill Restoration Project annual report (Restoration Project 93046), Alaska Dept. Fish and Game, Wildlife Conservation Division, Fairbanks. 99pp.

Hollowed, A. B., and B. A. Megrey. 1989. Gulf of Alaska pollock: population assessment and status of the resource in 1989. *In*: T. K. Wilderbuer ed. Condition of the groundfish resources of the Gulf of Alaska in 1989. Unpublished rept. submitted to the annual meeting of the International North Pacific Fisheries Commission, Anchorage.

Hollowed, A. B., and W. S. Wooster. 1992. Variability of winter ocean conditions and strong year classes of Northeast Pacific groundfish. ICES Journal of Marine Science 195:433-444.

Hoover, A. A. 1983. Behavior and ecology of harbor seals (*Phoca vitulina richardsi*) inhabiting glacial ice in Aialik Bay, Alaska. M.S. Thesis. University of Alaska, Fairbanks. 133pp.

Hoover-Miller, A. 1994. The harbor seal (*Phoca vitulina*) biology and management in Alaska.

Marine Mammal Commission, 1825 Connecticut Avenue, NW, Washington, D.C. 20009. (Updated account from Selected Marine Mammals of Alaska: Species accounts with research and management recommendations; Marine Mammal Commission. Washington, D.C.; 1-67; 2nd; Lentfer, J. W.).

Jemison, L. A. 1996. Report on the 1995 field season on Otter Island, Pribilof Islands, Alaska, 2 July to 8 August. Unpublished rept. Institute of Marine Science, University of Alaska Fairbanks. April 1996. 20pp.

---. 1997. Recent history and demography of harbor seals on Tugidak Island, Alaska. M.S. Thesis. University of Alaska, Fairbanks. 82pp.

Johnson, B. W. 1976a. Harbor seal investigations on Tugidak Island, 1976. Unpublished manuscr., University of Alaska, Anchorage. 54pp.

---. 1976b. Studies of the northernmost colonies of Pacific harbor seals, *Phoca vitulina richardsi*, in the eastern Bering Sea. Unpublished manuscr., Alaska Dept. Fish and Game, Fairbanks. 67pp.

Kelly, B. P. 1978. Biological observations on Otter Island, Pribilof Islands, July 1978 - a report to the National Marine Fisheries Service. Unpublished rept., Biological Sciences program, University of Alaska, Fairbanks. 10pp.

LeBoeuf, B. J., and K. T. Briggs. 1977. The cost of living in a seal harem. Mammalia 41:167-195.

Lewis, J. P., G. W. Pendleton, K. W. Pitcher, and K. Wynne. 1996. Harbor seal population trends in Southeast Alaska and the Gulf of Alaska. Annual report: harbor seal investigations in Alaska. NOAA Grant NA57FX0367. Alaska Dept. Fish and Game, Douglas, AK. 203pp.

Loughlin, T. R. 1992. Abundance and distribution of harbor seals (*Phoca vitulina richardsi*) in Bristol Bay, Prince William Sound, and Copper River Delta during 1991. Annual report for 1991 under the National Marine Fisheries Service, MMPA Population Assessment Program submitted to the Office of Protected Resources, National Marine Fisheries Service, NOAA, Silver Springs, Maryland. 26pp.

Loughlin, T. R., A. S. Perlov, and V. A. Vladimirov. 1992. Range-wide survey and estimation of total number of Steller sea lions in 1989. Marine Mammal Science 8:220-239.

Lunn, N. J., and I. L. Boyd. 1993. Effects of maternal age and condition on parturition and the perinatal period of Antarctic fur seals. Journal of Zoology, London 229:55-67.

Lunn, N. J., I. L. Boyd, and J. P. Croxall. 1994. Reproductive performance of female Antarctic fur seals - the influence of age, breeding experience, environmental variation and individual quality. Journal of Animal Ecology 63:827-840.

Mathisen, O. A., and R. J. Lopp. 1963. Photographic census of the Steller sea lion herds in Alaska, 1956-1958. U.S. Department of the Interior, Fish and Wildlife Service, Spec. Sci. Rept.--Fish. No. 424. 20 pp. Appendix: Notes on distribution and abundance of harbor seals, *Phoca vitulina* in the Gulf of Alaska and Aleutian Islands area. pp18-20.

McFarlane, G. A., and R. J. Beamish. 1992. Climatic influence linking copepod production with strong year-classes in sablefish, *Anoplopoma fimbria.* Canadian Journal of Aquatic Sciences 49:743-753.

Merrick, R. L., T. R. Loughlin, and D. G. Calkins. 1987. Decline in abundance of northern sea lions, *Eumetopias jubatus*, in Alaska, 1956-86. Fishery Bulletin 85:351-365.

Moran, J. R., and C. A. Wilson. 1996. Abundance and distribution of marine mammals in northern Bristol Bay and southern Kuskokwim Bay: a status report of the 1995 marine mammal monitoring effort at Togiak National Wildlife Refuge. Unpublished rept. U.S. Fish and Wildlife Service, Dillingham, Alaska. 45pp.

Moss, J. 1992. Environmental and biological factors that influence harbor seal (*Phoca vitulina richardsi*) haulout behavior in Washington and their consequences for the design of population surveys. M. S. Thesis. University of Washington, Seattle. 123pp.

Olesiuk, P. F., M. A. Bigg, and G. M. Ellis. 1990. Recent trends in the abundance of harbour seals, *Phoca vitulina*, in British Columbia. Canadian Journal of Aquatic Sciences 47:992-1003.

Pascual, M. A., and M. D. Adkison. 1994. The decline of the Steller sea lion in the Northeast Pacific: demography, harvest, or environment. Ecological Applications 4:393-403.

Piatt, J. F., and P. Anderson. 1996. Response of common murres to the *Exxon Valdez* oil spill and long-term changes in the Gulf of Alaska. American Fisheries Society Symposium 18:720-737.

Pitcher, K. W. 1980. Food of the harbor seal, *Phoca vitulina richardsi*, in the Gulf of Alaska. Fishery Bulletin 78:544-549.

---. 1981. Prey of the Steller sea lion, *Eumetopias jubatus*, in the Gulf of Alaska. Fishery Bulletin 79:467- 472.

---. 1990. Major decline in number of harbor seals, *Phoca vitulina richardsi*, on Tugidak Island, Gulf of Alaska. Marine Mammal Science 6:121-134.

Pitcher, K. W., and D. G. Calkins. 1979. Biology of the harbor seal, *Phoca vitulina richardsi*, in the Gulf of Alaska. Final report to OCSEAP, U.S. Department of Interior, BLM. Res. Unit 229 Contract 03-5-002-69. 72pp.

Rachlow, J. L., and R. T. Bowyer. 1991. Interannual variation in timing and synchrony of parturition in Dall's sheep. Mammalia 72:487-492.

Reiter, J., K. J. Panken, and B. J. LeBoeuf. 1981. Female competition and reproductive success in northern elephant seals. Animal Behavior 29:670-687.

Rice, J. A. 1995. Mathematical statistics and data analysis. Second ed. Wadsworth Publ. Co., Belmont, CA. 602pp.

Roseneau, D. G., A. B. Kettle, and G. V. Byrd. 1996. Barren Islands seabird studies. *In*: D. C. Duffy (compiler), APEX: Alaska Predator Ecosystem Experiment. *Exxon Valdez* Oil Spill Restoration project annual rept. (Restoration Proj. 95163), University of Alaska Anchorage.

Roseneau, D. G., and G. V. Byrd. 1997. Using Pacific halibut to sample the availability of forage fishes to seabirds. Proceedings: Forage Fishes in Marine Ecosystems. Alaska Sea Grant College Program, AK- SG-97-01. 11pp.

Ruthven, D. C., E. C. Hellgren, and S. L.Beasom. 1994. Effects of root plowing on white-tailed deer condition, population status, and diet. Journal of Wildlife Management 58:59-70.

Scheaffer, R. L., W. Mendenhall, and L. Ott. 1990. Elementary Survey Sampling, Fourth Edition. PWS-Kent, Boston. 390pp.

Skogland, T. 1984. The effects of food and maternal conditions on fetal growth and size in wild reindeer. Rangifer 4:39-46.

---. 1993. Report of the seabird working group. Pages 14-29 *in* S. Keller, ed. Is it food? Addressing marine mammal and seabird declines (workshop summary). University of Alaska, Alaska Sea Grant Report 93-01, Fairbanks. 59pp.

Springer, A. M., D. G. Roseneau, D. S. Lloyd, C. P. McRoy, and E. C. Murphy. 1986. Seabird responses to fluctuating prey availability in the eastern Bering Sea. Marine Ecology Progress Series 32:1-12.

Stein, J. L. 1989. Reproductive parameters and behavior of mother and pup harbor seals, *Phoca vitulina richardsi*, in Grays Harbor, Washington. M. A. Thesis. San Francisco State University, San Francisco. 110pp.

Stewart, R. E. A., B. E. Stewart, D. M. Lavigne, and G. W. Miller. 1989. Fetal growth of northwest Atlantic harp seal (*Phoca groenlandica*). Canadian Journal of Zoology 67:2147-2157.

Stewart, B. S., and P. K. Yochem. 1984. Seasonal abundance of pinnipeds at San Nicholas Island, California, 1980-1982. Bulletin Southern California Academy of Sciences 83:121-132.

Temte, J. L. 1994. Photoperiod control of birth timing in the harbour seal (*Phoca vitulina*). Journal of Zoology, London 233:369-384.

Thompson, P. M., M. A. Fedak, B. J. McConnell, and K. S. Nicholas. 1989. Seasonal and sex-related variation in the activity patterns of common seals (*Phoca vitulina*). Journal of Applied Ecology 26:521-535.

Thompson, P. M., D. Miller, R. Cooper, and P. S. Hammond. 1994. Changes in the distribution and activity of female harbour seals during the breeding season: implications for their lactation strategy and mating patterns. Journal of Animal Ecology 63:24-30.

Thompson, P., and P. Rothery. 1987. Age and sex differences in the timing of the moult in the common seal, *Phoca vitulina*. Journal of Zoology, London 212:597-603.

Trenberth, K. E. 1990. Recent observed interdecadal climate changes in the northern hemisphere. National Center for Atmospheric Research 71:988-993.

Trenberth, K. E., and J. W. Hurrell. 1994. Decadal atmosphere-ocean variations in the Pacific. Climate Dynamics 9:303-319.

Trites, A. W. 1992. Northern fur seals: why have they declined? Aquatic Mammals 18:3-18.

Watts, P. 1996. The diel hauling-out cycle of harbour seals in an open marine environment: correlates and constraints. Journal of Zoology, London 240:175-200.

Wickett, W. P. 1967. Ekman transport and zooplankton concentration in the North Pacific Ocean. Journal Fisheries Research Board of Canada 24:581-594.

Wilson, C. A. 1995. Abundance and distribution of marine mammals in northern Bristol Bay and southern Kuskokwim Bay: a status report of the 1994 marine mammal monitoring effort at Togiak National Wildlife Refuge. Unpublished rept. U.S. Fish and Wildlife Service, Dillingham, Alaska. 43pp.

Wilson, C. A., and L. A. Jemison. 1994. Abundance and distribution of marine mammals in northern Bristol Bay and southern Kuskokwim Bay: a status report of the 1993 marine mammal monitoring effort at Togiak National Wildlife Refuge. Unpublished rept. U.S. Fish and Wildlife Service, Dillingham, Alaska 47pp.

Withrow, D. E., and T. R. Loughlin. 1996. Abundance and distribution of harbor seals (*Phoca vitulina richardsi*) along the north side of the Alaska Peninsula and Bristol Bay during 1995. National Marine Mammal Lab, National Marine Fisheries Service, NOAA, Seattle, Washington. 22pp.

Wolfe, R. J., and C. Mishler. 1996. The subsistence harvest of harbor seal and sea lions by Alaska Natives in 1995. Final report for year four, Subsistence Study and Monitor System (No. 50ABNF40080) prepared for the National Marine Fisheries Service by the Division of Subsistence, Alaska Dept. Fish and Game, Juneau.

York, A. E., and P. Kozloff. 1987. On the estimation of numbers of northern fur seal, *Callorhinus ursinus*, pups born on St. Paul Island, 1980-86. Fishery Bulletin 85:367-375.

Table 1. Synopsis of types of data collected each year on Tugidak Island

| | Pupping phenology | Count data | Demographic data |
|---|---|---|---|
| 1976[a] | X | X | |
| 1977[b] | X | | X |
| 1978 | X | X[c] | X |
| 1979 | X | X | |
| 1994 | X | X | X |
| 1995 | X | X | X |
| 1996 | X | X | X |

[a] unpublished data provided by B. & P. Johnson

[b] data unusable for most analyses due to disturbances during the peak pupping period

[c] pups counted only in a portion of the herd and, therefore, could not be used in comparisons with total numbers of pups in other years

Table 2. Harbor seal pupping phenology on Tugidak Island, Alaska.

| Year | Onset (> 1 attended pup) | Date of maximal pup count | Source |
|---|---|---|---|
| 1964 | mid-May | 13 June | Bishop 1967 |
| 1976 | 1 June | 22 June | Johnson 1976b |
| 1977 | 1 June | | this study |
| 1978 | 1 June | 21 June | this study |
| 1979 | | 20 June | McAllister unpublished |
| 1994 | | 11 June | this study |
| 1995 | | 11 June | this study |
| 1996 | 13 May | 12 June | this study |

Table 3. Summary of harbor seal pup and non pup counts during the peak pupping period on Tugidak Island, Alaska.

| | | PUPS | | | | | NON PUPS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | n[a] | Max | Max % Chg[b] | Mean | Std. Dev. | Mean % Chg[c] | Max | Max % Chg[b] | Mean | Std. Dev. | Mean % Chg[c] |
| 1976 | 4 | 833 | | 694 | 112.2 | | 2733 | | 2021 | 482.2 | |
| 1979 | 6 | 361 | -19* | 311 | 42.5 | -18* | 1350 | -17* | 1059 | 228.2 | -16* |
| 1994 | 6 | 225 | | 197 | 19.6 | | 459 | | 354 | 55.0 | |
| 1995 | 5 | 257 | 14 | 225 | 19.6 | 14 | 780 | 70 | 631 | 129.4 | 78 |
| 1996 | 7 | 292 | 14 | 251 | 26.6 | 12 | 773 | -1 | 627 | 104.8 | -1 |

Note: maximum pup and non pup counts did not necessarily occur on the same day during the peak pupping period

[a] n Number of days of counts within peak pupping period

[b] Percent change in the maximal number of seals since previous year

[c] Percent change in the mean number of seals since previous year

* Average of the 3-year period

Table 4. Summary of harbor seal counts during the peak pupping (June) and peak molting (Aug/Sept) periods on Tugidak Island, Alaska.

| | | TOTAL SEALS (JUNE) | | | | | TOTAL SEALS (AUG) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | n[a] (June) | Max | Max % Chg[b] | Mean | Std. Dev. | Mean % Chg[c] | n (Aug) | Max | Max % Chg[b] | Mean | Std. Dev. | Mean % Chg[c] |
| 1976 | 4 | 3566 | | 2715 | 577.3 | | 6 | 9300 | | 7708 | 1219.9 | |
| 1979 | 6 | 1649 | -18* | 1370 | 223.1 | -17* | 5 | 4886 | -16* | 4485 | 329.7 | -14* |
| 1994 | 6 | 652 | | 551 | 62.4 | | | | | | | |
| 1995 | 5 | 995 | 53 | 856 | 138.9 | 55 | | | | | | |
| 1996 | 7 | 1065 | 7 | 878 | 126.7 | 3 | 9 | 1015 | | 844 | 132.9 | |

[a] n Number of days of counts within peak pupping (June) and peak molting (August) periods

[b] Percent change in the maximal number of seals since previous year

[c] Percent change in the mean number of seals since previous year

* Average of the 3-year period

Table 5. Summary of harbor seal yearling, older female and older male counts during the peak pupping period on Tugidak Island, Alaska.

| | | YEARLINGS | | | | | OLDER FEMALES (seals older than yearlings) | | | | | OLDER MALES (seals older than yearlings) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | n[a] | Max | Max % Chg[b] | Mean | Std. Dev. | Mean % Chg[c] | Max | Max % Chg[b] | Mean | Std. Dev. | Mean % Chg[c] | Max | Max % Chg[b] | Mean | Std. Dev. | Mean % Chg[c] |
| 1994 | 6 | 28 | | 14 | 7.3 | | 298 | | 257 | 30.5 | | 133 | | 83 | 26.4 | |
| 1995 | 5 | 61 | 118 | 47 | 13.2 | 236 | 454 | 52 | 373 | 68.4 | 45 | 269 | 102 | 211 | 49.2 | 154 |
| 1996 | 7 | 51 | -16 | 42 | 7.8 | -11 | 447 | -2 | 356 | 55.0 | -5 | 281 | 4 | 230 | 47.8 | 9 |

[a] n Number of days of counts within peak pupping period

[b] Percent change in the maximal number of seals since previous year

[c] Percent change in the mean number of seals since previous year

Table 6. Indices of productivity (pup/female), abandonment (lone pup/pup), first year survival (yearling/non-pup), and proportion of older male (old male/old seal) harbor seals ashore during the peak pupping period on Tugidak Island, Alaska.

| Year | n[a] | Productivity | Abandonment | 1st Yr Survival | Older males |
|---|---|---|---|---|---|
| 1978 | 4 | 0.75 | 0.10[b,c] | 0.14* | 0.28[b,c] |
| 1994 | 6 | 0.76[a] | 0.06 | 0.04* | 0.24[c] |
| 1995 | 5 | 0.60 | 0.04 | 0.08 | 0.36 |
| 1996 | 7 | 0.70 | 0.04 | 0.07 | 0.39 |

[a] n Number of days of counts within peak pupping period

* Significantly different from every other year at $\alpha = 0.05$

[b] Indicates the year is significantly different from 1995 at $\alpha = 0.05$

[c] Indicates the year is significantly different from 1996 at $\alpha = 0.05$

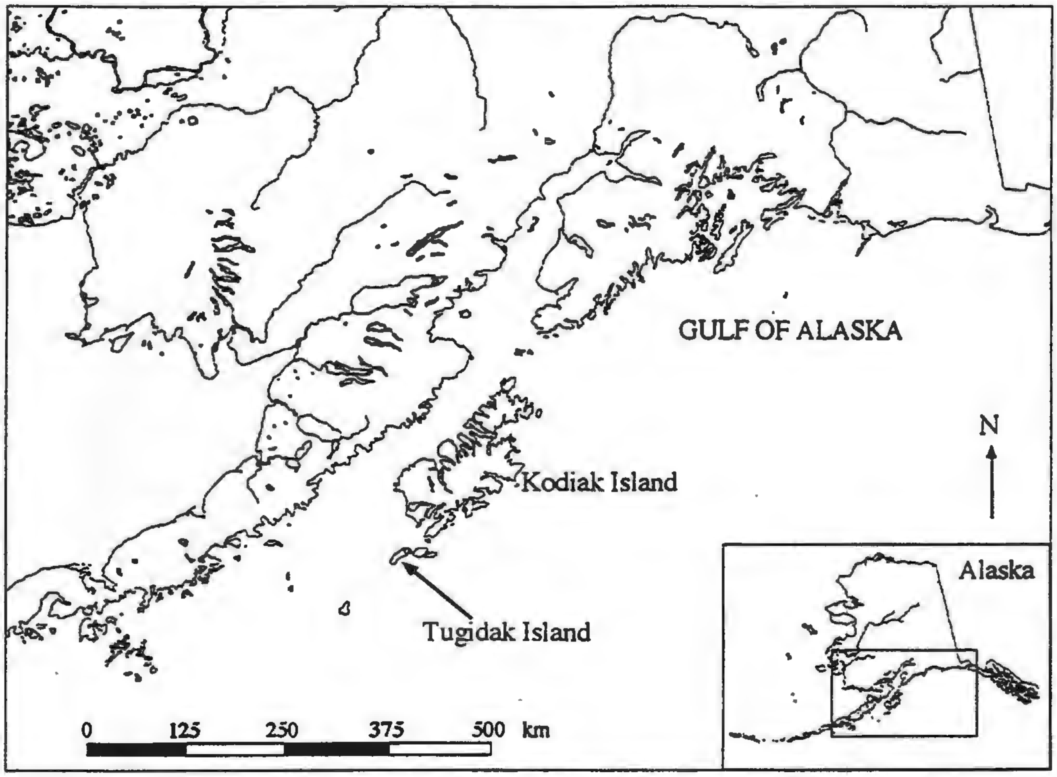


Figure 1. Location of Tugidak Island, Alaska.

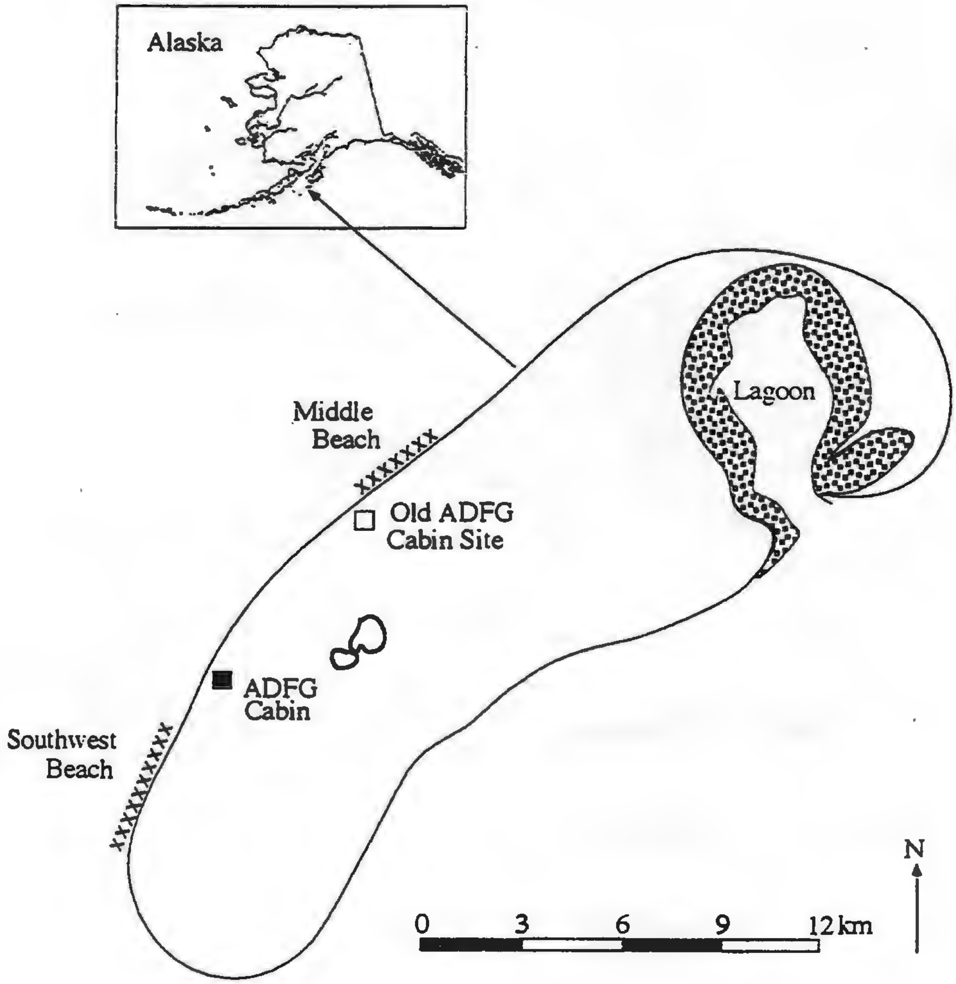


Figure 2. Primary harbor seal haulout locations on the western and southern shores of Tugidak Island, Alaska.

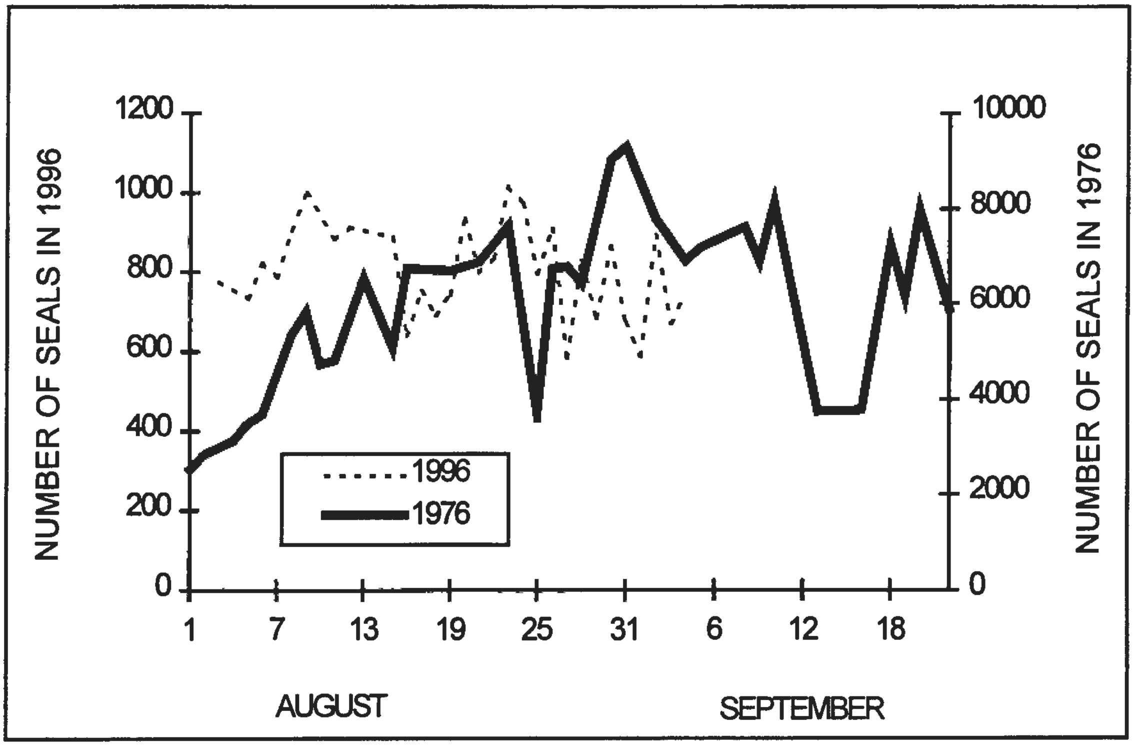


Figure 3. Harbor seal counts on Tugidak Island, Alaska, August - September 1976 and 1996.

# SURVEY OF GROWTH LAYERS IN HARBOR SEAL TEETH

Jason Baker and Peter Boveng

National Marine Mammal Laboratory, Alaska Fisheries Science Center
7600 Sand Point Way N.E., Seattle WA 98115

## PROJECT DESCRIPTION

The Alaska Department of Fish and Game (ADF&G) and the National Marine Fisheries Service (NMFS) are interested in using teeth to provide information about the life history and growth of harbor seals in Alaska. As a first step, we were asked to examine a sample of teeth to determine whether this area of research shows promise. Our examination focused on two separate topics:

1) Whether growth lines in teeth may provide information on the reproductive history of individuals, and;

2) Whether teeth can be used to derive age- or year-specific histories of growth and condition.

In this report, we discuss our findings primarily as they relate to point 1. As determination of both reproductive and growth histories will depend upon reliable age determination, we discuss our age estimates as well.

## METHODS

The ADF&G provided us with mounted and stained thin longitudinal sequential sections from 30 teeth, taken from harbor seals of both sexes in a range of ages. We were not provided with any information about the animals, excepting their identification number, until after our examinations were complete.

For each tooth we estimated the age of the animal and whether a "transition zone" (TZ) was apparent in the tooth cementum. The TZ occurs where there is a marked decrease in the width of annual layers in cementum. Studies of other phocids indicate that this TZ marks the age at sexual maturity or first reproduction (Laws 1977, Bengtson and Laws 1985). Baker and Boveng independently aged and scored the TZ of each section using a dissecting microscope and transmitted polarized light. The ADF&G then provided information on the age, sex, reproductive status and reproductive condition of each seal.

Dentine analysis was not performed. Previous studies on TZ's in teeth have focused on cementum growth layers because occlusion of the tooth pulp cavity complicates interpretation of dentine growth in older seals. Measurements of the magnitude of annual growth increments may be done in the future to index physical growth and/or condition. However, the specimens provided were sections of part or all of the tooth root, but were not complete sections of the entire tooth. To consistently measure growth increments, it is helpful to have a complete tooth section, so that reference points for standard measurements from tooth to tooth can be established.

## RESULTS

Our independent estimates of age were quite similar. The average absolute difference between Baker and Boveng's estimates for all 30 seals was 0.8 years. After obtaining the age estimates from ADF&G, we calculated the average maximum absolute difference between the three estimators (Baker, Boveng, ADF&G) as 1.3 years. The error increased with age of the animal (Figure 1). The maximum error tended to increase in animals 9 years and older.

### Transition Zone and Reproductive History

Of the 30 teeth, each reader was able to estimate the TZ in only 18. Most of the teeth in which no TZ was evident were from young animals. No animals younger than 5 years were judged to have had a TZ. Because the TZ is a more or less abrupt shortening in the width of a sequence of annual growth lines, one needs a sequence of at least several lines in order to discern it. For example, imagine two animals who died at ages 5 and 10 and who both had TZ's after age 4 years. As illustrated in the diagram below, where the width between vertical bars is used to indicate width between annual layers, it is easier to discern the TZ in the older animal's tooth.

5 year old:
|   |   |   |   | |
0  1  2  3  4 5

10 year old:
|   |   |   |   | | | | | | |
0  1  2  3  4 5 6 7 8 9 10

For example, the 3 nulliparous females did not have a TZ according to either Baker or Boveng. Of 3 likely primiparous females, Boveng identified a TZ on only one and Baker found none. Baker identified a TZ in 12, and Boveng in 10 of 13 multiparous females' teeth. However, there was no clear change in the width of annual lines with age in at least one of these females, indicating that maturity and parturition can occur without the formation of a TZ.

The teeth from male harbor seals were similar to the females' teeth. No TZ was visible in the teeth of animals younger than 6-7 years. Older males did have TZs, indicating that the growth pattern may indicate maturity in both sexes rather than simply parturition in females. There was some indication that where TZ's were identifiable in male teeth, they were sometimes less clear than in females. However, a larger sample size must be examined to confirm this.

## CONCLUSION

Preliminary results indicate that growth lines in cementum may prove a useful tool for assessing reproductive histories of harbor seals. The average age when the TZ formed in female teeth was similar to the average age at maturity or first reproduction. The correspondence between the appearance of a TZ and multiparity in individuals provides further support for this method. However, there are some important gaps in our ability to decode the growth lines and relate them to reproductive histories. Ideally, we require teeth from individuals known to have matured at various ages in order to match reproductive events with tooth growth. If such samples are unavailable, comparing the mean TZ's in teeth from two populations known to have different mean ages of maturity could provide more validation of the method. Based upon our preliminary analysis, we believe that further work on the harbor seal tooth cementum transition zone would be fruitful.

There was more variability among readers in assigning the transition zone than there was assigning age. Among the teeth for which both Boveng and Baker were able to assign a TZ ($n = 15$) the average absolute difference between the two estimates was 1.3 years, compared to 0.8 years for age estimation of all the teeth (Figure 2). The average age of the TZ estimated by Baker and Boveng were 5.67 and 5.44, respectively. These ages are consistent with the notion that the transition zone forms at the approximate time of first reproduction or at maturity. Some further support comes from the information about the reproductive status of the individual female harbor seals.

To improve the prospects for successful estimation of histories of physical growth and condition, the techniques for preparing tooth sections and slides must be improved. Sections should include major "landmarks", such as the enamel-dentine junction, and be oriented consistently on the slide (e.g., anterior surface to the left, or lingual side facing up). For better resolution of measurement and least distortion of the growth layers, teeth should be sectioned without decalcification. This requires a specialized petrographic thin-section machine and careful attention to detail by the technician preparing the teeth. We proposed to develop a refined technique for tooth-section preparation that can be used for future preparation of tooth samples. Following successful development of a preparation method, we propose to continue investigation of the prospects for estimating growth and condition histories by examining individual and cohort-specific deviations from an age-specific tooth growth model.

## LITERATURE CITED

Bengtson, J. L. and R. M. Laws. 1985. Trends in crabeater seal age at maturity: an insight into Antarctic marine interactions. Pp. 669-675 *in* W. R. Siegfried, P. R. Condy, and R. M. Laws (eds.), Antarctic Nutrient Cycles and Food Webs. Springer-Verlag, Berlin Heidelberg.

Laws, R. M. 1977. The significance of vertebrates in the Antarctic marine ecosystem. Pp. 411-438 *in* G. A. Llano (ed.), Adaptations Within Antarctic Ecosystems: Proceedings of the Third SCAR Symposium on Antarctic Biology. Smithsonian Institution, Washington, DC.

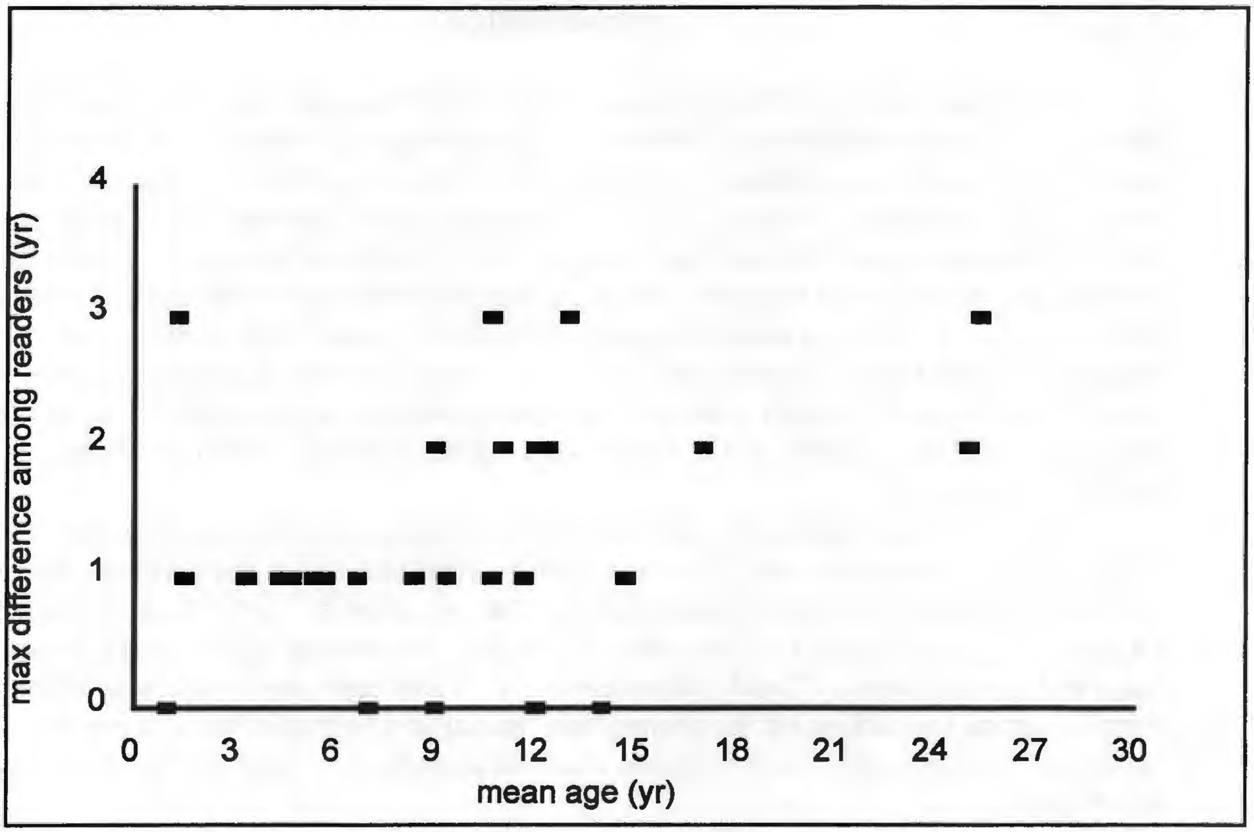


Figure 1. Mean difference in age estimation based on average ages assigned by three independent readers.

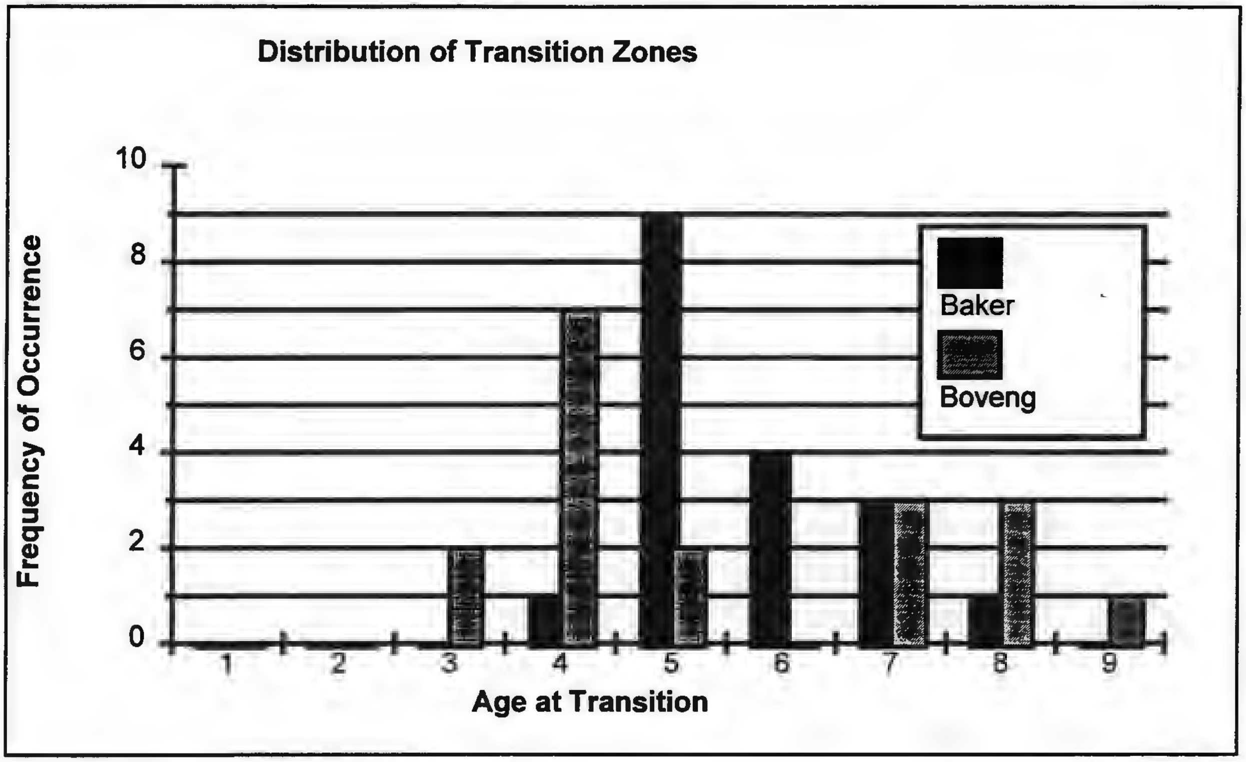


Figure 2. Distribution of transition zones estimated by J. Baker and P. Boveng.

# PREGNANCY DETERMINATION FOR CAPTURED HARBOR SEALS AND STELLER SEA LIONS

Kenneth W. Pitcher[1] and Kathryn J. Frost[2]

[1]Alaska Department of Fish and Game, Division of Wildlife Conservation,
333 Raspberry Road, Anchorage, AK 99518

[2]Alaska Department of Fish and Game, Division of Wildlife Conservation,
1300 College Road, Fairbanks, AK 99701

Estimation of pregnancy rates and/or birth rates is an important component of population dynamics studies of mammals. Recent research on declining populations of harbor seals (Phoca vitulina) and Steller sea lions (Eumetopias jubatus) in Alaska has involved capture of live animals. A reliable technique for determining pregnancy status for captured females would provide useful data from which pregnancy rates could be estimated, provided adequate samples were obtained.

Several methods are available which have potential for determining pregnancy status of live-captured harbor seals and Steller sea lions. Real-time ultrasound appeared to provide accurate assessments of early pregnancy status for harbor seals (Young and Grantmyre 1992). Plasma progesterone levels were demonstrated to have value in determining late gestation pregnancy status for harbor seals (Gardiner et al. 1996). The presence and level of chorionic gonadotrophin in harbor seal plasma may be useful for detecting pregnancy during the first trimester (Gardiner, personal communication) as it is produced by the blastocyst and has been found in the placentas of grey seals (Halichoerus grypus) and California sea lions (Zalophus californianus) (Hobson and Wide 1986). Reliable pregnancy determinations have been made for a number of ungulate species through the cross-reaction of pregnancy-specific antigens with radioimmunoassay for detection of bovine pregnancy specific protein B (PSPB) (Wood et al. 1986, Houston et al. 1986, Rowell et al. 1989).

Sera from nine harbor seals and nine Steller sea lions were assayed for cross-reactivity to a bovine PSPB antibody at Biotracking Laboratory in Moscow, Idaho. Cross-reactivity to bovine PSPB antibodies occurred in these specimens but did not appear to correspond directly with pregnancy status for harbor seals (Table 1) with apparent false negative and false positive results. The results for Steller sea lions appeared more promising with correct classifications for all known status animals (Table 1). These data suggest the presence of a substance in the plasma of these species that may be specific for pregnancy in Steller sea lions but probably is not for harbor seals. Additional testing will be required to fully evaluate this methodology.

Table 1. Pregnancy specific protein B levels in harbors seals and Steller sea lions during the period corresponding with late gestation. Values are the results of three radioimmunoassays. Values less than 93% binding are considered positive in pregnancy determinations for cattle.

| SPECIES ID# | SEX/AGE | PREGNANCY STATUS | PSPB LEVEL (%binding) |
|---|---|---|---|
| HARBOR SEAL | | | |
| 95PVSE2 | MALE/ADULT | | 89, 80, 83 |
| 95PVSE3 | FEMALE/ADULT | YES[1] | 95, 92, 93 |
| 95PVSE8 | MALE/ADULT | | 71, 75, 86 |
| 95PVSE17 | FEMALE/ADULT | YES[1] | 88, 85, 85 |
| 95PVSE18 | MALE/SUBADUT | | 88, 86, 88 |
| PVW027 | FEMALE | NO[2] | [3] |
| PV019 | FEMALE | NO[2] | [4] |
| PVL11208 | FEMALE | YES | [4] |
| PVs6969 | FEMALE | YES | [4] |
| STELLER SEA LION | | | |
| SL-408-85 | FEMALE/6 YRS | YES | 77, 79, 80 |
| SL-409-85 | MALE/4 YRS | | 94, 90, 88 |
| SL-412-85 | FEMALE/15 YRS | YES | 90, 87, 94 |
| SL-414-85 | FEMALE/2 YRS | NO | 94, 95, 91 |
| SL-424-85 | MALE/5 YRS | | 105, 107, 107 |
| SL-429-85 | FEMALE/7 YRS | YES | 83, 88, 92 |
| 93SL63 | MALE/1 YR | | 94, 97, 95 |
| 93CSE19 | FEMALE/ADULT | LIKELY | 89, 84, 85 |

[1] Assumed to be pregnant but not known for certain

[2] Not observed with pup, probably not pregnant

[3] Judged to be pregnant based on PSPB values

[4] Judged to be not pregnant based on PSPB values

Progesterone levels in the serum of 37 harbor seals were determined to evaluate the potential for pregnancy determinations (Table 2). These data appear to confirm the findings of Gardiner et al. (1996) that progesterone levels during late gestation have value in evaluating pregnancy status. However two adult females (PWS-8-95 and PWS-20-95) were thought to have been pregnant when handled but had very low progesterone levels

(Table 2). Perhaps these samples were mislabeled or misreported as progesterone levels are known to be elevated during the in the last six to seven weeks of gestation in harbor seals and is required to support a pregnancy (Raeside and Ronald 1981).

Ultrasound appears to work well for pregnancy determination after about 5 weeks post-implantation (Young and Grantmyre 1992). It requires chemical sedation, specialized equipment and a trained operator. The combination of assays for chorionic gonadotrophin and progesterone could likely be used to determine pregnancy status throughout implanted gestation and only require plasma samples. It is uncertain if an assay with antisera for bovine PSPB will reliably detect a pregnancy specific substance in pinniped plasma. Additional testing is required.

We acknowledge the contributions of Garth Sasser, Ron Silflow and Terry Spraker for their expertise in specimen analyses.

## LITERATURE CITED

Gardiner, K. J., I. L. Boyd, P. A. Racey, P. J. H. Reijnders and P. M. Thompson. 1996. Plasma progesterone concentrations measured using an enzyme-linked immunosorbent assay useful for diagnosing pregnancy in harbor seals (Phoca vitulina). Marine Mammal Science 12:265-273.

Hobson, B. M. and L. Wide. 1986. Gonadotrophin in the term placenta of the dolphin (Tursiops truncatus), the California sea lion (Zalophus californianus), the Grey seal (Halichoerus grypus) and man. Journal of Reproductive Fertility 76:637-644.

Houston, D. B., C. T. Robbins, C. A. Ruder and R. G. Sasser. 1986. Pregnancy determination in mountain goats by assay for pregnant specific protein B. Journal of Wildlife Management 50:740-742.

Raeside, J. I. And K. Ronald. 1981. Plasma concentrations of oestrone, progesterone and corticosteroids during late pregnancy and after parturition in the harbor seal, Phoca vitulina. Journal of Reproduction and Fertility 61:135-139.

Rowell, J. E., P. F. Flood, C. A. Rudder and R. G. Sasser. 1989. Pregnancy-specific protein in the plasma of captive muskoxen. Journal of Wildlife Management 53:899-901.

Wood, A. K., R. E. Short, A. Darling, G. Dusek, R. G. Sasser and C. A. Ruder. 1986. Serum assays for detecting pregnancy in mule and white-tailed deer. Journal of Wildlife Management 50:684-687.

Young, J. S. F. and E. B. Grantmyre. 1992. Real-time ultrasound for pregnancy diagnosis in the harbour seal (Phoca vitulina concolor). Veterinary Record 130: 328-330.

Table 2. Progesterone levels for 37 harbor seals captured in Prince William Sound during 1994 and 1995.

| Animal # | Date | Sex | Approximate Age | Progesterone Level (ng/ml) |
|---|---|---|---|---|
| PWS-25-94 | 19 Sept | F | Pup | 3-8 |
| PWS-24-95 | 25 Sept | F | Pup | 2.91 |
| PWS-35-95 | 26 Sept | F | Pup | 0.97 |
| PWS 13-94 | 18 Sept | M | Subadult | <1.8 |
| PWS-12-94 | 18 Sept | F | Subadult | 98 |
| PWS-16-94 | 18 Sept | F | Subadult | 3-8 |
| PWS-20-94 | 18 Sept | F | Subadult | <1.8 |
| PWS-31-94 | 22 Sept | F | Subadult | 3-8 |
| PWS-33-94 | 22 Sept | F | Subadult | <1.8 |
| PWS-23-95 | 25 Sept | F | Subadult | 1.74 |
| PWS-25-95 | 26 Sept | F | Subadult | 6.08 |
| PWS-33-95 | 26 Sept | F | Subadult | 6.26 |
| PWS-34-95 | 26 Sept | F | Subadult | 0.54 |
| PWS-36-95 | 26 Sept | F | Subadult | 3.73 |
| PWS-39-95 | 27 Sept | F | Subadult | 7.56 |
| PWS-11-94 | 18 Sept | F | Adult | 3-8 |
| PWS-24-94 | 19 Sept | F | Adult | 3-8 |
| PWS-27-94 | 22 Sept | F | Adult | 3-8 |
| PWS-30-94 | 22 Sept | F | Adult | 3-8 |
| PWS-32-94 | 22 Sept | F | Adult | 3-8* |
| PWS-35-94 | 22-Sept | F | Adult | 3-8 |
| PWS-26-95 | 26 Sept | F | Adult | 3.72 |
| PWS-27-95 | 26 Sept | F | Adult | 5.21 |
| PWS-30-95 | 26 Sept | F | Adult | 15.58 |
| PWS-38-95 | 27 Sept | F | Adult | 4.79 |
| PWS-21-95 | 14 May | F | Pup (11 mos) | 1.07 |
| PWS 1-94 | 26 April | F | Subadult | <1.8 |
| PWS-6-95 | 11 May | F | Subadult | 0.52 |
| PWS-9-95 | 11 May | F | Subadult | 0.91 |
| PWS-11-95 | 11 May | F | Subadult | 0.31 |
| PWS-13-95 | 11 May | F | Subadult | 0.06 |
| PWS-17-95 | 12 May | F | Subadult | 0.36 |
| PWS-19-95 | 12 May | F | Subadult | 0.50 |
| PWS-3-94* | 27 April | F | Adult | 16/40 |
| PWS-7-94* | 28 April | F | Adult | 16/40 |
| PWS-8-95* | 11 May | F | Adult | 0.87 |
| PWS-20-95* | 14 May | F | Adult | 0.09 |

*Thought to be pregnant

# CHAPTER TWO

# MOVEMENTS AND DIVING BEHAVIOR OF ALASKAN HARBOR SEALS

## OBJECTIVE 3

Describe the distribution and use of harbor seal haulouts in southeastern Alaska and the Kodiak Archipelago, including temporal and spatial patterns of haulout use

## OBJECTIVE 4

Describe the areas and depths used for feeding by harbor seals in southeastern Alaska and the Kodiak Archipelago

# MOVEMENTS AND DIVING BEHAVIOR OF HARBOR SEALS IN SOUTHEAST ALASKA AND THE KODIAK ARCHIPELAGO

Una G. Swain and Robert J. Small

Alaska Department of Fish and Game, Division of Wildlife Conservation
333 Raspberry Road, Anchorage, Alaska 99518

## INTRODUCTION

The harbor seal (*Phoca vitulina richardsi*) population in Alaska has declined throughout much of its range (Sease 1992, Loughlin 1993, Alaska Department of Fish and Game (ADF&G) 1995). The greatest decline in harbor seal numbers has been observed in southcentral Alaska, from Prince William Sound (PWS) through the Kodiak Archipelago. Populations at Tugidak Island and in the Kodiak Archipelago have declined by 90% since the mid-1970s (Pitcher and Calkins 1979, Pitcher 1990, Loughlin 1992), although recent data suggest numbers in the Kodiak Island area may be increasing (Lewis *et al.* 1996, Small *et al.* 1997, Chapter 1). In PWS, harbor seal numbers have decreased by 62% between 1984 and 1996, and only part of this decline is attributable to the *Exxon Valdez* oil spill in 1989 (Frost *et al.* 1997). Meanwhile populations in Southeast Alaska (SE) have increased since 1983 (Pitcher 1989, ADF&G 1995, Small *et al.* 1997, Chapter 1).

Harbor seals, Steller sea lions (*Eumetopias jubatus*), and northern fur seals (*Callorhinus ursinus*) as well as several species of sea birds have all declined in numbers in Alaska since the 1960s. Causes for the declines are not well understood (Pitcher 1990, Swartzman and Hoffman 1991, Springer 1993). Factors possibly involved in the declines include natural population fluctuations, direct and indirect effects from commercial fisheries, subsistence harvest, pollution, disease, predation, and a reduction in habitat (Sease 1992, Hoover-Miller 1994). One of the principal causes for the recent declines in Steller sea lion abundance is hypothesized to be a decrease in prey availability which could be caused by environmental changes and/or commercial fishing activities (Loughlin and Merrick 1989; Lowry *et al.* 1989, Merrick 1995).

Foraging theory predicts an animal should optimize its behavior to maximize energy intake under changing environmental conditions (Stephens and Krebs 1986); thus, foraging behavior would be expected to vary in response to changes in prey distribution and abundance. Past research on otariids suggests foraging patterns and activity budgets are likely to change during periods of nutritional stress to meet energy demands (*e.g.*, Ono *et al.* 1987, Croxall *et al.* 1988, Trillmich *et al.* 1991, Boyd *et al.* 1994). Differences in prey availability and diet were shown to be related to changes in harbor seals' foraging and haulout distribution in Moray Firth in Scotland (Thompson *et al.* 1995). The similarities between the harbor seal and Steller sea lion declines in Alaska suggest that the harbor seal decline may also be related to nutritional factors, and diving is likely to be a good measure of foraging activity.

Few data on the diving behavior of harbor seals are available. Recent developments in instrumentation have provided new methods to measure movements and diving behavior of pinnipeds at sea (e.g., Croxall *et al.* 1985, Kooyman *et al.* 1986, Stewart *et al.* 1989, Hindell *et al.*

1991, Bengston *et al.* 1993). Much of the previous research on harbor seals focused on behavioral observations of foraging and habitat use (Hoover-Miller 1983, Harvey 1988, Thompson and Miller 1990). Studies in Scotland and Nova Scotia have used time-depth recorders (TDRs) and VHF telemetry to study the aquatic behavior of harbor seal males during the mating season (Coltman *et al.* 1995, Van Parijs *et al.* 1995), the characteristics of harbor seal foraging trips (Mackay *et al.* 1995), and the development of diving in juvenile harbor seals (Corpe *et al.* 1995). Stewart *et al.* (1989) investigated at-sea behavior and movements of a single harbor seal in California using satellite telemetry. Using more sophisticated satellite-linked depth recorders (SDRs), the movements and diving behavior of harbor seals in PWS have been investigated since 1993 (Frost and Lowry 1994, Frost *et al.* 1995, Frost *et al.* 1996). Studies on the foraging behavior of harbor seals in SE, where by contrast the population is stable or increasing, include SDR investigations during 1993-1994 (Swain *et al.* 1996) as well as a study which used VHF transmitters to describe haulout behavior (Withrow and Loughlin 1994). The diving behavior of harbor seals in the Kodiak Archipelago (KO) (Swain *et al.* 1996), where substantial declines have occurred in the past, continues to be investigated in this study. Differences in the prey available to the different populations of harbor seals could lead to different foraging strategies and prey utilization, which could influence the divergent population dynamics of the different populations.

The goal of this study was to enhance our understanding of the foraging ecology of harbor seals and, in particular, to continue to investigate the foraging behavior of harbor seals in SE and KO. We examined the movements and diving behavior of harbor seals by using SDRs to collect information on at-sea behavior. The main objectives of the study were to (1) describe the movements and diving behavior, (2) investigate behavioral indices of foraging effort, and (3) continue to collect data to determine whether differences in movements and diving behavior (and thus, presumably foraging behavior) could indicate differences in prey availability for the two populations.

## METHODS

### Seal Capture

Harbor seals were captured in SE during April and September 1995 and KO during March and October 1995. Seals were captured by entanglement in a multifilament nylon net deployed near their haulout sites. The net was 240 m long and 8 m deep with a 28 cm stretch mesh, a float-core line and a lead line. The net was set from a 7 m boat by a swimmer who carried one end of the net into the water and to shore while the boat continued to encircle the haulout. A second 6 m boat approached the haulout to ensure the seals stayed within the deployed net. The seals became entangled in the net as they attempted to swim away from the presence of boats and people. Once the net was deployed, both boats tended it. When the seals became entangled in the capture net, they were removed, brought into the boats, and placed into temporary holding nets. Seals were handled and processed either on a nearby beach or on the support vessel.

Seals were immobilized using a mixture of ketamine and diazepam administered intramuscularly at dosages of 5.5 mg/kg and 0.09 mg/kg, respectively. Each seal was weighed, measured, and tagged in the hind flippers with individually numbered plastic tags. Blood was drawn from the extradural intervertebral vein. In addition, a number of samples were collected from each animal to address a variety of research questions: morphometric measurements and blubber thickness for body condition, whiskers for stable isotope analysis, skin samples for genetic analysis, blubber biopsies for analyses of fatty acids and energy content. Results from these research studies are presented in ADF&G 1996 and in this report.

## Instrumentation

SDRs were glued with netting and fast-setting epoxy resin (Fedak *et al.* 1984) to the fur of the mid-dorsal region of the harbor seal. The 0.5 watt ST-6 transmitters, packaged as Type III SDRs (Wildlife Computers), measured 14.8 cm x 10 cm x 3.8 cm and weighed approximately 750 g. In September/October 1994, a smaller version of the 0.5 watt SDR which measured 11.9 cm x 5.1 cm x 4.5 cm and weighed 385 g was used on four of the smaller seals. These smaller transmitters used six lithium 2/3A batteries in place of four lithium C-cell batteries, which greatly reduced the size of the SDR. The larger units had a projected capacity of 100,000 transmissions, while the smaller units had approximately 30,000 transmissions. The epoxy attachments and SDRs were shed when the seals molted, which generally occurred in June or July. The SDRs were equipped with pressure sensors to determine depths of dives and conductivity sensors to determine whether the SDR was immersed in water or dry (i.e., whether the seal was hauled out on land or at sea). Pressure transducers were capable of measuring depths from 0-500 m with 2 m resolution. The pressure sensor was sampled at 10 second intervals, and these data were summarized into histogram bins prior to transmission. Programmable micro-processors collected and summarized data on maximum dive depths and durations, as well as the amount of time spent at depths, and stored them for later transmissions.

The SDRs merged generalized time-depth recorder (TDR) capabilities with the data-relaying capabilities of the Service ARGOS data collection and location system (Fancy *et al.* 1988, Keating *et al.* 1991). The SDRs transmitted information to two polar-orbiting satellites administered by the National Oceanic and Atmospheric Administration (NOAA). Information could be received only when the harbor seal was hauled out on land or at the ocean surface and when the satellite was in direct line of sight of the transmitter.

The Type III SDRs stored, summarized, and transmitted dive data as histograms. A histogram is a set of "bins", each of which contains counts for a given range of dive depths or dive durations or for the amount of time spent at a given range of dive depths (time at depth). The daily counts were accumulated into four 6-hr "histogram periods" (2100-0300, 0300-0900, 0900-1500, 1500-2100 local sun time). Dive depths, dive durations, and the proportion of time spent at depth were summarized separately for the same four periods and stored in a "transmit buffer" that contained the previous four histogram periods (24 hours). Each histogram contained ten separate bins which were set prior to deployment. The minimal depth for a dive was considered 4 m. The dive depth bins for the SDRs were 4-20 m, 20-50 m, 50-76 m, 76-100 m, 100-150 m, 150-200 m, 200-250 m, 250-300 m, 300-350 m and > 350 m. Dive duration bins were 0-2 min, 2-4 min, 4-6 min, 6-8 min, 8-10 min, 10-12 min, 12-14 min, 14-16 min, 16-18 min, and > 18 min. The bins for time at depth were similar to the dive depth bins (0 m, 0-20 m, 20-50 m, 50-76 m, 76-100 m, 100-150 m, 150-200 m, 200-250 m, 250-300 m, and > 300 m), however, data were also accumulated in a bin of 0 m depth when the conductivity sensor was "dry", which stored the proportion of time during a 6-hr histogram period that the seal was on land. In addition, SDRs were equipped with software that collected and reported the precise maximum dive depth recorded for each 24 hour period and the amount of time that the seal spent at the surface in the two previous six hour periods. The maximum depth for accumulating "at surface" time was set at 0 m. At-surface times reflect the amount of time the unit was dry plus the amount of time spent at or above the maximum depth for the surface.

The smaller SDR units attached in the fall were programmed for a transmission cycle of one day on and two days off to conserve battery power, ie. duty-cycled. SDRs attached in the spring were not duty-cycled and transmitted continuously. In addition, the SDRs deployed in the fall were set to suspend transmissions after 6 hours 'hauled-out'. The 'haul-out' ended when the seal reentered the water and the SDR was "wet" for four successive transmission intervals.

## Data Analyses

Data from satellite tagged seals were obtained from Service ARGOS. The ARGOS system recorded the date and time of each satellite uplink and calculated a location for the SDR based on the Doppler shift whenever sufficient signals were received during a satellite overpass. Only sensor data were received with one uplink. For analysis and presentation of the data, Greenwich dates and times, as reported by Service ARGOS, were converted to local solar time by subtracting 9-11 hours to account for the actual position of the sun.

### *Movements and Haulout Behavior*

The accuracy of the estimated locations depended in part on the number of uplinks that occurred during a satellite overpass. Service ARGOS assigned a quality ranking to each estimated location. Locations resulting from standard data processing were ranked as either 1, 2, or 3, with quality 3 providing the highest degree of accuracy. Special data processing provided locations from satellite passes with few uplinks or other potential problems. These locations were assigned a location class of A, B, or Z, where records with a Z designation were ones that failed validation tests performed by Service ARGOS.

Methodology developed by Frost *et al.* (1995, 1996) was used to identify and eliminate erroneous location records based on an error index value and the time, distance, and speed between sequential pairs of locations. First, records that failed validation tests performed by Service ARGOS were deleted from the database. An error index was then calculated for each remaining location according to the equation described by Keating (1994). This index value accounts for the distances and directions between sequential locations and was used to identify erroneous locations based on the assumption that records indicating a single, large movement followed immediately by a return to a point near the origin are likely to be in error. All location records that had an error index of greater than 25 were removed from the database. Other inaccurate locations were identified by investigating possible movement speeds of the seals. Time, distance, and speed between each sequential pair of locations were calculated for all location records remaining in the database. A three-stage process was used to mark records that produced improbable movements. These were based on the following speeds: (1) calculated speeds of more than 10km/hr for a period of more than 5 minutes, (2) calculated speeds of more than 100km/hr for a period of more than 1 minutes, and (3) calculated speeds of more than 500km/hr for any length of time. Flagged records were inspected visually, and the locations that were most distant from adjacent records were removed from the database. Finally, an error index was recalculated for each remaining record and any records with an error index of greater than 25 were deleted. Location records described in this report include only those records that remained after the complete screening process.

The SDRs reported with each transmission whether the seal was dry (hauled out on land) or wet (at sea) based on the status of the conductivity sensors. The 'land-sea' sensor data were merged with location records to produce a datafile that included SDR number, date, time, latitude, longitude, and location quality, as in Frost *et al.* (1995, 1996). From this datafile, a computer program calculated an average location for each period a seal was either hauled out or at sea. The resulting average-position datafiles were used to determine where the seals hauled out and where they were at sea. Geographic information system coverages in ArcInfo were produced from the all-location and average-position datafiles, and datasets were selected and displayed using ArcView. The figures presented in this report are from the average position datafiles.

The movements of individual seals were determined by observing their average locations sequentially in ArcView. Distinguishing a distinct movement away from areas where seals spent the majority of their time was subjective, due to imprecision in the locations but also because a quantitative method of delineating movements was not employed. The large majority of locations for each seal were in one, occasionally in two or three, main areas. We interpreted the occurrence of several sequential locations concentrated away from a main area both as the movement to and occupation of a different area. A single location away from a main area was sometimes observed, but these were usually not interpreted as a movement. The decision not to include such possible movements was based on the idea that, after examining each location for all SDR tagged seals, they were not typical seal movements.

The length of time a seal spends at sea or on land can be estimated from the 'land-sea' sensor data as in Swain *et al.* (1996), however, the analysis revealed that the results should be interpreted with caution because of the limitations of the 'land-sea' sensor data. Specifically, information on whether a seal is on land or at sea at a particular time is limited to the times of the satellite overpasses. The information is also biased by incomplete satellite coverage and the greater probability of signal reception when the seal is on land. It is possible for an animal to go out to sea, for no signals to reach the satellite, and for the animal to return to land without any record of the at-sea time in the 'land-sea' sensor data. Time at sea would be underestimated. Interpretation of data is further biased by the SDR programming which suspends transmissions after six hours 'hauled-out'. A haulout ends after the SDR is 'wet' for four consecutive at-sea transmissions. Therefore, the amount of time a seal spends on land after a six hour haulout would not be recorded, and time hauled-out would be underestimated. Because of small sample sizes and because of these limitations in the data collection, different approaches for analyzing the proportion of time at sea and on land are currently being explored. Alternative estimates could use dive histogram or 'time-at-depth' data that are not subject to these biases because the data are not dependent on actual transmission times.

Time 'at depth' will be analyzed in the future and will provide a measure of the amount of time harbor seals spent on land as well as the amount of time spent at various depths. Time 'at surface' will also be considered in the future, which estimates how much time harbor seals spent on land and at or near the surface of the water.

### *Diving Behavior*

Dive data from SDRs were extracted from the ARGOS files using software provided by Wildlife Computers. Transmissions were validated by an error-checking algorithm, and histogram messages were sorted by date, period, and type. Duplicate messages were removed. The Wildlife Computers' software also extracted status messages which provided information on battery voltage, maximum dive depths, and time spent "at surface". SAS (SAS Institute Inc.) was used to create datasets and to summarize and analyze the dive data.

The total number of dives in each depth and duration bin were summed for each 6-hr histogram period prior to transmission to the satellite. Mean dive depths and durations were determined based on the number of dives in each of the ten duration or depth ranges (bins) multiplied by the average duration or depth of that bin. The midpoint of a bin was used to represent the average for all dives in that bin (e.g. 12 m for the 4-20 m bin). Dive frequencies were calculated directly from the duration histograms by summing the number of dives for each 6-hr period. Mean dive depths, durations, and frequencies were determined for individual seals and for the different sex and age classes in each location. Differences in dive frequencies by time of day were tested using a one-way ANOVA and Tukey's multiple comparisons.

Small sample sizes precluded comparisons among the different sex and age classes and different geographic locations. The diving behavior of individual seals was described and examined for patterns relating to season, time of day, and geographic location. However, the results presented are simply examples of the available dive data and are of limited use in describing general patterns of foraging behavior. Methods for analyzing dive data and for investigating patterns related to age, sex, or geographic location are currently being developed.

## RESULTS

A total of 21 harbor seals were captured for SDR deployment in spring and fall of 1995; six adults, three subadults, and one pup in SE and four adults and seven subadults in KO. Harbor seals were captured in a several locations in SE and KO (Table 1). The raw ARGOS sensor data could not be extracted from one of the SDRs deployed in KO (SDR 5051), so only locations are available for this subadult. Five SDRs were attached in both SE and KO in the spring of 1995 and provided transmissions for a mean of 79.6 and 86.4 days, respectively. The five SDRs attached in SE and the six SDRs attached in KO in fall 1995 recorded data for an average of 227 and 215.5 days, respectively. Overall, the period of time over which data were received ranged from 57-263 days (Table 1).

### Movements and Haulout Behavior

Based on the average daily locations for each recorded period at sea and on land, all harbor seals exhibited a strong fidelity to the general area where they were captured. Additionally, some seals made numerous movements away from their main areas, usually for just a few (2-5) days, but sometimes up to several weeks or nearly two months. Yet, all seals returned to their main areas after such movements, except when transmissions from the SDR ceased. Summaries of the dates when seals were found in different areas are presented in tabular form in Appendix 1, along with figures displaying the locations.

### *Southeast Alaska*

In SE, all five seals captured in late April of 1995 remained in the general area of either Gambier or Pybus Bay, near their respective capture locations, until SDR transmissions ceased from mid-June to mid-July (Table 1A, Figures 1-5A). Locations for two female subadults were less concentrated than for the three adults (two females, one male). One of the subadult females (SDR 2087) made several trips between Gambier and Pybus Bays and two larger islands (The Brothers) about 10 km offshore (Fig. 4A). The other subadult female (SDR 2085) traveled to the end of Endicott Arm between May 8-10, a round-trip of 150-200 km, and also made at least two trips out to smaller islands (The Five Fingers) about 20 km offshore (Fig 3A). Although the adults displayed a stronger fidelity to a main area than the subadults, the one adult male (SDR 3088) did make a trip to Endicott Arm during April 22-25, yet otherwise remained in Gambier Bay (Figure 1A). One of the two adult females (SDR 3090) spent four days at The Brothers (Figure 2A), whereas the other adult female (SDR 3086), the only seal captured at Pybus Reef, remained in Pybus Bay (Figure 5A).

Five seals were captured in late September 1995 at Vixen Island in Hoonah Sound, and four of the five were in Hoonah Sound when transmissions ceased in late April to late May 1996 (Table 2A, Figures 6-9A). The remaining seal, a female pup (SDR 5048), was in southern Sitka Sound when the last transmission was received in late April 1996. This pup made the most extensive movements of all seals tagged in 1995 (Figure 10A). She remained in Hoonah Sound until 9 November, then traveled approximately 150 km to the northwest end of Tenakee Inlet for over a week (13 Nov – 21 Nov). She then traveled 150 km back to Hoonah Sound where she stayed until 19 December. She then moved about 40 km through Peril Strait to Salisbury Sound where she stayed for two weeks (22 Dec – 3 Jan) before moving 40 km south into northern Sitka Sound where she stayed for over six weeks (5 Jan – 20 Feb). The pup then traveled 20 km further south into southern Sitka Sound for five days before departing on 26 February and traveling at least 100 km in two days to return to Hoonah Sound. She stayed in Hoonah Sound for only four days (28 Feb – 3 Mar), traveled back to Salisbury Sound for two days, then returned to southern Sitka Sound on 8 March and remained there until her last transmission was received on 28 April.

The only male captured in Hoonah Sound, an adult (SDR 5043), remained there for the seven months transmissions were recorded (Figure 6A). The two adult females showed similar patterns of movement between Hoonah and Salisbury Sounds, with one of them (SDR 5042) traveling to Salisbury Sound for two days in late September, and twice in April; once for nearly 3 weeks (3 – 20 April), and then again on 26 April (Figure 7A). The other adult female (SDR 5041) visited Salisbury Sound for five days in late September, then again for over six weeks (8 Feb – 24 Mar), followed by a week in Fish Bay before returning to Hoonah Sound on 2 April (Figure 9A). Thereafter, she moved between the two Sounds six times until the end of May. The remaining seal, a subadult female (SDR 5047), left Hoonah Sound only twice, both times to Fish Bay for just one or two days in late September and early March (Figure 8A).

### *Kodiak Archipelago*

In KO, three of the five seals captured at Uganik Passage in late March 1995, an adult male (SDR 3089) and female (SDR 2090) and a subadult female (SDR 3087), all remained in that general area until transmissions ceased in June or July (Table 3A, Figures 11A, 13A, 15A). The other two seals, a subadult female (SDR 2086) and male (SDR 2089), made extensive movements away from Uganik Passage (Table 3A). The subadult female spent the first three weeks after capture along the southeast side of Uganik Island, then left the area on 19 April for over two weeks before returning on 4 May. She moved southwest along the coast, spending 5 days in Spiridon Bay, three days at Ayakulik Island, two days in Alitak Bay, then back to Ayakulik Island for one day before returning to Uganik Passage where she remained for the next five weeks until transmissions ceased (Figure 14A). The subadult male left Uganik Passage just two days after capture, traveling approximately 100 km northeast in one day to the Seal Islands just off the northeast end of Afognak Island (Figure 15A) where he stayed for just three days before returning to the southeast side of Uganik Island for two weeks. He then moved to the northwest side of Uganik Island for three weeks before heading back to Seal Islands on 18 May, where he remained for a week before transmissions ceased.

In the fall 1995, six seals were captured along the south side of Kodiak Island. Of the four seals captured on 9 October in Ugak Bay, one adult male and female (SDRs 5046 and 5045) and one subadults male (SDR 5049) did not leave the head of the bay for the seven to eight months that transmissions were received (Table 4A, Figures 17-19A). The other subadult, a female (SDR 5044), made numerous 25 km movements from her main area at the head of Ugak Bay to the mouth. Often she stayed for just one day at the mouth of the bay, but she also remained there for a week in early November, nearly three weeks at the end of April, and for four weeks from 9 May through 6 June when transmissions ceased (Figure 16A). Two subadult females were captured in Kiliuda Bay on 10 October (Table 4A), with one of them (SDR 5050) remaining in the upper bay for the seven months that transmission were received (Figure 21A). The other (SDR 5051) traveled up the coast into Ugak Bay twice for two days in late November and again in mid-January. She also spent three days about 30 km southeast of Kiliuda Bay in the Gulf of Alaska in early December (Figure 20A). After her second trip to Ugak Bay, she remained in upper Kiliuda Bay from 20 January through 7 April when transmissions ceased.

## Diving Behavior

Depth histograms summarized data from 188,274 dives made by seals in SE and 209,424 dives made by seals in KO from late March 1995 to July 1996 (Table 2). For all 10 seals in SE, 46% of the total number of dives were less than 20 m, 64% were to depths less than 50 m, and only 2% of all dives exceeded 150 m. For the 10 seals in KO, 48% of the total dives were less than 20 m, 86% were to depths less than 50 m, and less than 1% were greater than 150 m (Figure 1).

Mean dive depths for all dives greater than 4 m for seals in SE was 48.1 m (se=5.98) for adult females, 54.8 m (se=25.15) for adult males, 33.5 m (se=9.20) for subadults, and 38.5 m (se=0.18) for the pup. In KO, mean dive depths for adult females, adult males, and subadults were 19.1 m (se=3.55), 25.6 m (se=5.07), and 33.6 m (se=4.98). Considerable variability existed among individual seals.

The maximum daily dive depths were summarized for each seal (Table 3). The status data did not record the actual maximum depths for two of the young seals (5049 and 5050) because duty cycling suspended transmissions during two thirds of the deployment period; maximum depths were instead recorded in the histogram data. The deepest dives which exceeded 350 m were recorded for a subadult male in KO (5049) during each month that transmissions were received (Oct.-May). Most of the dives greater than 350 m occurred in November and December. Although daily maximum dive depths varied considerably both within and between individual seals, seals in KO appeared to have shallower dives during January to April and to show greater variability in maximum daily dive depths during the fall and late spring. Maximum dive depths were generally shallower in KO than in SE and were most likely due to differences in bathymetry between the two areas. Mean maximum dive depths for all seals in Kodiak waters ranged from 35 m for a pregnant female to 147 m for a subadult female. The deepest dives in KO were by the youngest seals.

The deepest recorded dives in SE were 308 m for an adult male (SDR 3088) and 264 m for an adult female (SDR 5041). These dives were made on 24 April in Endicott Arm and on 27 September in Salisbury Sound, respectively. Maximum daily dive depths for the adult male were deeper and varied more during mid-April to mid-May than later in the spring and early summer when maximum daily depths rarely exceeded 90 m. The adult female was monitored from fall through spring and dove consistently to maximum depths close to 180-200 m on a daily basis from September to March; dive depths then declined during the spring. The subadult seals in SE did not dive as deeply as the adult seals. The average maximum daily dive depths for subadults ranged from 160 m to 192 m compared to 160 m to 308 m for the adults. Despite considerable variability in maximum dive depths in SE, there appeared to be a pattern of deeper dives during the winter and shallower dives during the spring and summer.

Clear seasonal patterns in dive depths were evident in both areas (Figures 2 and 3). During January and February, 57% of the dives of all seals in SE were to depths greater than 50 m compared to 16% during June and July. After July, the proportion of deeper dives increased again steadily and was 42% in November and 60% in December. The percentage of shallow dives (4-20 m) gradually increased from 26% in January to a peak of 76% in July and then gradually declined again to 40% in November and 23% in December. Seals in KO showed a similar seasonal pattern, although gradual seasonal increases and decreases in dive depths were less apparent. The proportion of shallow dives (4-20 m) declined from 46% in October to 35% in December and from 43% in January to 31% in March, then increased from 54% in April to 68% in June and July. As the percentage of shallow dives declined during the fall and winter, there was a marked increase in the percentage of dives between 20-50 m, especially in March; the percentage of dives in this depth category increased from 25% in October to 60% in March. Dives were also generally deeper during the winter and fall. During October to January, 19-29% of all dives exceeded 50 m compared to 1-7% during June and July. As with dive depths, there was considerable variability among seals, as shown by SE seals during the spring (Figure 4), although distinct seasonal patterns were evident for most seals.

Duration histogram data were collected on 188,622 dives in SE and 209,228 dives in KO. The number of dives containing duration and depth information differed because of the difference in the number of depth and duration histograms successfully transmitted to the satellite. Mean dive duration for all dives in SE was 3.5 min (se = 0.47) for adult females, 3.4 min (se=1.10) for adult males, 2.2 min (se=0.24) for subadults, and 2.0 min (1.03) for the pup.

For seals in KO waters, mean dive durations were 2.8 min (se=0.21) for adult females, 2.8 min (se=0.36) for adult males, and 2.6 min (se=0.57) for subadults. Most dives were short: 41% were less than 2 min and 31% were 2-4 min in SE, while in KO 38% were less than 2 min and 44% were 2-4 min (Figure 5). The SDR software did not record maximum dive duration, so maximum dive duration was considered equal to that of the longest bin which contained dives. The maximum dive duration for most seals was greater than 18 min, however, only one of the smaller subadult seals (24-31 kg) dove longer than 18 min on one of his 21,596 dives. The smaller subadult seals (SDRs 2087, 5047, 5049, and 5050) had few (1-24) dives exceeding 8 min; whereas for the pup only six dives recorded dive durations greater than 6 min.

Considerable variability in dive duration existed among individual seals. Subadult seals generally had shorter dives and less dives in the longer duration categories. Adult harbor seals in SE appeared to be diving longer as well as deeper than adult seals in KO. Dive duration corresponded with dive depth in the distribution of the proportion of dives in the various depth and duration bins. Generally, harbor seals with a high proportion of shallow dives had a high proportion of short dives. As with dive depths, dive durations changed during the seasons. Dives tended to be shorter in the summer and longer in the winter, especially for adult females that had much shorter dives in June and July. Dive duration appeared more consistent for subadults throughout the year.

The mean number of dives per 6-hr period were summarized by sex and age class and by area (Table 4). Mean dive frequencies for individual seals in SE ranged from 4.7 to 14.8 dives per hour compared to 6.6 to 12.5 dives per hour in KO. The highest dive frequencies were recorded for a small subadult male (SDR 5049) and an adult male (SDR 5045), both tagged at Uagk Bay in KO during the fall. Subadults in both areas generally had the highest dive frequencies. Significant diurnal patterns in dive frequency ($p<0.0001$-$0.05$) were observed (Figure 6). All harbor seals dove most frequently at night (2100-0300) with the exception of three seals: in KO, a subadult female (SDR 3087) and adult male (SDR 5045) dove most frequently during the early morning (0300-0900) while in SE, the pup (SDR 5048) dove most frequently during the late afternoon (1500-2100). For some seals a seasonal effect on the frequency of dives was observed.

## DISCUSSION

Movements, diving, and time spent at sea varied widely among individuals. Seasonal and diurnal variations in diving patterns suggest the frequency, depth and duration of individual dives could be influenced by the rate of prey encounter, as has been documented for a variety of otariid species (e.g., Feldkamp *et al.* 1988, Boyd *et al.* 1994). Considerable variation in foraging behavior between individuals also suggests that individuals can adjust their foraging strategies to differences in habitat and prey availability. Age appears to play a role in determining at-sea behavior. Interpretation of results is confounded by small and unequal sample sizes and because not all age and sex classes are represented in all months. The conclusions that can be drawn are limited, and results presented in this report should be considered preliminary.

## Movements and Haulout Behavior

All 21 seals tagged with SDRs in 1995 exhibited strong fidelity to the area in which they were captured. When transmissions ceased, all ten adults were in the same general area where they had been captured, with a round-trip movement from Gambier Bay to Endicott Arm by a male the only extensive movement. Subadults made more extensive movements than adults, often undertaking repeated visits to the same area(s), and six of ten were in the same general area of capture when the SDRs stopped transmitting. Three female subadults spent the last 3-4 weeks that data were received at sites 10-20 km away from their capture site, and one male spent the last month about 100 km away from his capture area.

These results are similar to what Swain *et al.* (1996) reported for seals tagged in 1993 and 1994 in SE and KO. Frost *et al.* (1996) also reported strong fidelity among harbor seals tagged with SDRs in PWS, as 29 of 30 seals monitored from spring 1992 through spring 1995 were in PWS when last located; 24 were at or near their capture site or an adjacent haulout and the other five were 5-30 km away. The results of these recent movement studies in Alaska suggest that extensive one-way movements of harbor seals are not common. However, three of eight seals, tagged in PWS during the fall of 1995, were at the Copper River Delta when transmissions ceased in May-June of 1996 (Frost *et al.* 1997), and we observed one of five seals captured at Uganik Passage in spring 1995 to be over 100 km away. In addition, the one pup which was tagged in fall 1995 in Hoonah Sound made extensive movements throughout her first winter, and had been in southern Sitka Sound for nearly two months when her last location was recorded; a longer period than at any other site and 100 km away from her capture site.

Without monitoring seals of all ages continuously between successive reproductive periods, characterizing the extent of dispersal in harbor seals from such studies is equivocal. Breeding dispersal, the movement by adults between successive breeding areas, appears to be rare for harbor seals based on the limited movements of adult seals. Natal dispersal, movement of subadults from their area of birth to the area where they first reproduce, has not been adequately described for harbor seals. Determining the extent of natal dispersal is quite difficult, as a pup's natal area must be located along with the area where it first breeds which is not known for at least 3-4 years.

We did not examine the proportion of time hauled-out by seals, because of limitations in sample sizes, seasonal coverage, and the 'land-sea' sensor data. Methods for the analysis of this data are currently being considered and will be explored in the future. Combining data collected during 1993, 1994, and 1995 will allow comparisons of the proportion of time on land between sexes, age classes, and areas.

## Diving Behavior

The diving behavior of harbor seals is characterized by relatively short and shallow dives. The majority of dives were less than 4 min and less than 50 m in depth. Harbor seals rarely dove deeper than 150 m with 1% or less of all dives being to greater depths. The distribution of dives among different depth categories varied considerably by seal and by area. Seals in SE tended to show a bimodal pattern with most of the dives either less than 20 m or greater than 50 m. In KO, the highest proportion (48%) of dives was less than 20 m and seals use the 20-50 m depth stratum considerably more than seals in SE. Greater dive depths by seals in SE and differences in the proportion of dives to different depths between the two areas may simply reflect differences in bathymetry.

Depth data indicated that diving behavior varied by geographic location. An adult male (SDR 3088) generally dove to 90-100m when in Gambier Bay, however, when the seal moved to the deeper waters of Endicott Arm for four days in April, maximum dive depths ranged from 208-308 m. Another seal (SDR 2085), a subadult female, that was tagged in SE during the spring also dove deepest when in Endicott Arm. A subadult female in KO (SDR 2086) undertook considerable movements from her tagging location in Uganik Passage. Maximum dive depths (124-184 m) were recorded as the seal traveled in the open waters of Shelikof Strait, while maximum daily dive depths rarely exceeded 80 m when the seal was in KO coastal waters. One of the subadult seals captured in Uganik Passage during the spring (SDR 2089) dove considerably deeper than the two other subadults and used entirely different habitats . In general, seals that showed very little movement had consistent daily maximum depths, whereas those that traveled had considerable more variation in their daily maximum dive depths. The variation in maximum depth with geographic location seems to suggest harbor seals are diving to the bottom at least some of the time. Seals in Norway were found to feed near the bottom (15-200 m) in a diversity of habitats (Bjorge 1995).

Maximum depth data can provide indirect evidence about pupping dates and perinatal periods, as seen for adult females in KO during 1993 (Swain *et al.* 1996). An adult female in SE (SDR 3086) appeared to give birth in early June (June 9) and to be closely tied to land for over a week, as maximum depths did not exceed 12 m. For the following week, maximum depths continued to be comparatively shallow and ranged from 56-96 m. It is likely that this was a period when the female was closely attending her pup and when the diving skills of the pup were developing. The nursing period for harbor seals has been reported to last three to six weeks (Johnson 1976, Hoover 1983). Data from a pregnant female tagged in KO (SDR 2090) did not indicate a distinct perinatal period; there was a period of three days in mid-May where maximum depth did not exceed 8 m. However, maximum depths were consistently to 30-40 m and 92% of all dives in June were less than 20 m.

Harbor seals in both areas showed strong seasonal and diurnal patterns in diving. Dive depths decreased markedly during the late spring and summer, while deeper dives were more common during the fall and winter. Maximum daily dive depths also changed with the seasons. In general, seals used a greater diversity of depth strata during the winter. The increased proportion of shallower dives in late spring and summer corresponds to a time when fish such as herring (*Clupea harengus*), eulachon (*Thaleicthys pacificus*) and salmon (*Oncorhynchus spp.*) are abundant in the area. Consistent diurnal variations in dive patterns also imply that prey availability strongly influences diving. High dive frequencies at night, which for many of the seals were twice that observed during other periods of the day, could indicate harbor seals are pursuing vertically migrating prey, such as herring and walleye pollock (*Theragra chalcogramma*).

The diving behavior of seals tagged in 1995 was similar in many respects to seals tagged previously in SE and KO (Swain *et al.* 1996). Considerable individual variability and shallow dive depths have also been reported for seals in PWS (Frost *et al.* 1996, 1997), although seasonal patterns in dive depths were not observed. Significant diurnal patterns in dive frequency were not evident for seals tagged previously in SE and KO, however, dives did tend to occur more often at night and during the late afternoon and evening, especially in SE. Seals in PWS (Frost *et* *al.* 1995, 1996) and in southern California (Stewart and Yochem 1994) are reported to be quite variable with respect to the amount of time spent diving during different periods of the day: some seals dove primarily during the day, while others dove mostly at night.

Significant differences in dive depths are apparent in both areas between 1993/1994 and 1995 seals. Histogram and maximum depth data indicate seals dove to considerably shallower depths during 1995 and 1996. The maximum dive depth recorded for any seal tagged in 1995 was 308 m for an adult male in SE; although histogram data recorded the deepest dive as exceeding 350 m. Seals tagged in SE during 1993 and 1994 consistently dove to maximum depths of 400-500 m on a daily basis (Swain *et al.* 1996). The deepest dives, by three adult males and one subadult male (504-508 m), were deeper than the maximum dive depths of 404 m recorded for seals in PWS (Frost and Lowry 1994) and 446 m for a harbor seal in the California Channel Islands (Stewart and Yochem 1994). The distribution of dives in the various depth strata also indicate a greater percentage of dives to shallower depths by seals tagged in 1995. Mean dive depths for 1995 KO seals were considerably lower. It is unknown whether these changes in foraging depths are related to changes in the prey base.

There are differences in the diving behavior of subadult and adult seals. The smaller body size of pups two to four months of age has been shown to affect their diving abilities (Corpe *et al.* 1995). Although some size-based physiological constraints were evident in the diving behavior of the subadults in this study, especially in the younger and smaller seals and in SE, they appear able to dive as deep and as long as the adults. In fact, the deepest dives were by a small subadult male in KO (SDR 5049), most likely a yearling, that dove 41 times to depths exceeding 350 m. Overall, subadult seals in KO had deeper mean dive depths than adults as well as the deepest dives, while subadults in SE had far more shallow and short dives. The higher dive frequencies by subadults are suggestive of less developed foraging skills which would require more dives to successfully obtain prey, while the deep dives may be exploratory dives. The greater diversity in diving patterns, apparent in the diving behavior of young seals, along with greater movements, may be characteristic of young seals as they develop their foraging skills.

Foraging patterns varied widely among the individual harbor seals. Differences in foraging behavior between SE and KO are not obvious and may be masked by variability among seals. Harbor seals show a plasticity in behavioral responses which suggests that individuals have a suite of foraging strategies they can adjust to changing local and temporal conditions. Individual diving performance seems to be influenced by age, season, location, and water depth. Furthermore, individual strategies may differ but translate to the same net energy intake. The variation in foraging behavior does suggest behavioral indices of foraging effort may be able to determine differences in prey availability. The predictive value of foraging behavior in terms of prey distribution and abundance has been well documented for otariids (e.g., Bengston 1988; Costa et al 1991; Trillmich and Ono 1991; Boyd *et al.* 1994), however, the measures need to be sensitive enough to discriminate large variations between individuals. Greater sample sizes are therefore necessary to discern potential differences in foraging behavior between the SE and KO seals.

The data collected on harbor seal movements and diving from the 21 seals tagged in 1995 will be combined with the data from 27 seals reported last year (Swain *et al.* 1996) and from the 16 seals tagged in the fall of 1996 to conduct a more detailed and complete analysis. With a sample size of 64 individual seals, diving patterns as well as the spatial and temporal use of haulouts will be compared between males and females, adults and subadults, and SE and KO. In addition, the movement data will be integrated with the results of dive data analyses to provide insight on the foraging behavior of seals.

## LITERATURE CITED

Alaska Department of Fish and Game. 1995. Investigations of harbor seals in Alaska. Final rep. for NOAA award NA37FX0142. Office of Protected Resources, National Marine Fisheries Service, NOAA, Silver Spring, MD. 26pp

Alaska Department of Fish and Game. 1996. Harbor seal investigations in Alaska. Annual rep. for NOAA award NA57FX0367. Office of Protected Resources, National Marine Fisheries Service, NOAA, Silver Spring, MD. 203pp

Bengston, J.L., R.D. Hill, and S.E. Hill. 1993. Using satellite telemetry to study the ecology and behaviour of Antarctic seals. Korean Journal of Polar Research 4:109-115.

Bjorge, A. 1995. Comparative habitat use and foraging behaviour of harbour seals and grey seals in western Norway. ICES C.M. 1995. n:1. 13pp.

Boyd, I.L., J.P.Y. Arnould, T. Barton, and J.P. Croxall. 1994. Foraging behaviour of Antarctic fur seals during periods of contrasting prey abundance. Journal of Animal Ecology 63:703-713.

Calkins, D.G. and E.A. Goodwin. 1988. Investigation of the declining sea lion population in the Gulf of Alaska. Unpubl. rep., Alaska Dept. Fish and Game, 333 Raspberry Rd., Anchorage, AK 99518. 76 pp.

Coltman, D. W., M. D. Bowen, and D. J. Boness. 1995. Does body mass affect aquatic behaviour of harbour seal (*Phoca* vitulina) males during the mating season? Abstract. Eleventh Biennial Conf. on the Biology of Marine Mammals, 14-18 Dec. 1995, Orlando, FL.

Corpe, H. M., P. M. Thompson, A. Mackay, D. J. Tollit, and D. J. Reid. 1995. The development of diving in juvenile harbour seals. Abstract. Eleventh Biennial Conf. on the Biology of Marine Mammals, 14-18 Dec. 1995, Orlando, FL.

Croxall, J.P., I. Everson, G.L. Kooyman, C. Ricketts, and R.W. Davis. 1985. Fur seal diving behaviour in relation to vertical distribution of krill. Journal of Animal Ecology 54:1-8.

Croxall, J.P., T.S. McCann, P.A. Prince, and P. Rotherby. 1988. Reproductive performance of sea birds and seals at South Georgia and Signy Island, South Orkney Islands, 1976-1987: implications for Southern Ocean Monitoring Studies. Pages 261-285 *in* D. Sahrhage, ed. Antarctic Ocean and Resources Variability. Springer Verlag, Berlin, Germany.

Fancy, S.G., L.F. Pank, D.C. Douglas, C.H. Curby, G.W. Garner, S.C. Amstrup, and W.L. Regelin. 1988. Satellite telemetry: a new tool for wildlife research and management. U.S. Fish and Wildlife Service Resource Publ. No. 172.

Fedak, M. A, S. S. Anderson, and M. G. Curry. 1984. Attachment of a radio tag to the fur of seals. Notes from the Mammal Society. 46:298-300.

Feldkamp, S.D., R.L. Delong, and G.A. Antonelis. 1989. Diving patterns of California sea lions, *Zalophus californianus*. Canadian Journal of Zoology 67:872-883.

Frost, K. J. and L. F. Lowry. 1994. Habitat use, behavior, and monitoring of harbor seals in Prince William Sound, Alaska. Annual Rep. for *Exxon Valdez* Oil Spill Restoration Science Study 93064. Alaska Dept. of Fish and Game, Wildlife Conservation Division, Fairbanks. 99pp.

Frost, K. J., L. F. Lowry, and J. Ver Hoef. 1995. Habitat use, behavior, and monitoring of harbor seals in Prince William Sound, Alaska. Annual Rep. for *Exxon Valdez* Oil Spill Restoration Project (Restoration Projects 94064 and 94320-F), Alaska Dept. of Fish and Game, Wildlife Conservation Division, Fairbanks. 88pp.

Frost, K. J., L. F. Lowry, R. J. Small, and S. J. Iverson. 1996. Monitoring, habitat use, and trophic interactions of harbor seals in Prince William Sound, Alaska. Annual Rep. for *Exxon Valdez* Oil Spill Restoration Project (Restoration Project 95064), Alaska Dept. of Fish and Game, Wildlife Conservation Division, Fairbanks. 87pp.

Frost, K. J., L. F. Lowry, J. VerHoef, and S. J. Iverson. 1997. Monitoring, habitat use, and trophic interactions of harbor seals in Prince William Sound, Alaska. Annual Rep. for *Exxon Valdez* Oil Spill Restoration Project (Restoration Project 96064), Alaska Dept. of Fish and Game, Wildlife Conservation Division, Fairbanks. 56pp.

Harvey, J. T. 1988. Abundance and distribution of harbor seals, *Phoca vitulina*, in Oregon. Ph.D. thesis, Oregon State Univ., Corvallis.

Hindell, M.A., D.J. Slip, and H.R. Burton. 1991. The diving behaviour of adult male and female southern elephant seals, *Mirounga leonina* (Pinnipedia: Phocidae). Australian Journal of Zoology 39:595-619.

Hoover, A. A. 1983. Behavior and ecology of harbor seals *Phoca vitulina richardsi* inhabiting glacial ice in Aialik Bay, Alaska. M.S. thesis, Univ. of Alaska, Fairbanks. 133pp.

Hoover-Miller, A. A. 1994. Harbor seal (*Phoca vitulina*): Biology and management in Alaska. Final rep. for MMC contract T75134749. U. S. Marine Mammal Commission, Washington, D.C. 44pp.

Johnson, B. W. 1976. Studies on the northernmost colonies of Pacific harbor seals, *Phoca vitulina richardsi*, in the eastern Bering Sea. Unpubl. rep., Alaska Dept. of Fish and Game, Fairbanks. 67pp.

Keating, K.A., W.G. Brewster, C.H. Key. 1991. Satellite telemetry: performance of animal-tracking systems. Journal of Wildlife Management 55:160-171.

Keating, K.A. 1994. An alternative index of satellite telemetry location error. J. Wildl. Manage. 58:414-421.

Kooyman, G.L., R.W. Davis, and J.P. Croxall. 1986. Diving behaviour of Antarctic fur seals. Pages 186-195 *in* R.L. Gentry and G.L. Kooyman, eds. Fur seals: maternal strategies on land and at sea. Princeton University Press, Princeton, N.J.

Lewis, J.P., G.W. Pendleton, K.W. Pitcher, and K. M. Wynne. 1996. Harbor seal population trends in Southeast Alaska and the Gulf of Alaska. Pages 8-57 *in* Harbor seal investigations in Alaska. Annual rep. for NOAA award NA57FX0367, Alaska Dept. of Fish and Game, Anchorage, AK. 203pp.

Loughlin, T. R. 1992. Abundance and distribution of harbor seals (*Phoca vitulina richardsi*) in Bristol Bay, Prince William Sound, and Copper River Delta during 1991. Unpubl. rep., National Marine Fisheries Service, Seattle, WA. 26pp.

Loughlin, T. R. 1993. Abundance and distribution of harbor seals (*Phoca vitulina richardsi*) in the Gulf of Alaska and Prince William Sound in 1992. Annual rep. for 1992 to the MMPA Assessment Program, Office of Protected Resources, National Marine Fisheries Service, NOAA, Silver Spring, MD. 25pp.

Loughlin, T.R., and R.L. Merrick. 1989. Comparison of commercial harvests of walleye pollock and northern sea lion abundance in the Bering Sea and Gulf of Alaska. Pages 679-700 *in* Proc. Int. Symp. Biol. Manage. Walleye Pollock. Alaska Sea Grant Rpt. 89-1. Univ. of Alaska, Fairbanks, AK.

Lowry, L.F., K.J. Frost, and T.R. Loughlin. 1989. Importance of walleye pollock in the diets of marine mammals in the Gulf of Alaska and Bering Sea, and implications for fishery management. Pages 701-726 *in* Proc. Int. Symp. Biol. Manage. Walleye Pollock. Alaska Sea Grant Rpt. 89-1. Univ. of Alaska, Fairbanks, AK.

Mackay, A., P. Thompson, and D. J. Tollit. 1995. Characteristics of harbour seal foraging trips. Abstract. Eleventh Biennial Conf. on the Biology of Marine Mammals, 14-18 Dec. 1995, Orlando, FL.

Merrick, R.L. 1995. The relationship of the foraging ecology of Steller sea lions (*Eumetopias jubatus*) to their population decline in Alaska. Ph.D. thesis, Univ. of Washington, Seattle. 171pp.

Ono, K.A., D.J. Boness and O.T. Oftedal. 1987. The effect of a natural environmental disturbance on maternal investment and pup behavior in the California sea lion. Behav. Eco. Sociobiol. 21:109-118.

Pitcher, K. W. 1989. Harbor seal trend count surveys in southern Alaska, 1988. Final rep. for MMC contract MM4465853-1. Marine Mammal Commission, Washington, D.C. 15pp. (Natl. Tech. Inf. Serv., PB90-209929.)

Pitcher, K. W. 1990. Major decline in the number of harbor seals, *Phoca vitulina richardsi*, on Tugidak Island, Gulf of Alaska. Mar. Mammal Sci. 6: 121-134.

Pitcher, K. W. and D. G. Calkins. 1979. Biology of the harbor seal, *Phoca vitulina richardsi*, in the Gulf of Alaska. U. S. Dep. Commer., NOAA, OCSEAP Final Rep. 19: 231-310.

Sease, J. L. 1992. Status review: harbor seals (*Phoca vitulina*) in Alaska. Processed rep., U. S. Dep. Coomer., NOAA, National Marine Fisheries Service, Alaska Fish. Sci. Cent., Seattle, WA. Alaska Fisheries Science Center Processed Report 92-15. 74pp.

Small, R. J., G.W. Pendleton, and K. M. Wynne. 1997. Harbor seal population trends in the Ketchikan, Sitka, and Kodiak Island areas of Alaska. Pages 7-32 *in* Harbor seal investigations in Alaska. Annual rep. for NOAA award NA57FX0367, Alaska Dept. of Fish and Game, Anchorage, AK. ??pp.

Springer, A. M. 1993. Report of the Seabird Working Group. Is it Food? Addressing marine mammal and seabird declines: workshop summary. Alaska Sea Grant AK-SG-93-01. University of Alaska, Fairbanks, AK.

Stephens, D.W., and J.R. Krebs. 1986. Foraging theory. Princeton University Press, Princeton, N.J.

Stewart, B. S. and P. Yochem. 1994. Ecology of harbor seals in the southern California bight. Pages 123-134 *in* W. L. Halvorson and G. J. Maender, eds. The fourth California islands symposium: update on the status of resources. Santa Barbara Museum of Natural History.

Stewart, B.S., S. Leatherwood, P.K. Yochem, and M.-P. Heide-Jorgensen. 1989. Harbor seal tracking and telemetry by satellite. Marine Mammal Science 5:361-375.

Swain, U.G., J.P. Lewis, and G.W. Pendleton. 1996. Movements, haulout, and diving behavior of harbor seals in Southeast Alaska and Kodiak Island. Pages 59-144 *in* Harbor seal investigations in Alaska. Annual rep. for NOAA award NA57FX0367, Alaska Dept. of Fish and Game, Anchorage, AK. 203pp.

Swartzman, G. L. and R. J. Hofman. 1991. Uncertainties and research needs regarding the Bering Sea and Antarctic marine ecosystems. Final report for MMC contracts T75133669 and

T75134820. Marina Mammal Commission, Washington, D. C. 111pp. (Natl. Tech. Inf. Serv., PB91-201731)

Thompson, P. and D. Miller. 1990. Summer foraging activity and movements of radio-tagged common seals (*Phoca vitulina* L.) in the Moray Firth, Scotland, J. Appl. Ecol. 27:492-501.

Thompson, P. M., D. J. Tollit, S. P. R. Greenstreet, A. Mackay, and H. M. Corpe. 1995. Between year differences in harbour seal diet and behaviours; causes and consequences. Abstract. Eleventh Biennial Conf. on the Biology of Marine Mammals, 14-18 Dec. 1995, Orlando, FL.

Trillmich, F., K.A. Ono, D.P. Costa, R.L. DeLong, S.D. Feldkamp, J.M. Francis, R.L. Gentry, C.B. Heath, B.J. LeBoeuf, P. Majluf, and A.E. York. 1991. The effects of El Nino on pinniped populations in the eastern Pacific. Pages 247-260 *in* F. Trillmich and K.A. Ono, eds. Pinnipeds and El Nino: responses to environmental stress. Springer Verlag, Berlin, Germany.

Van Parijs, S., P. M. Thompson, D. J. Tollit, and A. Mackay. 1995. Aquatic display behaviour of mating male harbour seals: distribution, vocalisations and dive patterns. Abstract. Eleventh Biennial Conf. on the Biology of Marine Mammals, 14-18 Dec. 1995, Orlando, FL.

Withrow, D. E. and T. R. Loughlin. 1994. Haulout behavior and method to estimate the proportion of harbor seals missed during molt census surveys in Alaska. Annual rep. for 1994 to the MMPA Assessment Program, Office of Protected Resources, National Marine Fisheries Service, NOAA, Silver Spring, MD. 39pp.

Table 1. Duration of deployments of 21 harbor seals tagged in Southeast Alaska (SE) and the Kodiak Archipelago (KO) during spring and fall 1995.

| SDR (Seal No.) | Sex | Age | Mass (kg) | Capture Location | Deployment Dates | Total Days Operational |
|---|---|---|---|---|---|---|
| ***SE*** | | | | | ***Spring*** | |
| 3088 (SE95S01) | M | Adult | 56 | Price Island | 19 April - 13 July | 86 |
| 3090 (SE95S02) | F | Adult | 69 | Price Island | 19 April - 8 July | 81 |
| 2085 (SE95S03) | F | Subadult | 36 | Price Island | 19 April - 4 July | 77 |
| 2087 (SE95S04) | F | Subadult | 31 | Price Island | 19 April - 17 June | 60 |
| 3086 (SE95S05) | F | Adult | 93 | Pybus Reef | 21 April - 21 July | 94 |
| | | | | | ***Fall*** | |
| 5043 (SE95F01) | M | Adult | 70 | Vixen Island | 21 Sept - 20 April | 211 |
| 5042 (SE95F02) | F | Adult | 81 | Vixen Island | 21 Sept - 28 April | 219 |
| 5047 (SE95F03) | F | Subadult | 31 | Vixen Island | 22 Sept - 13 May | 234 |
| 5041 (SE95F04) | F | Adult | 54 | Vixen Island | 22 Sept - 30 May | 251 |
| 5048 (SE95F05) | F | Pup | 24 | Vixen Island | 22 Sept - 29 April | 220 |
| ***KO*** | | | | | ***Spring*** | |
| 3089 (KO95S01) | M | Adult | 85 | Uganik Passage | 29 March - 29 July | 123 |
| 2086 (KO95S02) | F | Subadult | 49 | Uganik Passage | 29 March - 7 June | 71 |
| 2090 (KO95S03) | F | Adult | 113 | Uganik Passage | 29 March - 15 June | 79 |
| 2089 (KO95S04) | M | Subadult | 50 | Uganik Passage | 29 March - 24 May | 57 |
| 3087 (KO95S05) | F | Subadult | 57 | Uganik Passage | 29 March - 8 July | 102 |
| | | | | | ***Fall*** | |
| 5044 (KO95F01) | F | Subadult | 54 | Ugak Bay | 9 Oct - 4 June | 144 |
| 5049 (KO95F02) | M | Subadult | 31 | Ugak Bay | 9 Oct - 27 May | 231 |
| 5046 (KO95F03) | F | Adult | 75 | Ugak Bay | 9 Oct - 28 June | 263 |
| 5045 (KO95F04) | M | Adult | 93 | Ugak Bay | 9 Oct - 18 June | 253 |
| 5051 (KO95F05)[1] | F | Subadult | 47 | Kiliuda Bay | 10 Oct - 8 April | 182 |
| 5050 (KO95F06) | F | Subadult | 31 | Kiliuda Bay | 10 Oct - 16 May | 220 |

[1] Only location data are presented for this seal.

Table 2. Dive depths for 20 SDR-tagged harbor seals in Southeast Alaska (SE) and the Kodiak Archipelago (KO) during 1995-96.

| SDR | No. of Dives | Dates | Percentage of Total Dives | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | < 20 m | 20-50 m | 50-76 m | 76-100 m | 100-150 m | 150-200 m | > 200 m |
| ***SE - Adult Males*** | | | | | | | | | |
| 3088 | 16,128 | April-July | 66.2 | 12.2 | 8.4 | 12.3 | 0.7 | 0.2 | 0.08 |
| 5043 | 18,472 | Sept-April | 30.6 | 8.4 | 5.4 | 10.9 | 36.8 | 6.9 | 1.0 |
| All | 34,600 | | 48.4 | 10.3 | 6.9 | 11.6 | 18.8 | 3.6 | 0.5 |
| ***SE - Adult Females*** | | | | | | | | | |
| 3090 | 11,362 | April-July | 57.0 | 8.5 | 8.8 | 13.7 | 10.8 | 1.2 | 0.02 |
| 3086 | 15,116 | April-June | 62.8 | 10.6 | 9.4 | 13.4 | 3.8 | 0.02 | - |
| 5042 | 22,909 | Sept-April | 33.1 | 17.6 | 19.9 | 10.3 | 16.1 | 3.0 | 0.02 |
| 5041 | 26,665 | Sept-May | 43.0 | 12.1 | 9.5 | 9.2 | 21.6 | 4.6 | 0.1 |
| All | 76,052 | | 49.0 | 12.2 | 11.9 | 11.7 | 13.1 | 2.2 | 0.06 |
| ***SE - Subadults*** | | | | | | | | | |
| 2085 $^{F}$ | 16,766 | April-July | 63.3 | 22.7 | 11.2 | 2.8 | 0.04 | 0.01 | - |
| 2087 $^{F}$ | 15,322 | April-June | 64.1 | 26.0 | 8.4 | 1.3 | 0.2 | 0.02 | - |
| 5047 $^{F}$ | 19,000 | Sept-May | 27.8 | 24.4 | 27.1 | 8.7 | 11.5 | 0.5 | - |
| All | 51,088 | | 51.7 | 24.3 | 15.5 | 4.2 | 3.9 | 0.2 | |
| ***SE - Pup*** | | | | | | | | | |
| 5048 $^{F}$ | 26,534 | Sept-April | 38.8 | 31.2 | 18.5 | 8.3 | 3.2 | 0.02 | - |

Table 2. Continued.

| SDR | No. of Dives | Dates | Percentage of Total Dives | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | < 20 m | 20-50 m | 50-76 m | 76-100 m | 100-150 m | 150-200 m | > 200 m |
| ***KO - Adult Males*** | | | | | | | | | |
| 3089 | 25,707 | Mar-July | 69.0 | 26.3 | 4.1 | 0.5 | 0.02 | - | - |
| 5045 | 32,238 | Oct-June | 43.3 | 38.6 | 15.5 | 2.6 | | - | - |
| All | 57,945 | | 56.2 | 32.5 | 9.8 | 1.6 | 0.02 | - | - |
| ***KO - Adult Females*** | | | | | | | | | |
| 2090 | 8,552 | Mar-June | 88.7 | 11.2 | 0.1 | 0.01 | - | - | - |
| 5046 | 38,262 | Oct-June | 44.7 | 49.6 | 4.8 | 0.9 | - | - | - |
| All | 46,814 | | 66.7 | 30.4 | 2.5 | 0.5 | - | - | - |
| ***KO - Subadults*** | | | | | | | | | |
| 2086 F | 13,062 | Mar-July | 61.9 | 29.2 | 7.1 | 1.6 | 0.02 | 0.01 | - |
| 2089 M | 6,589 | Mar-May | 39.0 | 27.4 | 8.5 | 3.9 | 12.5 | 8.4 | 0.3 |
| 3087 F | 15,098 | Mar-July | 62.0 | 32.0 | 5.6 | 0.4 | 0.02 | - | - |
| 5044 F | 32,195 | Oct-June | 25.4 | 43.0 | 26.7 | 4.9 | 0.01 | - | - |
| 5049 M | 21,420 | Oct-May | 55.0 | 36.2 | 5.6 | 3.0 | | - | 0.2 |
| 5050 F | 16,172 | Oct-May | 30.5 | 41.0 | 27.2 | 1.3 | 0.08 | 0.02 | - |
| All | 104,536 | | 45.6 | 34.8 | 13.5 | 2.5 | 2.1 | 1.4 | 0.1 |

For subadults and pup: M = Male; F = Female

Table 3. Maximum daily dive depths (m) for 20 SDR-tagged harbor seals in Southeast Alaska (SE) and the Kodiak Archipelago, March 1995 - July 1995.

| SDR | Sex | Age[a] | Deployment Dates | n[b] | Max Depth | Mean Max Depth | Range | Maximum Depth Date[c] | Comments |
|---|---|---|---|---|---|---|---|---|---|
| ***SE*** | | | ***Spring 1995*** | | | | | | |
| 3088 | M | Ad | April-July | 85 | 308 | 111.9 | 32-308 | 4/24/95 | Mid-May through July consistent max. depth dives to 90-100m |
| 3090 | F | Ad | April-July | 79 | 228 | 140.2 | 4-228 | 6/23/95 | |
| 3086 | F | Ad | April-June | 88 | 160 | 100.1 | 8-160 | 7/12/95 | Max. depth did not exceed 12m from 6/9-6/17 (possible natal period) |
| 2085 | F | Sub | April-July | 64 | 160 | 80.8 | 4-160 | 5/10/95 | |
| 2087 | F | Sub | April-June | 58 | 192 | 77.7 | 0-192 | 4/24/95 | Deep dives correspond to movements to Pybus Bay and The Brothers Islands |
| | | | ***Fall 1995*** | | | | | | |
| 5043 | M | Ad | Sept-April | 169 | 260 | 168.7 | 0-260 | 11/5/95<br>1/24-25 & 2/10/96 | Max. depths highly variable |
| 5042 | F | Ad | Sept-April | 194 | 220 | 143.2 | 0-220 | 9/24/95 | Max. depths highly variable |
| 5041 | F | Ad | Sept-May | 72 | 172 | 104.4 | 0-172 | 9/27/95 | Oct - early Dec consistent max. depths to 80m; mid-April - May max depth did not exceed 90 m |
| 5047 | F | Sub | Sept-May | 218 | 264 | 158.1 | 0-264 | 1/27/96 | Sept to March consistent max. depths to 180-200m |
| 5048 | F | Pup | Sept-April | 59 | 164 | 107.2 | 0-164 | 12/28/95 | Max. depths vary, increase during Nov. to March |

Table 3. Continued.

| SDR | Sex | Age[a] | Deployment Dates | n[b] | Max Depth | Mean Max Depth | Range | Maximum Depth Date[c] | Comments |
|---|---|---|---|---|---|---|---|---|---|
| ***KO*** | | | ***Spring 1995*** | | | | | | |
| 3089 | M | Ad | Mar-July | 112 | 116 | 68.2 | 8-116 | 5/4/95 | Max. depths vary 40-100m |
| 2090 | F | Ad | Mar-June | 67 | 80 | 35.4 | 4-80 | 5/18/95 | Consistent max. depths @ 36m |
| 2086 | F | Sub | Mar-July | 51 | 184 | 78.2 | 12-184 | 4/20/95 | Max. depths vary less in May; deepest dives during movements through Shelikof Strait |
| 2089 | M | Sub | Mar-May | 34 | 236 | 147.3 | 0-236 | 4/3 & 4/10/95 | April - May max. depths to 200m; max. depths decline in May to 60m |
| 3087 | F | Sub | Mar-May | 95 | 112 | 61.7 | 0-112 | 4/25/95 | Max. depths variable |
| | | | ***Fall 1995*** | | | | | | |
| 5045 | M | Ad | Oct-April | 224 | 92 | 62.8 | 0-92 | 10/24/95 | Max. depths 60-80m, except Jan through March most max. depth dives to 44m |
| 5046 | F | Ad | Oct-July | 224 | 84 | 48.1 | 0-84 | 5/5-6, 5/10 & 5/23/95 | Late Jan - late April max. depths 24-48m |
| 5044 | F | Sub | Oct-June | 191 | 104 | 74.3 | 24-104 | 11/5/95 & 5/20/96 | Jan through March max. depth did not exceed 80m |
| 5049 | M | Sub | Oct-Jan | 54 | > 350 | 55.6 | 28->350 | Oct - May (41 dives) | Status data did not record max. depth; late Jan - mid April most max. depths to 40m |
| 5050 | F | Sub | Oct-June | 60 | 150-200 | 66.3 | 0-(150-200) | Dec, Feb, Mar (4 dives) | Status data did not record max. depth; most max. depth dives 60-80m |

[a] Ad = Adult; Sub = Subadult

[b] The number of days with maximum daily dive depths.

[c] The dates of the dive with the maximum depth are given. When more than one date recorded the maximum dive, the dates or range of dates are given.

Table 4. Mean dive frequencies for 27 SDR-tagged harbor seals in Southeast Alaska and the Kodiak Island area during 1995-1996.

| Sex/Age Class (n)[a] | No. of 6-hr periods[b] | Dive frequency[c] | Maximum dive frequency |
|---|---|---|---|
| ***SOUTHEAST*** | | | |
| AF (4) | 2,239 | 5.9 (0.51) | 30.0 |
| AM (2) | 964 | 6.3 (1.62) | 38.7 |
| Sub (3) | 837 | 10.3 (0.59) | 37.7 |
| Pup (1) | 327 | 14.8 (0.39) | 36.0 |
| ***KODIAK*** | | | |
| AF (2) | 1,346 | 6.1 (0.89) | 29.3 |
| AM (2) | 1,301 | 8.2 (2.32) | 41.0 |
| Sub (6) | 2,018 | 8.9 (0.89) | 43.8 |

[a] AF = Adult female, AM = Adult Male, Sub = Subadult, (n) = number of seals.

[b] No. of 6-hr periods (histograms) in which data was collected.

[c] Mean no. of dives per hr (se).

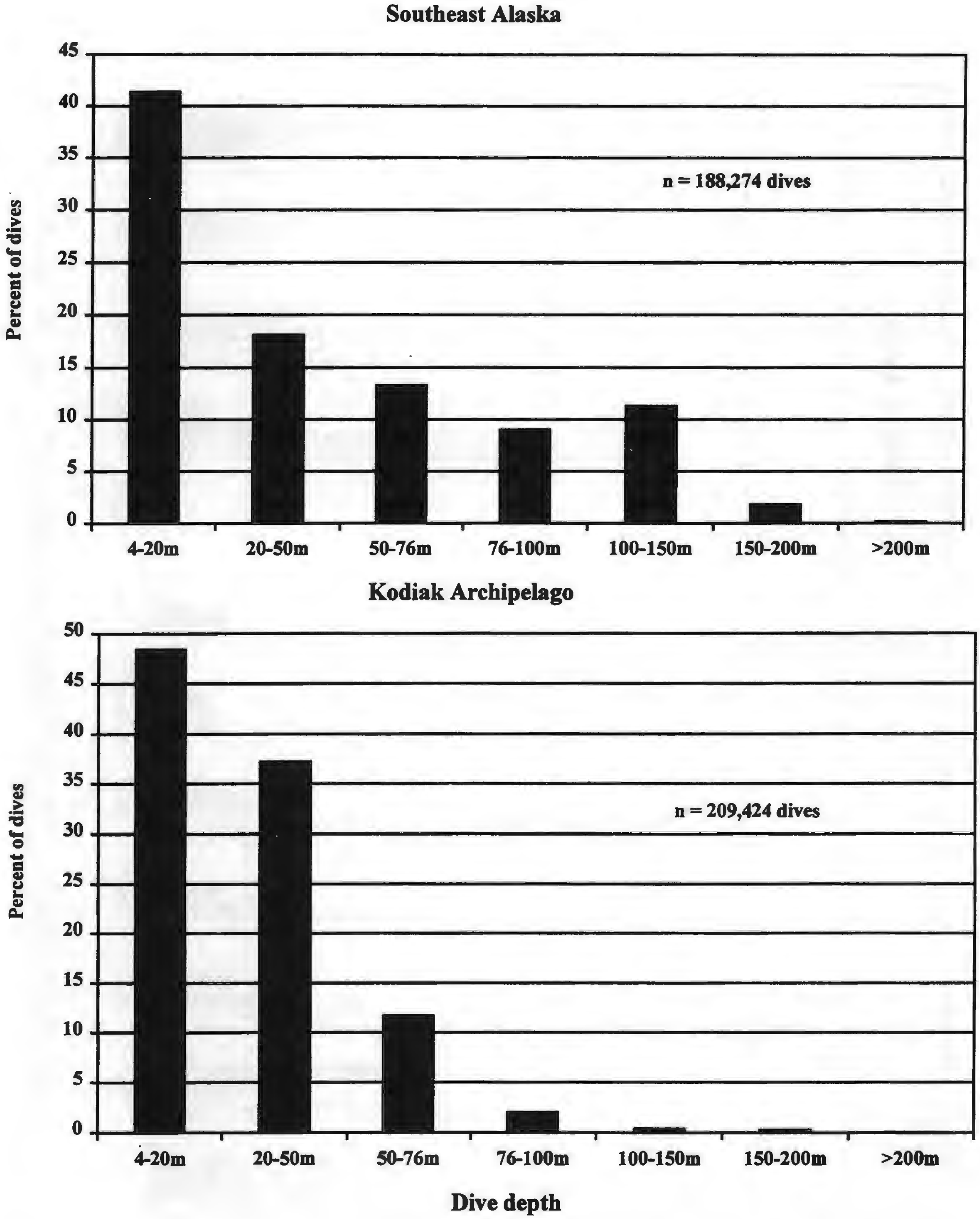


Figure 1. Percentage of all dives by depth category (bin) for 20 SDR-tagged harbor seals in Southeast Alaska and the Kodiak Archipelago, March 1995 - June 1996.

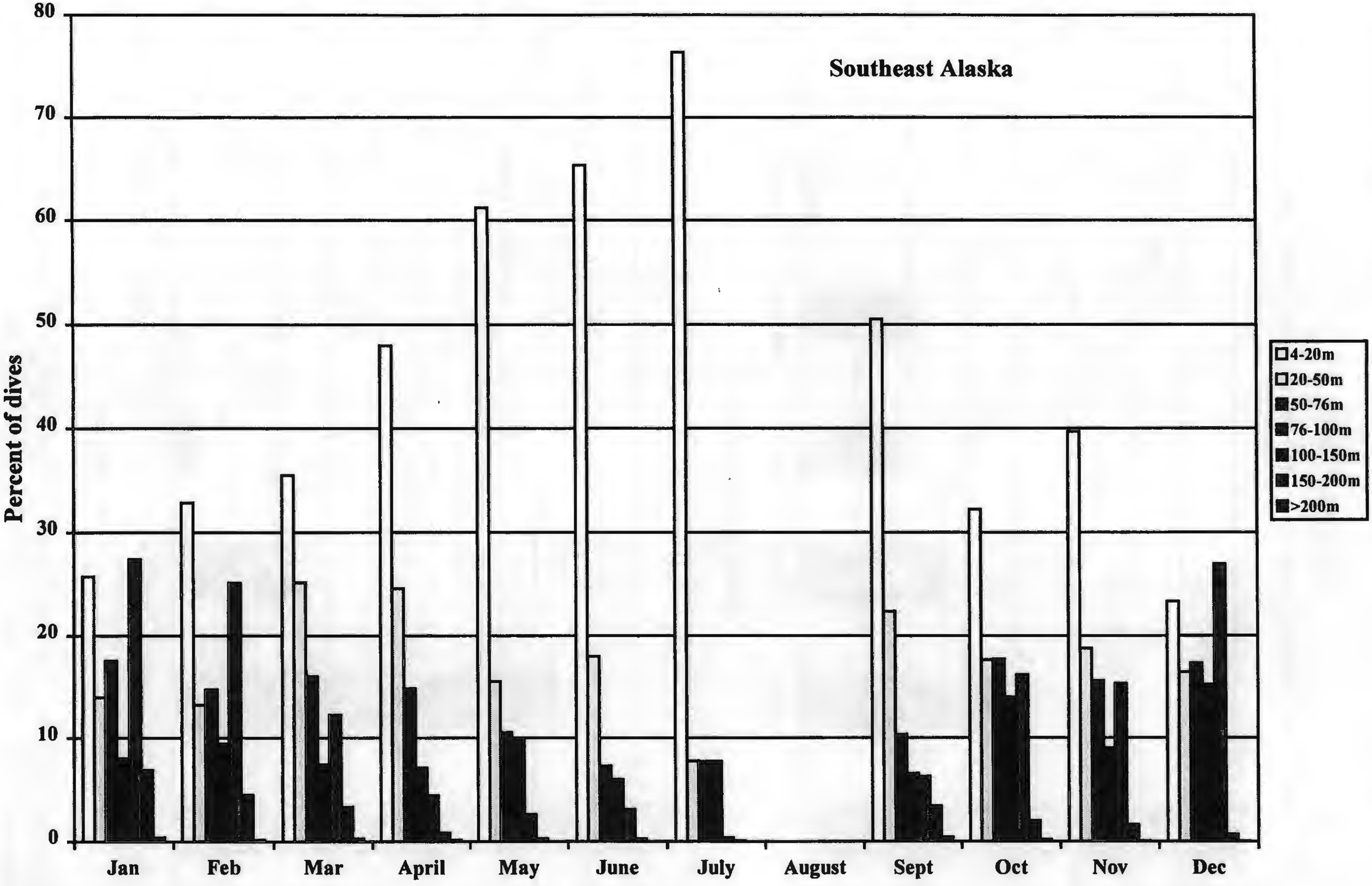


Figure 2. Seasonal distribution of dive depths (m) for 10 SDR-tagged harbor seals in Southeast Alaska, April 1995 - May 1996.

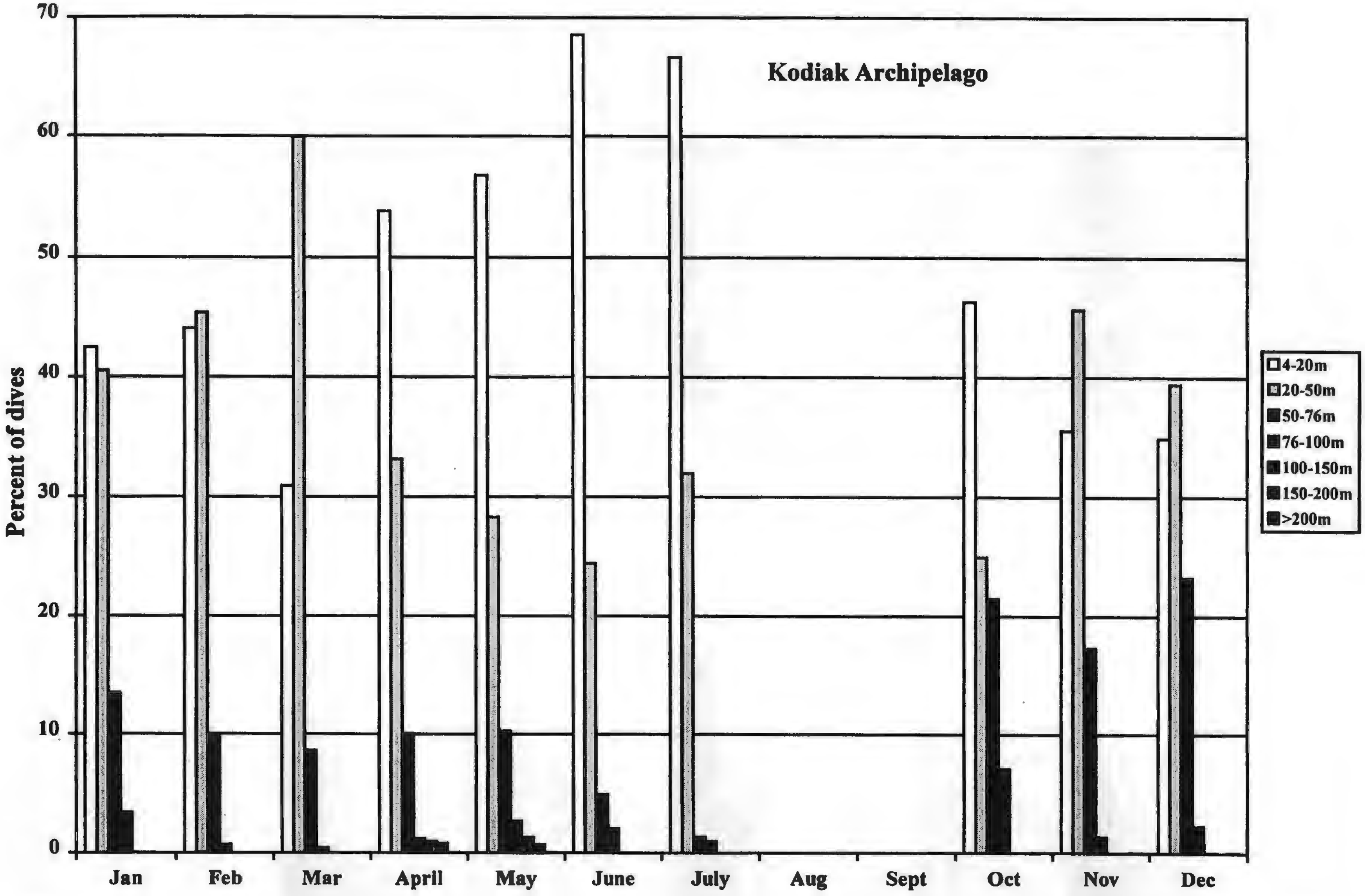
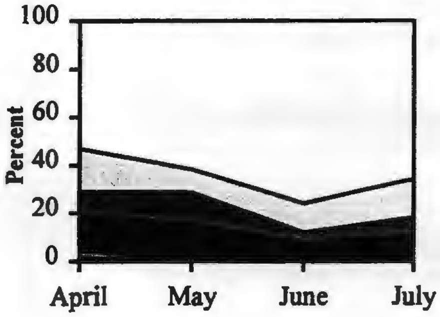
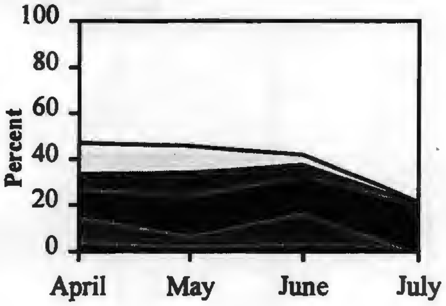


Figure 3. Seasonal distribution of dive depths (m) for 10 SDR-tagged harbor seals in the Kodiak Archipelago, March 1995 - June 1996.

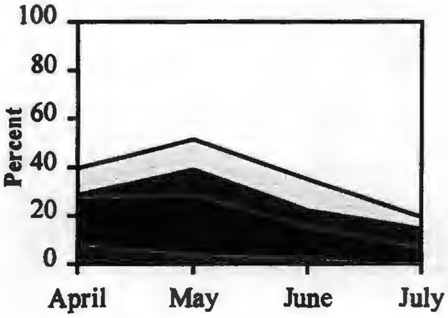
Seal SE95S01 (SDR 3088)
Adult Male - Price Is.



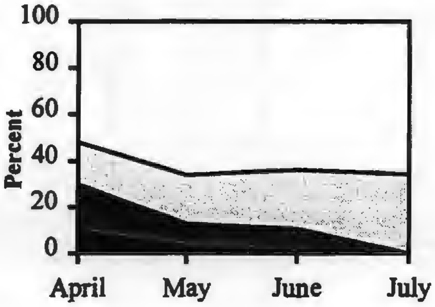
Seal SE95S02 (SDR 3090)
Adult Female - Price Island



Seal SE95S05 (SDR 3086)
Adult Female - Pybus Reef



Seal SE95S03 (SDR 2085)
Subadult Female - Price Island



Seal SE95S04 (SDR 2087)
Subadult Female - Price Island

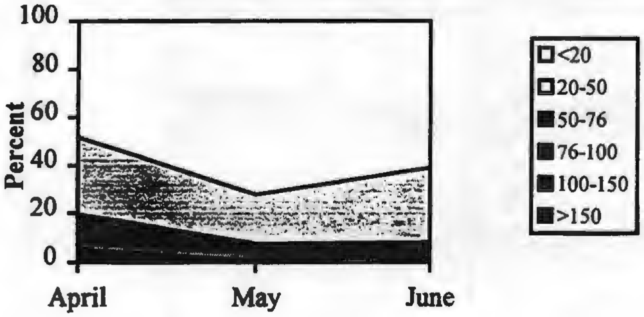
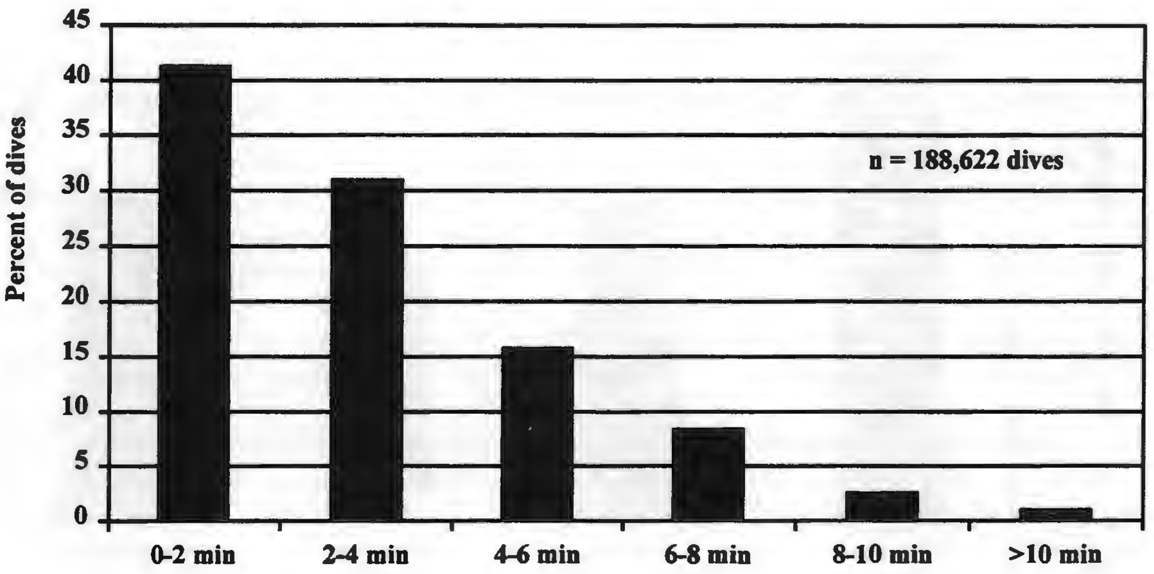


Figure 4. Monthly distribution of dive depths (m) for 5 SDR-tagged harbor seals in Southeast Alaska, April-July 1995.

**Southeast Alaska**



**Kodiak Archipelago**

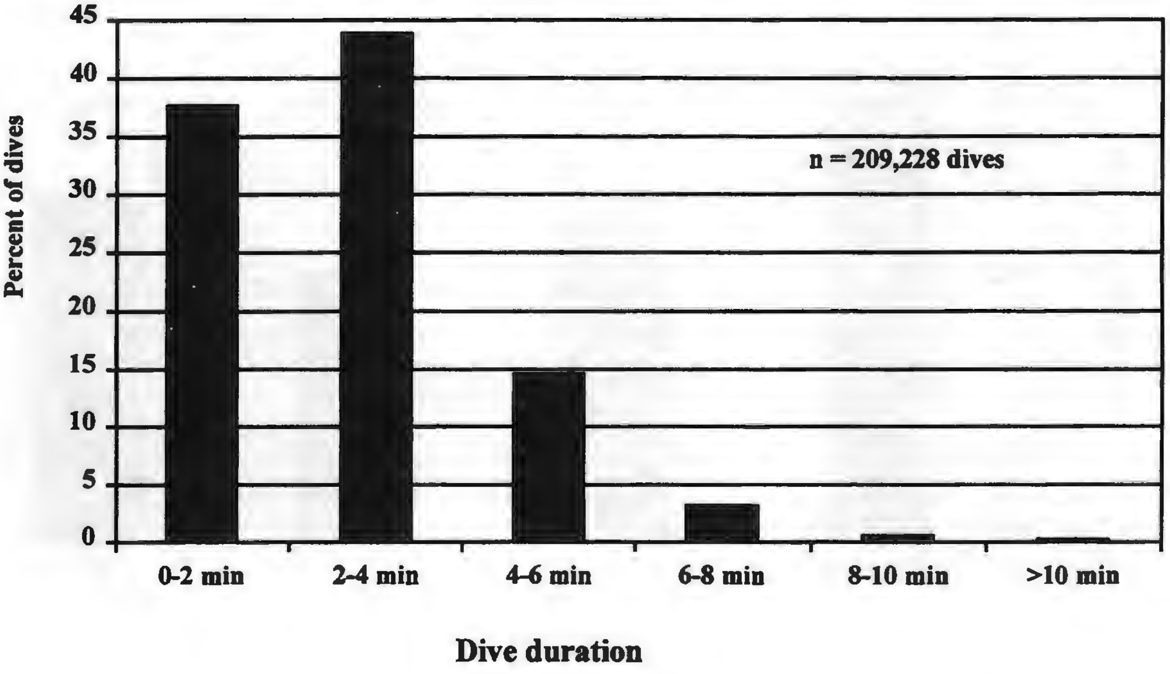


Figure 5. Percentage of all dives by duration category (bin) for 20 SDR-tagged harbor seals in Southeast Alaska and the Kodiak Archipelago, March 1995 - June 1996.

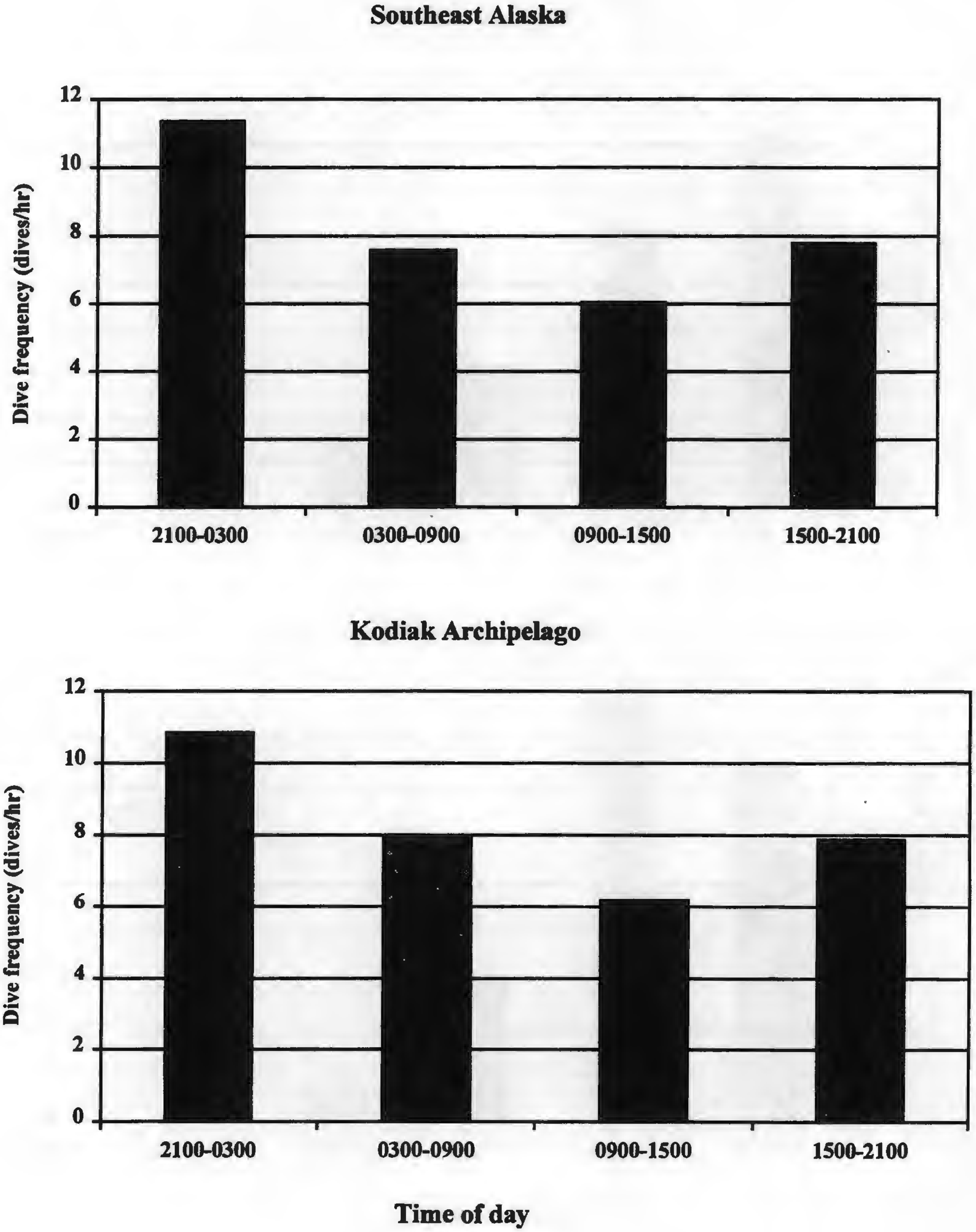


Figure 6. Dive frequency by time of day for 20 SDR-tagged harbor seals in Southeast Alaska and the Kodiak Archipelago, March 1995 - July 1996.

## Appendix 1. Movements of satellite tagged harbor seals in Southeast Alaska and the Kodiak Archipelago

Table 1A. Summary of movements made by harbor seals tagged with satellite transmitters in Southeast Alaska, spring 1995. The general areas where seal locations were concentrated are listed by consecutive dates.

**SDR 3088 (Seal# SE95S01) Adult Male captured at Price Island[1]**

| *Gambier Bay* | *Endicott Arm* |
|---|---|
| 19 Apr – 21 Apr | |
| | 22 Apr – 25 Apr |
| 26 Apr – 13 Jul | |

**SDR 3090 (Seal# SE95S02) Adult Female captured at Price Island[1]**

| *Gambier Bay* | *The Brothers Islands* |
|---|---|
| 19 Apr – 4 May | |
| | 5 May – 9 May |
| 10 May – 7 Jul | |

**SDR 2085 (Seal# SE95S03) Subadult Female captured at Price Island[1]**

| *Gambier Bay* | *Endicott Arm* | *The Five Fingers* |
|---|---|---|
| 20 Apr – 7 May | | |
| | 8 May – 10 May | |
| 11 May – 30 May | | |
| | | 31 May – 7 Jun |
| 8 Jun – 9 Jun | | |
| | | 10 Jun – 30 Jun |

**SDR 2087 (Seal# SE95S04) Subadult Female captured at Price Island[1]**

| *Gambier Bay* | *Pybus Bay* | *The Brothers Islands* |
|---|---|---|
| 19 Apr – 20 Apr | | |
| | 21 Apr | |
| | | 22 Apr – 27 Apr |
| 28 Apr – 3 May | | |
| | | 4 May – 5 May |
| | 6 May – 13 May | |
| 14 May – 19 May | | |
| | 20 May – 16 Jun | |

**SDR 3086 (Seal# SE95S05) Adult Female captured at Pybus Reef[2]**

*Pybus Bay*: 21 Apr – 21 Jul

---

[1] Price Island is just south of the mouth of Gambier Bay; see Figures 1-4.

[2] Pybus Reef is just south of the mouth of Pybus Bay; see Figure 5.

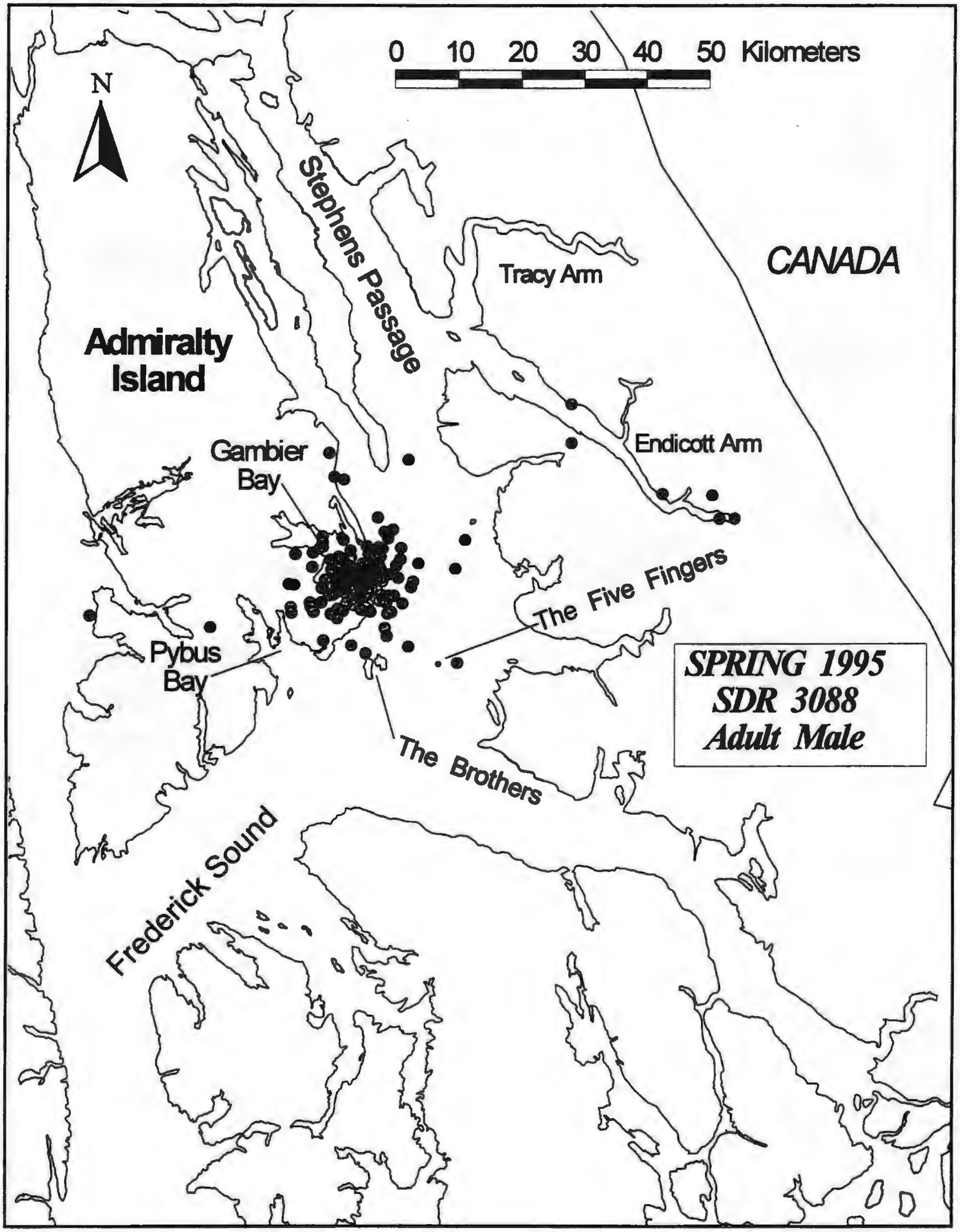


Figure 1A. Average daily locations for adult male harbor seal SE95S01 (SDR 3088) in Southeast Alaska from 19 April to 13 July 1995.

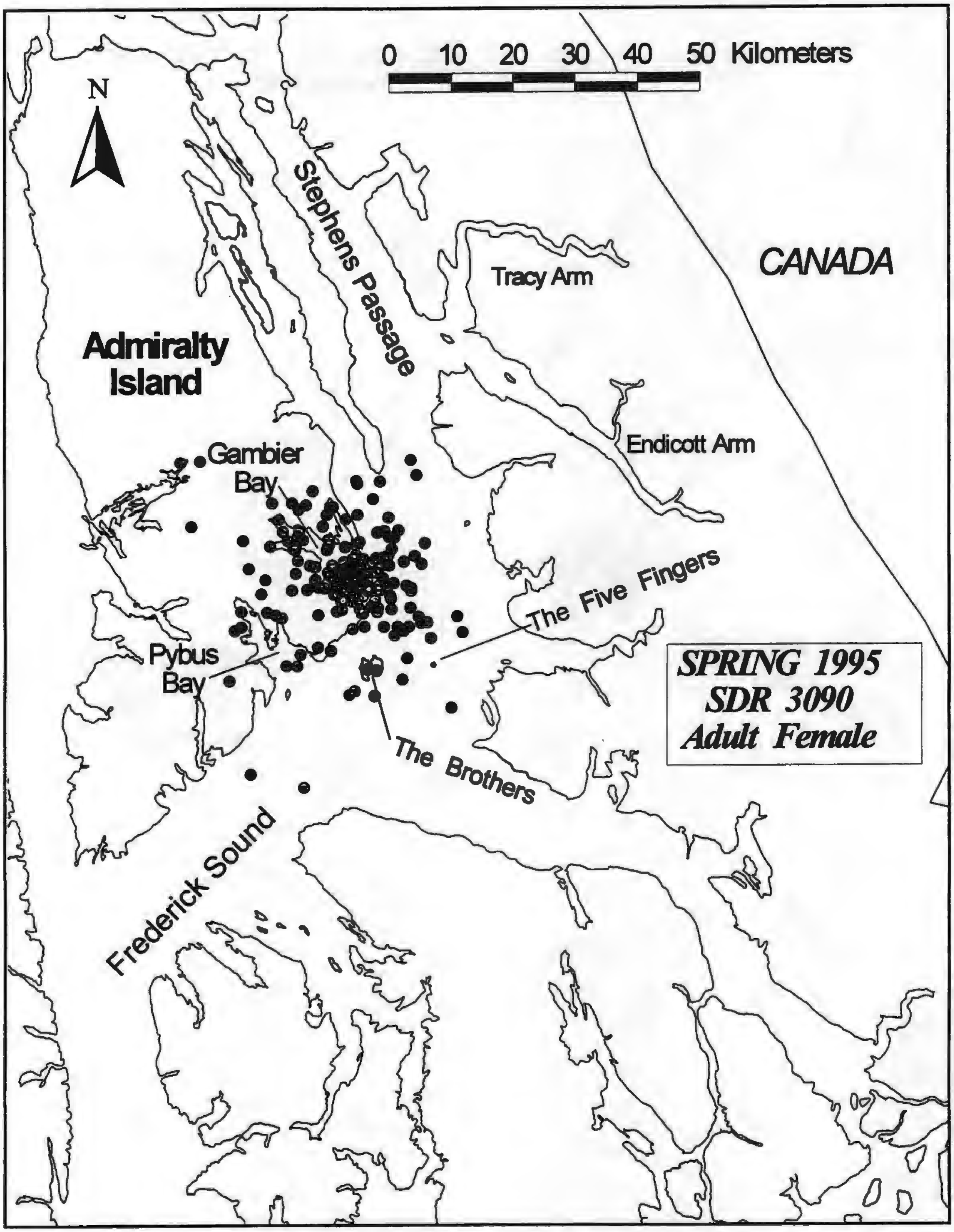


Figure 2A. Average daily locations for adult female harbor seal SE95S02 (SDR 3090) in Southeast Alaska from 19 April to 7 July 1995.

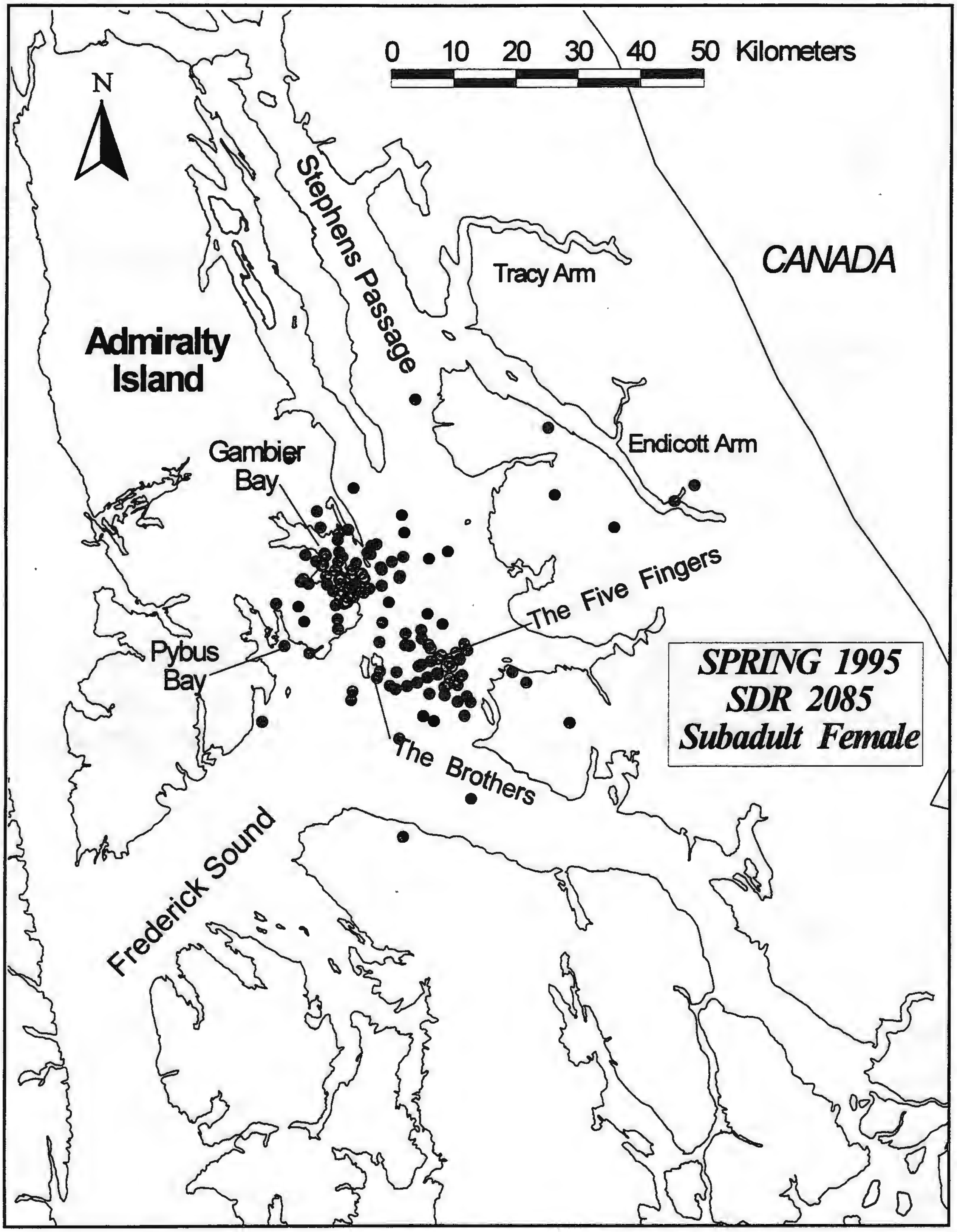


Figure 3A. Average daily locations for subadult female harbor seal SE95S03 (SDR 2085) in Southeast Alaska from 20 April to 30 June 1995.

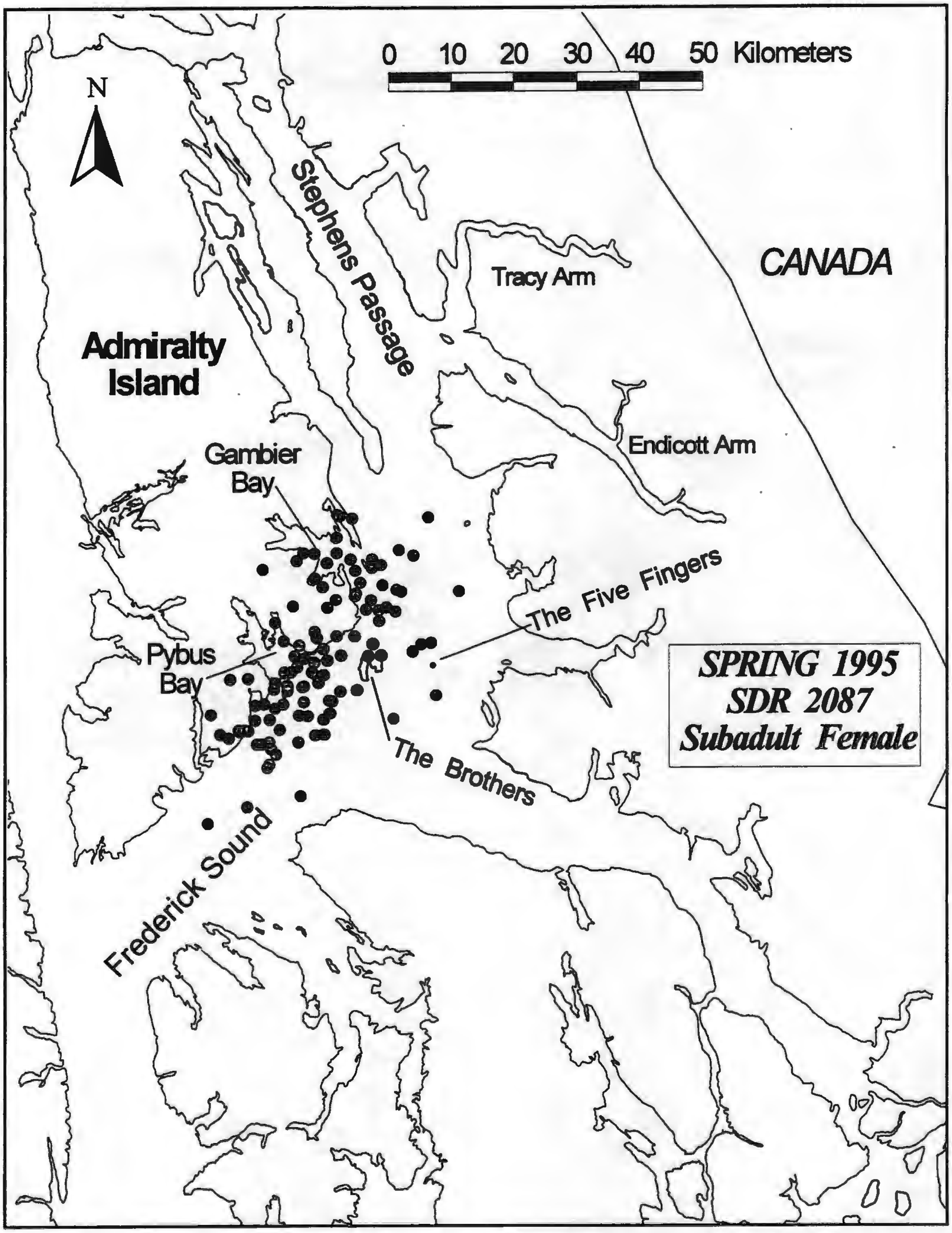


Figure 4A. Average daily locations for subadult female harbor seal SE95S04 (SDR 2087) in Southeast Alaska from 19 April to 16 June 1995.

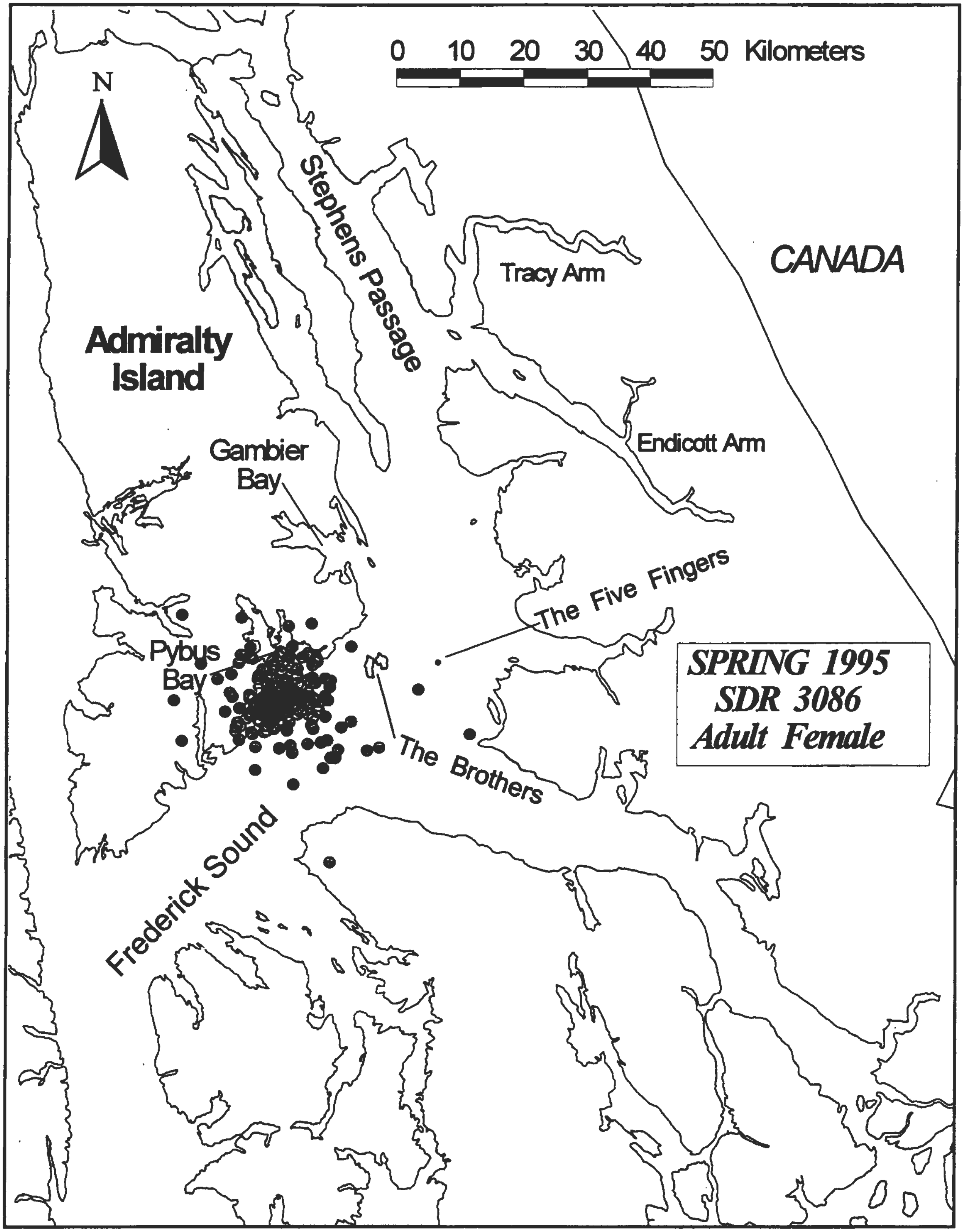


Figure 5. Average daily locations for adult female harbor seal SE95S05 (SDR 3086) in Southeast Alaska from 21 April to 21 July 1995.

Table 2A. Summary of movements made by harbor seals tagged with satellite transmitters in Southeast Alaska, fall 1995. The general areas where seal locations were concentrated are listed by consecutive dates.

**SDR 5043 (Seal# SE95F01) Adult Male captured at Vixen Island[1]**

*Hoonah Sound*: 22 Sep 1995 – 20 Apr 1996

**SDR 5042 (Seal# SE95F02) Adult Female captured at Vixen Island[1]**

| *Hoonah Sound* | *Salisbury Sound* |
|---|---|
| 22 Sep – 26 Sep | |
| | 27 Sep – 28 Sep |
| 29 Sep – 1 Apr (1996) | |
| | 3 Apr – 20 Apr |
| 21 Apr – 25 Apr | |
| | 26 Apr |
| 27 Apr – 28 Apr | |

**SDR 5047 (Seal# SE95F03) Subadult Female captured at Vixen Island[1]**

| *Hoonah Sound* | *Fish Bay* |
|---|---|
| 22 Sep – 26 Sep | |
| | 28 Sep – 29 Sep |
| 1 Oct – 8 Mar (1996) | |
| | 9 Mar |
| 11 Mar – 13 May | |

**SDR 5041 (Seal# SE95F04) Adult Female captured at Vixen Island[1]**

| *Hoonah Sound* | *Salisbury Sound* | *Fish Bay* |
|---|---|---|
| 23 Sep | | |
| | 24 Sep – 29 Sep | |
| 30 Sep – 7 Feb (1996) | | |
| | 8 Feb – 24 Mar | |
| | | 25 Mar – 31 Mar |
| 2 Apr – 27 Apr | | |
| | 28 Apr – 29 Apr | |
| 30 Apr – 11 May | | |
| | 12 May – 16 May | |
| 17 May – 22 May | | |
| | 23 May – 25 May | |
| 26 May – 29 May | | |

Table 2A. Continued.

**SDR 5048 (Seal# SE95F05) Female Pup captured at Vixen Island[1]**

| *Hoonah Sound* | *NW Tenakee Inlet* | *Salisbury Sound* | *N Sitka Sound* | *S Sitka Sound* |
|---|---|---|---|---|
| 23 Sep – 9 Nov | | | | |
| | 13 Nov – 21 Nov | | | |
| 22 Nov – 19 Dec | | | | |
| | | 22 Dec – 3 Jan | | |
| | | | 5 Jan – 20 Feb | |
| | | | | 22 Feb – 26 Feb |
| 28 Feb – 3 Mar | | | | |
| | | 5 Mar – 6 Mar | | |
| | | | | 8 Mar – 28 Apr |

[1] Vixen Island is in Hoonah Sound; see Figures 6-10.

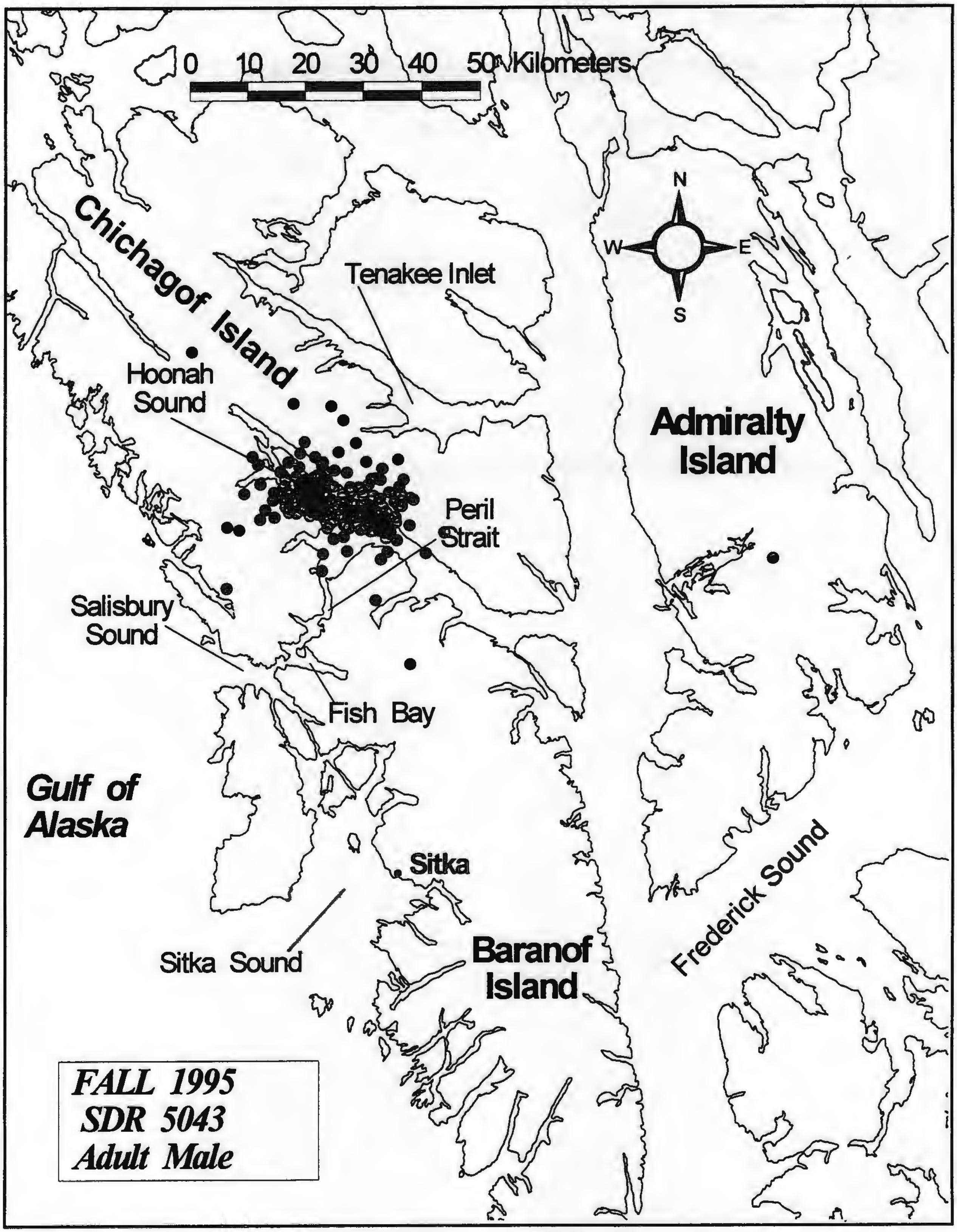


Figure 6A. Average daily locations for adult male harbor seal SE95F01 (SDR 5043) in Southeast Alaska from 22 September 1995 to 20 April 1996.

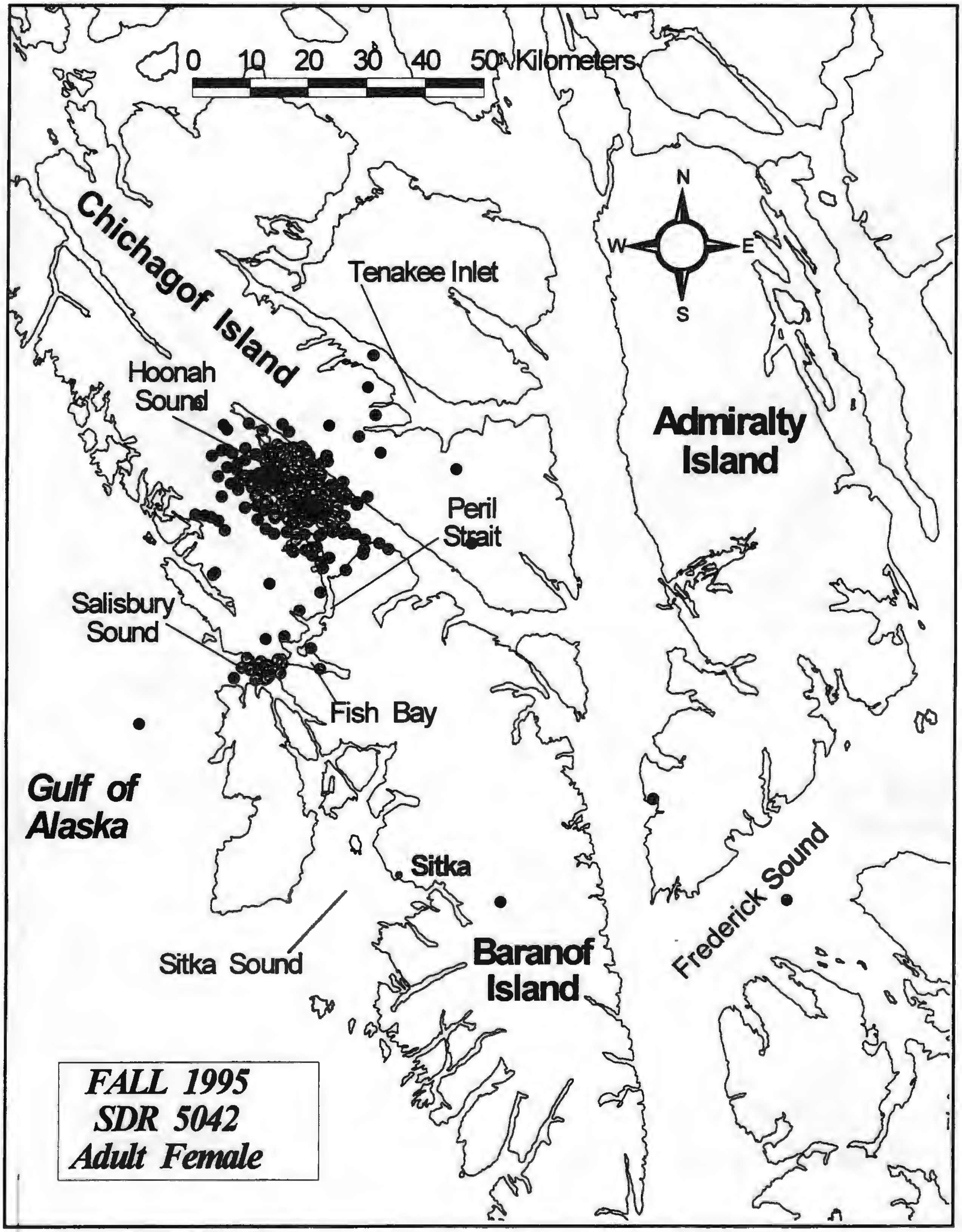


Figure 7A. Average daily locations for adult female harbor seal SE95F02 (SDR 5042) in Southeast Alaska from 22 September 1995 to 28 April 1996.

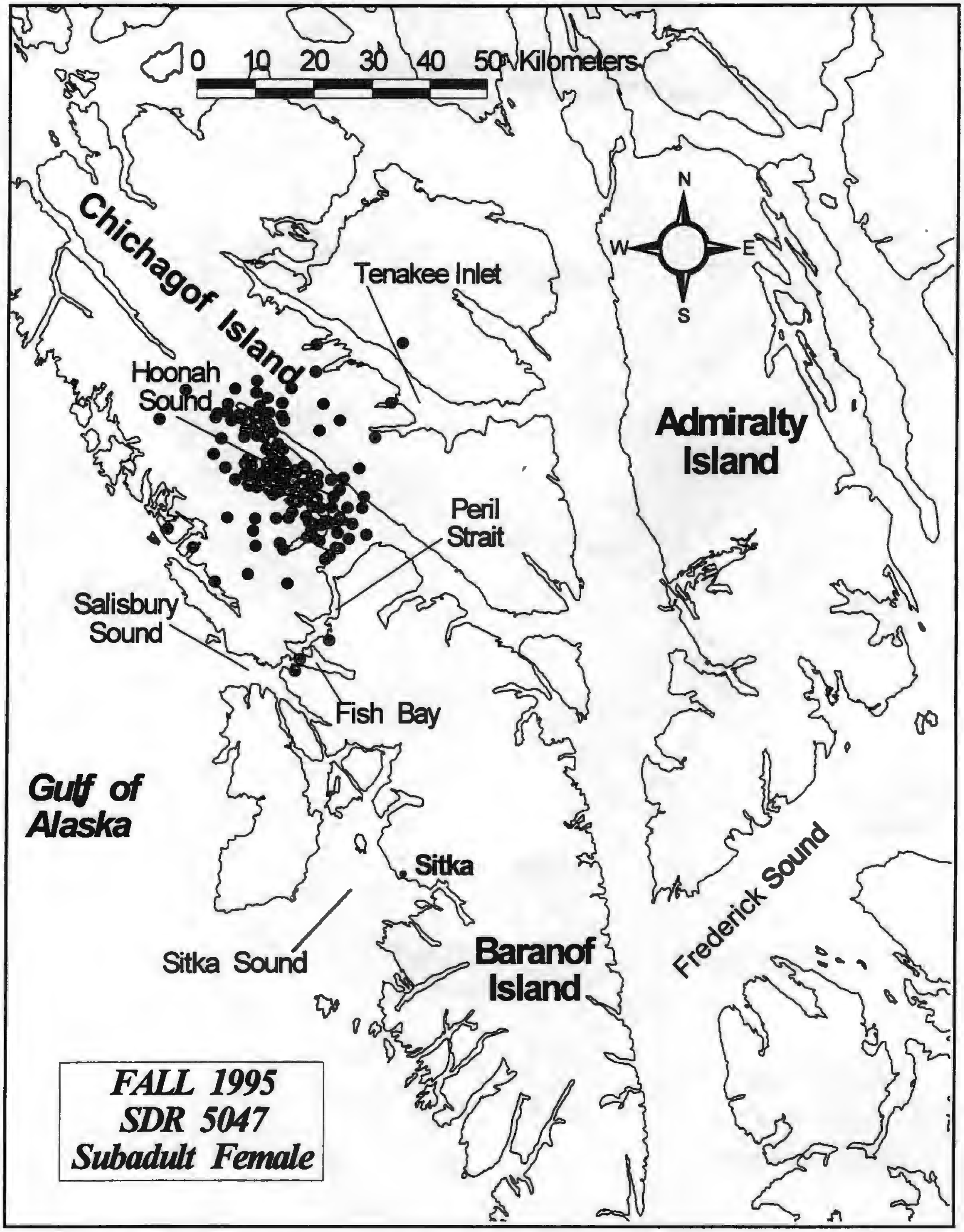


Figure 8A. Average daily locations for subadult female harbor seal SE95F03 (SDR 5047) in Southeast Alaska from 22 September 1995 to 13 May 1996.

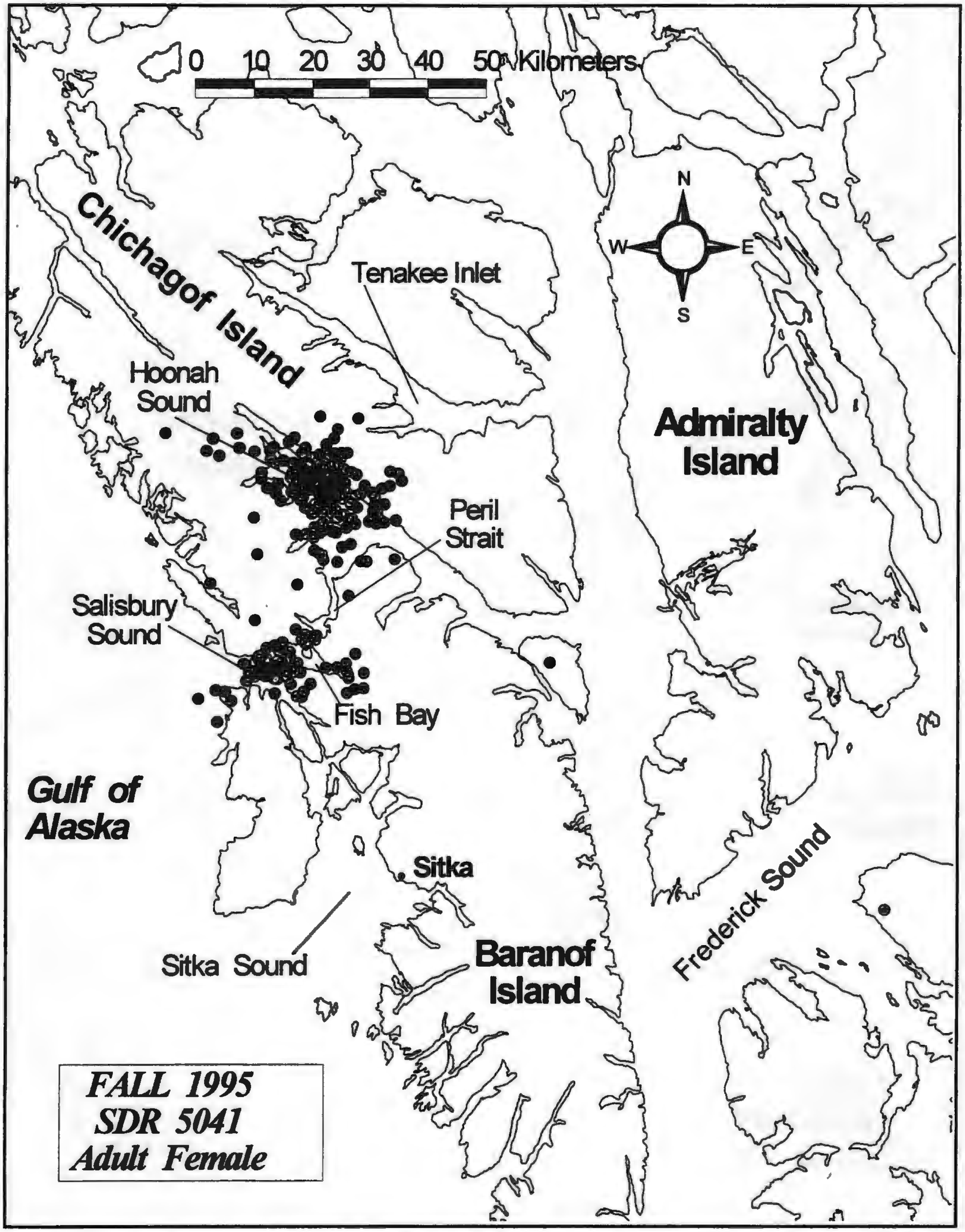


Figure 9A. Average daily locations for subadult female harbor seal SE95F04 (SDR 5041) in Southeast Alaska from 23 September 1995 to 29 May 1996.

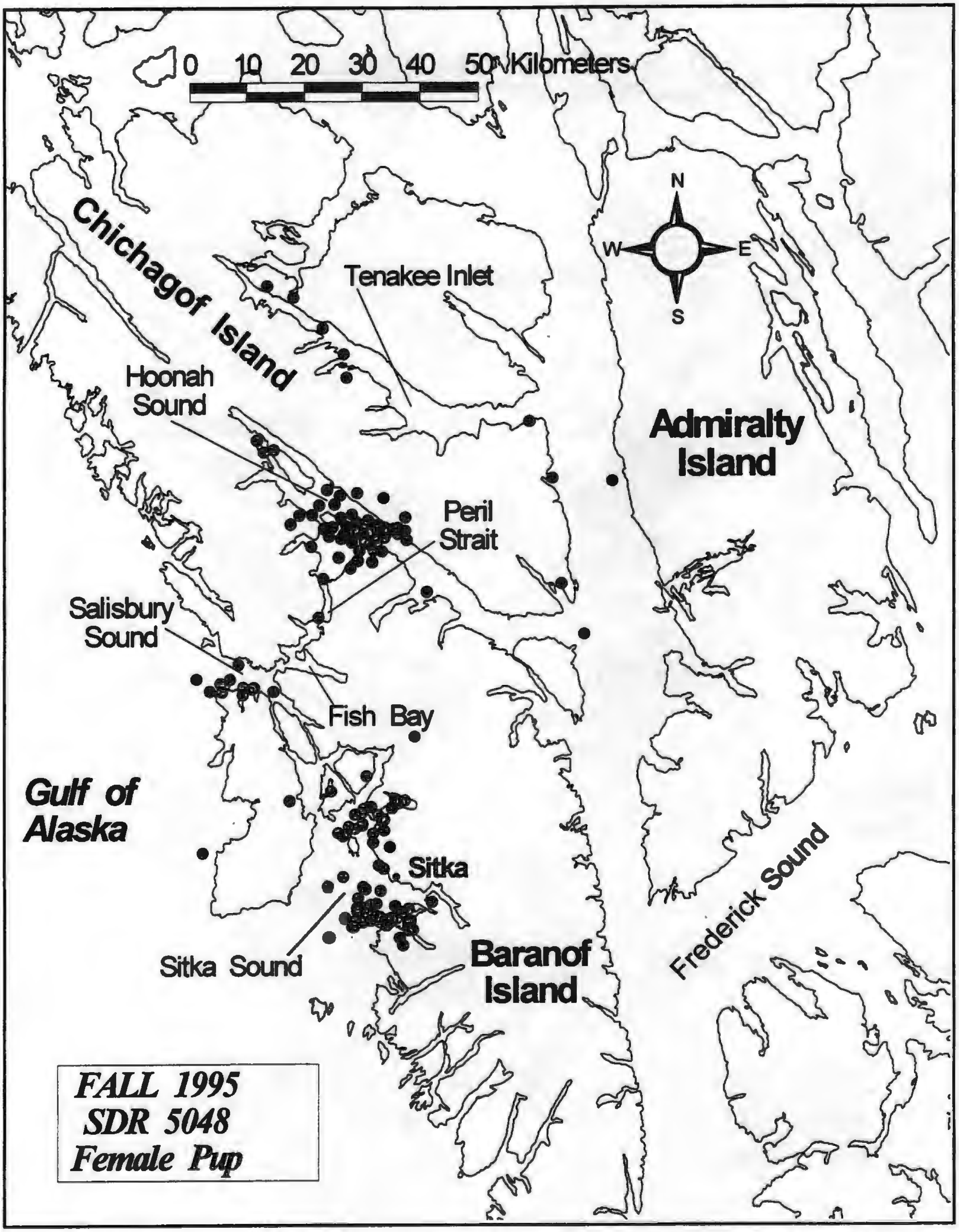


Figure 10A. Average daily locations for adult female harbor seal SE95F05 (SDR 5048) in Southeast Alaska from 23 September 1995 to 28 April 1996.

Table 3A. Summary of movements made by harbor seals tagged with satellite transmitters in the Kodiak Island area, spring 1995. The general areas where seal locations were concentrated are listed by consecutive dates.

**SDR 3089 (Seal# KO95S01) Adult Male captured at Uganik Passage**[1]

*Southeast side of Uganik Island*: 30 Mar – 29 Jul

**SDR 2086 (Seal# KO95S02) Subadult Female captured at Uganik Passage**[1]

| *SE of Uganik Island* | *Spiridon Bay* | *Ayakulik Island* | *Alitak Bay* |
|---|---|---|---|
| 31 Mar – 18 Apr | | | |
| | 20 Apr – 24 Apr | | |
| | | 27 Apr – 29 Apr | |
| | | | 30 Apr – 1 May |
| | | 2 May | |
| 4 May – 10 Jun | | | |

**SDR 2090 (Seal# KO95S03) Adult Female captured at Uganik Passage**[1]

*Southeast side of Uganik Island*: 30 Mar – 14 Jun

**SDR 2089 (Seal# KO95S04) Subadult Male captured at Uganik Passage**[1]

| *SE of Uganik Island* | *Seal Islands* | *NW of Uganik Island* |
|---|---|---|
| 31 Mar – 1 Apr | | |
| | 2 Apr – 4 Apr | |
| 7 Apr – 24 Apr | | |
| | | 26 Apr – 16 May |
| | 18 May – 25 May | |

**SDR 3087 (Seal# KO95S05) Subadult Female captured at Uganik Passage**[1]

*Southeast side of Uganik Island*: 30 Mar – 15 Jul

---

[1] Uganik Passage is on the southeast and southwest sides of Uganik Island; see Figures 11-15.

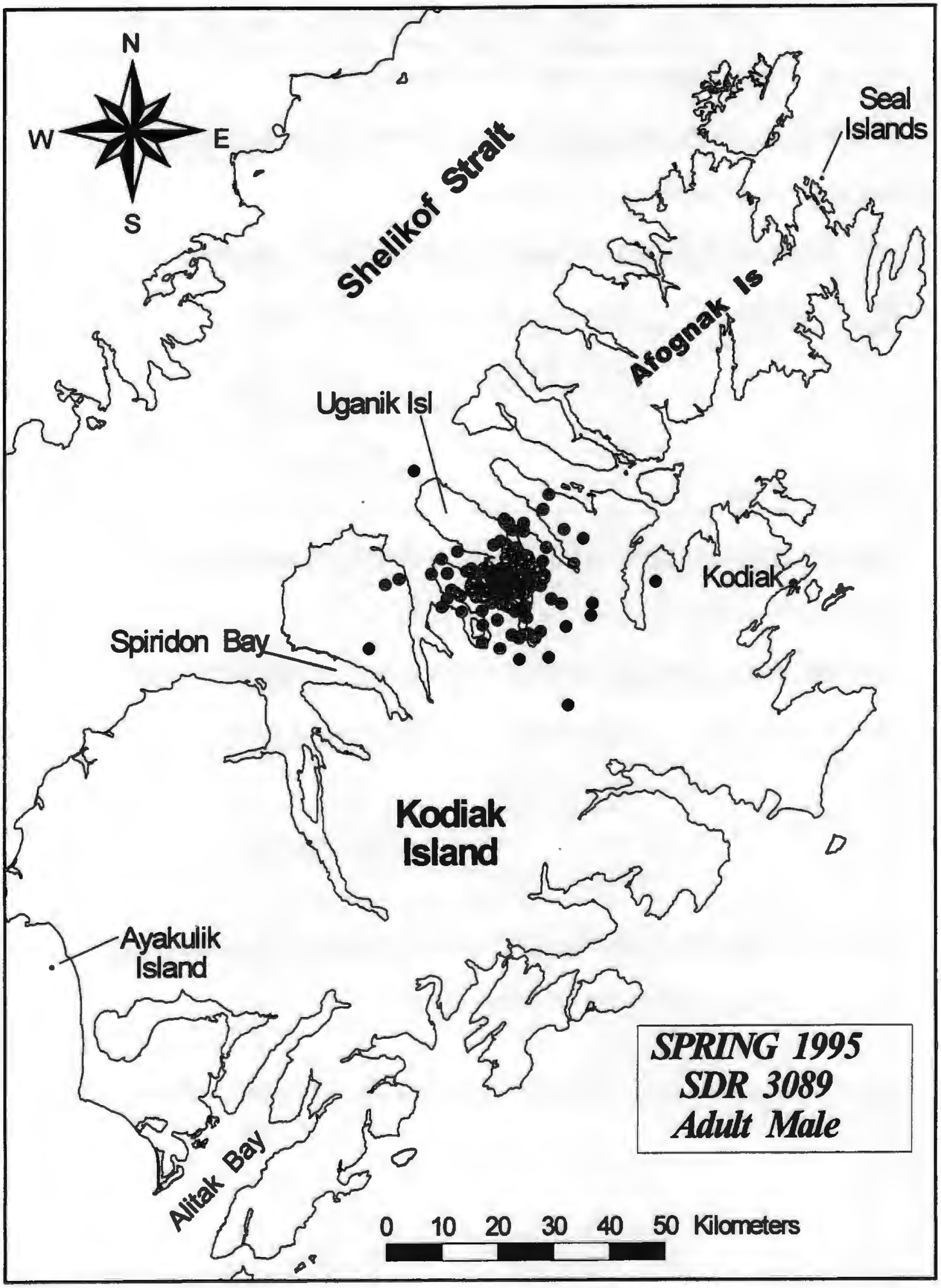


Figure 11A. Average daily locations for adult male harbor seal KO95S01 (SDR 3089) in the Kodiak Island area, Alaska, from 30 March to 29 July 1995.

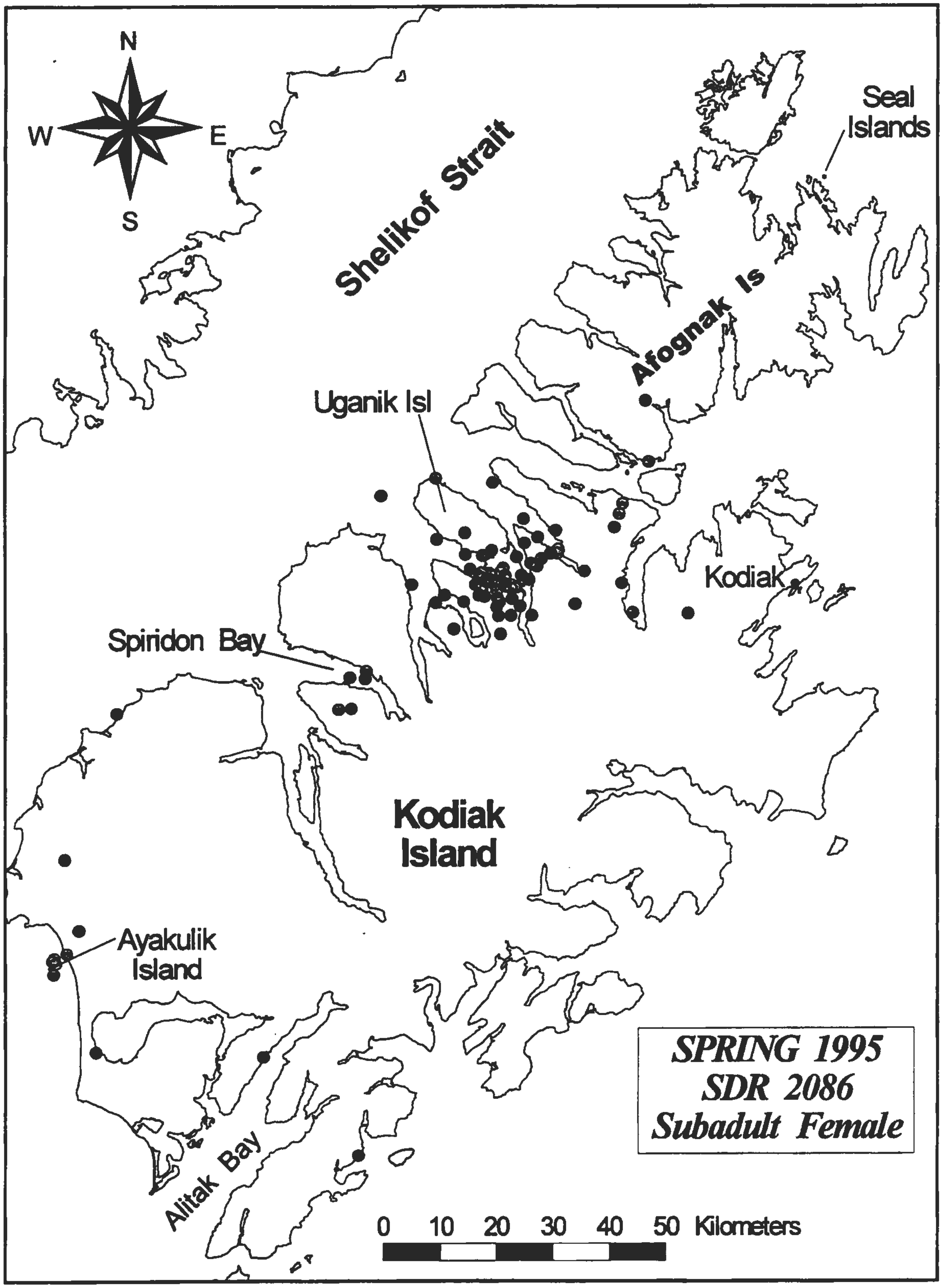


Figure 12A. Average daily locations for subadult female harbor seal KO95S02 (SDR 2086) in the Kodiak Island area, Alaska, from 31 March to 10 June 1995.

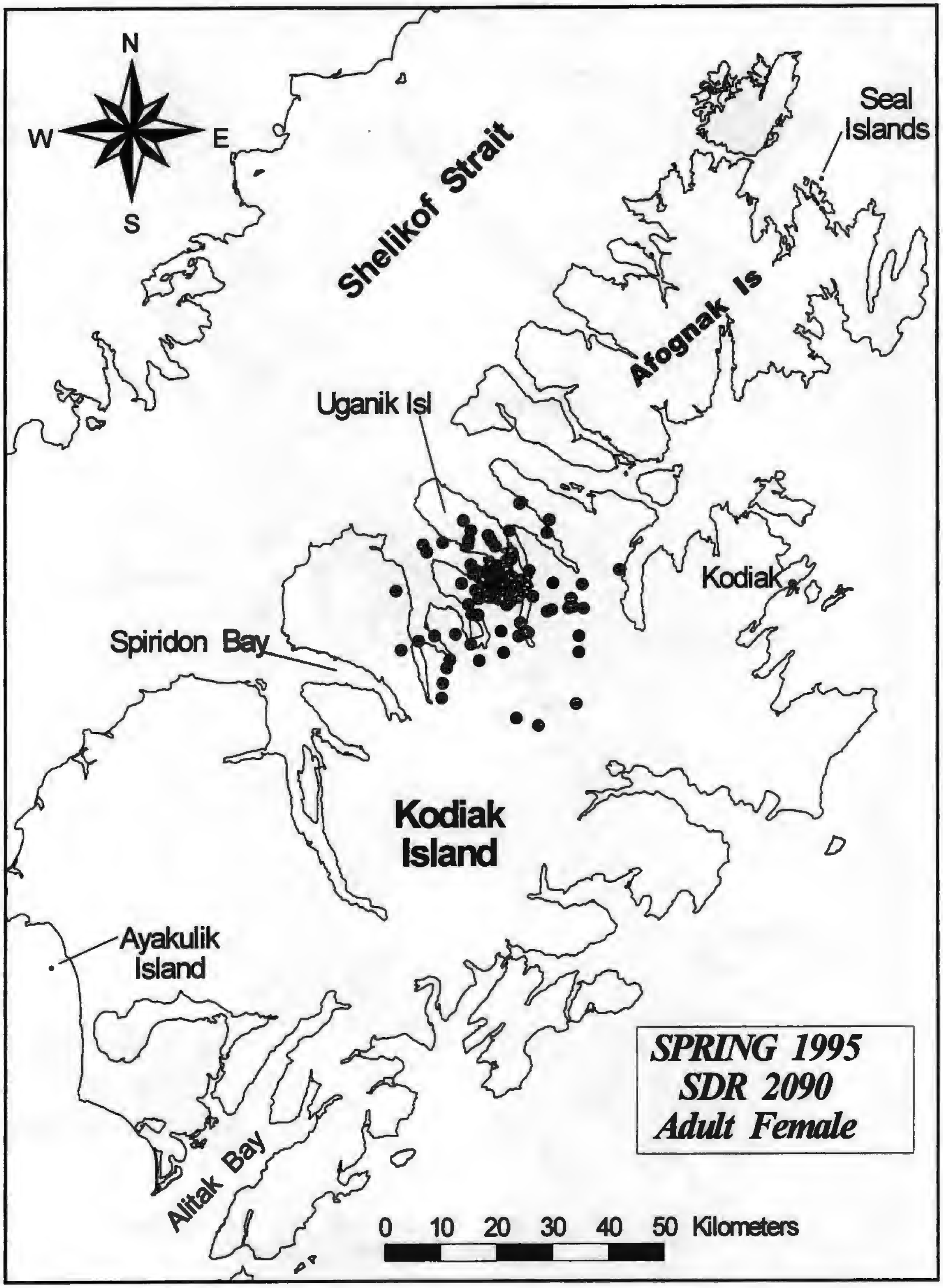


Figure 13A. Average daily locations for adult female harbor seal KO95S03 (SDR 2090) in the Kodiak Island area, Alaska, from 30 March to 14 June 1995.

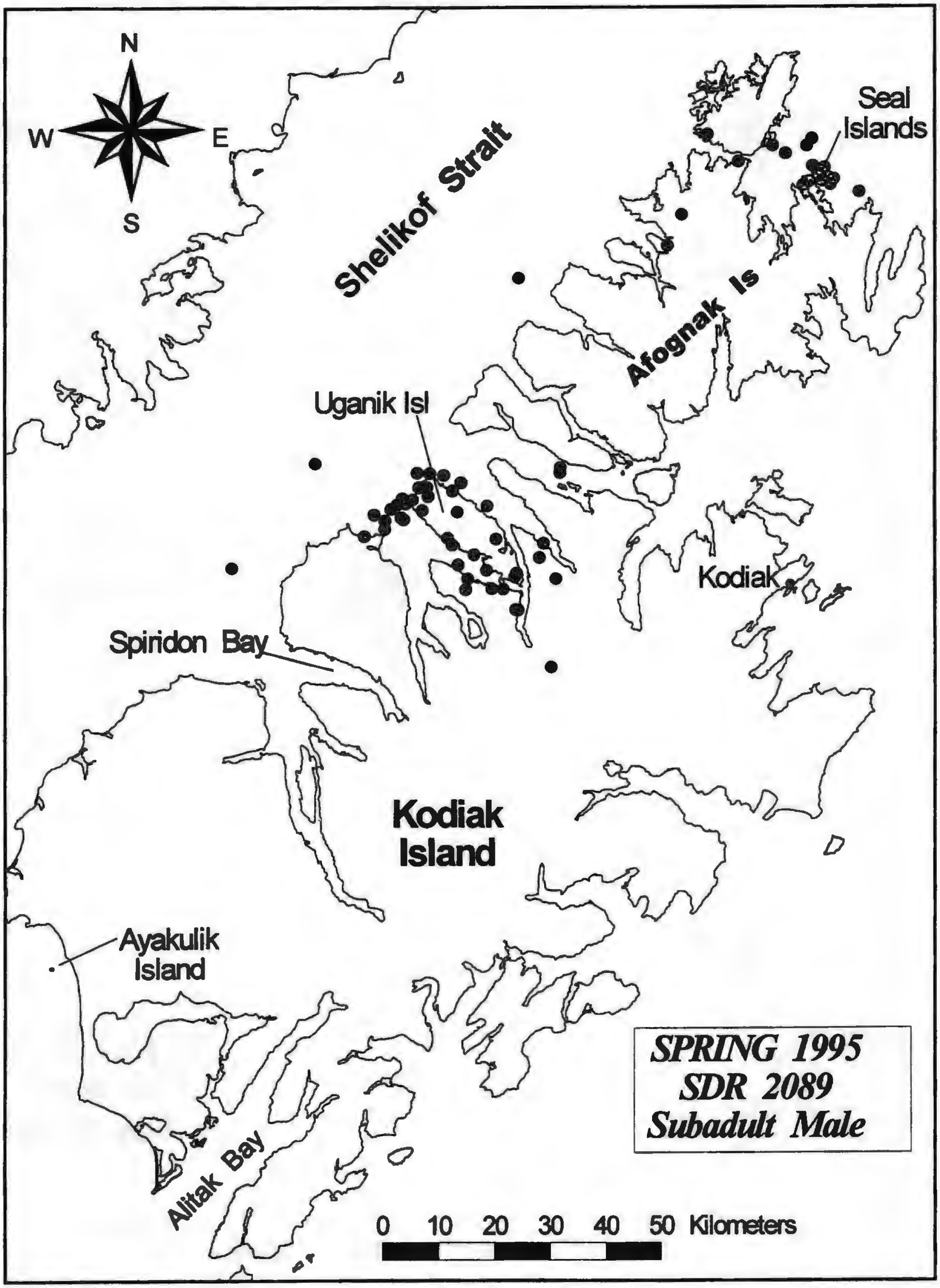


Figure 14A. Average daily locations for subadult male harbor seal KO95S04 (SDR 2089) in the Kodiak Island area, Alaska, from 31 March to 25 May 1995.

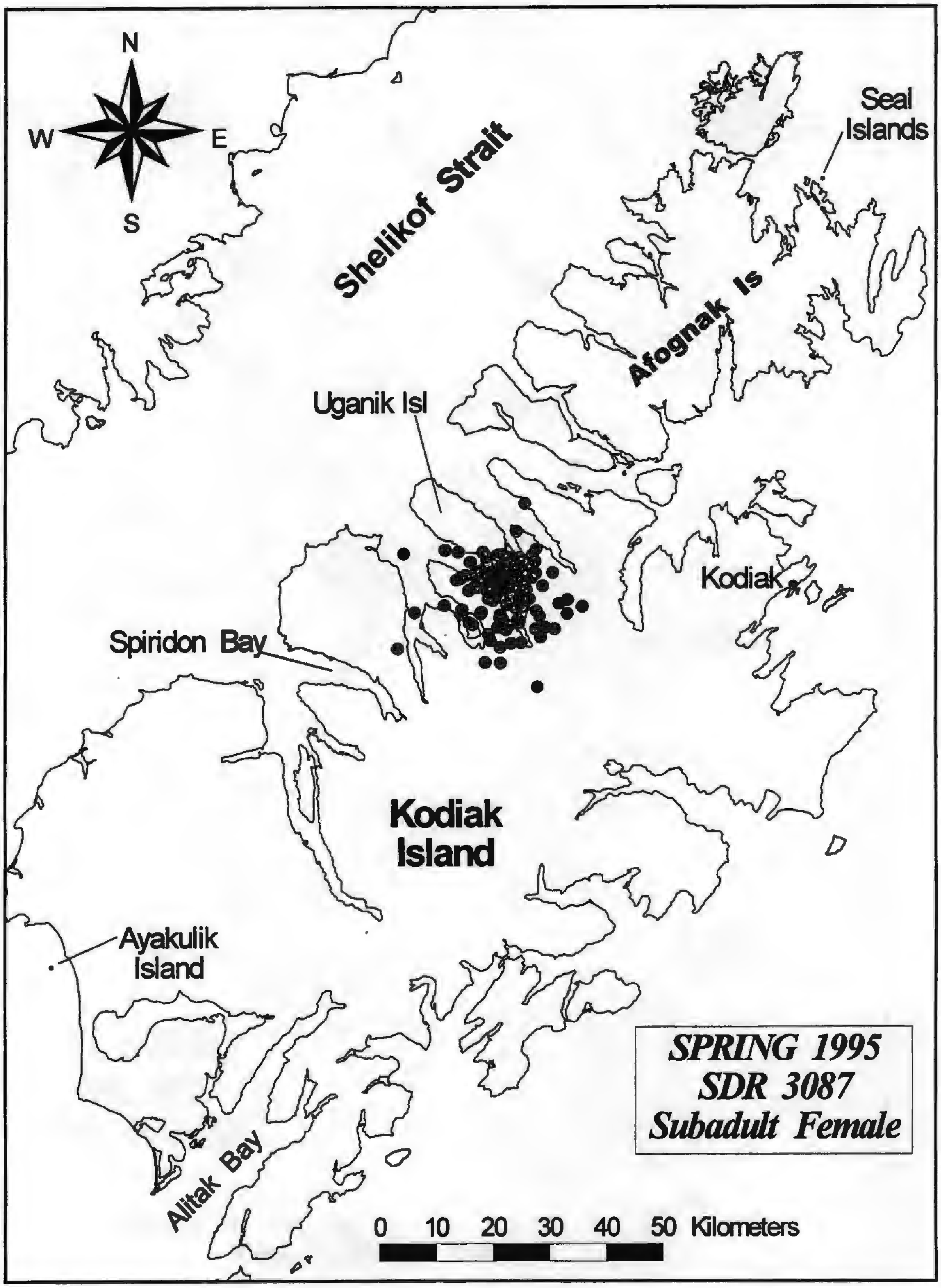


Figure 15A. Average daily locations for subadult female harbor seal KO95S05 (SDR 3087) in the Kodiak Island area, Alaska, from 30 March to 15 July 1995.

Table 4A. Summary of movements made by harbor seals tagged with satellite transmitters in the Kodiak Island area, fall 1995. The general areas where seal locations were concentrated are listed by consecutive dates.

**SDR 5044 (Seal# KO95F01) Subadult Female captured at Ugak Bay**

| *West Ugak Bay* | *East Ugak Bay* |
|---|---|
| 9 Oct – 1 Nov | |
| | 2 Nov – 8 Nov |
| 9 Nov – 27 Mar (1996) | |
| | 28 Mar – 30 Mar |
| 1 Apr – 17 Apr | |
| | 18 Apr – 5 May |
| 6 May – 8 May | |
| | 9 May – 6 Jun |

**SDR 5049 (Seal# KO95F02) Subadult Male captured at Ugak Bay**

*West Ugak Bay*: 11 Oct 1995 - 27 May 1996

**SDR 5046 (Seal# KO95F03) Adult Female captured at Ugak Bay**

*West Ugak Bay*: 9 Oct 1995 - 27 Jun 1996

**SDR 5045 (Seal# KO95F04) Adult Male captured at Ugak Bay**

*West Ugak Bay*: 10 Oct 1995 - 16 Jun 1996

**SDR 5051 (Seal# KO95F05) Subadult Female captured at Kiliuda Bay**

| *West Kiliuda Bay* | *Ugak Bay* | *SE of Kiliuda Bay* |
|---|---|---|
| 10 Oct – 26 Nov | | |
| | 28 Nov – 29 Nov | |
| 30 Nov – 6 Dec | | |
| | | 8 Dec – 10 Dec |
| 11 Dec – 17 Jan (1996) | | |
| | 18 Jan – 19 Jan | |
| 20 Jan – 7 Apr | | |

**SDR 5050 (Seal# KO95F06) Subadult Female captured at Kiliuda Bay**

*West Kiliuda Bay*: 10 Oct 1995 - 15 May 1996

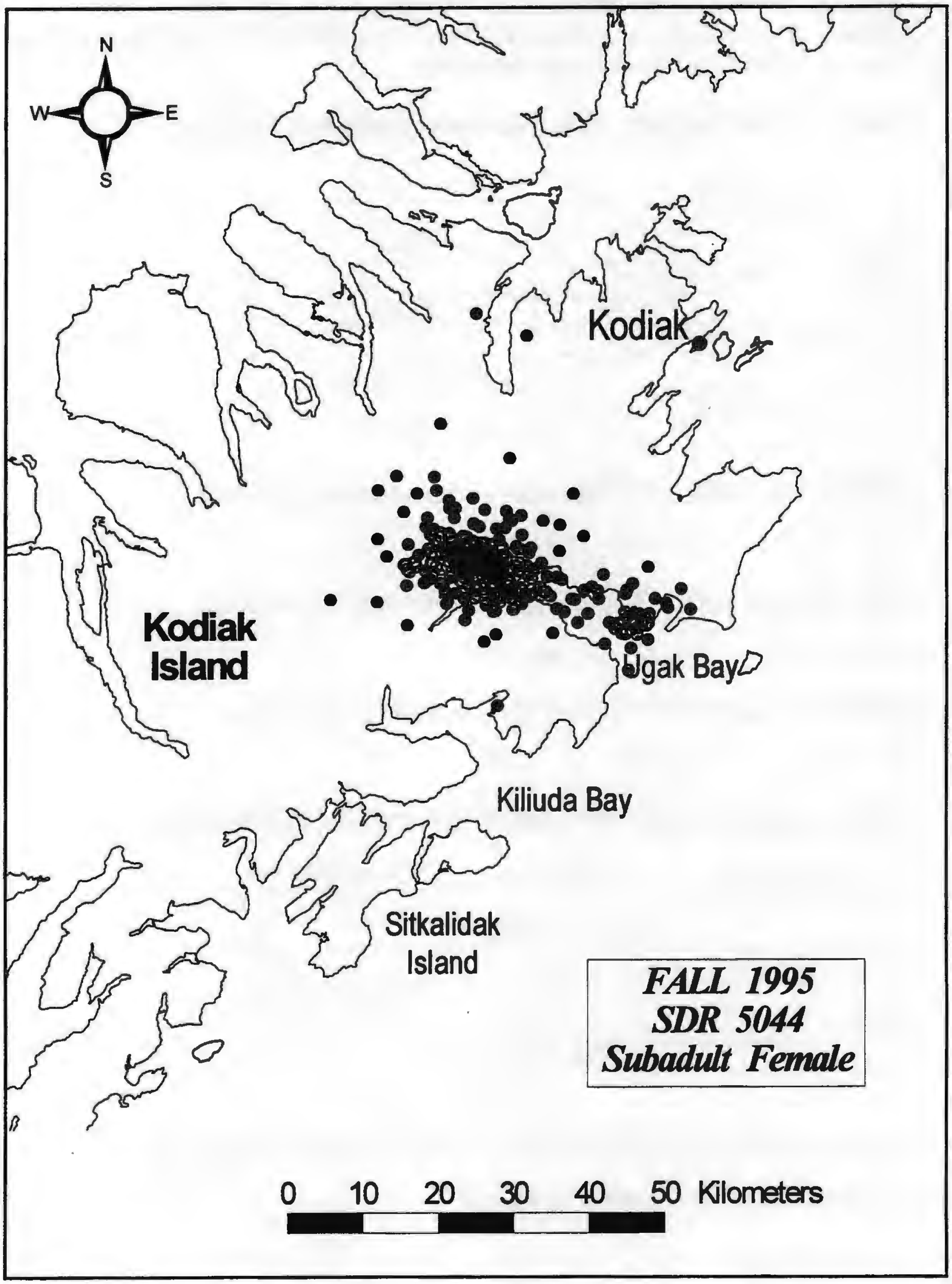


Figure 16A. Average daily locations for subadult female harbor seal KO95F01 (SDR 5044) in the Kodiak Island area, Alaska, from 9 October 1995 to 6 June 1996.

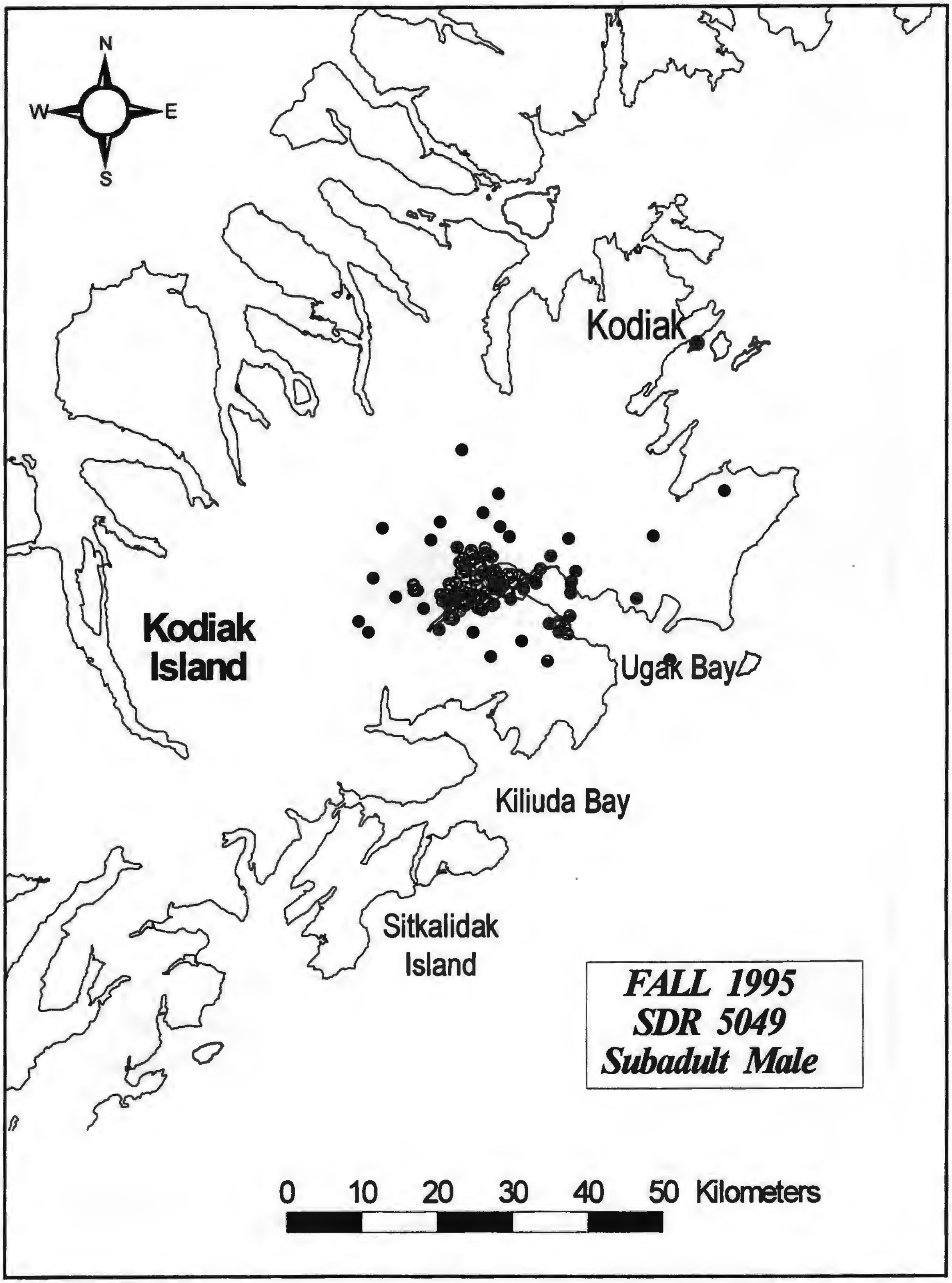


Figure 17A. Average daily locations for subadult male harbor seal KO95F02 (SDR 5049) in the Kodiak Island area, Alaska, from 11 October 1995 to 27 June 1996.

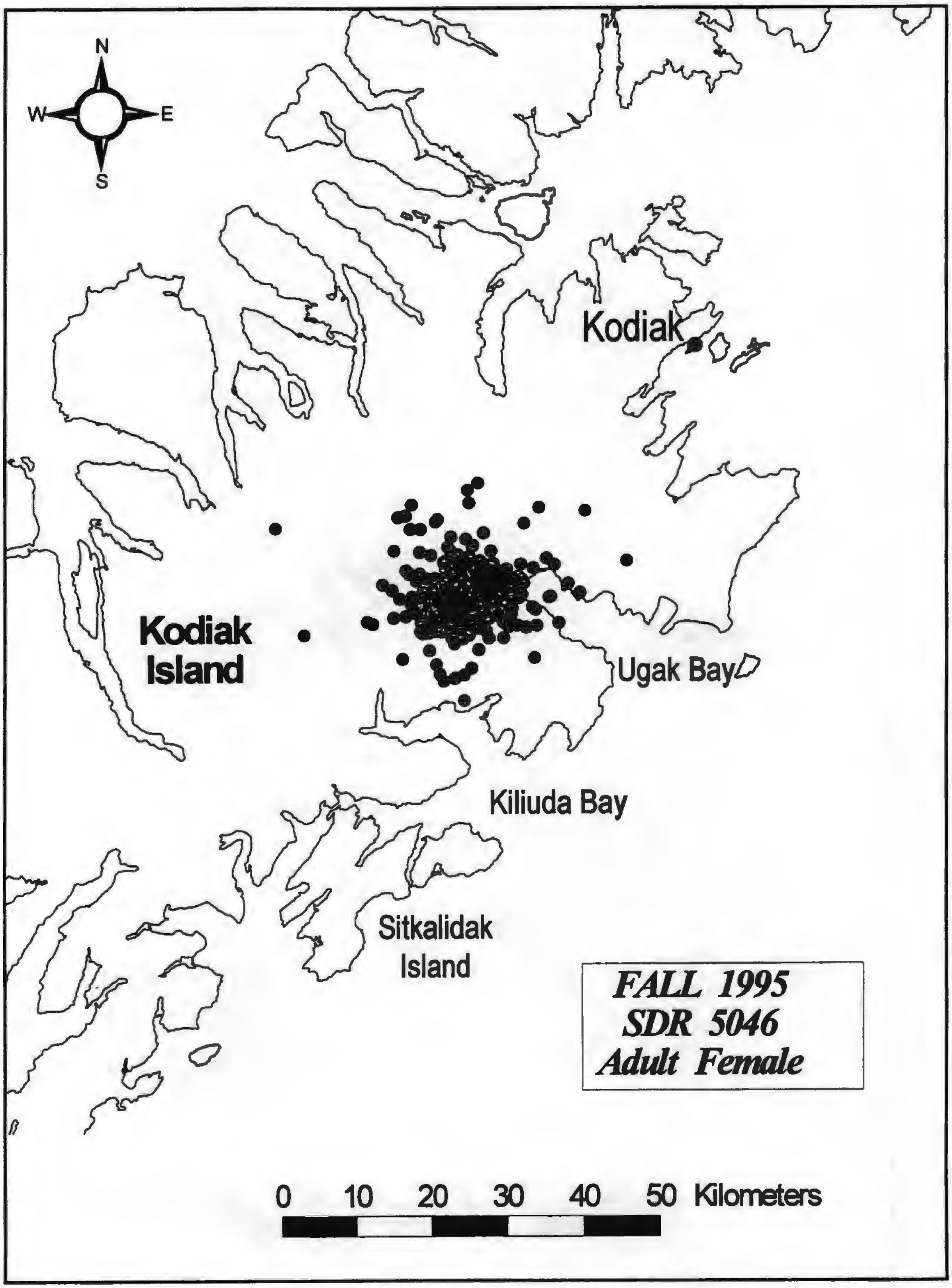


Figure 18A. Average daily locations for adult female harbor seal KO95F03 (SDR 5046) in the Kodiak Island area, Alaska, from 9 October 1995 to 27 June 1996.

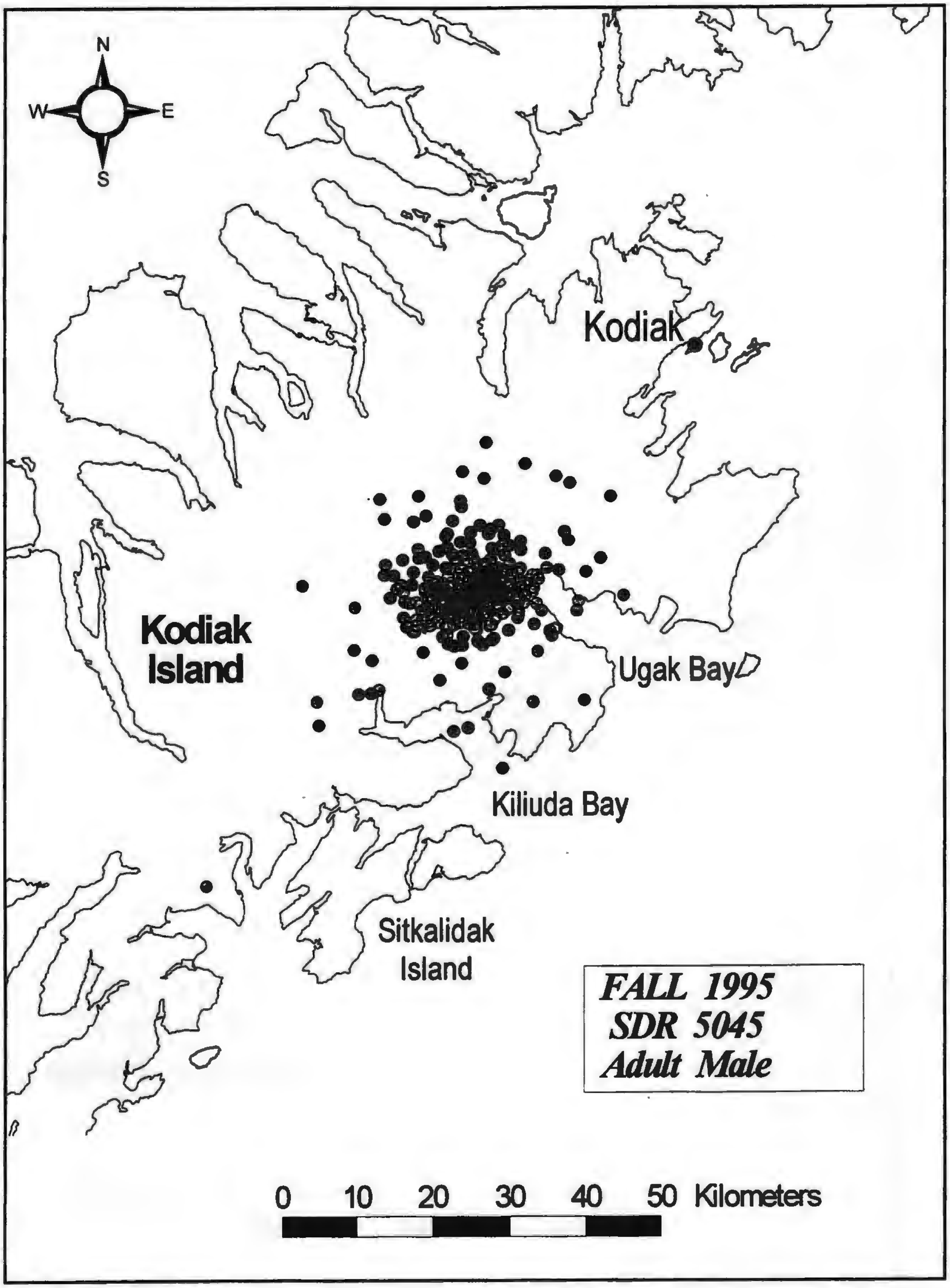


Figure 19A. Average daily locations for adult male harbor seal KO95F04 (SDR 5045) in the Kodiak Island area, Alaska, from 10 October 1995 to 16 June 1996.

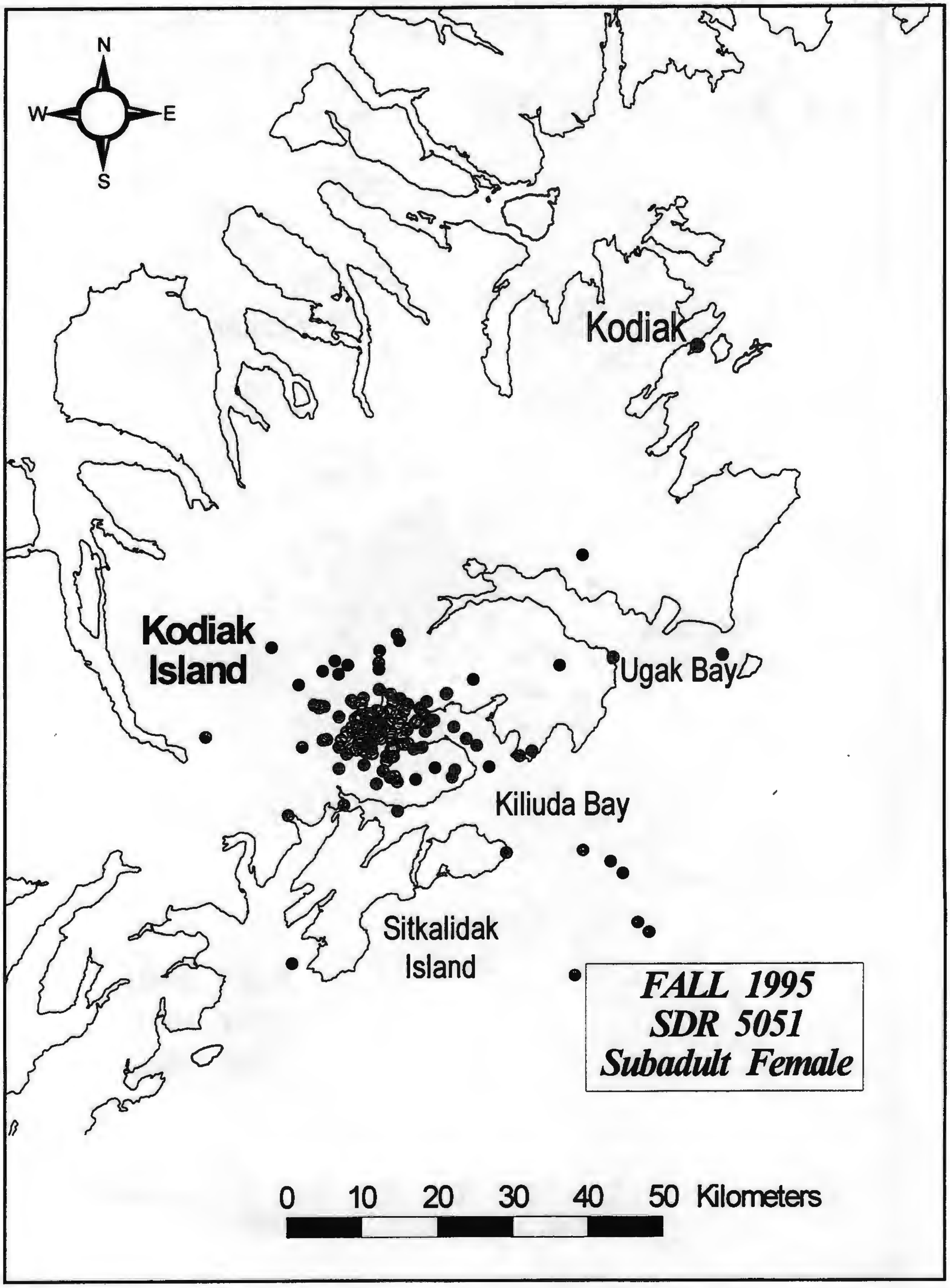


Figure 20A. Average daily locations for subadult female harbor seal KO95F05 (SDR 5051) in the Kodiak Island area, Alaska, from 10 October 1995 to 7 April 1996.

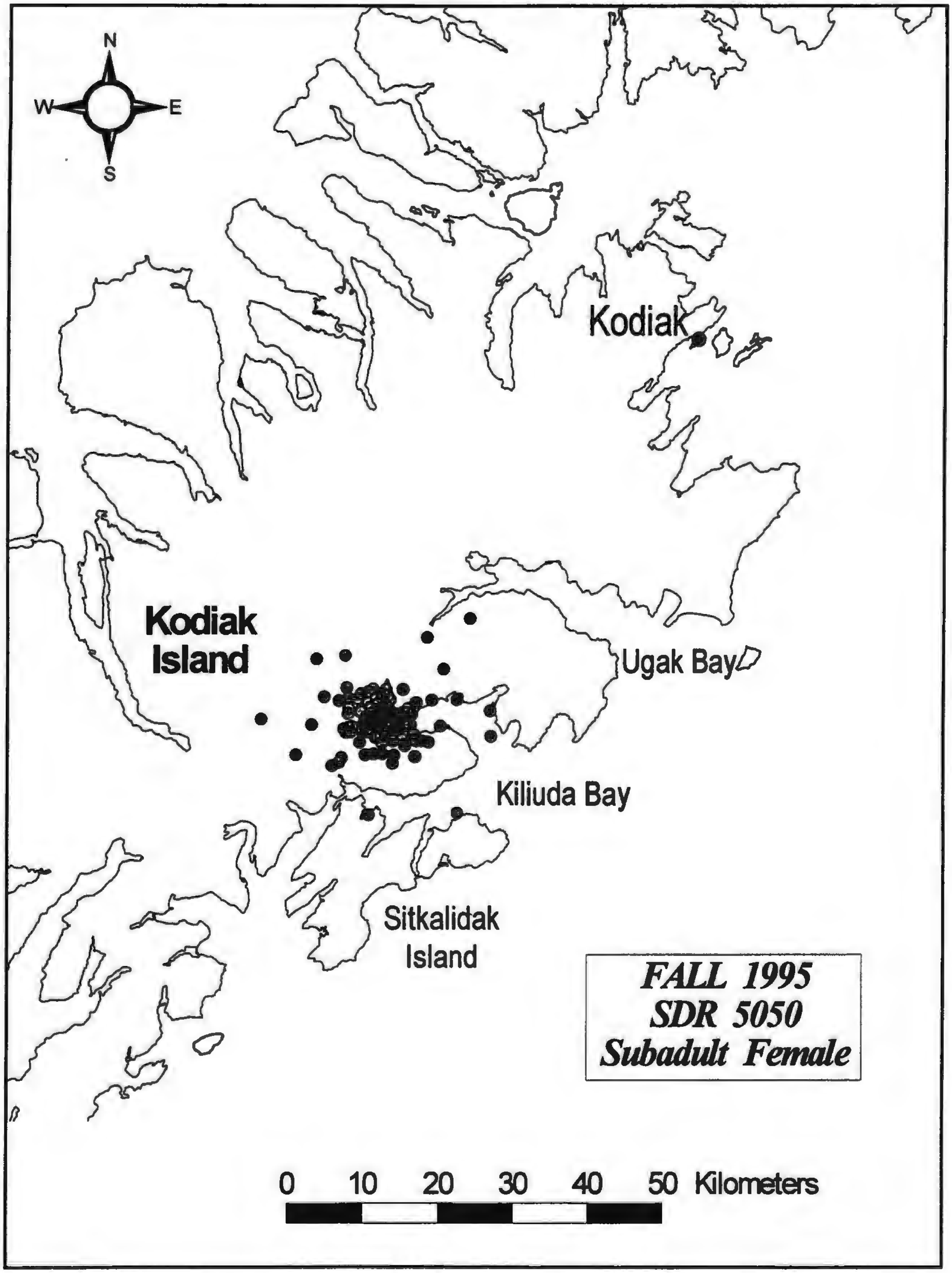


Figure 21A. Average daily locations for subadult female harbor seal KO95F06 (SDR 5050) in the Kodiak Island area, Alaska, from 10 October 1995 to 15 May 1996.

# CHAPTER THREE

# DISEASE AND CONTAMINANT STUDIES OF ALASKAN HARBOR SEALS

## OBJECTIVE 5

Compare indices of health status and the prevalence of some infectious diseases of harbor seals in southeastern Alaska and the Kodiak archipelago

## OBJECTIVE 9 (*Supplemental Proposal*)

Compile information on contaminants in Alaskan harbor seals, evaluate adequacy of current information and make recommendations for future contaminants work

# SUMMARIES OF SEROLOGIC DATA COLLECTED FROM HARBOR SEALS IN THE BERING SEA, GULF OF ALASKA, AND SOUTHEAST ALASKA, 1978-1995

Gay Sheffield, Lloyd Lowry, and Randall Zarnke

Alaska Department of Fish and Game, Division of Wildlife Conservation
1300 College Road, Fairbanks, AK 99701

## INTRODUCTION

During 1978-1997, the Alaska Department of Fish and Game (ADF&G) obtained sera from harbor seals (*Phoca vitulina richardsi*) collected and captured in the Bering Sea, the Kodiak region, Prince William Sound (PWS), and Southeast Alaska. These sera were collected to determine the antibody prevalence of selected microbial disease agents. Samples were provided by a number of investigators who collected blood while conducting a variety of scientific studies. Specimens from 352 harbor seals were analyzed at several laboratories that specialized in particular disease agents (Table 1).

A preliminary summary of ADF&G harbor seal disease studies was presented in Lowry *et al.* (1996). Since that report, test results have been entered into a computer database and some additional interpretation has been made of results. This report provides an update of the current status of the harbor seal serological survey.

## METHODS

Sera were tested for evidence of exposure to eight disease agents: canine distemper virus (CDV), phocine distemper virus (PDV), phocid herpesvirus 1 (PhHV), *Toxoplasma gondii* (TOXO), influenza A (FLU), *Brucella* spp. (BS4), *Chlamydia psittaci* (CHLAM), and caliciviruses (CALICI). Data were transferred electronically from previously archived computer files or were entered manually into a computerized database (Foxpro 2.5b).

A serum neutralization method was used to test for evidence of exposure to CDV, PDV, PhHV, and CALICI. For CDV, PDV, and PhHV the challenge dose consisted of 60 tissue culture infective doses ($TCID_{50}$) of virus. TOXO tests were done using a modified agglutination method. FLU tests were done using a double agar immunodiffusion assay. BS4 tests were done with an indirect enzyme-linked immunosorbent assay. CHLAM tests were done using a complement fixation method.

Threshold titers were selected for each disease agent (Table 2). Sera that met or exceeded these titers were considered indicative of previous natural exposure to the agent in question. Such sera are referred to as "positive". Sera with titers below the threshold were interpreted as coming from animals that had not been exposed to the agent. Those sera are referred to as "negative". Only harbor seal records that contained positive or negative test results were tabulated. Summaries of the number of harbor seals tested, by year, are given in Tables 3-4. Summary statistics of test results were calculated by year and age class (Tables 5-12).

Location-specific antibody prevalences (i.e., proportion of positive responses) were compared (all years combined) using Fisher's exact test. Fisher's test was used because of small expected values for the contingency tables of some of the diseases. No analyses were performed for CDV (one positive sample) or FLU (no positive samples) or CHLAM (two positive samples and data from only two regions). Time-specific patterns of prevalences (all regions combined) were evaluated with logistic regression. The explanatory variables used were year and year$^2$. Inclusion of year$^2$ allows for a nonlinear (on the logit scale) pattern of change through time. The importance of the explanatory variables were determined with likelihood ratio tests. No temporal analyses were performed for CDV, FLU, or CHLAM.

## RESULTS AND DISCUSSION

### Canine distemper virus

Two hundred ninety-five sera, collected between 1978 and 1994, were tested for evidence of exposure to CDV. One hundred two samples were from PWS, 91 were from the Kodiak region, 62 were from Southeast Alaska, and 40 were from the Bering Sea (Table 3). Only one sample was positive (Table 5).

Early serological surveys following the European and Lake Baikal epizootics used CDV as an antigen (Heide-Jørgensen *et al.* 1992). Later studies (e.g., Barrett *et al.* 1992) showed that PDV-1 that affected European harbor seals is distinct from CDV, while PDV-2 that affected Baikal seals (*Phoca sibirica*) is very similar to CDV. The single positive result for exposure to CDV found in this study was likely due to cross-reactivity, and is of no significance to Alaskan harbor seals.

### Phocine distemper virus

Two hundred eighty-six samples, collected between 1978 and 1994, were tested for evidence of exposure to PDV. Ninety-five samples were from PWS, 92 were from the Kodiak region, 59 were from Southeast Alaska, and 40 were from the Bering Sea (Table 3). Though there was evidence of exposure in each region, only 3% of the total samples were positive (Table 6).

Osterhaus *et al.* (in prep) tested 1,099 serum samples from eight species of marine mammals from Alaska and eastern Russia for exposure to PDV. All species showed evidence of having been exposed to PDV, but mostly with low prevalences and low titers. Low antibody prevalence extending over a period of several years suggests that the virus has been enzootic in the region for some time.

PDV is a morbillivirus. Morbillivirus infection in pinnipeds causes symptoms similar to canine distemper virus in dogs: fever, nasal discharge, gastrointestinal problems, cutaneous lesions, and central nervous system effects (Visser *et al.* 1991). Disease outbreaks caused by two different morbilliviruses occurred in seals in Siberia (Lake Baikal) in 1987 and in northwestern Europe in 1988 (Visser *et al.* 1990). The European seal epizootic, which resulted in the death of more than 18,000 animals, was particularly well studied (reviewed in Heide-Jørgensen *et al.* 1992). Exposure to PDV has also been documented for harbor seals in eastern Canada (Ross *et al.* 1992) and New York (Duignan *et al.* 1993).

## Phocid herpesvirus 1

Two hundred ninety-seven samples, collected between 1978 and 1994, were tested for evidence of exposure to PhHV. Eighty-six samples were from the Kodiak region, 83 were from PWS, 66 were from the Bering Sea, and 62 were from Southeast Alaska (Table 3). Evidence of exposure was found in samples from all regions and years, except for the Bering Sea in 1985 (Table 7).

Based on an analysis of 1,125 samples from nine marine mammal species sampled in Alaska and eastern Russia, Zarnke *et al.* (1997) concluded that exposure to PhHV-1 or a closely related virus has been common, geographically widespread, and long term. The lack of documented epizootics suggests that PhHV-1 has not been highly pathogenic in marine mammals of the region.

PhHV was first isolated from harbor seal pups in a sanctuary in the Netherlands where they developed clinical signs of acute viral infection, including fever, nasal discharge, vomiting, and diarrhea (Borst *et al.* 1986). Eleven of 23 affected seals died. The disease outbreak was apparently confined to the seal sanctuary, although later studies showed that PhHV or a related herpesvirus commonly infects pinnipeds worldwide (Vedder *et al.* 1987). Herspesvirus infection may have played a role in deaths of neonatal harbor seals in California and Washington (Lowenstine *et al.* 1992).

## *Toxoplasma gondii*

One hundred thirty samples, collected between 1978 and 1995, were tested for evidence of exposure to TOXO. Seventy-five samples were from PWS, 22 were from the Bering Sea, 19 were from the Kodiak region, and 14 were from Southeast Alaska (Table 4). Some samples from each region and year tested positive (Table 8).

*T. gondii* has been found in several species of pinnipeds including harbor seals. Infected animals show necrosis of organs such as heart, brain, liver, lung, lymph nodes, and stomach (Haebler and Moeller 1993). Van Pelt and Dietrich (1973) described *T. gondii* infection of a harbor seal pup that was captured shortly after birth in Cold Bay, AK, and died 23 days later. They postulated that the pup had become infected through the placenta.

## Influenza A

One hundred twenty-seven samples, collected from 1978 to 1995, were tested for evidence of exposure to influenza A virus. Seventy-three samples were from PWS, 21 were from the Bering Sea, 19 were from the Kodiak region, and 14 were from Southeast Alaska (Table 4). None of the samples tested positive (Table 9).

These results suggest that Alaskan harbor seals have not been exposed to influenza A virus. One ringed seal (*Phoca hispida*) sample from Alaska tested positive for influenza A (Olsen, pers. commun.), which demonstrates that some seals in the Pacific have been exposed to this virus.

Influenza virus caused the deaths of more than 400 harbor seals along the New England coast in 1979-1980 (Geraci *et al.* 1982). Clinical symptoms included weakness, lack of coordination, and respiratory distress, and death was caused by pneumonia. Influenza virus was again isolated from seals that died in this region in 1991-1992 (Callan *et al.* 1995). Disease outbreaks reported in other species and areas may have been caused by influenza, but could also have been due to morbillivirus (Visser *et al.* 1991).

## *Brucella* spp.

One hundred thirty-one samples, collected from 1978 to 1995, were tested for evidence of exposure to BS4 (Table 4). Seventy-four samples were from PWS, 24 were from the Bering Sea, 19 were from the Kodiak region, and 14 were from Southeast Alaska. Evidence of exposure was found in samples from every region and was most common in the Bering Sea (33%), Prince William Sound (30%), and Southeast Alaska regions (29%) (Table 10). Only 5% of all Kodiak samples were considered positive.

*Brucella* spp. have been isolated from several marine mammal species, including harbor seals, in the North Atlantic (MacMillan, pers. commun.). Similarly, in the North Pacific there is serologic evidence of exposure in ringed, spotted (*Phoca largha*), and ribbon (*P. fasciata*) seals, and Pacific walrus (*Odobenus rosmarus divergens*) (Zarnke and MacMillan, unpubl. data). Possible effects of *Brucella* spp. on marine mammals are unknown. The most typical result of brucellosis in other species is abortion (Witter 1981). A *Brucella* sp. was isolated from an aborted bottlenose dolphin (*Tursiops truncatus*) fetus from the coast of California (Ewalt *et al.* 1994).

## *Chlamydia psittaci*

Eighteen samples, collected in 1993, were tested for evidence of exposure to *Chlamydia psittaci* (Table 11). Fifteen samples were from Southeast Alaska and three were from the Kodiak region. One sample from each region was positive with a low titer. This could be interpreted as current or recent low-level immune response, or that seals were strongly infected in the past and their immunity is now waning.

There is little information available on *C. psittaci* in marine mammals. Serum from Pribilof fur seals (*Callorhinus ursinus*) showed some immune response to chlamydial antigen (Eddie *et al.* 1966). Calkins and Goodwin (1988) reported that 53 of 109 Steller sea lions (*Eumetopias jubatus*) tested for *C. psittaci* had titers of 16 or greater, and 25 had titers of 128 or greater. Spraker and Bradley (1996) reported that 22 of 41 Steller sea lions sampled during 1992-1994 were positive. Effects of *C. psittaci* on seals have not been documented, but in other animals it is known to cause abortion, stillbirths, and production of weak young (Shewen 1980).

## Calicivirus

Twenty-two harbor seal sera collected in 1993 (17 from Southeast Alaska and 5 from Prince William Sound) tested negative for calicivirus (Table 12). Of 38 Alaskan harbor seal sera tested in 1983, one had a titer of 20 to San Miguel Sea Lion Virus (SMSV) serotype 6, and all others were negative (Zarnke, unpubl. data). In 1996, samples were sent to Dr. Nigel Ferris (Institute of Animal Health, United Kingdom) to be tested for calicivirus using a monoclonal antibody test. However, due to funding problems those tests have not been conducted.

SMSV has been implicated in abortions of California sea lions (*Zalophus californianus*) and also caused formation of vesicular lesions on the flippers (Visser *et al.* 1991). Thirteen different serotypes have been identified from pinnipeds, all of which cause similar symptoms. SMSV appears to be a widely transmissible calicivirus prevalent in the North Pacific. In addition to California sea lions, Smith and Boyt (1990) cite serologic evidence of exposure in Steller sea lions, northern fur seals, northern elephant seals (*Mirounga angustirostris*), and walruses, but apparently there is no record of calicivirus exposure in harbor seals (Visser *et al.* 1991). Steller sea lions in Alaska continue to show serologic evidence of exposure to six serotypes of SMSV (Spraker and Bradley 1996).

### Geographic and temporal patterns

There were no major geographical differences in antibody prevalences of between the Bering Sea, Kodiak, PWS, and Southeast Alaska regions for PDV ($P=0.389$), *Toxoplasma* ($P=0.143$), or *Brucella* ($P=0.111$) (Table 13). There is evidence of differing regional prevalence for PhHV ($P=0.057$). Antibody prevalence was highest in the Kodiak region, followed in decreasing order by Southeast, PWS, and the Bering Sea.

When the data were compiled by year, sample sizes were small in some cases and prevalences varied considerably (Table 14). No temporal patterns were found in antibody prevalence for PDV ($P=0.820$) or *Toxoplasma* ($P=0.686$). There is moderate evidence that the prevalence of *Brucella* increased through time ($P=0.094$). The pattern of change for PhHV is complex; both year and year$^2$ were found to be important ($P<0.001$), but the fit of the regression model is poor ($P<0.001$). However, data for the year 1985 appear anomalous; 0 of 24 seals were positive for PhHV in 1985, while the next lowest prevalence is 32 of 51 positive in 1993. The 1985 samples came only from seals collected along the north side of the Alaska Peninsula, and they all had low titers to PhHV. Repeating the analysis for PhHV after omitting the 1985 data results in a good model fit ($P=0.447$), and indicates that the prevalence of PhHV has declined ($P=0.001$).

### Archived and untested sera

Frozen serum samples from 317 of the tested harbor seals described in this report remain archived at the ADF&G office in Fairbanks. Additionally, sera from 432 other harbor seals collected between 1976-1978 (n = 197) and 1989-1997 (n = 235) have not been tested and are archived. Future testing of archived sera is anticipated.

## CONCLUSIONS

This study reports preliminary results from disease testing of more than 300 harbor seals sampled in Alaska during 1978-1995. Eight potential disease-causing agents were included in the tests. Alaskan harbor seals have apparently been exposed to phocid herpesvirus, phocine distemper virus, *Brucella* spp., *Toxoplasma gondii*, and *Chlamydia psittaci*. There is no evidence of exposure to influenza A virus, calicivirus, or canine distemper virus.

The possible significance of exposure to these disease agents is unclear. In most cases titers are low, which could be indicative of mild exposure, weak immune reaction, or waning antibody response. Some of these disease agents are known to cause mortality or to have reproductive effects. However, symptoms of disease have not been documented in Alaskan harbor seals. There are no obvious differences in antibody prevalence between Southeast Alaska and other parts of the state. Therefore, the data collected to date do not support the hypothesis that disease has been an important factor in the decline of seal numbers in some regions of Alaska.

These summaries provide a basis for future serologic studies of harbor seals. The database provides access to serologic data and the specimen's sex, age, and collection date. Additionally, the database provides information regarding the current availability of archived sera. The serologic database will be updated as additional historical data or future test results become available.

## ACKNOWLEDGMENTS

Sera were provided by a number of people, especially John Burns, Francis Fay, Kathy Frost, Mona Haebler, Jon Lewis, Lloyd Lowry, Ken Pitcher, Terry Spraker, Dave Withrow, and others at the National Marine Mammal Laboratory. Many other biologists helped to collect the animals and blood samples used in this report and their efforts are greatly appreciated. Grey Pendleton helped with statistical analysis, and Ken Pitcher provided comments on a draft of the report. Analysis of data and preparation of this report were supported by the Alaska Department of Fish and Game.

## LITERATURE CITED

Barrett, T., J. Crowther, A. D. M. E. Osterhaus, S. M. Subbarao, J. Groen, L. Haas, L. V. Mamaev, A. M. Titenko, I. K. G. Visser, and C. J. Bostock. Molecular and serological studies on the recent seal virus epizootics in Europe and Siberia. Sci. of the Total Environ. 115:117-132.

Borst, G. H. A., H. C. Walvoort, P. J. H. Reijnders, J. S. van der Kamp, and A. D. M. E. Osterhaus. 1986. An outbreak of a herpesvirus infection in harbor seals (*Phoca vitulina*). J. Wildl. Dis. 22:1-6.

Calkins, D., and E. Goodwin. 1988. Investigation of the declining sea lion population in the Gulf of Alaska. Unpubl. Rep. AK Dept. Fish and Game, Anchorage, AK. 76 p.

Callan, R. J., G. Early, H. Kida, and V. S. Hinshaw. 1995. The appearance of H3 influenza viruses in seals. J. General Virology 76:199-203.

Duignan, P. J., S. Sadove, J. T. Saliki, and J. R. Geraci. 1993. Phocine distemper in harbor seals (*Phoca vitulina*) from Long Island, New York. J. Wildl. Dis. 29:465-469.

Eddie, B., W. J. L. Sladen, B. K. Sladen, and K. F. Meyer. 1966. Serological studies and isolation of Bedsonia agents from northern fur seals on the Pribilof Islands. Am. J. Epidem. 84:405-441.

Ewalt, D. R., J. B. Payeur, B. M. Martin, D. R. Cummins, and W. G. Miller. 1994. Characteristics of a *Brucella* species from a bottlenose dolphin (*Tursiops truncatus*). J. Vet. Diagn. Invest. 6:448-452.

Geraci, J. R., D. J. St. Aubin, K. Barker, R. G. Webster, V. S. Hinshaw, W. J. Bean, H. L. Ruhnke, J. H. Prescott, G. Early, A. S. Baker, S. Madoff, and R. T. Schooley. 1982. Mass mortality of harbor seals: pneumonia associated with influenza A virus. Science 215:1129-1131.

Haebler, R., and R. B. Moeller, Jr. 1993. Pathobiology of selected marine mammal diseases. Pages 217-244 *in*: J. A. Couch and J. W. Fournie, eds. Pathobiology of marine and estuarine organisms. CRC Press, Ann Arbor, MI.

Heide-Jørgensen, M.-P., T. Härkönen, R. Dietz, and P. M. Thompson. 1992. Retrospective of the 1988 European seal epizootic. Dis. Aquat. Org. 13:37-62.

Lowenstine, L. J., L. J. Gage, D. M. Smith, and C. Fitzgerald. 1992. Mortality in neonatal harbor seals (*Phoca vitulina richardsi*) from the California coast: possible role of a herpes-like virus infection. Pages 243-247 *in*: B. Osburn, G. Castrucci, and C. Shore (eds.). New and emerging infectious diseases. Proceedings of the 12th International Symposium of the World Association of Veterinary Microbiologists, Immunologists and Specialists in Infectious Diseases.

Lowry, L. F., R. L. Zarnke, and J. P. Lewis. 1996. Disease studies of Alaska harbor seals. Pages 146-162 *in*: Harbor seal investigations in Alaska. Fin. Rep. Award NA57FX0367 from Alaska Dep. Fish and Game to the National Oceanic and Atmospheric Administration. 203 p.

Osterhaus, A. D. M. E., R. de Swart, R. L. Zarnke, and J. Ver Hoef. in prep. Serologic survey for phocine distemper and canine distemper viruses in marine mammals from Alaska and adjacent areas, 1978-1994.

Ross, P. S., I. K. G. Visser, H. W. J. Broeders, M. W. G. van de Bilt, W. D. Bowen, and A. D. M. E. Osterhaus. 1992. Antibodies to phocine distemper virus in Canadian seals. Vet. Record 130:514-516.

Sease, J. L. 1992. Status review: harbor seals (*Phoca vitulina*) in Alaska. NMFS AFSC Processed Rep. 92-15. 74 p.

Shewen, P. E. 1980. Chlamydial infection in animals: a review. Can. Vet. J. 11:2-11.

Smith, A. W., and P. M. Boyt. 1990. Caliciviruses of ocean origin: a review. J. Zoo and Wildl. Medicine 21:3-23.

Spraker, T. R., and D. Bradley. 1996. Investigations into the health status of Steller sea lions, *Eumetopias jubatus*, from 1992 to 1995. Pages 87-108 *in*: Steller sea lion recovery investigations in Alaska, 1992-1994. AK Dept. Fish and Game Tech. Bull. No. 13.

Van Pelt, R. W., and R. A. Dietrich. 1973. Staphylococcal infection and toxoplasmosis in a young harbor seal. J. Wildl. Dis. 9:258-261.

Vedder, E. J., R. Zarnke, H. E. M. Spijkers, and A. D. M. E. Osterhaus. 1987. Prevalence of virusneutralizing antibodies to seal herpesvirus (Phocid herpesvirus 1) in different pinniped species. Seventh Biennial Conference on the Biology of Marine Mammals, Miami, FL. abstract only.

Visser, I. K. G., V. P. Kumarev, C. Orvell, P. de Vries, H. M. J. Broeders, M. W. G. van de Bilt, J. Groen, J. S. Teppema, M. C. Burger, F. G. C. M. UytdeHaag, and A. D. M. E. Osterhaus. 1990. Comparison of two morbilliviruses isolated from seals during outbreaks of distemper in North West Europe and Siberia. Archives of Virology 111:149-164.

Visser, I. K. G., J. S. Teppema, and A. D. M. E. Osterhaus. 1991. Virus infections of seals and other pinnipeds. Rev. Medical Microbiology 2:105-114.

Witter, J. F. 1981. Brucellosis. Pages 280-287 *in*: J. W. Davis, L. H. Karstad, and D. O. Trainer, eds. Infectious diseases of wild mammals. Second Ed. Iowa State Univ. Press, Ames, IO.

Zarnke, R. L., H. W. Vos, J. M. Ver Hoef, and A. D. M. E. Osterhaus. 1997. Serologic survey for phocid herpesvirus-1 and -2 in marine mammals from Alaska and Russia. J. Wildl. Dis. 33(3):459-465.

Table 1. Laboratories that conducted serologic tests for evidence of exposure to selected microbial disease agents.

| Disease agent | Acronym | Laboratory |
|---|---|---|
| Canine distemper virus | (CDV) | Dept. of Virology, Erasmus University, Rotterdam, Netherlands |
| Phocine distemper virus | (PDV) | Dept. of Virology, Erasmus University, Rotterdam, Netherlands |
| Phocid herpesvirus 1 | (PhHV) | Dept. of Virology, Erasmus University, Rotterdam, Netherlands |
| *Toxoplasma gondii* | (TOXO) | Parasite Biology and Epidemiology Lab., Beltsville, Maryland |
| Influenza A virus | (FLU) | School of Vet. Medicine, U. of Wisconsin, Madison, Wisconsin |
| Brucella spp. bacteria | (BS4) | CVL, Bacteriology Dept., Surrey KT, United Kingdom |
| *Chlamydia psittaci* | (CHLAM) | National Veterinary Services Laboratory, Ames, Iowa |
| Calicivirus | (CALICI) | Institute of Animal Health, United Kingdom |

Table 2. Threshold titers for selected microbial disease agents.

| Disease agent | Acronym | Threshold titer |
|---|---|---|
| Canine distemper virus | (CDV) | 100 |
| Phocine distemper virus | (PDV) | 100 |
| Phocid herpesvirus 1 | (PhHV) | 20 |
| *Toxoplasma gondii* | (TOXO) | 25 |
| *Chlamydia psittaci* | (CHLAM) | 20 |
| Calicivirus | (CALICI) | 16 |

Table 3. Samples sizes of harbor seals tested for canine distemper, phocine distemper, and phocid herpes viruses between 1978 and 1996, by year.

| Canine distemper virus | 1978 | 1979 | 1981 | 1985 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 |
|---|---|---|---|---|---|---|---|---|---|---|
| Bering Sea | - | 15 | 25 | - | - | - | - | - | - | - |
| Kodiak | 70 | - | - | - | 6 | - | - | - | 5 | 10 |
| Prince William Sound | 1 | - | - | - | 12 | 7 | 8 | 8 | 28 | 38 |
| Southeast | - | - | - | - | - | 2 | - | - | 18 | 42 |
| **Phocine distemper virus** | 1978 | 1979 | 1981 | 1985 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 |
| Bering Sea | - | 15 | 25 | - | - | - | - | - | - | - |
| Kodiak | 71 | - | - | - | 6 | - | - | - | 5 | 10 |
| Prince William Sound | 1 | - | - | - | 13 | 7 | 7 | 5 | 26 | 36 |
| Southeast | - | - | - | - | - | 2 | - | - | 15 | 42 |
| **Phocid herpesvirus 1** | 1978 | 1979 | 1981 | 1985 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 |
| Bering Sea | - | 15 | 27 | 24 | - | - | - | - | - | - |
| Kodiak | 71 | - | - | - | - | - | - | - | 5 | 10 |
| Prince William Sound | 1 | - | - | - | - | - | 8 | 8 | 28 | 38 |
| Southeast | - | - | - | - | - | 2 | - | - | 18 | 42 |

Table 4. Sample sizes of harbor seals tested for *Toxoplasma gondii*, influenza A, *Brucella* spp., and calicivirus between 1978 and 1994, by year.

| *Toxoplasma gondii* | 1978 | 1985 | 1989 | 1993 | 1994 | 1995 |
|---|---|---|---|---|---|---|
| Bering Sea | - | 22 | - | - | - | - |
| Kodiak | 9 | - | 6 | 4 | - | - |
| Prince William Sound | - | - | 9 | 11 | 29 | 26 |
| Southeast | - | - | - | 14 | - | - |
| **Influenza A** | 1978 | 1985 | 1989 | 1993 | 1994 | 1995 |
| Bering Sea | - | 21 | - | - | - | - |
| Kodiak | 9 | - | 6 | 4 | - | - |
| Prince William Sound | - | - | 9 | 11 | 29 | 24 |
| Southeast | - | - | - | 14 | - | - |
| ***Brucella* spp.** | 1978 | 1985 | 1989 | 1993 | 1994 | 1995 |
| Bering Sea | - | 24 | - | - | - | - |
| Kodiak | 9 | - | 6 | 4 | - | - |
| Prince William Sound | - | - | 9 | 11 | 29 | 25 |
| Southeast | - | - | - | 14 | - | - |
| **Calicivirus** | 1978 | 1985 | 1989 | 1993 | 1994 | 1995 |
| Bering Sea | - | - | - | - | - | - |
| Kodiak | - | - | - | 5 | - | - |
| Prince William Sound | - | - | - | 17 | - | - |
| Southeast | - | - | - | - | - | - |

Table 5. Results of serologic tests conducted on harbor seal samples from the Bering Sea, the Kodiak and Prince William Sound regions of the Gulf of Alaska, and Southeast Alaska between 1978 and 1993 for evidence of exposure to canine distemper virus (CDV).

| CDV | n | age | % positive | | n | age | % positive |
|---|---|---|---|---|---|---|---|
| **1978** | | | | **1993** | | | |
| Kodiak | 3 | adults | 0 | Kodiak | 4 | adults | 0 |
| | 67 | * | 0 | | 1 | 2-5 yr. | 0 |
| PWS | 1 | * | 0 | PWS | 3 | pups | 0 |
| | | | | | 14 | 2-5 yr. | 0 |
| **1979** | | | | | 11 | adults | 0 |
| Bering Sea | 15 | * | 0 | Southeast | 3 | pups | 0 |
| | | | | | 3 | yearlings | 0 |
| **1981** | | | | | 2 | 2-5 yr. | 0 |
| Bering Sea | 25 | * | 0 | | 10 | adults | 0 |
| **1989** | | | | **1994** | | | |
| Kodiak | 5 | adults | 0 | Kodiak | 3 | yearlings | 0 |
| | 1 | * | 0 | | 4 | 2-5 yr. | 0 |
| PWS | 5 | pup | 0 | | 3 | adults | 0 |
| | 6 | adults | 0 | PWS | 2 | pups | 0 |
| | 1 | * | 0 | | 17 | 2-5 yr. | 0 |
| | | | | | 18 | adults | 0 |
| **1990** | | | | | 1 | * | 0 |
| PWS | 1 | fetus | 0 | Southeast | 3 | pups | 0 |
| | 1 | adults | 0 | | 1 | yearling | 0 |
| | 5 | NA | 0 | | 10 | 2-5 yr. | 0 |
| Southeast | 2 | * | 0 | | 28 | adults | 0 |
| **1991** | | | | | | | |
| PWS | 8 | * | 13 | | | | |
| **1992** | | | | | | | |
| PWS | 8 | * | 0 | | | | |

Test method: serum neutralization

Threshold titer: 100

* unknown age

Table 6. Results of serologic tests conducted on harbor seal samples from the Bering Sea, the Kodiak and Prince William Sound regions of the Gulf of Alaska, and Southeast Alaska between 1978 and 1996 for evidence of exposure to phocine distemper virus (PDV).

| **PDV** | n | age | % positive | | n | age | % positive |
|---|---|---|---|---|---|---|---|
| **1978** | | | | **1993** | | | |
| Kodiak | 1 | pup | 0 | Kodiak | 1 | 2-5 yr. | 0 |
| | 2 | adult | 0 | | 4 | adults | 25 |
| | 68 | * | 4 | PWS | 2 | pup | 0 |
| PWS | 1 | * | 0 | | 14 | 2-5 yr. | 0 |
| | | | | | 10 | adults | 0 |
| **1979** | | | | Southeast | 3 | pups | 0 |
| Bering Sea | 15 | * | 7 | | 2 | yearling | 0 |
| | | | | | 1 | 2-5 yr. | 0 |
| **1981** | | | | | 9 | adults | 0 |
| Bering Sea | 25 | * | 4 | | | | |
| | | | | **1994** | | | |
| **1989** | | | | Kodiak | 3 | yearlings | 0 |
| Kodiak | 5 | adults | 0 | | 4 | 2-5 yr. | 0 |
| | 1 | * | 0 | | 3 | adults | 33 |
| PWS | 5 | pups | 0 | PWS | 2 | pup | 0 |
| | 7 | adults | 0 | | 16 | 2-5 yr. | 0 |
| | 1 | * | 0 | | 17 | adult | 12 |
| | | | | | 1 | * | 0 |
| **1990** | | | | Southeast | 1 | yearling | 0 |
| PWS | 1 | fetus | 0 | | 3 | pup | 0 |
| | 1 | adult | 0 | | 10 | 2-5 yr. | 0 |
| | 5 | * | 0 | | 28 | adult | 4 |
| Southeast | 2 | * | 0 | | | | |
| **1991** | | | | | | | |
| PWS | 7 | * | 0 | | | | |
| **1992** | | | | | | | |
| PWS | 5 | * | 0 | | | | |

Test method: serum neutralization
Threshold titer: 100
* unknown age

Table 7. Results of serologic tests conducted on harbor seal samples from the Bering Sea, the Kodiak and Prince William Sound regions of the Gulf of Alaska, and Southeast Alaska between 1978 and 1996 for evidence of exposure to phocid herpesvirus 1 (PhHV).

| **PhHV** | n | age | % positive | | n | age | % positive |
|---|---|---|---|---|---|---|---|
| **1978** | | | | **1993** | | | |
| Kodiak | 1 | pup | 100 | Kodiak | 1 | 2-5 yr. | 100 |
| | 3 | adult | 67 | | 4 | adults | 75 |
| | 67 | * | 81 | PWS | 3 | pup | 33 |
| PWS | 1 | * | 100 | | 14 | 2-5 yr. | 43 |
| | | | | | 11 | adults | 82 |
| **1979** | | | | Southeast | 3 | pups | 33 |
| Bering Sea | 15 | * | 93 | | 3 | yearling | 67 |
| | | | | | 2 | 2-5 yr. | 50 |
| **1981** | | | | | 10 | adults | 80 |
| Bering Sea | 27 | * | 85 | | | | |
| | | | | **1994** | | | |
| **1985** | | | | Kodiak | 3 | yearlings | 67 |
| Bering Sea | 2 | fetus | 0 | | 4 | 2-5 yr. | 75 |
| | 22 | * | 0 | | 3 | adults | 33 |
| | | | | PWS | 2 | pup | 50 |
| **1990** | | | | | 17 | 2-5 yr. | 65 |
| Southeast | 2 | * | 100 | | 18 | adults | 50 |
| | | | | | 1 | * | 100 |
| **1991** | | | | Southeast | 1 | yearling | 100 |
| PWS | 8 | * | 75 | | 3 | pup | 33 |
| | | | | | 10 | 2-5 yr. | 50 |
| **1992** | | | | | 28 | adult | 82 |
| PWS | 8 | * | 88 | | | | |

Test method: serum neutralization
Threshold titer: 20
* unknown age

Table 8. Results of serologic tests conducted on harbor seal samples from the Bering Sea, the Kodiak and Prince William Sound regions of the Gulf of Alaska, and Southeast Alaska between 1978 and 1994 for evidence of exposure to *Toxoplasma gondii* (TOXO).

| TOXO | n | age | % positive |
|---|---|---|---|
| **1978** | | | |
| Kodiak | 9 | * | 22 |
| | | | |
| **1985** | | | |
| Bering Sea | 2 | fetus | 0 |
| | 20 | * | 25 |
| | | | |
| **1989** | | | |
| Kodiak | 5 | adults | 20 |
| | 1 | * | 0 |
| PWS | 2 | pup | 0 |
| | 6 | adult | 0 |
| | 1 | * | 0 |
| | | | |
| **1993** | | | |
| Kodiak | 1 | 2-5 yr. | 0 |
| | 3 | adults | 33 |
| PWS | 6 | 2-5 yr. | 17 |
| | 5 | adults | 20 |
| Southeast | 3 | pups | 0 |
| | 2 | yearling | 0 |
| | 9 | adults | 22 |
| | | | |
| **1994** | | | |
| PWS | 2 | pup | 0 |
| | 10 | 2-5 yr. | 0 |
| | 17 | adults | 12 |
| | | | |
| **1995** | | | |
| PWS | 15 | 2-5 yr. | 7 |
| | 6 | adults | 17 |
| | 5 | * | 0 |

Test method: modified agglutination test
Threshold titer: 25
* unknown age

Table 9. Results of serologic tests conducted on harbor seal samples from the Bering Sea, the Kodiak and Prince William Sound regions of the Gulf of Alaska, and Southeast Alaska between 1978 and 1994 for evidence of exposure to influenza A virus (FLU).

| FLU | n | age | % positive |
|---|---|---|---|
| **1978** | | | |
| Kodiak | 9 | * | 0 |
| **1985** | | | |
| Bering Sea | 2 | fetus | 0 |
| | 19 | * | 0 |
| **1989** | | | |
| Kodiak | 5 | adults | 0 |
| | 1 | * | 0 |
| PWS | 2 | pup | 0 |
| | 6 | adult | 0 |
| | 1 | * | 0 |
| **1993** | | | |
| Kodiak | 1 | 2-5 yr. | 0 |
| | 3 | adults | 0 |
| PWS | 6 | 2-5 yr. | 0 |
| | 5 | adults | 0 |
| Southeast | 3 | pups | 0 |
| | 2 | yearling | 0 |
| | 9 | adults | 0 |
| **1994** | | | |
| PWS | 2 | pup | 0 |
| | 10 | 2-5 yr. | 0 |
| | 17 | adults | 0 |
| **1995** | | | |
| PWS | 13 | 2-5 yr. | 0 |
| | 6 | adults | 0 |
| | 5 | * | 0 |

Test method: double agar immunodiffusion assay

* unknown age

Table 10. Results of serologic tests conducted on harbor seal samples from the Bering Sea, the Kodiak and Prince William Sound regions of the Gulf of Alaska, and Southeast Alaska between 1978 and 1994 for evidence of exposure to *Brucella* spp. bacteria (BS4).

| **BS4** | n | age | % positive |
|---|---|---|---|
| **1978** | | | |
| Kodiak | 2 | adults | 0 |
| | 7 | * | 0 |
| **1985** | | | |
| Bering Sea | 2 | fetus | 0 |
| | 22 | * | 36 |
| **1989** | | | |
| Kodiak | 5 | adults | 20 |
| | 1 | * | 0 |
| PWS | 2 | pup | 0 |
| | 6 | adult | 17 |
| | 1 | * | 0 |
| **1993** | | | |
| Kodiak | 1 | 2-5 yr. | 0 |
| | 3 | adults | 0 |
| PWS | 6 | 2-5 yr. | 33 |
| | 5 | adults | 0 |
| Southeast | 3 | pups | 67 |
| | 2 | yearling | 0 |
| | 9 | adults | 22 |
| **1994** | | | |
| PWS | 2 | pup | 0 |
| | 10 | 2-5 yr. | 50 |
| | 17 | adults | 18 |
| **1995** | | | |
| PWS | 14 | 2-5 yr. | 57 |
| | 6 | adults | 33 |
| | 5 | * | 20 |

Test method: indirect enzyme-linked immunosorbent assay

* unknown age

Table 11. Results of serologic tests conducted on harbor seal samples from the Kodiak and Southeast Alaska during 1993 for evidence of exposure to *Chlamydia psittaci* (CHLAM).

| **CHLAM** | age | n | % positive |
|---|---|---|---|
| **1993** | | | |
| Kodiak | 2-5 yr. | 1 | 0 |
| | adults | 2 | 50 |
| Southeast | pup | 3 | 0 |
| | yearling | 2 | 0 |
| | 2-5 yr. | 2 | 50 |
| | adults | 8 | 0 |

Test method: complement fixation
Threshold titer: 20

Table 12. Results of serologic tests conducted on harbor seal samples from the Kodiak and Southeast Alaska during 1993 for evidence of exposure to calicivirus.

| **CALICI** | age | n | % positive |
|---|---|---|---|
| **1993** | | | |
| Kodiak | 2-5 yr. | 1 | 0 |
| | adults | 4 | 0 |
| Southeast | pup | 3 | 0 |
| | yearling | 2 | 0 |
| | 2-5 yr. | 2 | 0 |
| | adults | 10 | 0 |

Test method: serum neutralization
Threshold titer: 16

Table 13. Percent positive tests and sample sizes (parentheses) for eight disease agents tested, separated by region.

| Disease agent | Bering Sea | Kodiak | PWS | Southeast |
|---|---|---|---|---|
| CDV | 0%(40) | 0%(91) | 1%(102) | 0%(62) |
| PDV | 0%(40) | 5%(92) | 2%(95) | 2%(59) |
| PhHV | 56%(66) | 76%(86) | 63%(83) | 71%(62) |
| TOXO | 23%(22) | 21%(19) | 8%(75) | 14%(14) |
| FLU | 0%(21) | 0%(19) | 0%(73) | 0%(14) |
| BS4 | 33%(24) | 5%(19) | 30%(74) | 29%(14) |
| CHLAM | - | 33%(3) | - | 7%(15) |
| CALICI | - | 0%(5) | - | 0%(17) |

Table 14. Percent positive tests and sample sizes (parentheses) for seven diseases agents tested, separated by year of collection.

| Disease agent | 1978 | 1979 | 1981 | 1985 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 |
|---|---|---|---|---|---|---|---|---|---|---|
| CDV | 0%(71) | 0%(15) | 0%(25) | - | 0%(18) | 0%(9) | 12%(8) | 0%(8) | 0%(51) | 0%(90) |
| PDV | 4%(72) | 0%(15) | 0%(25) | - | 0%(19) | 0%(9) | 0%(7) | 0%(5) | 2%(46) | 5%(88) |
| PhHV | 81%(72) | 93%(15) | 85%(27) | 0%(24) | - | 100%(2) | 75%(8) | 88%(8) | 63%(51) | 64%(90) |

| Disease agent | 1978 | 1985 | 1989 | 1993 | 1994 | 1995 |
|---|---|---|---|---|---|---|
| TOXO | 22%(9) | 23%(22) | 7%(15) | 17%(29) | 7%(29) | 8%(26) |
| FLU | 0%(9) | 0%(21) | 0%(15) | 0%(29) | 0%(29) | 0%(24) |
| BS4 | 0%(9) | 33%(24) | 13%(15) | 21%(29) | 28%(29) | 44%(25) |
| CHLAM | - | - | - | 11%(18) | - | - |
| CALICI | - | - | - | 0%(22) | - | - |

# ALASKA HARBOR SEAL CONTAMINANTS REVIEW

Paul R. Becker and Rebecca S. Papa

NIST Charleston Laboratory, 219 Ft. Johnson Road
Charleston, SC 29412

## INTRODUCTION

The numbers of harbor seals (*Phoca vitulina*) have declined steadily and substantially over the last two decades in the Central and Western Gulf of Alaska, including Prince William Sound. Although the reasons for this decline have not been identified, hypotheses have included fishery interactions, changes in availability of food resources, human harvests, disease, increase in predation, increase in disturbance, and pollution. The decline of the harbor seals in this region of Alaska has coincided with the decline in the numbers of the Steller sea lion (*Eumatopias jubatus*), suggesting common reasons for the decrease in numbers of both pinniped species.

Although the presence of contaminants has been suggested as one possible causative factor in the decline of both the harbor seal and Steller sea lion, very little information is readily available on contaminant concentration loads in these animals. One of the initial steps in addressing the possible role of anthropogenic contaminants in the decline of these species is to establish the database that can be used to define the types of studies needed to address this question. As part of this initial step, existing data and information on levels of contaminants in the harbor seals of Alaska, as well as other regions, are being reviewed. The goal is to produce a synthesis of what is known regarding contaminants in and their effects on harbor seals in Alaska, and develop recommendations on research needed to better define the degree of contamination in Alaska harbor seals and the effects of this contamination on animal health. More specifically, the objectives of this review are to:

1. Compile and review information available on contaminants in harbor seals with emphasis on Alaska.

2. Evaluate the available information to determine whether it is sufficient to assess the likely impacts of contaminants on harbor seals in Alaska.

3. Determine what additional sampling and analysis should be done.

## METHODS

Although past research and monitoring in Alaska are emphasized, a significant amount of comparative information is available from Canada, other areas of the North Pacific, and the

North Atlantic. Information on other marine mammal species is being included only as it lends to the interpretation of harbor seal data. Contaminants to be addressed are hydrocarbons (both chlorinated and non chlorinated), heavy metals, and radionuclides. Other contaminants of interest are being identified and evaluated.

The approach being used in this project includes the following: 1) library and computer database searches for peer-reviewed scientific literature as well as "gray" literature and unpublished databases; 2) telephone surveys of researchers in the field, to identify gray literature and unpublished databases. A significant source of comparative information for the harbor seal is available from Northern Europe (particularly the Baltic Sea region), the East Coast of the U.S., and Canada.

The determination of what additional sampling and analysis are needed is being made within the context of how this contributes to defining the overall health status of the animal. New avenues of analysis and research that should be used to better define contaminant effects are being identified. Research programs presently in place or planned for the future that could provide information to address the issue of contaminants in harbor seals in Alaska are being identified.

## PROJECT STATUS

The report for this project is being produced in two volumes. Volume I is the synthesis report describing what is known about contaminants in harbor seals and their likely effects, recommendations for additional research needed to better define these effects, and identification of research activities (ongoing and planned) that could contribute to these needs. The following outline indicates how Volume I is being organized and how the results of this review are being presented:

### ALASKA HARBOR SEAL CONTAMINANTS REVIEW, Volume I

I. Introduction
    A. Objectives
    B. Scope of the review and report
    C. General description of the harbor seal
        1. Distribution (Alaska and World Wide)
        2. Contaminant database

II. Contaminants of Concern
    A. Persistent Organic Pollutants (POP's)
    B. Hydrocarbons
    C. Heavy metals and metalloids
    D. Radionuclides

III. Contaminants in Alaska harbor seals - status of knowledge

IV. Contaminants in harbor seals and other pinnipeds in U.S., Canada, and Europe - status of knowledge

V. Contaminant levels and health effects in pinnipeds
    A. Status of knowledge
    B. Past research approaches

V. Recommendations

VII. References

Volume II is the annotated bibliography, which will be provided in a hard copy report as well as on PC disk (Pro-Cite 3.1 for Windows). The Pro-Cite program will allow for the entering of additional references to this bibliography as they are published.

The annotated bibliography is nearing completion. Presently, 324 references have been entered. Each reference includes an abstract and a keyword index. Many of the "gray literature" reports have no abstracts; therefore, abstracts have been written for including in the bibliography. Nineteen of the 324 references deal with contaminants in Alaska harbor seals, eight of which concern Prince William Sound and the *Exxon Valdez* oil spill. The great majority of the information on contaminants and their potential health effects on harbor seals in the bibliography (47%) is derived from European studies. Additional information is derived from studies of other pinniped species and, in some cases, small cetaceans.

# CHAPTER FOUR

# GENETICS STUDIES OF ALASKAN HARBOR SEALS

## OBJECTIVE 6

Determine genetic structure of harbor seals in Alaska

# GENETIC INVESTIGATION OF ALASKAN HARBOR SEAL STOCK STRUCTURE USING mtDNA

Robin L. Westlake and Gregory O'Corry-Crowe

National Marine Fisheries Service, Southwest Fisheries Science Center
8604 La Jolla Shores Dr., La Jolla CA 92038

## INTRODUCTION

The population structure of Pacific harbor seals (*Phoca vitulina*) has been of particular interest to researchers over the last 25 years, and a plethora of various biological studies have been conducted regarding this species' patterns of variation across its range (Bigg 1973, Shaughnessy and Fay 1977, Kelly 1981, Burns *et al.* 1984, Temte *et al.* 1991, Lehman *et al.* 1993, Burg 1996, Lamont *et al.* 1996, Stanley *et al.* 1996). Harbor seals breed in hundreds of small groups throughout a vast latitudinal and longitudinal range, under various environmental conditions. They tend to concentrate in estuaries and protected waters and are found from San Ignacio Lagoon, Mexico (27°N), northward throughout the North Pacific coastlines and westward as far as northern Japan (43°N) (Shaughnessy and Fay 1977, Frost *et al.* 1982, Burns and Gol'tsev 1984). Both local and clinal patterns of variation in morphology, physiology, and behavior (i.e., body size, pelage coloration, and time of pupping) are apparent in this species. This is partly due to occupying such an expansive coastal range relative to individual home ranges and is biased towards an east-west continuum (Bigg 1973, Shaughnessy and Fay 1977, Kelly 1981, Burns *et al.* 1984, Temte 1991).

More specifically, harbor seals in Alaska (*P. v. richardsi*) haul out along shorelines from the southeastern part of the state across the northern Gulf of Alaska, up into Bristol Bay, and westward throughout the Aleutian Islands (Fig. 1). But, distribution of haulouts is not continuous, and their abundance is not uniform. Prince William Sound (PWS, 61°N) and Kuskokwim Bay (60°N) are the northernmost pupping areas, while haulout sites on land or ice have been identified as far north as Nunivak Is. and eastern Kamchatka, Russia (63°N) (Shaughnessy and Fay 1977, Frost *et al.* 1982, Burns and Gol'tsev 1984). The seals are also found in Lake Iliamna, and the animals there may constitute a discrete population (Everitt and Braham 1980, O. Mathisen pers. commun. *in* Loughlin 1992).

Harbor seals are considered relatively sedentary animals, generally making local movements (5-10 km) associated with such factors as tides, weather, food availability, aquatic reproduction, and season (Bigg 1973, 1981, Lowry *et al.* 1979, Everitt and Braham 1980). Tagging studies have shown considerable site fidelity (Frost *et al.* 1995, Swain *et al.* 1996). However, some long-distance movements (up to 550 km) between haul-outs occur (Pitcher and McAllister 1981, Brown and Mate 1983). It is important to recognize that these long-distance movements do not contribute to gene flow between local populations unless mating occurs when animals are beyond the general vicinity of their home range.

Varying rates of decline have been reported for Pacific harbor seals at some of the major breeding and haulout areas in Alaska. The most dramatic decline in population trends in recent times (approx. 70% since the 1970's) has occurred in the Gulf of Alaska (Pitcher 1990, Sease 1992, Loughlin 1993). Therefore, a greater understanding of population stock structure is required for estimating minimum population abundance for conservation and management purposes. These estimates are needed for making decisions regarding allowable harbor seal takes in Alaska by subsistence hunters and commercial fisheries and for managing fishing effort on important prey species (Sease 1992).

Since the genetic structure of a population of animals is a result of behavioral and demographic structure, a genetic analysis can reveal detailed information without having to perform long-term comprehensive studies (Hoelzel 1993). Mitochondrial (mtDNA) is widely used for population structure studies because of its relatively rapid rate of evolution, allowing resolution of closely related forms, and its maternal mode of inheritance in mammals (Brown *et al.* 1979). Use of mtDNA techniques can help clarify which Alaskan harbor seal populations are genetically discrete from one another, and can provide managers with a better concept of the overall population structure, including estimates of dispersal and gene flow between populations. Genetic variation and differentiation, effective population size, and demographic history can also be extracted from genetic data to gain knowledge and help ensure that genetic diversity is conserved (Hoelzel 1992) in harbor seal populations.

The purpose of this study is to implement molecular genetic techniques in order to determine if any population-level differences in harbor seals exist. Several questions were addressed, including (1) Are harbor seals in Alaska genetically discrete from those in other parts of their range? (2) Within Alaska, can harbor seals be divided into more than one management stock, and if so, where are the boundaries of those stocks? (3) Are defined genetic populations temporally stable? (4) Are there differences in migration patterns of males vs. females? And (5) are the two currently recognized subspecies of Pacific harbor seals (*P. v. richardsi* and *P. v. stejnegeri*) genetically distinct?

The Alaska Scientific Review Group (SRG) designated three management areas primarily based on differing population trends of harbor seals (Hill *et al.* 1996). These Potential Biological Removal (PBR[1]) areas are shown in Figure 1 and include: (1) Bering Sea (including the Pribilof Islands and Bristol Bay, north of Unimak Pass), (2) Gulf of Alaska (Aleutian Islands, S. Alaska Peninsula, Kodiak archipelago, Kenai, and Prince William Sound to Cape Suckling), and (3) Southeast, AK (from Cape Suckling to the border of Alaska and British Columbia). Tissue samples of geographically dispersed harbor seals from these three putative PBR areas were analyzed for mtDNA variation.

Harbor seals from the western Aleutian Islands are geographically closer to and more similar in morphology and behavior to animals found in Russia and Japan (*P. v. stejnegeri* form) than they are to those found in the eastern Aleutian Islands (Burns and Gol'tsev 1984). Although samples were not available from the western Aleutians, a number of samples were obtained from the Commander Is. (Russia) and northern Japan to investigate any genetic differences between them and samples from throughout Alaska.

This report summarizes the findings of the mtDNA stock structure study to date,

---

[1] The PBR is defined as the maximum number of animals that can be removed (human-caused mortality) from a population stock, while allowing that stock to reach or maintain its optimum sustainable population (NMFS 1994).

stratifying the samples according to the larger PBR areas, and also smaller geographic divisions from Japan to Southeast Alaska (based on abundance and distribution), referred to as "subpopulations" in this report. The results are based on various analyses of 213 harbor seal samples, many of which were obtained from biologists and subsistence hunters from areas around Alaska, Russia, and Japan. Several recommendations for further work regarding harbor seal stock structure are also discussed, stressing the importance of how sample size and dispersal rates affect the results.

## MATERIALS AND METHODS

### Sample collection, DNA extraction, PCR, and sequencing

Currently, there are over 500 harbor seal tissue samples from Alaska, Russia, and Japan archived at the Southwest Fisheries Science Center (SWFSC) stored in salt-saturated 20% (v/v) dimethyl sulfoxide (DMSO). For this study, total genomic DNA was extracted from skin, muscle, or liver samples using both CTAB (Cetyltrimethylammonium bromide) and phenol/chloroform protocols, and precipitated with ethanol (Winnepenninckx *et al.* 1993, Maniatus *et al*. 1982). The concentration and quality of the DNA was visually inspected on a 1% agarose gel and estimated by spectrophotometry. A section of the mtDNA genome containing the proline tRNA gene and adjacent d-loop control region (due to it's highly variable, non-coding properties) was amplified in a Perkin Elmer 9600 thermocycler using PCR (Polymerase Chain Reaction) techniques (Saiki *et al*. 1988). Both strands of the target mtDNA were then sequenced with fluorescent technology, and analyzed on an autosequencer. Sequences were aligned and edited by eye with the SeqEd™ multiple editor sequence program (ABI, 1992). A 435 base pair sequence of the heavy strand from each sample (213 total) served as the raw data on which the analyses were performed, and the sequences were analyzed using both distance and phylogenetic methods.

### Distance methods

#### *Analysis of Molecular Variance*

The genetic or evolutionary distance separating each pair of sequences was estimated as the proportion of nucleotide differences employed by MEGA (Kumar *et al.* 1993). Insertion/deletion events (indels) were treated as transition substitutions, and both transversions and transitions were treated equally. The derived matrix of pairwise genetic distances ((N x [N-1])/2) was examined for evidence of geographic structure, employing an analysis of variance method (AMOVA) modified for use with molecular sequence data (Excoffier *et al*. 1992). Both populations and groups (nested populations) of individuals were defined by non-genetic criteria, which were the hypothesized PBR stocks.

For a more discrete analysis (a "micro-management" approach), these areas were also stratified into 10 subpopulations within Alaska (Fig. 2), and Japan and Russia. Estimates of variance components and *F*-statistic analogs, designated PHI-statistics ($\Phi_{st}$), were computed (1000 permutations) for various pairwise combinations and overall subpopulation comparisons. The $\Phi_{st}$ is the correlation of a random haplotype drawn from within an area to a random haplotype drawn from among all the areas (Excoffier *et al.* 1992). It provides an estimate of the degree of population subdivision based on the genetic metric distance employed (nucleotide differences among haplotypes), and whether or not grouped "subpopulations" are valid. The three sources of variation are "within populations (individuals)," " among populations within groups," and "among groups."

### *Isolation by distance*

A Mantel t-test was also performed on the 10 Alaska subpopulations (see Fig. 2) to test for evidence of genetic isolation by geographic distance. It allowed us to look at the correlation of pairwise genetic distances with corresponding geographic distances between 10 central areas of sampled individuals.

### Phylogenetic inference methods

The number of haplotypes was found using MacClade software (Maddison and Maddison 1992), and the number of variable and phylogenetically informative sites was calculated using MEGA software (Kumar *et al.* 1993). A table was compiled to show shared haplotypes (present in two or more animals) and unique ones among six regions throughout Alaska, Russia, and Japan.

Various phylogenetic analyses were conducted to examine any resultant geographical concordance between haplotypes. These included tree-building algorithms using parsimony, or discrete-character methods (PAUP, Swofford 1993), and UPGMA (unweighted pair-group method using arithmetic means) and neighbor-joining trees (both distance-based) in MEGA (Kumar *et al.* 1993). A minimum spanning network of haplotype relationships (mutational events) using NTSYS-pc (Rohlf 1990) aided in the construction of a network tree connecting closest haplotypes in the most parsimonious way.

## RESULTS

### MtDNA sequence variation

The overall sampled populations in this study were highly polymorphic, with most of the variation (about 95%) due to individual-to-individual variation. A total of 435 base pairs of the mtDNA control region was sequenced from 213 harbor seals: 192 from Alaska, 16 from Russia, and 5 from Japan. Individuals and their haplotypes, location of collection, age-class and sex are listed in Table 1, organized by the 12 subpopulations used in subsequent analyses. We found 108 haplotypes overall, most of which were represented in a single individual (77/108). The distribution of the 31 shared haplotypes, as well as the number of unique ones among six geographical areas from Japan to Southeast Alaska, are shown in Table 2. Sixty-one variable sites were identified, including four indel regions, and 40 sites were phylogenetically informative (Fig. 3). Sequence divergence ranged up to 4.4%. Within Alaska, 98 haplotypes were found among 192 individuals; only four haplotypes were found in all three PBR areas, with the majority again being unique (70/98).

## Distance analyses

### *Temporal variation*

We had a unique opportunity to investigate temporal changes in genetic composition of harbor seals within an area (i.e. Kodiak and Prince William Sound), over a period of roughly four generations, spanning the most recent dramatic population declines. Many of the sequences were from Gulf of Alaska animals collected by ADF&G in the 1970's. A second group of samples were collected from this region in the 1990's. The analysis failed to show any differences between animals in the Gulf of Alaska from the 1970's (n = 42) and the 1990's (n = 24), based on an analysis of molecular variance ($\Phi_{st} = 0.0003$, $p = 0.3297$), so the samples were pooled and used in the subsequent analyses.

### *Japanese and Russian harbor seals*

Japan and Russian samples were used in the analyses because of the somewhat equivocal boundary between the two recognized subspecies in the North Pacific, and samples from the western Aleutian Islands were not available. Based on AMOVA, the Russian population was significantly different from Japan and all 10 of the Alaskan subpopulations ($p < 0.01$). Japan animals, on the other hand, were significantly different only from Russia and the southernmost animals of Southeast, Alaska. The sample size from Japan was quite small (N=5), and thus failure to find differences between the more distant populations is probably due to lack of statistical power.

### *Alaskan harbor seals - smaller subpopulations*

Sequence data were analyzed to test for genetic differentiation between the 10 previously defined Alaskan subpopulations (Fig. 2) (pairwise comparisons, Table 3). The Pribilof animals (N=6) were significantly different from those in Bristol Bay, so it did not seem appropriate to group these two subpopulations together to represent the Bering Sea stock in some of the subsequent analyses. The sample size for the Pribilofs was quite small, although we did find differences at the 5% level between animals there and all subpopulations east of the south Alaska Peninsula (Table 3).

Some microgeographic structure was apparent in the three Southeast Alaska subpopulations (north, central, and south, Fig. 2). Harbor seals from the central subpopulation were different from the southern one ($p = 0.028$), but the northern and southern ones could not be discriminated (Table 3). Interestingly, the northern and southern subpopulations are characterized as being adjacent to "open ocean," whereas the sampled central subpopulation was from inland waters (Frederick Sound). These recorded patterns of genetic differentiation may, however, be an artifact of the sampling regime, or due to unequal or insufficient sample sizes. Again, increasing sample sizes in Southeastern Alaska would most likely improve resolution of population structure in this area.

### *Alaskan harbor seals - PBR subpopulations*

On a larger geographic scale, genetic analysis revealed significant subdivision among the three proposed "SRG" subpopulations: (1) Bering Sea, (2) Gulf of Alaska, and (3) Southeast (Table 4 - overall $\Phi st = 0.02$, $p = 0.024$ ). Genetic differentiation was found between animals in the Bering Sea (including Pribilofs) and Southeast Alaska stocks ($p = 0.022$), and also between the Gulf of Alaska and Southeast stocks ($p = 0.046$). We failed, however, to find any evidence of genetic substructure between the Bering Sea and Gulf of Alaska animals ($p = 0.184$). Considering the hypothetical nature of the proposed PBR boundaries and the underlying assumptions that a high level of mtDNA differentiation reflects a real break in terms of population structure and dispersal, we decided to take an alternative approach to searching for the most biologically meaningful PBR boundaries. We searched for the highest level of genetic differentiation among areas in Alaska by moving the proposed PBR boundaries and testing for mtDNA subdivision. The highest significant $\Phi st$ value (0.038) was revealed when the Bering Sea (less Pribilofs) and western Gulf animals (including E. Aleutians to lower Cook Inlet) were tested against those from the central/eastern Gulf (Kenai and Prince William Sound) grouped with Southeast animals ($p < 0.01$). The "new" boundary is shown in Fig. 2 near the Kenai Peninsula and lower Cook Inlet area (152°W meridian).

In addition, a similar approach using female genetic distance data only also suggested a separation of two stocks near the 152°W meridian (see Fig. 4 - $\Phi st = 0.11$, $p = 0.02$). Similar groupings of only male genetic distance data failed to detect any differences ($\Phi st = 0.031$, $p = 0.11$).

### *Isolation by distance*

Employing the 10 geographical centers of sampled individuals within Alaska, a Mantel t-test showed genetic isolation by geographic distance, suggesting a strong clinal pattern to genetic variability with subpopulations at the extremes of the range being significantly different ($p < 0.01$, see Fig. 5). This result was also evident in the AMOVA analysis (Table 3), with Bristol Bay and eastern Aleutian Island animals being differentiated from seals in the southern part of Southeast ($p < 0.05$).

### Phylogenetic analyses

A parsimony analysis of 108 haplotypes resulted in poor resolution of groups from similar geographic locations due to the large number of taxa and too few informative sites (40). Both clustering methods (UPGMA and neighbor-joining trees) also failed to show any strong geographic concordance between haplotypes, due to so many unique ones and lack of phylogenetic signal. There were, however, several small groups of Gulf of Alaska/Southeast animals that clustered together, a few smaller groups of animals from the two larger distinguished areas (from AMOVA analysis), but also very small groups from distant geographical areas (i.e., Bristol Bay and north Southeast) were found clustered together (tree not shown).

The minimum spanning network tree constructed showed how the 108 haplotypes were related to each other through a series of linked pathways (the number of mutational steps from closest haplotype, not shown). The two most common haplotypes (#6 and #14) were in the "center" of the network, being 9 mutational steps apart. The next most common haplotypes were close (one or two mutational steps away) to the two most common ones, and the least common haplotypes radiated in all directions from the more common ones. Again, it was difficult to determine any geographic substructure within the overall network, so these analyses will not be discussed further in this report.

## DISCUSSION

### Genetic diversity of haplotypes

Based on this study, harbor seals in Alaska exhibit high levels of diversity within the mtDNA genome, as demonstrated by the large number of unique haplotypes and relatively few numbers of shared ones between areas (Table 2). Only four haplotypes (#6,14,15,16) were found among the three designated PBR areas, which were also the most common ones, presumably ancestral polymorphisms. Fifty-seven percent of haplotypes were unique to individuals in the sampled Alaskan population. High levels of genetic diversity are common in large populations and new haplotypes have a greater chance of arising in large populations (Hartl 1988). The high proportion of rare haplotypes in the overall sample also suggests the analysis may not have determined the complete haplotype composition of the populations as yet. Thus the data collected to date may have limited power in detecting genetic differentiation in some cases.

Overall, there appears to be a clinal trend of haplotypes unique to an area, and shared with an adjacent area, in a somewhat "step-wise" order. By inspection of the shared haplotypes in Table 2 and eliminating the four most common ones, there are more shared haplotypes between the central/eastern Gulf of Alaska and Southeast animals than between the former with the western Gulf of Alaska. The 152°W meridian lies between these two areas, and the highest proportion of unique haplotypes (22:49, 45%) was found among the western Gulf of Alaska animals. It's possible that the large population decline near Kodiak Island (85% between 1976-1988, Pitcher 1990) resulted in a loss of haplotypes in the western Gulf of Alaska that are more commonly found today east of the 152°W meridian.

### Geographic subdivision

Russian harbor seals from the Commander Islands were differentiated from all of the 10 Alaskan subpopulations. However, an initial investigation regarding inferred phylogenetic relationships among nucleotide sequences from *P. v. richardsi* (one sequence each from Bristol Bay, Kodiak, Prince William Sound, and Southeast Alaska) and *P. v. stejnegeri* (one sequence from Bering Is., Russia) did not appear to represent phylogenetically distinct mtDNA assemblages (O'Corry-Crowe and Westlake 1997: Fig. 5). The definition of subspecies is typically subjective (Mayr 1963). If based on phylogeny, this initial analysis supports the hypothesis that a single, polytypic form of harbor seal occurs in the North Pacific, with *richardsi* and *stejnegeri* forming two extremes of a trans-Pacific *Rassenkreis*. With this result in mind, and considering the clinal nature of morphological variation (Burns and Gol'tsev 1984) and clinal pattern of genetic variation among this species, W. Aleutian seals (no samples analyzed) may be genetically intermediate to the Russian and E. Aleutian/Bristol Bay animals. It would be of great interest to fill in this sample "gap."

The Pribilofs were found to be genetically differentiated from all other subpopulations at the 10% level, which could be a "false positive" result, due to the small sample size (N=6). However, the four haplotypes found within the Pribilofs were unique to only that area. Geographically, these small, remote islands are more than 400 km from the nearest land mass (E. Aleutians), a distance greater than what harbor seals typically travel ouside their home range (Frost *et al.* 1995, Swain *et al.* 1996). Again, it would be best to analyze more animals from the Pribilofs to determine whether or not they constitute a genetically discrete population.

The Southeast animals showed some interesting results when subdivided into three subpopulations. As mentioned previously, samples in the central part of Southeast were from inland waters (Frederick Sound), and those from the north and south parts of this region were mostly from areas adjacent to open ocean (Cross Sound and Dixon Entrance, respectively). In addition, the central animals were largely biased towards males, whereas the south animals were biased towards females. If there are differences in dispersal patterns including differences between males and females in various habitats within Alaska, it may help explain the significant differences between the central and south areas. Increasing sample sizes in Southeast would most likely improve resolution of population structure in this area.

We also need to test the hypothesis whether seals from British Columbia and Southeast are closely related on a finer scale. Burg (1996) found significant structure between harbor seals from southern British Columbia and northern B.C./SE Alaska using mtDNA and microsatellite techniques. It is important to clarify the microgeographic structure throughout these international areas. Larger sample sizes are required for a comprehensive analysis of geographic structure in this region.

When a species such as harbor seals in Alaska exhibit a clinal pattern in genetic variability, as shown by increasing genetic distance with geographic distance in Fig. 5, it becomes difficult to determine where to draw meaningful, biological boundaries on a map regarding "stocks." Because of this, we found it appropriate to "move" the PBR boundaries in order to detect the highest significant $\Phi_{st}$ value between two areas, having the largest amount of among group variation. The combined gender data ("New" PBRs, Table 5) and the female distance data (Fig. 4) suggest the "best" boundary lies between grouped subpopulations on either side of the lower Cook Inlet area (152°W meridian). Males could not be differentiated between areas, suggesting male-biased dispersal and possibly male-mediated gene flow throughout the Gulf of Alaska. Collectively, animals from Kodiak/lower Cook Inlet were found to be significantly different (10% level) from animals across the Inlet from Kenai to Prince William Sound. Whether this is a valid biological boundary remains questionable (see conclusions and recommendations), although female harbor seals seem to be driving the overall pattern of population subdivision detected in this study.

Interestingly, Bickham *et al.* (1996) found a clear pattern of macrogeographic variation between two populations of Steller sea lions (*Eumetopias jubatus*) using mtDNA sequences - a western population (from the Commander Is, Russia to the Gulf of Alaska-Cape Suckling) and an eastern population (from Southeast Alaska to Oregon). There were no common haplotypes shared throughout the range of this species, and were similar to harbor seals, in that there were many haplotypes of low frequency. Steller sea lions have experienced a similar decline in population abundance in the Gulf of Alaska (Merrick et al. 1987, Loughlin et al. 1990), and reasons for the concurrent declines have not been identified with any certainty (Pitcher 1989, Hoover-Miller 1994).

## Dispersal and gene flow

Genetic differentiation depends on both abundance and the amount of dispersal between populations, and knowledge of dispersal rates is of primary concern in order to effectively manage any population. To demonstrate how effect size depends on abundance, and to address gene flow and dispersal rates (taking mtDNA properties into account), preliminary calculations of the current data were performed based on modification of Wright's (1943) island model (Equation 1)

$$F_{st} = 1 / [(2N_e m) + 1] \qquad (1)$$

where $F_{st}$ is the estimate of population subdivision (analogous to $\Phi_{st}$), and $N_e$ m (estimated gene flow) is the number of effective female migrants exchanged between populations per generation. The overall genetic differentiation detected depends on both population abundance in PBR areas and the amount of annual dispersal between populations. Current population estimates for the three PBR areas are 37,450 (Southeast), 23,504 (Gulf of Alaska), and 13,312 (Bering Sea), for a total abundance estimate of 74,266 animals (Hill *et al.* 1996).

If generation time is assumed to be five years for harbor seals, then the current $\Phi_{st}$ estimates among pairs of the three PBR populations (Table 5, "SRG" PBRs) calculate that 12 females/year disperse between the Bering Sea and the Gulf of Alaska, 2 females/year disperse between the Bering Sea and Southeast, and 6 females/year disperse between the Gulf of Alaska and Southeast. Although two of the three pair-wise $\Phi_{st}$ values rejected the null hypothesis of panmixia at the 5% level, we still would not expect to see a large $\Phi_{st}$ when abundance is large, even with low dispersal rates.

For comparison purposes using the two stock areas defined from this study (Table 5, "NEW" PBRs), the number of female dispersers between the "Bering Sea/lower Cook Inlet" stock and the "Kenai/Southeast" stock" averages 2.5 females/year, or 13 per generation. Genetic drift is of less consequence because of large population sizes, although it is possible that gene flow between these two larger areas may be low enough to promote significant geographic subdivision between them, and drift could become an important force in evolution of distinct populations. These are rather crude estimates of dispersal, as the model (Wright 1943) used here makes some assumptions about populations which generally do not occur in nature (i.e. equal sample sizes, non-overlapping generations). More "realistic" models are currently being developed at the SWFSC regarding dispersal in marine mammal populations.

## CONCLUSIONS AND RECOMMENDATIONS

Several conclusions can be made regarding this study: (1) there were no apparent temporal differences in the genetic composition of harbor seals from the 1970s and 1990s, based on mtDNA sequences from the Gulf of Alaska area, (2) mtDNA differentiation in harbor seals throughout Alaska is clinal, along a coastal continuum from Southeast to Bristol Bay, (3) some microgeographic structure is apparent in several smaller subpopulations (Pribilofs, central and south Southeast), and (4) on a larger geographic PBR scale, significant substructure was found between animals on either side of the lower Cook Inlet: (Bristol Bay, E. Aleutians, S. Alaska Peninsula to lower Cook Inlet) vs. (Kenai, PWS, Icy Bay to south Southeast).

Harbor seals in Russia were different from all other subpopulations, but we failed to detect differences between most Alaskan subpopulations and Japan animals, probably due to lack of statistical power. Both Russia and Japan animals shared at least one haplotype with a Gulf of Alaska animal. These shared haplotypes are probably ancestral, and most likely have persisted in these subpopulations for a long time.

Alaskan animals exhibited a high degree of genetic diversity (98 haplotypes, 192 individuals), typical of larger populations, with rare haplotypes predominating the genetic make-up of the overall population. This could also indicate there may be a question of having enough resolving power to detect discrete populations, especially in areas where seals are more abundant.

More importantly, these analyses have revealed where higher sample sizes are warranted: Pribilof Islands, Kodiak, Prince William Sound, and Southeast Alaska. These areas are of particular interest to management, and increased sample sizes will provide valuable information on estimating the probability distribution for dispersal rates, given the genetic data. This would provide an ideal situation to explore the number of samples needed to detect the level of dispersal required for a stock definition decision regarding Alaskan harbor seals. Samples from Kodiak and Prince William Sound are available at the SWFSC for additional sequencing.

An updated phylogenetic analysis should be conducted using a number of mtDNA sequences from Japan, Russia, and areas throughout Alaska. This would give us more information regarding the existent monophyly of this group with the inclusion of Japan animals, and whether or not a trans-Pacific *Rassenkreis* of these two recognized subspecies truly exists.

Lastly, microsatellite studies have been initiated on harbor seals from Kodiak and Prince William Sound (see O'Corry-Crowe report in this issue) to address differences in allelic variability between these two populations, due to their past population declines. This project will be expanded to parallel the mtDNA study as a second type of molecular marker in determining identification of stocks at the nuclear level, and providing managers with more information regarding dispersal patterns of male and female harbor seals.

## ACKNOWLEDGEMENTS

We thank Kristi Raschen, Clay Reed, A. Sean Costa, and Cristi Lux from SWFSC for helping with the harbor seal mtDNA extractions, and also Andrew Dizon, Barbara Taylor, and Susan Chivers for valuable suggestions regarding data analyses. Many thanks to the Alaska Dept. of Fish and Game (Jon Lewis, Lloyd Lowry, Kathy Frost, Una Swain, Kate Wynne, Vicki Vanek and others), and the National Marine Fisheries Service (Tom Loughlin and Dave Withrow, NMML and Linda Shaw, PRMD) for samples and support concerning this project. Subsistence samples obtained by native hunters were, and continue to be a very important source for this study, and are greatly appreciated. The work performed was under contract Ref. Order No. 43ABNF601182 to R.L.W. by the USDOC/NOAA/NMFS/SWFSC La Jolla laboratory, serving as the basis for her Masters thesis project.

## LITERATURE CITED

Applied BioSystems, Inc. 1992. SeqEd™675 (DNA Sequence Editor), Version 1.0 computer program.

Bickham, J.W., J.C. Patton, and T.R. Loughlin. 1996. High variability for control-region sequences in a marine mammal: implications for conservation and biogeography of steller sea lions (*Eumetopias jubatus*). J. Mamm. 77: 95-108.

Bigg, M. A. 1973. Adaptations in the breeding of the harbour seal *Phoca vitulina*. J. Reprod. Fertil., Suppl. 19:131-142.

Bigg, M. A. 1981. Harbour seal, *Phoca vitulina* Linnaeus, 1758 and *Phoca largha* Pallas, 1811. Pages 1-27 *in* S. H. Ridgway, and R. J. Harrison, eds. Handbook of marine mammals. Vol. 2. Seals. Academic Press, New York.

Brown, W.M., M.George Jr., A.C. Wilson. 1979. Rapid evolution of animal mitochondrial DNA. Proceedings of the National Academy of Sciences of the USA, 76: 1967-1971.

Brown, R. F., and B. R. Mate. 1983. Abundance, movements, and feeding habits of harbor seals, *Phoca vitulina*, at Netarts and Tillamook bays, Oregon. U.S. Natl. Mar. Fish. Serv. Fish. Bull. 81:291-301.

Burg, T.M. 1996. Genetic analysis of eastern Pacific harbour seals *(Phoca vitulina richardsi*) from British Columbia and parts of Alaska using mitochondrial DNA and microsatellites. M.S. thesis, Univ. of British Columbia. 77 pgs.

Burns, J.J., F.H. Fay, and G.A. Fedoseev. 1984. Pages 5-16 *in* F.H. Fay and G.A. Fedoseev, eds. Soviet-American cooperative research on marine mammals. Vol. 1. Pinnipeds. NOAA Tech. Rep. NMFS 12.

Burns, J.J. and V.N. Gol'tsev. 1984. Pages 17-24 *in* F.H. Fay and G.A. Fedoseev, eds. Soviet-American cooperative research on marine mammals. Vol. 1. Pinnipeds. NOAA Tech. Rep. NMFS 12.

Excoffier, L., Smouse, P.E., and J.M. Quattro. 1992. Analysis of molecular variance inferred from metric distances among DNA haplotypes: application to human mitochondrial DNA restriction data. Genetics 131:479-491.

Everitt, R. D. and H. W. Braham. 1980. Aerial survey of Pacific harbor seals in the southeastern Bering Sea. Northwest Sci. 54:281-288.

Frost, K. J., L. F. Lowry, and J. J. Burns. 1982. Distribution of marine mammals in the coastal zone of the Bering Sea during summer and autumn. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 20:365-561.

Frost, K. J., L. F. Lowry, and J. Ver Hoef. 1995. Habitat use, behavior, and monitoring of harbor seals in Prince William Sound, Alaska. *Exxon Valdez* Oil Spill Restoration Project Annual Report. Projects 94064 and 94320-F, Fairbanks, AK. 88 pp.

Hartl, D.L. 1988. A Primer of Population Genetics. Sinauer Assoc., Inc., Sunderland, MA. 305 pp.

Hill, P.S., D.P. DeMaster and R.J. Small. 1996. Draft Alaska Marine Mammal Stock Assessments 1996. National Marine Mammal Laboratory-October 11, 1996. Draft, 129 pp.

Hoelzel, A. R. 1992. Conservation genetics of whales and dolphins. Molec. Ecol. 1:119-125.

Hoelzel, A. R. 1993. Genetic ecology of marine mammals. Symp. zool. Lond. 66:15-32.

Hoover-Miller, A. A. 1994. Harbor seal (*Phoca vitulina*) biology and management in Alaska. Marine Mammal Commission, Washington, D.C., Contract #T75134749. 45 pp.

Kelly, B. P. 1981. Pelage polymorphism in Pacific harbor seals. Can. J. Zool. 59:1212-1219.

Kumar, S., Tamura, K., and M. Nei. 1993. *Molecular Evolutionary Genetics Analysis,* Version 1.01. The Pennsylvania State University, University Park, PA.

Lamont, M.M., J.T. Vida, J.T. Harvey, S. Jeffries, R. Brown, H.H. Huber, R. DeLong, W.K. Thomas. 1996. Genetic substructure of the Pacific harbor seal (*Phoca vitulina richardsi*) off Washington, Oregon, and California. Mar. Mamm. Sci. 12:402-413.

Lehman, N., R. K. Wayne, and B. S. Stewart. 1993. Comparative levels of genetic variability in harbour seals and northern elephant seals as determined by genetic fingerprinting. Symp. Zool. Soc. Lond. 66:49-60.

Loughlin, T. R. 1992. Abundance and distribution of harbor seals (*Phoca vitulina richardsi*) in Bristol Bay, Prince William Sound, and Copper River Delta during 1991. Annual Report for 1991, NMFS, MMPA Popul. Assessment Program. Office of Protected Resouces, NMFS, Silver Spring, MD. 27 pp.

Loughlin, T. R. 1993. Abundance and distribution of harbor seals (*Phoca vitulina richardsi*) in Bristol Bay, Prince William Sound, and Copper River Delta during 1991. Annual Report for 1992, NMFS, MMPA Popul. Assess. Prog. OPR, NMFS, Silver Spring, MD 25 pp.

Loughlin, T. R., A. S. Perlov and V. V. Vladimirov. 1990. Survey of northern sea lions (*Eumetopias jubatus*) in the Gulf of Alaska and Aleutian Islands during June 1989. U.S. Dep. Comm., NOAA Tech Memo. NMFS F/NWC-176. 26 pp.

Lowry, L. F., K. J. Frost, and J. J. Burns 1979. Potential resource competition in the southeastern Bering Sea: fisheries and phocid seals. Pages 287-296 *in* Proc. 29th Alaska Science Conference, Fairbanks.

Maddison, W.P. and D.R. Maddison. 1992. MacClade: *Analysis of phylogeny and character evolution,* Version 3.02 computer software and manual. Sinauer, Sunderland, MA.

Maniatus, T., E. F. Fritsch, and J. Sambrook. 1982. Molecular Cloning (A Laboratory Manual). Cold Spring Harbor Laboratory, Cold Spring Harbor, New York.

Mayr, E. 1963. Animal species and evolution. Harvard University Press, Cambridge, MA.

Merrick, R. L., T. R. Loughlin and D. G. Calkins. 1987. Decline in abundance of the northern sea lion, *Eumetopias jubatus*, in Alaska, 1956-86. Fishery Bulletin, U.S. 85:351-365.

NMFS. 1994. Overview of the 1994 MMPA Amendments. NMFS, MMPA Bull., Sept. 2 pp.

Pitcher, K. W. 1989. Harbor seal trend count surveys in southern Alaska, 1988. Final rep. for contract MM4465853-1. Marine Mammal Commission, Washington, D.C. 15pp. (Natl. Tech. Inf. Serv., PB90-208828.)

O'Corry-Crowe, G.M. and R.L. Westlake. 1997. Molecular investigations of spotted seals *(Phoca largha)* and harbor seals (*P. vitulina*), and their relationship in areas of sympatry. Mar. Mamm. Sci. Spec. Pub. 325-338.

Pitcher, K. W. 1990. Major decline in the number of harbor seals, *Phoca vitulina richardsi*, on Tugidak Island, Gulf of Alaska. Mar. Mamm. Sci. 6: 121-134.

Pitcher, K. W., and D. C. McAllister. 1981. Movements and haulout behavior of radio-tagged harbor seals, *Phoca vitulina.* Can. Field-Nat. 95:292-297.

Rohlf, F.J. 1990. NTSYS-pc. *Numerical taxonomy and multivariate analysis system*, Version 1.6. Exeter Publishing Ltd., Setauket, New York.

Saiki, R.K., Gelfand, D.G., Stoffel, S., Scark, S.J., Higuchi, R., Horn, G., Mullis, K.B., and H.A. Erlich. 1988. *Science* 239:487-491.

Sease, J. L. 1992. Status review: Harbor seals (*Phoca vitulina*) in Alaska. U.S. Dep. Comm., NOAA, NMFS, AFSC, Seattle, WA.

Shaughnessy, P. D., and F. H. Fay. 1977. A review of the taxonomy and nomenclature of North Pacific harbour seals. J. Zool. (Lond.) 182:385-419.

Stanley, H.F., S. Casey, J.M. Carnaham, S. Goodman, J. Harwood and R.K. Wayne. 1996. Worldwide patterns of mitochondrial DNA differentiation in the harbour seal (*Phoca vitulina*). Mol. Biol. Evol. 13:369-382.

Swain, U., J. Lewis, G. Pendleton and K. Pitcher. 1996. Movements, haulout, and diving behavior of harbor seals in Southeast Alaska and Kodiak Island. Pages 58-144 *in* Annual Report: Harbor Seal Investigations in Alaska, NOAA Grant NA57FX0367.

Swofford, D.L. 1993. *Phylogenetic Analysis Using Parsimony,* Version 3.1. computer program distributed by the Illinois Natural History Survey, Champaign, Illinois.

Temte, J.L., M.A. Bigg and O. Wiig. 1991. Clines revisited: the timing of pupping in the harbour seal (*Phoca vitulina*). J. Zool. London 224:616-632.

Winnepenninckx, B., T. Backeljau, and R. De Wachter. 1993. Extraction of high molecular weight DNA from molluscs. Trends in Genetics 12:407.

Wright, S. 1943. Isolation by distance. Genetics 28: 114-138.

Table 1. List of harbor seals sequenced in this study from Southeast Alaska to Japan. Haplotype and ID numbers, age-class/sex, and sample locality are listed for each individual, grouped into 12 subpopulations.

KEY: A=adult,SA=subadult, J=juvenile, P=pup; M=male, F=female, U/?=unknown.

| Haplotyp number | SWFSC Lab Z# | Other Field ID# | Age-class and sex | Location of collection; * harvested | Alaskan subpopulation |
|---|---|---|---|---|---|
| 6 | 4337 | PV94GI02 | AF | Grand Island - | **SOUTH** |
| 28 | 4338 | PV94GI03 | AF | (near Dixon Entrance) | **SOUTHEAST** |
| 30 | 4339 | PV94GI05 | PM | " | N = 25 |
| 22 | 4340 | PV94GI06 | AF | " | |
| 93 | 4341 | PV94GI08 | PF | " | |
| 16 | 4342 | PV94GI09 | PM | " | |
| 28 | 4343 | PV94GI22 | AF | " | |
| 28 | 4344 | PV94GI24 | AF | " | |
| 31 | 4345 | PV94GI27 | AF | " | |
| 31 | 4346 | PV94GI28 | AF | " | |
| 94 | 4347 | PV94GI30 | AF | " | |
| 22 | 4348 | PV94GI31 | AF | " | |
| 14 | 4349 | PV94GIMORT1 | AF | " | |
| 100 | 4852 | PV95RH02 | P | Ketchikan | |
| 101 | 5398 | AF 13836 | M | Tatosh; Ketchikan* | |
| 102 | 5399 | AF 13835 | M | " | |
| 14 | 5400 | AF 13834 | M | " | |
| 103 | 5401 | AF 13838 | F | " | |
| 104 | 5402 | AF 13837 | F | " | |
| 21 | 5403 | AF 13839 | F | Big Salt Lake; Klawock* | |
| 105 | 5404 | AF 13841 | M | " | |
| 106 | 5405 | AF 13840 | F | " | |
| 6 | 5406 | AF 13842 | M | Harmoney Is; Klawock* | |
| 107 | 5407 | AF 13843 | M | " | |
| 108 | 5408 | AF 13859 | M | Palisade Is; Craig* | |
| 27 | 2288 | SE-1 | P F | Gambier Bay | **CENTRAL** |
| 87 | 2290 | SE-3 | A M | Sail Island | **SOUTHEAST** |
| 88 | 2291 | SE-4 | J M | SW Brothers | N = 16 |
| 6 | 2292 | SE-5 | P F | " | |
| 89 | 2295 | SE-8 | P M | " | (all from Frederick |
| 90 | 2296 | SE-9 | A M | " | Sound area) |
| 27 | 2297 | SE-10 | A M | Gambier Bay | |
| 6 | 2301 | SE-14 | J M | " | |
| 23 | 2302 | SE-15 | A M | " | |
| 21 | 2304 | SE-17 | J M | " | |
| 91 | 2305 | SE-18 | A M | " | |
| 26 | 2306 | SE-19 | A F | " | |
| 6 | 2307 | SE-20 | A M | " | |
| 6 | 2574 | SE-1-94 | A M | Price Island | |

Table 1, continued.
KEY: A=adult, SA=subadult, J=juvenile, P=pup; M=male, F=female, U/?=unknown.

| Haplotyp number | SWFSC Lab Z# | Other Field ID# | Age-class and sex | Location of collection; * harvested | Alaskan subpopulation |
|---|---|---|---|---|---|
| **15** | 2575 | SE-2-94 | A F | Price Island | |
| **92** | 2576 | SE-3-94 | A M | " | |
| **95** | 4561 | PV95SE20 | AM | Vixen Island - | **NORTH** |
| **29** | 4562 | PV95SE21 | AF | (Cross Sound) | **SOUTHEAST** |
| **96** | 4563 | PV95SE22 | AM | " | N = 19 |
| **97** | 4564 | PV95SE23 | AM | " | |
| **30** | 4565 | PV95SE24 | J F | " | |
| **27** | 4566 | PV95SE25 | AF | " | |
| **98** | 4567 | PV95SE26 | A M | " | |
| **27** | 4568 | PV95SE27 | AM | " | |
| **99** | 4569 | PV95SE28 | P F | " | |
| **29** | 6432 | PV96SE1 | A M | " | |
| **16** | 6433 | PV96SE2 | A M | " | |
| **29** | 6434 | PV96SE3 | A F | " | |
| **23** | 6439 | PV96SE8 | A F | " | |
| **6** | 6441 | PV96SE10 | SA M | Outer Krugloi | |
| **24** | 6442 | PV96SE11 | A M | " | |
| **14** | 6445 | PV96SE14 | SA F | Vixen Is. | |
| **14** | 6448 | 96SESEmort-1 | SA F | Outer Krugloi | |
| **25** | 6486 | 95061302 | P U | Glacier Bay | |
| **16** | 6487 | 96072503 | A F | " | |
| **27** | 5383 | AF 13844 | M | Disenchanment Bay; | **ICY BAY/YAKUTAT** |
| **85** | 5384 | AF 13845 | F | Yakutat* | E. Gulf of Alaska |
| **20** | 5390 | AF 13851 | M | " | N = 15 |
| **6** | 5391 | AF 13852 | F | " | |
| **86** | 5396 | AF 13857 | F | " | |
| **14** | 5397 | AF 13858 | F | " | |
| **26** | 4313 | YAK-1-76 | AF | Yakutat Bay | |
| **77** | 4314 | YAK-2-76 | AM | " | |
| **17** | 4315 | YAK-3-76 | AF | " | |
| **78** | 4321 | ICE-2-76 | AF | Icy Bay | |
| **6** | 4322 | ICE-4-76 | AF | " | |
| **79** | 4323 | ICE-5-76 | AF | " | |
| **80** | 4324 | ICY-7-76 | AM | " | |
| **22** | 4325 | ICY-10-76 | AM | " | |
| **21** | 4326 | ICY-11-76 | AF | " | |
| **71** | 4255 | PWS-4-75 | SAF | Gull Island, PWS | **KENAI / PRINCE** |
| **6** | 4256 | PWS-29-75 | JM | Herring Bay | **WILLIAM SOUND** |
| **2** | 4258 | PWS-32-75 | AM | Johnston Bay | C. Gulf of Alaska |
| **19** | 4259 | PWS-35-75 | AM | Drier Bay | N = 33 |

Table 1, continued.
KEY: A=adult, SA=subadult, J=juvenile, P=pup; M=male, F=female, U/?=unknown.

| Haplotyp number | SWFSC Lab Z# | Other Field ID# | Age-class and sex | Location of collection; * harvested | Alaskan subpopulation |
|---|---|---|---|---|---|
| 72 | 4261 | PWS-49-75 | AF | Elrington Is | |
| 73 | 4262 | PWS-53-75 | U | Pr of Whale P. | |
| 21 | 4264 | PWS-59-75 | JM | Nassau Fiord | PWS samples |
| 14 | 4268 | PWS-69-75 | SAF | Long Bay | |
| 13 | 4269 | PWS-71-75 | AF | Fairmont Is | |
| 23 | 4270 | PWS-74-75 | JM | Easlik Bay | |
| 6 | 4271 | PWS-75-75 | AF | " | |
| 74 | 4275 | PWS-83-75 | AM | Bald Headed | |
| 15 | 4276 | PWS-85-75 | AF | Olsen Island | |
| 21 | 2275 | PW-1 | A M | Seal Island | |
| 57 | 2276 | PW-2 | SA F | " | |
| 6 | 2277 | PW-3 | A M | " | |
| 18 | 2278 | PW-4 | A M | Applegate Rcks | |
| 24 | 2280 | PW-6 | SA F | Seal Island | |
| 24 | 2282 | PW-8 | SA M | Applegate Rcks | |
| 58 | 2286 | PW-12 | SA M | Seal Island | |
| 22 | 2207 | PWS-21-93 | SA M | " | |
| 55 | 2208 | PWS-22-93 | SA M | " | |
| 17 | 2211 | PWS-25-93 | SA M | " | |
| 23 | 2213 | PWS-27-93 | P F | " | |
| 18 | 2215 | PWS-29-93 | A M | " | |
| 14 | 2216 | PWS-30-93 | SA F | " | |
| 56 | 2218 | PWS-32-93 | A M | Channel Island | |
| 6 | 2219 | PWS-33-93 | SA M | " | |
| 16 | 2220 | PWS-34-93 | SA F | " | |
| 6 | 4293 | KEN-1-77 | AM | Port Chatham | Kenai samples |
| 20 | 4294 | KEN-2-76 | AF | Nuka Is. | |
| 16 | 4295 | KEN-8-77 | AF | Nuka Pass | |
| 16 | 4296 | KEN-11-77 | AF | Nuka Bay | |
| 25 | 4303 | LCI-2-78 | AM | Kamishak Bay, LCI | **KODIAK / LOWER** |
| 6 | 4304 | LCI-9-78 | AF | " | **COOK INLET** |
| 6 | 4306 | LCI-14-78 | AF | " | W. Gulf of Alaska |
| 75 | 4283 | PUL-1-78 | AM | Puale Bay | N = 28 |
| 76 | 4284 | PUL-2-78 | PM | " | |
| 10 | 4228 | KOD-3-76 | JF | Zachar Bay, KOD | Kodiak samples |
| 63 | 4229 | KOD-4-76 | JF | " | |
| 64 | 4231 | KOD-6-76 | AM | Seal Bay | |
| 15 | 4232 | KOD-7-76 | AF | " | |
| 65 | 4234 | KOD-10-76 | AF | Shuyak Island | |
| 66 | 4235 | KOD-11-76 | AM | Big Bay | |
| 6 | 4236 | KOD-12-76 | AM | " | |
| 67 | 4237 | KOD-13-76 | AF | " | |

Table 1, continued.
KEY: A=adult, SA=subadult, J=juvenile, P=pup; M=male, F=female, U/?=unknown.

| Haplotyp number | SWFSC Lab Z# | Other Field ID# | Age-class and sex | Location of collection; * harvested | Alaskan subpopulation |
|---|---|---|---|---|---|
| 68 | 4239 | KOD-15-76 | AM | Foul Bay | Kodiak samples |
| 69 | 4240 | KOD-16-76 | AM | " | |
| 6 | 4241 | KOD-17-76 | AM | Afobnak Bay | |
| 19 | 4243 | KOD-19-76 | AM | Kitoi Bay | |
| 14 | 4253 | KOD-61-76 | AF | Kaguyak Bay | |
| 70 | 4254 | KOD-64-76 | PF | " | |
| 59 | 2308 | KOD-1 | A F | S. Sitkinak | |
| 11 | 2309 | KOD-2 | A F | " | |
| 60 | 2310 | KOD-3 | A F | " | |
| 12 | 2311 | KOD-4 | J F | " | |
| 6 | 2583 | KOD-1-94 | A M | Ugak Bay | |
| 61 | 2584 | KOD-2-94 | A M | " | |
| 10 | 2585 | KOD-3-94 | A M | " | |
| 25 | 2587 | KOD-5-94 | P/J F | " | |
| 62 | 2588 | KOD-6-94 | J F | " | |
| 11 | 4327 | SAN-1-78 | M | Sanak Island | SOUTH ALASKA |
| 81 | 4328 | SAN-2-78 | F | " | PENINSULA |
| 15 | 4329 | SAN-5-78 | SAM | " | W. Gulf of Alaska |
| 10 | 4330 | SAN-10-78 | AF | " | N = 10 |
| 14 | 4331 | SAN-11-78 | AF | " | |
| 82 | 4332 | SHU-1-78 | AF | Ltl. Koniuji, Shumagin Is | |
| 6 | 4333 | SHU-2-78 | AF | " | |
| 6 | 4334 | SHU-3-78 | AF | " | |
| 83 | 4335 | SHU-4-78 | JM | " | |
| 84 | 4336 | SHU-5-78 | AM | " | |
| 47 | 3826 | Aleutian-1 | U | Atka Island* | E. ALEUTIAN |
| 14 | 5608 | AF 13936 | A | Unalaska* | ISLANDS |
| 10 | 6794 | 692-HBSL-005 | F | Amlia / Atka* | W. Gulf of Alaska |
| 9 | 6795 | 692-HBSL-006 | M | " | (N = 11) |
| 10 | 6838 | AF 13950 | F | Atka* | |
| 9 | 6839 | AF 13951 | M | " | (all subsistence |
| 52 | 6840 | AF 13952 | M | " | samples) |
| 5 | 6841 | AF 13953 | F | Akutan* | |
| 13 | 6842 | AF 13954 | F | " | |
| 53 | 6844 | AF 13956 | F | Unalaska* | |
| 54 | 6845 | AF 13957 | M | " | |
| 7 | 2373 | AH-2-85 | M | Pt. Heiden | BRISTOL BAY |
| 40 | 2374 | AH-3-85 | F | " | Bering Sea |
| 7 | 2375 | AH-4-85 | F | " | N = 29 |
| 7 | 2377 | AH-6-85 | A M | Ugashik | |

Table 1, continued.

KEY: A=adult, SA=subadult, J=juvenile, P=pup; M=male, F=female, U/?=unknown.

| Haplotyp number | SWFSC Lab Z# | Other Field ID# | Age-class and sex | Location of collection; * harvested | Alaskan subpopulation |
|---|---|---|---|---|---|
| 7 | 2378 | AH-7-85 | SA? M | Nanvak Bay | Bristol Bay |
| 15 | 2379 | AH-8-85 | SA F | " | |
| 41 | 2380 | AH-9-85 | SA M | " | |
| 42 | 2381 | AH10-85 | M | Pt. Heiden | |
| 14 | 2382 | AH-11-85 | M | " | |
| 43 | 2383 | AH-12-85 | J F | " | |
| 44 | 2384 | AH-13-85 | A? M | " | |
| 14 | 2385 | AH-14-85 | I M | " | |
| 51 | 4839 | DILL-95-01 | U | Cape Pierce | |
| 6 | 6403 | AF 13948 | A F | Togiak | |
| 11 | 5609 | AF 13935 | P F | Nanvak Bay; Cp Pierce* | |
| 14 | 6479 | AF 13946 | U | " | |
| 7 | 6480 | AF 13947 | U | " | |
| 7 | 5984 | AF 13937 | J? M | Lake Iliamna* | |
| 6 | 5986 | AF 13939 | A F | Egegik Bay* | |
| 15 | 5987 | AF 13940 | A F | " | |
| 39 | 2372 | AH-1-85 | SA F | Pt. Moller | |
| 15 | 2386 | AH-15-85 | J M | Nelson Lagoon | |
| 45 | 2387 | AH-16-85 | J M | " | |
| 7 | 2388 | AH-17-85 | J M | " | |
| 46 | 2389 | AH-18-85 | A F | " | |
| 16 | 2390 | AH-19-85 | J F | " | |
| 12 | 2391 | AH-20-85 | A M | " | |
| 15 | 2392 | AH-21-85 | A F | " | |
| 12 | 2393 | AH-22-85 | A M | Amak Island | |
| 8 | 4555 | PV-OI-07-95 | P M | Otter Island | **PRIBILOF ISLANDS** |
| 8 | 4556 | PV-OI-08-95 | P F | " | Bering Sea |
| 48 | 4557 | PV-OI-02-95 | P M | " | N = 6 |
| 49 | 4558 | PV-OI-01-95 | P M | " | |
| 8 | 4559 | PV-OI-03-95 | P F | " | |
| 50 | 4560 | PV-OI-04-95 | P M | " | |
| 5 | 4351 | BI-RV-N2 | U | Bering Island | **RUSSIA** |
| 37 | 4352 | BI-RV-N3 | U | " | N = 16 |
| 3 | 4353 | BI-RV-N4 | U | " | |
| 6 | 4355 | BI-RV-N6 | U | " | (Commander |
| 38 | 4356 | BI-RV-N7 | U | " | Islands) |
| 5 | 4357 | BI-RV-N8 | U | " | |
| 5 | 2797 | Burk-94-N4 | F | Cp Bunyan Reef, BI | |
| 34 | 2801 | Burk-94-N8 | F | Toporkov Is. | |
| 3 | 2803 | Burk-94-N10 | F | " | |
| 35 | 3684 | BI-1 | M | Bering Island | |

Table 1, continued.

KEY: A=adult, SA=subadult, J=juvenile, P=pup; M=male, F=female, U/?=unknown.

| **Haplotyp number** | **SWFSC Lab Z#** | **Other Field ID#** | **Age-class and sex** | **Location of collection; * harvested** | **Subpopulation** |
|---|---|---|---|---|---|
| 3 | 3685 | BI-2 | F | " | Russia |
| 36 | 3718 | AHTYP | P | Medny Island | |
| 5 | 3719 | AHTYP#1 | P | " | |
| 5 | 3720 | AHTYP#2 | P | " | |
| 4 | 3721 | AHTYP#4 | P | " | |
| 4 | 3722 | AHTYP#3 | P | " | |
| 32 | 4979 | Pvs-1 | M | Cape Erimo | **JAPAN** |
| 1 | 4980 | Pvs-81 | F | Cape Nosappu | N = 5 |
| 1 | 4981 | Pvs-83 | M | " | |
| 33 | 4982 | Pvs-84 | M | " | (Northern Japan) |
| 2 | 4983 | Pvs-85 | F | " | |

Table 2. Frequencies of the 31 shared and 77 unique haplotypes of *P. vitulina* from Japan, Russia, and Alaska (N = 213). C/E Gulf of Alaska refers to Kenai through Yakutat.

| | **Japan** | **Russia** | **Bering Sea** | **W. Gulf of Alaska** | **C/E Gulf of Alaska** | **Southeast** | |
|---|---|---|---|---|---|---|---|
| **Haplotype number** | N = 5 | N = 16 | N = 35 | N = 49 | N = 48 | N = 60 | **Total frequency** |
| 1 | 2 | | | | | | 2 |
| 2 | 1 | | | | 1 | | 2 |
| 3 | | 3 | | | | | 3 |
| 4 | | 2 | | | | | 2 |
| 5 | | 5 | | 1 | | | 6 |
| 6 | | 1 | 2 | 7 | 7 | 7 | 24 |
| 7 | | | 7 | | | | 7 |
| 8 | | | 3 | | | | 3 |
| 9 | | | | 2 | | | 2 |
| 10 | | | | 5 | | | 5 |
| 11 | | | 1 | 2 | | | 3 |
| 12 | | | 2 | 1 | | | 3 |
| 13 | | | | 1 | 1 | | 2 |
| 14 | | | 3 | 3 | 3 | 4 | 13 |
| 15 | | | 4 | 2 | 1 | 1 | 8 |
| 16 | | | 1 | | 3 | 3 | 7 |
| 17 | | | | | 2 | | 2 |
| 18 | | | | | 2 | | 2 |
| 19 | | | | 1 | 1 | | 2 |
| 20 | | | | | 2 | | 2 |
| 21 | | | | | 3 | 2 | 5 |
| 22 | | | | | 2 | 2 | 4 |
| 23 | | | | | 2 | 2 | 4 |
| 24 | | | | | 2 | 1 | 3 |
| 25 | | | | 2 | | 1 | 3 |
| 26 | | | | | 1 | 1 | 2 |
| 27 | | | | | 1 | 4 | 5 |
| 28 | | | | | | 3 | 3 |
| 29 | | | | | | 3 | 3 |
| 30 | | | | | | 2 | 2 |
| 31 | | | | | | 2 | 2 |
| **Totals:** | 3 | 11 | 23 | 27 | 34 | 38 | 136 |
| No. of unique haplotypes: | 2 | 5 | 12 | 22 | 14 | 22 | 77 |
| | | | | | | | 213 |

Table 3. Average $\Phi_{st}$ estimates (below diagonal) and p-value significance (above diagonal) among 10 harbor seal subpopulations in Alaska (* denotes significance at the 5% level, ** denotes significance at the 10% level, and ns = not significant). PRIBS = Pribilof Islands, BBAY = Bristol Bay, EALS = eastern Aleutian Islands, SAKP = southern Alaska Peninsula, KOD/LCI = Kodiak to lower Cook Inlet, KEN/PWS = Kenai to Prince William Sound, ICY/YAK = Icy Bay to Yakutat, NSE = north Southeast, CSE = central Southeast, and SSE = south Southeast.

|  | 1 PRIBS | 2 BBAY | 3 EALS | 4 SAKP | 5 KOD/LCI | 6 KEN/PWS | 7 ICY/YAK | 8 NSE | 9 CSE | 10 SSE |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | - | * | ** | ** | * | * | * | * | * | * |
| 2 | 0.11252 | - | ns | ns | ns | ns | ns | ns | ns | * |
| 3 | 0.08044 | -0.02229 | - | ns | ns | ns | ns | ** | ns | * |
| 4 | 0.08468 | -0.01120 | -0.03361 | - | ns | ns | ns | ns | ns | ** |
| 5 | 0.16579 | -0.00207 | -0.00307 | -0.03015 | - | ** | ns | * | ns | * |
| 6 | 0.14081 | 0.01505 | 0.00720 | 0.00247 | 0.02644 | - | ns | ns | ns | ns |
| 7 | 0.14079 | 0.03029 | 0.00904 | -0.01059 | 0.03375 | -0.02254 | - | ns | ns | ns |
| 8 | 0.20935 | 0.03479 | 0.05942 | 0.05640 | 0.06327 | -0.01022 | 0.01509 | - | ns | ns |
| 9 | 0.19831 | 0.00307 | 0.02285 | 0.00331 | -0.02150 | 0.02431 | 0.02895 | 0.04291 | - | * |
| 10 | 0.17851 | 0.07339 | 0.07344 | 0.07652 | 0.10689 | 0.00266 | 0.01020 | -0.00512 | 0.10061 | - |

Table 4. Average $\Phi_{st}$ estimates (below diagonal) and p-value significance (above diagonal) for the current designated PBR areas: 1) Bering Sea (includes Bristol Bay and Pribilofs), 2) Gulf of Alaska (includes Aleutian Islands and eastward to Cape Suckling), and 3) Southeast (includes Cape Suckling to the Southeast AK/Bristish Columbia border. * denotes significance at the 5% level, ns = not significant.

| | Bering Sea | Gulf of Alaska | Southeast |
|---|---|---|---|
| Bering Sea | - | ns | * |
| Gulf of Alaska | 0.0081 | - | * |
| Southeast | 0.0406 | 0.0157 | - |

Table 5. Pairwise comparisons and calculated dispersal and gene flow between various subpopulations of Alaskan harbor seals.

| Population pair | Mean abundance | PHIst estimate | p-value | Female dispersal/yr | Gene flow (per generation) |
|---|---|---|---|---|---|
| **"SRG" PBRs:** | | | | | |
| Bering Sea vs. Gulf of Alaska | 18,408 | 0.0081 | 0.1838 | 12 | 60 |
| Bering Sea vs Southeast | 25,381 | 0.0406 | 0.022* | 2 | 10 |
| Gulf of Alaska vs. Southeast | 30,477 | 0.0157 | 0.046* | 6 | 30 |
| **"NEW" PBRs:**** | | | | | |
| Bering Sea-lower Cook Inlet vs. Kenai-Southeast | 37,133 | 0.038 | 0.003* | 2.5 | 13 |

* denotes significance

** based on this study

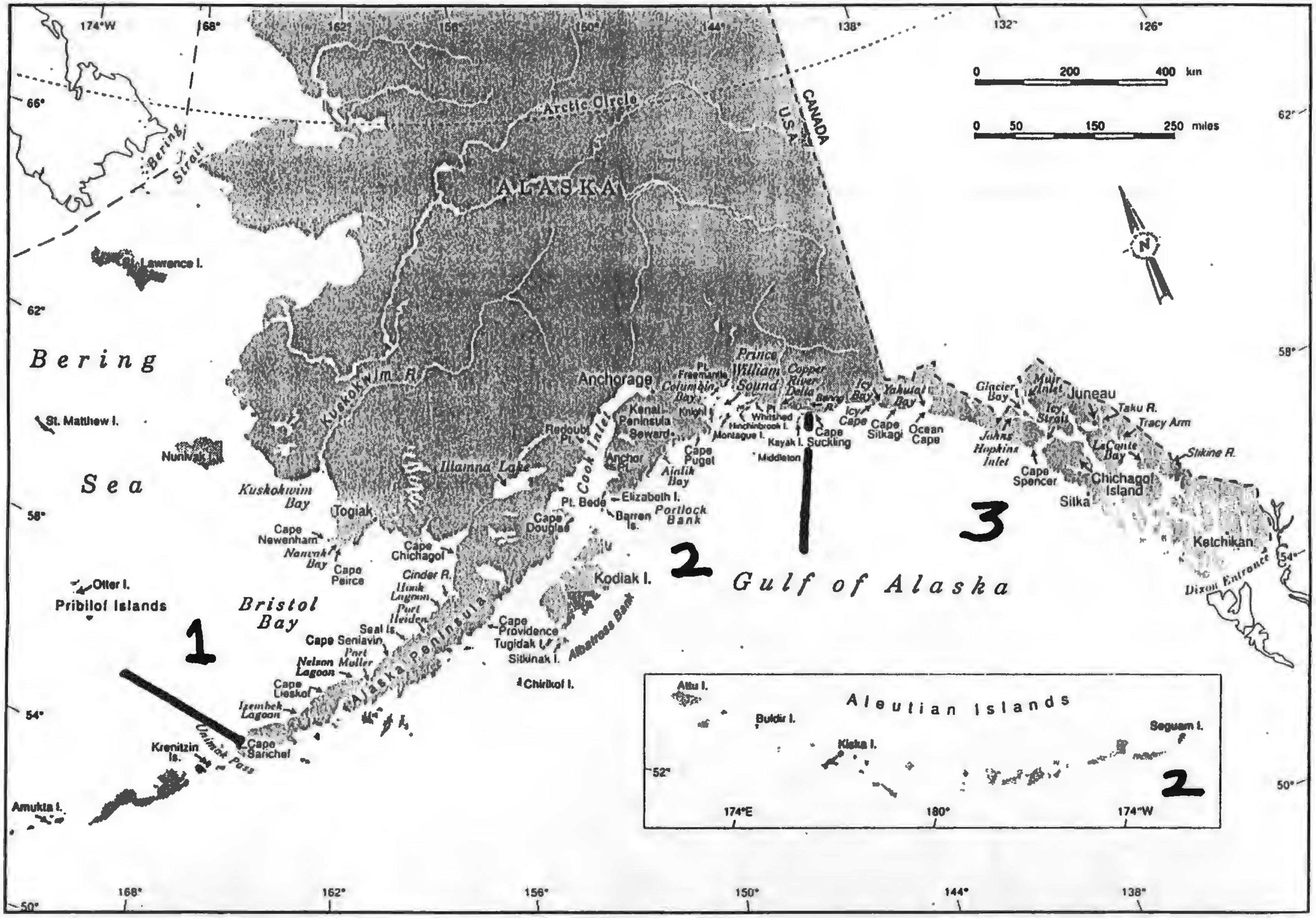


Figure 1. The three designated PBR areas for harbor seals in Alaska: (1) Bering Sea, (2) Gulf of Alaska, and (3) Southeast, Alaska.

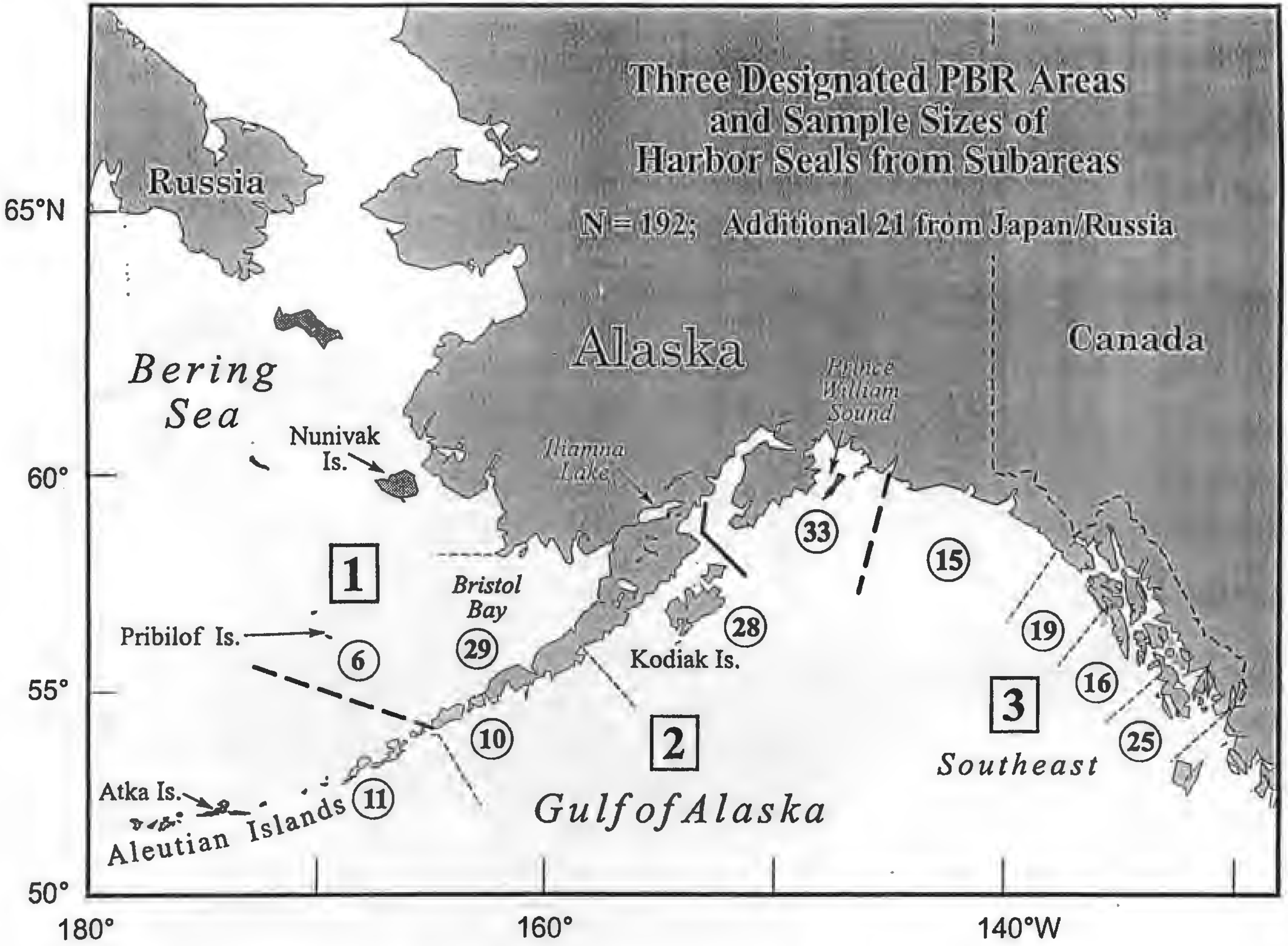


Figure 2. Ten subpopulation areas and sample sizes of Alaskan harbor seals used in this study, within the three designated PBR areas. The solid, bold line indicates "new" boundary from this study, suggesting two stocks for harbor seals.

VARIABLE SITES

```
                    1 1111111112 2222222223 3333333334 4444444445 5555555556 6
           1234567890 1234567890 1234567890 1234567890 1234567890 1234567890 1

HAPLOTYPE
 #1        AGTAGTGCGA CATCGCGTAA TCCTCA-CAG GGGGG-AGCA CGAAGAAA-T GAATG-GCGC C
 #2        .......... ..C....... .......... .......... .......... .......... .
 #3        ........A. ..C..TACG. .....G.... .......... ..G....... .......... .
 #4        G.......A. T....TA... .....G.... ......G.T. T......... .......... .
 #5        ........A. ..C..TACG. .....G.... .......... .......... .......... .
 #6        .......... ..C..T.... .......... .......... .......... .......... .
 #7        .......... ..C..T.... ...C...... .......... .......... .......... .
 #8        ........A. ..C..T.... .T...G.... ........T. .......G.. .......... .
 #9        ..C.A...A. ..C..T.... C....G.... .......... .......... .......... .
 #10       .......... T.C..T.... ...C...... .......... .......... .......... .
 #11       ...G.CA.A. TGCT.TAC.. C.T..G.... .......A.. .........C .......... .
 #12       ........A. ..C..TA... .....G.... .......... .......... .......... .
 #13       ...G..A... T....TAC.. .....G.... .......A.. .........C .......... .
 #14       ......A.A. T.C..TA... .....G.... .......... ........T. ....A..... .
 #15       .......... ..C..T.... .......... ..A....... .......... .......... .
 #16       ......A.A. T.C..TA... ..T..G.... .......... ........T. ....A..... .
 #17       ...G.CA... T....TAC.. .....G.... .......A.. .........C .......... .
 #18       ........A. ..C..T.... .T...G.... A......... .......... .......... .
 #19       .......... ..C..T.... .......... .......... .....G.... .......... .
 #20       ......A.A. T.C..TA... ..T..G.... .......... ...G....T. ....A..... .
 #21       ........A. ..C..T.... .......... .A........ .......... .......... .
 #22       ......A.A. T.C..TA... .....G.... .......A.. ........T. ....A..... .
 #23       ........A. ..C..T.... .......... .......... .......... .......... .
 #24       ......A.A. T.C..TAC.. .....G.... .......... ........T. ....A..... .
 #25       ........A. ..C..T.... .....G.... .......... .......... .......... .
 #26       ......A.A. T.CT.TAC.. ..T..G.... .......... ........T. ....A..... .
 #27       .......... ..CT.T.... .......... .......... .......... .......... .
 #28       ......A.A. T.C..TA... .T..TG.... .......... ........T. ....A..... .
 #29       ......A.A. T.C..TA... .....G.... .......... ........T. ....A..T.. .
 #30       .......... ..C..TA... .......... .......... .......... .......... .
 #31       ..C...A.A. T.C..TA... ...C.G.... .......... ..G.....T. ....A..... T
 #32       ........A. ..CT.T.... .....G.... ....A.GA.. .......... .......... .
 #33       ........A. ..C..T.... .....GG... ....A..A.. .......... .......... .
 #34       .......... ..C..T.... .T.C...... .......... .AG....... .......... .
 #35       ........A. ..C..TACG. .....G.... .......... .......... ......C... .
 #36       ........A. T.C..TACG. .....G.... .......... .......... .......... .
 #37       ..C.....A. ..C..T.... C....G.... .......... .......... .......... .
 #38       ........A. ..C..TAC.. .....G.... .......... .......... .......... .
 #39       ........A. ..C..TA... .....G.... .......... ..G....... .......... .
 #40       .......... ..C..T.... ...C...... .......... .......... ........C. .
 #41       ......A.A. T.CTATA... C....G.T.. .......... ..G.....T. ....A..T.. .
 #42       .T......A. ..C..T.... .T...G.... .......... .......... .......... .
 #43       ........A. ..C..T.... .....G.... .......... ...G...... .......... .
 #44       ........A. ..C..TA... .....G.... .......... .......G.. .......... .
 #45       ......A.A. T.C..TA... ..T..G.... ........T. ..G.....T. ....A..... .
 #46       ........A. T..T.T.... .T...G.... .......... .......... ........C. .
 #47       .......... ..CT.T.... .....G.... ........T. .......... ........C. .
 #48       .......... ..CT.T.... .T.C...... .........G .AG....... .......... .
 #49       ........A. ..C..TACG. .....G.... .....G.... ..G....... .......... .
 #50       ........A. T....TA... .....G.... .......... .......... ....A..... .
 #51       ........A. ..C..TACG. .T...G.... .......... .......... .......... .
 #52       ........A. T....TA... .....G.... .......... .......... .......... .
 #53       .......... ..C..TA... .......... ..A....... .......... .......... .
 #54       .......... ..C..T.... .T.C...... .......... .......... .......... .
 #55       .......... T.CT.T.... ...C...... .......... .......... .......... .
 #56       ..C...A.A. T.C..TA... .....G.... ........T. ........T. ....A...C. .
 #57       ......A.A. T.C..T.... .....G.... .......... ........T. ....A..... .
 #58       ........A. ..C..TA... .....G.... ...A.G.... .......... .......... .
 #59       G.....A.AG T.C.ATAC.. .....G..G. ........T. .........C .......... .
 #60       .......... ..CT.T.... .......... ..A....... .......... .......... .
 #61       ..C...A... ..C..T.... .......... .......... .......... ........C. .
```

```
                              VARIABLE SITES

                   1 1111111112 2222222223 3333333334 4444444445 5555555556 6
          1234567890 1234567890 1234567890 1234567890 1234567890 1234567890 1

HAPLOTYPE
#62       ..C...A... ..C..T.... .......... .....G.A.. .......... .......... .
#63       ......A.A. T.C..TA... ..T..G.... .......... T.G.....T. ....A..... .
#64       ......A.A. T.C..TA... .....G.... .......... ........T. ....A.C.C. .
#65       .....C.... T.C..T.... ...C...... .......... .......... .......... .
#66       ......A.A. ..C..TAC.. .....G.... .......AT. ........T. ....A..... .
#67       ........A. ..C..T.... .......... .......... .......... ........C. .
#68       ........A. ..C..T.... .......... ..A....... .......... .......... .
#69       .......... T.C..T.... ...C.....A .....G.... .......... .......... .
#70       .......... ..C..T.... .......... ......G... .......... .......... .
#71       ...G.C.TAG ..CT.T.... .....G.... ..A.A..A.. T......... ...C...... .
#72       .......... T.C..T.... ...C.....A .......... .......... .......... .
#73       ...G.CA... T....TAC.. .....G.... .....G.A.. .........C .......... .
#74       ......A.A. T.C..TA... CT...G.... .......... ........T. ....A..... .
#75       ..C...A... ..C..T.... .......... .......A.. .......... .......... .
#76       .......... ..C..T.... .......... .AA....... .......... .......... .
#77       .......... .....T.... .......... ..A....... .......... .......... .
#78       ...G.CA.A. T....TAC.. .....G.... ..A....A.. T........C .......... .
#79       ......A.A. T.C..TA... .....G.... .......... ..G.....T. ....A..... .
#80       .......... ..C..T.... .......... .......... .......... ........C. .
#81       ........A. ..C..TA... .....G.... .....G..T. .......... .......... .
#82       .......... ..C..T.... ...C...... ........T. .......... .......... .
#83       ...G..A.A. ..C..TAC.. .....G.... ......GAT. .........C .....G.... .
#84       .....C..A. ..C..T.... .......... .A........ .......... .......... .
#85       .......... ..CT.T.... .......... .AA....... .......... .......... .
#86       ...G.CA.A. .....TAC.. .T...G.... .......A.. .........C .......... .
#87       .......... T.C..T.... .......... .......... .......... A......... .
#88       .......... ..C..T.... .......... .....G.... .......... ........C. .
#89       .......... .....TA... .......... .AA....... .......... .......... .
#90       ......A.A. T.C..T.... .....G.... .......... ........T. ....A....T .
#91       ......A.A. T.C..TAC.. .....G.... .......... ...G....T. ....A..... .
#92       ......A.A. T.C..TA... .....G.... .......... ........T. ....A...C. .
#93       .......... ..CT.T.... .......... .......A.. .......... .......... .
#94       .......... T.C..T.... .......... .......... .......... .......... .
#95       .......... ..CT.T.... .......... .......... .......... ..G....... .
#96       ........A. T.C..TA... .....G.... .......... ........T. ....A..T.. .
#97       .......... ..C..T.... .......... ...A.G.... .......... .......... .
#98       ........A. ..C..T.... .......... .A.....A.. .......... .......... .
#99       .......... ..C..TA... .........A .......... .......... .......... .
#100      .......... ..C..T.... .T........ ..A....... .......... .......... .
#101      ......A.A. T.CT.TAC.. ..T..G.... ........T. ........T. ....A..... .
#102      ........A. ..C..T...G .......... .......... .......... .......... .
#103      ........A. T.C..TA... ..T..G.... .......... ........T. ....A..... .
#104      ...G.CA.A. T....TAC.. .....G.... .......A.. ....A....C .......... .
#105      ........A. T.C..TA... .....G.... ........T. T.......T. ....A..... .
#106      ........A. ..C..T.... .......... .......... .......... .G........ .
#107      ......A.A. T.CT.TAC.. ..T..G.... .......A.. ........T. ....A..... .
#108      .......... .GCT.TA... .......... .......... .......... .......... .
```

Figure 3. Variable sites (61) within mtDNA control region sequences (5' to 3') for *P. v. richardsi/stejnegeri*, showing 108 haplotypes representative of 213 individuals from Alaska, Russia and Japan. There are four insertion/deletion sites (-) and 40 informative sites.

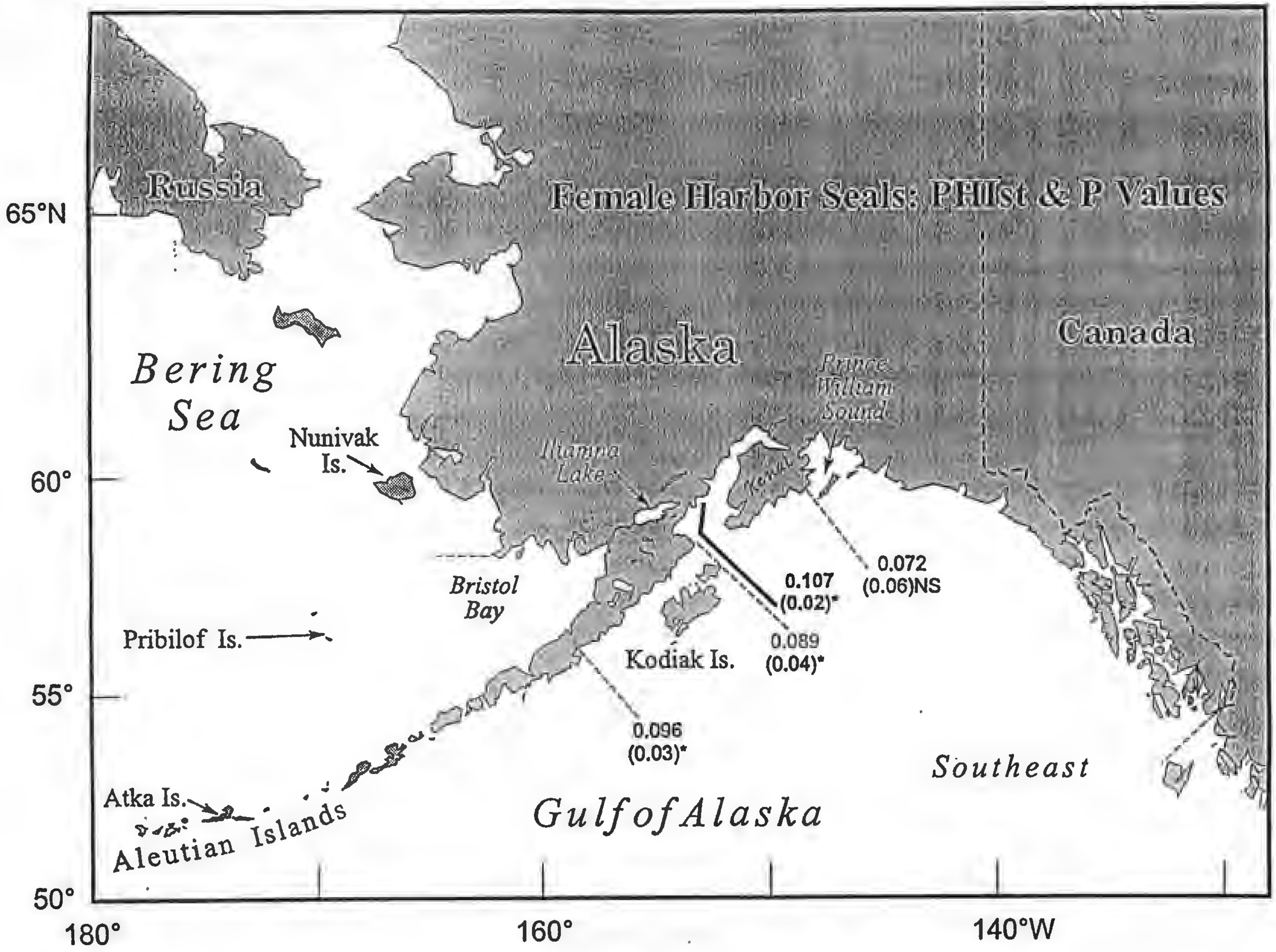


Figure 4. PHIst (upper value) and respective p values (lower) at various "boundaries" between two larger adjacent areas, according to female harbor seal genetic distance data. The highest PHIst value (0.107) occurs when Bristol Bay and E. Aleutian Islands through lower Cook Inlet animals are grouped and tested against animals grouped within Kenai through Southeast Alaska areas.

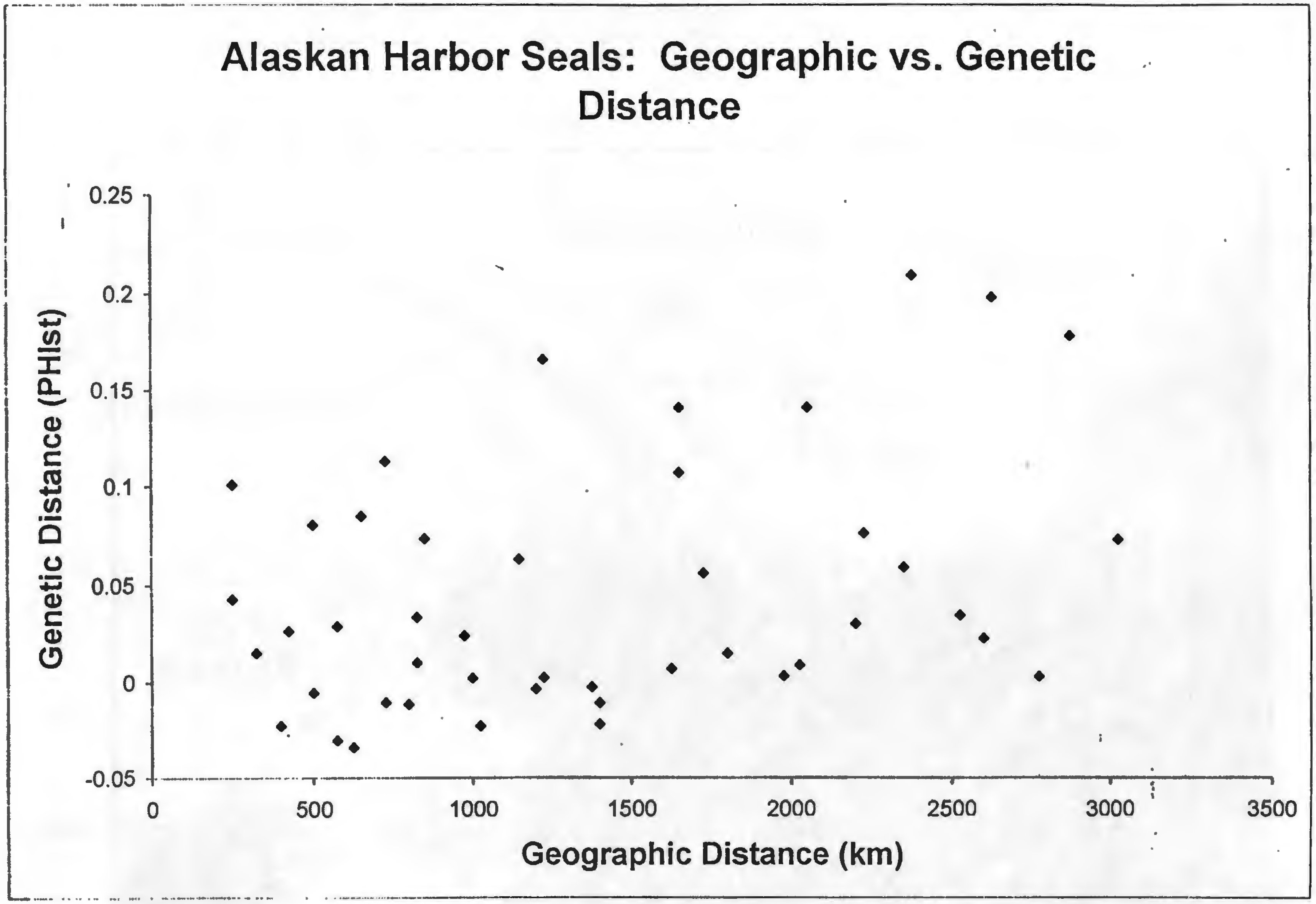


Figure 5. Plot of average genetic distance vs. corresponding geographical distance between 10 harbor seal subpopulations within Alaska. For example, the three highest X:Y values (upper right) correspond to the Pribilof Islands vs. north, central, and south southeast, all being genetically isolated by distance from the Pribilof animals.

# ANALYSIS OF GENETIC AND BEHAVIOURAL DIFFERENCES AMONG HARBOUR SEAL POPULATIONS IN ALASKA USING MICROSATELLITE DNAs: PRELIMINARY FINDINGS

Gregory O'Corry-Crowe

National Marine Fisheries Service, Southwest Fisheries Science Center
8604 La Jolla Shores Dr., La Jolla CA 92038

## INTRODUCTION

Molecular genetic techniques are increasingly being used to investigate intraspecific structure, and, more specifically, to identify genetically discrete populations that can be managed as separate management stocks (Avise, 1994; Dizon *et al.*, 1992). At present a study of variation within the mitochondrial genome (mtDNA) is being conducted to identify separate management units of harbour seals throughout Alaska (Westlake and O'Corry-Crowe, 1996, 1997) where a number of populations have experienced dramatic declines over the past few decades, while others appear to be stable or increasing (Pitcher, 1990; Loughlin, 1993; Hoover-Miller, 1994).

As well as revealing population genetic structure, molecular techniques can be used to investigate the consequences of population decline on spatial and temporal patterns of genetic variation. Rapid population declines can result in the loss of important genetic heterozygosity which may affect individual and population 'fitness' and compromise a population's ability to respond to environmental change (Franklin, 1980; O'Brien and Evermann, 1988). Caution is needed, however, when using estimates of genetic diversity as indices of fitness, as low levels of genetic diversity may be due to natural spatial organization and mating systems instead of severe reductions in population size (Pimm *et al.*, 1989; Caro and Laurenson, 1994). Nevertheless, estimates of diversity at several independent loci may be informative when used in conjunction with detailed ecological data in determining the relative importance of environmental and genetic factors in not only causing population decline, but also in inhibiting population recovery.

Harbour seals have experienced major population declines in a number of regions of Alaska over the past few decades while numbers in other areas of the State appear to be stable or increasing (Pitcher, 1990; Loughlin, 1993; Hoover-Miller, 1994). Several factors, including reduced carrying capacity, fishery-related mortality and pollution have been proposed as possibly causing, or at least contributing to the declines (Pitcher, 1990; Hoover-Miller, 1994). The observed differences in population trends of harbour seals among regions within Alaska may be due in part to differences in the ecology and behaviour of harbour seals within each region. For example, seals in one area may be more philopatric or exhibit more closed mating strategies or grouping patterns than seals in another area. Such differences could determine survival rates and influence productivity and rates of recolonization of depleted areas. Molecular genetic studies can provide important insights into behavioural ecology and demography (Amos, *et al.*, 1995; Avise, 1995; O'Corry-Crowe *et al.*, in press). In particular, such investigations could determine whether aspects of harbour seal biology differ among regions and whether these differences can help explain the differing population trends.

The discovery of microsatellites, a class of highly variable nuclear markers similar to the minisatellites used in DNA fingerprinting, has revolutionized the study of breeding strategies and social organization of natural populations (Bruford & Wayne, 1993; Queller *et al.*, 1993). By combining such studies with an examination of variation within the maternally inherited mtDNA, a more complete understanding of grouping, mating and movement patterns may be achieved (G. O'Corry-Crowe, unpublished data). Furthermore, estimates of genetic diversity from several independent, selectively neutral genetic markers with varying modes of inheritance will give a more representative picture of a population's evolutionary history and potential than would a single genetic system.

### Objectives

1. Develop laboratory protocols to screen for allelic variation at a number of microsatellite loci for harbour seals in Alaska.

2. Screen a set of samples from a number of well studied haulout areas that represent different habitats and experience differing population trends for each variable microsatellite locus to determine whether microsatellite analysis can yield important information on the history and behavioural ecology of harbour seal populations in Alaska that may be used in the design of management policies of predictive value.

## MATERIALS AND METHODS

### Sample collection and DNA extraction

Tissue samples were collected from animals at coastal haulouts during tagging operations and from beachcast animals. Two tissue types have been used to date in this study: liver stored at -80°C and flipper plugs preserved in 20% (v/v) dimethyl sulphoxide (DMSO) saturated with sodium chloride. Total cellular DNA was isolated from both tissue types as follows: 0.2 - 1g of tissue was powdered in liquid nitrogen using a pestle and mortar and the cells lysed overnight with proteinase K in a 0.5% sodium dodecyl sulphate (SDS) solution. Following treatment with RNAase, the DNA was recovered by phenol-chloroform extraction and ethanol precipitation (Sambrook *et al.*, 1989). The concentration and quality of resultant DNA was estimated by spectrophotometry and electrophoresis of an aliquot on 1% agarose gels stained with ethidium bromide.

### Microsatellite analysis

The relevant scientific literature and the GenBank DNA sequence archive on the World Wide Web were searched for microsatellite PCR primers on harbour seals and closely related species. Table 1 lists the eight microsatellite loci tested in this study, the species upon which the loci were screened, and references to the original articles in which they were published. Primer sequences were custom made by GENSET Corp. and the forward primer of each primer pair was labelled with a fluorescent label.

PCRs were carried out on a Perkin Elmer (PE) 9600 thermocycler and amplified product was electrophoresed on 2% NuSieve agarose gels (with 0.5µg/ml EtBr) at 100V in 1XTBE and visualized by exposure to UV light. Approximate fragment size was estimated by comparison to a 100bp DNA ladder (GibcoBRL). Amplification products were prepared for analysis on an Applied Biosystems (ABI) 377 Automated Sequencer with Genescan 672 software according to the ABI 672 protocol. Allelic verification and sizing were completed with the Genescan 672 system software on a Macintosh computer.

Table 1. The eight microsatellite loci tested in this study, the species upon which they were originally typed and the original publications.

| Locus | Species | Publication |
|---|---|---|
| SGPv9 | *P. vitulina* | Allen *et al.*, 1995 |
| Pvc19 | *P. vitulina* | Coltman *et al.*, 1996 |
| Pvc63 | *P. vitulina* | Coltman *et al.*, 1996 |
| Pvc78 | *P. vitulina* | Coltman *et al.* 1996 |
| Hg3.6 | *H. grypus* | Allen *et al.*, 1995 |
| Hg6.1 | *H. grypus* | Allen *et al.*, 1995 |
| Hg8.9 | *H. grypus* | Allen *et al.*, 1995 |
| Hg8.10 | *H. grypus* | Allen *et al.*, 1995 |

## RESULTS

The standard approach to optimization of a primer set for a specific microsatellite locus was to begin with a four-way experiment where both $MgCl_2$ concentration in the PCR buffer and the primer concentration were varied (typically between 1.5mM and 2.0mM for the former and between 10µM and 20µM for the latter, see Fig. 2). The PCR was run at the annealing temperature recommended by the original paper. Four samples were tested for each [$MgCL_2$] - [primer] combination. Amplified products were then visualized on agarose mini-gels.

If we failed to amplify the target locus or if multiple non-specific fragments were amplified as well as the target microsatellite, further optimization was performed. This consisted of a rigorous process of independently varying each element of the PCR reaction, including annealing temperature, template DNA concentration, primer concentration, *Taq* concentration and PCR buffer composition (i.e., [$MgCl_2$]), until a clean, primer-specific product was attained.

Once optimal amplification conditions were achieved, a number of samples from the Kodiak Archipelago and Prince William Sound (Fig. 1) were screened for polymorphism at each locus. These areas were chosen for a number of reasons. Firstly, harbour seals have experienced well-documented population declines in both areas over the past 12 - 20 years (Pitcher, 1990; Frost and Lowry, 1993; Frost *et al.*, 1995). Secondly, a wide range of studies on harbour seals, some ongoing, have been conducted in these two areas, including investigations on diet, movement patterns and haulout behaviour (e.g., Pitcher and McAllister, 1981; Frost *et al.*, 1995). Furthermore a large number of samples collected throughout the period of the most recent declines are available to genetic investigation. Finally, a concurrent study of population structure in harbour seals in Alaska using mitochondrial DNA variation has concentrated on these two areas (Westlake and O'Corry-Crowe, 1996, 1997).

In order to investigate possible temporal changes in genetic composition in seal populations across the period of most dramatic declines, samples collected prior to the documented declines in both areas should be compared with more recently collected samples. In this preliminary study, 10 seals were selected from both locations from the 1970s and from the 1990s, giving a total of 40 seals, and typed for all eight loci. Some samples failed to amplify for several loci and total DNA will be extracted once more from these samples and subjected to microsatellite analysis. Nevertheless, the majority of samples were amplifiable for six or more loci. Between three and eight alleles were recorded per locus. Loci originally typed on harbour seals generally gave cleaner, more consistent products, but a number of grey seal loci were highly variable and potentially highly informative. Following is a description of optimal amplification conditions plus the number and size range of alleles recorded to date for each locus.

## Locus SGPv9

One microlitre of a standard 1:10 DNA extract dilution was amplified in a 25µl hot start PCR (Saiki et al., 1985; Sambrook *et al.*, 1989) using 10µm of fluorescently dye-labelled oligonucleotide primer SGPv 9-F and unlabelled oligonucleotide primer SGPv9-R (Allen *et al.*, 1995), 600µm of each dNTP, 2.5 units *Taq* DNA polymerase (Saiki *et al.*, 1988), and PCR buffer (10mM Tris-HCl, ph 8.3, 50 mM KCl, 1.5mM MgCl2, 0.01% gelatin). Amplifications on the PE 9600 were initiated by a 2 minute (min) denaturation at 95°C, followed by 35 cycles with denaturation at 90°C for 30 seconds, annealing at 50°C for 1 min, and extension at 72°C for 1 min. This was followed by a final extension at 72°C for 5 min and ramp down to 4°C.

| | |
|---|---|
| Number of alleles: | 6 |
| Allele size range (bp): | 160-173 |

## Locus Pvc19

One microlitre of a standard 1:10 DNA extract dilution was amplified in a 25µl hot start PCR (Saiki *et al.*, 1985; Sambrook *et al.*, 1989) using 10µm of fluorescently dye-labelled oligonucleotide primer Pvc19-F and unlabelled oligonucleotide primer Pvc19-R (Coltman et al, 1996), 600µm of each dNTP, 2.5 units *Taq* DNA polymerase (Saiki *et al.*, 1988), and PCR buffer (10mM Tris-HCl, ph 8.3, 50 mM KCl, 1.5mM MgC12, 0.01% gelatin). Amplifications on the PE 9600 were initiated by a 2 minute (min) denaturation at 95°C, followed by 35 cycles with denaturation at 90°C for 30 seconds, annealing at 48°C for 1 min, and extension at 72°C for 1 min. This was followed by a final extension at 72°C for 5 min and ramp down to 4°C.

| | |
|---|---|
| Number of alleles: | 3 |
| Allele size range (bp): | 107-111 |

## Locus Pvc63

One microlitre of a standard 1:10 DNA extract dilution was amplified in a 25µl hot start PCR (Saiki *et al.*, 1985; Sambrook *et al.*, 1989) using 10µm of fluorescently dye-labelled oligonucleotide primer Pvc63-F and un-labelled oligonucleotide primer Pvc63-R (Coltman *et al.*, 1996), 600µm of each dNTP, 2.5 units *Taq* DNA polymerase (Saiki *et al.*, 1988), and PCR buffer (10mM Tris-HCl, ph 8.3, 50 mM KCl, 1.5mM MgC12, 0.01% gelatin). Amplifications on the PE 9600 were initiated by a 2 minute (min) denaturation at 95°C, followed by 35 cycles with denaturation at 90°C for 30 seconds, annealing at 47°C for 1 min, and extension at 72°C for 1 min. This was followed by a final extension at 72°C for 5 min and ramp down to 4°C.

| | |
|---|---|
| Number of alleles: | 3 |
| Allele size range (bp): | 105-109 |

## Locus Pvc78

One microlitre of a standard 1:10 DNA extract dilution was amplified in a 25µl hot start PCR (Saiki eta l., 1985; Sambrook *et al.*, 1989) using 10µm of fluorescently dye-labelled oligonucleotide primer Pvc78-F and unlabelled oligonucleotide primer Pvc78-R (Coltman et al, 1996), 600µm of each dNTP, 2.5 units *Taq* DNA polymerase (Saiki *et al.*, 1988), and PCR buffer (10mM Tris-HCl, ph 8.3, 50 mM KCl, 1.5mM MgC12, 0.01% gelatin). Amplifications on the PE 9600 were initiated by a 2 minute (min) denaturation at 95°C, followed by 35 cycles with denaturation at 90°C for 30 seconds, annealing at 55°C for 1 min, and extension at 72°C for 1 min. This was followed by a final extension at 72°C for 5 min and ramp down to 4°C.

| | |
|---|---|
| Number of alleles: | 4 |
| Allele size range (bp): | 148-156 |

Locus Hg 3.6

One microlitre of a standard 1:10 DNA extract dilution was amplified in a 25µl hot start PCR (Saiki *et al.*, 1985; Sambrook *et al.*, 1989) using 10µm of fluorescently dye-labelled oligonucleotide primer Hg3.6-F and unlabelled oligonucleotide primer Hg3.6-R (Allen *et al.*, 1995), 600µm of each dNTP, 2.5 units *Taq* DNA polymerase (Saiki *et al.*, 1988), and PCR buffer (10mM Tris-HCl, ph 8.3, 50 mM Kcl, 1.5mM MgCl2, 0.01% gelatin). Amplifications on the PE 9600 were initiated by a 2 minute (min) denaturation at 95°C, followed by 35 cycles with denaturation at 90°C for 30 seconds, annealing at 56°C for 1 min, and extension at 72°C for 1 min. This was followed by a final extension at 72°C for 5 min and ramp down to 4°C.

| | |
|---|---|
| Number of alleles: | 8 |
| Allele size range (bp): | 92-108 |

Locus Hg6.1

One microlitre of a standard 1:10 DNA extract dilution was amplified in a 25µl hot start PCR (Saiki *et al.*, 1985; Sambrook *et al.*, 1989) using 10µm of fluorescently dye-labelled oligonucleotide primer Hg6.1-F and unlabelled oligonucleotide primer Hg6.1-R (Allen et al, 1995), 600µm of each dNTP, 2.5 units *Taq* DNA polymerase (Saiki *et al.*, 1988), and PCR buffer (10mM Tris-HCl, ph 8.3, 50 mM KCl, 1.5mM MgCl2, 0.01% gelatin). Amplifications on the PE 9600 were initiated by a 2 minute (min) denaturation at 95°C, followed by 35 cycles with denaturation at 90°C for 30 seconds, annealing at 60°C for 1 min, and extension at 72°C for 1 min. This was followed by a final extension at 72°C for 5 min and ramp down to 4°C.

| | |
|---|---|
| Number of alleles: | (No amplification) |
| Allele size range (bp): | - |

Locus Hg8.9

One microlitre of a standard 1:10 DNA extract dilution was amplified in a 25µl hot start PCR (Saiki *et al.*, 1985; Sambrook *et al.*, 1989) using 10µm of fluorescently dye-labelled oligonucleotide primer Hg8.9-F and unlabelled oligonucleotide primer Hg8.9-R (Allen *et al.*, 1995), 600µm of each dNTP, 2.5 units *Taq* DNA polymerase (Saiki *et al.*, 1988), and PCR buffer (10mM Tris-HCl, ph 8.3, 50 mM KCl, 1.5mM MgCl2, 0.01% gelatin). Amplifications on the PE 9600 were initiated by a 2 minute (min) denaturation at 95°C, followed by 35 cycles with denaturation at 90°C for 30 seconds, annealing at 50°C for 1 min, and extension at 72°C for 1 min. This was followed by a final extension at 72°C for 5 min and ramp down to 4°C.

| | |
|---|---|
| Number of alleles: | 3 |
| Allele size range (bp): | 189-203 |

Locus Hg8.10

One microlitre of a standard 1:10 DNA extract dilution was amplified in a 25µl hot start PCR (Saiki eta l., 1985; Sambrook *et al.*, 1989) using 10µm of fluorescently dye-labelled oligonucleotide primer Hg8.10-F and unlabelled oligonucleotide primer Hg8.10-R (Allen *et al.*, 1995), 600µm of each dNTP, 2.5 units *Taq* DNA polymerase (Saiki *et al.*, 1988), and PCR buffer (10mM Tris-HCl, ph 8.3, 50 mM KCl, 1.5mM MgCl2, 0.01% gelatin). Amplifications on the PE 9600 were initiated by a 2 minute (min) denaturation at 95°C, followed by 35 cycles with denaturation at 90°C for 30 seconds, annealing at 55°C for 1 min, and extension at 72°C for 1 min. This was followed by a final extension at 72°C for 5 min and ramp down to 4°C.

Number of alleles: 3
Allele size range (bp): 183-187

## DISCUSSION

The initial aim of this project was to test 5 microsatellite loci on a small number of harbour seals from two or more distinct areas in Alaska and conduct some preliminary data analysis. Our experience with the application of variation at microsatellite loci to studies on the molecular ecology of marine mammals over the past few years, however, has convinced us that initial efforts are better spent screening/optimizing a large number of loci. We thus decided to focus on screening a larger number of loci (i.e., 8) across a greater number of individuals (i.e., 40). We believe this has given us a better understanding of: (1) which loci are the most appropriate markers for particular questions, and (2) what level of variability exists within each locus.

A number of studies have found that primer sets initially designed on one species may be used on a wide range of closely related species because the priming sites are highly conserved (Schlötterer *et al.*, 1991; Allen *et al.*, 1995; Coltman *et al.*, 1996; Engel *et al.*, 1996). Recent molecular genetic investigation suggests that the grey seal may be a member of the same genus (*Phoca*) as harbour seals (Árnason *et al.*, 1995; O'Corry-Crowe and Westlake, 1997). Therefore, we tested four primer sets originally typed on grey seals (Allen *et al.*, 1995). Three out of the four consistently amplified and were polymorphic.

The wide range of variability recorded within the seven amplifiable loci to date may reflect differing ages and rates of evolution. Whatever the proximate causes, the differeing levels of polymorphism suggest that a range of population and behavioural genetic questions can be addressed using these markers. For example, loci with low levels of variability (e.g. Pvc19) may evolve at a slow enough rate to resolve ancient divisions among populations or sub-species but would not be variable, and therefore informative enough in assessing relatedness of kin. Conversely, a highly variable locus (e.g., Hg3.6) when used in conjunction with other equally variable loci may resolve questions of kinship, paternity and local dispersal but may be too variable and 'noisy' (i.e., homoplasy) to resolve population structure or deeper divergences.

## FUTURE RESEARCH

This report covers the first step in a long-term investigation of the genetic and behavioural differences among harbour seal populations in Alaska. Future research will focus on estimating levels of variability at a number of microsatellite loci in a number of harbour seal populations throughout Alaska, and comparing these data to similar studies on harbour seals elsewhere. We also plan to investigate how movement patterns of harbour seals within distinct regions relate to breeding behaviour and gene flow. At present we are screening more microsatellite loci for polymorphisms and plan to extend our study to include at least one other area. Below is an outline of our research rational and objectives for the following year.

A number of studies have examined variability in both nuclear (isozymes, blood proteins, RAPDs, minisatellites) and cytoplasmic (mtDNA) markers in harbour seals. Swart *et al.* (1996) attributed the lack of variability recorded in 21 isozyme and blood protein systems in harbour seals from the Dutch Wadden Sea and British Wash to genetic bottlenecks during the Pleistocene. They suggested that the lack of heterozygosity may have compromised the immune response of seals in the Wadden Sea where an epidemic caused by the Phocine Distemper Virus (PDV) in 1988 reduced the population by 80%. A study of variation in the DNA itself also revealed low levels of variation in the Dutch Wadden Sea population and a much larger population in Scotland (Kappe *et al.*, 1995). The authors suggested that harbour seals in the North Sea have experienced one or more bottlenecks, and reached similar conclusions as Swart and colleagues about the relationship between genetic variation and susceptibility to PDV (Kappe *et al.*, in press). The limited data available on genetic variation in Pacific harbour seals presents a somewhat more complex picture. An electrophoretic study of three Alaskan populations found no variation at 9 loci (Shaughnessy, 1975). By contrast, high levels of heterozygosity have been recorded at multiple minisatellite loci in Alaskan (Kappe *et al.*, in press), as well as Californian and Washington harbour seal populations (Lehman *et al.*, 1993). Similarly, substantial levels of variation have been recorded within the mtDNA genome in Alaskan populations (Westlake & O'Corry-Crowe, 1996, 1997). Few conclusions have been drawn about the evolutionary, ecological and management implications of any of these findings.

Overall, apart from invoking historical bottlenecks to explain low levels of variability, little consideration has been given to elucidating the factors that influence patterns of genetic variation in harbor seals. Similarly, although the correlation between levels of genetic variation and mortality from PDV is highly suggestive, we understand little about the relevance of genetic variation to harbour seal viability. Estimates of diversity at several independent loci may be informative when used in conjunction with detailed ecological data in determining the relative importance of environmental and genetic factors, in not only causing population decline, but also in inhibiting population recovery.

As mentioned above, the observed differences in population trends of harbour seals among regions in Alaska may be due in part to differences in the ecology and behaviour of harbour seals within each region. Future study will also focus on how movement patterns of harbour seals within distinct regions relate to breeding behaviour and gene flow. Recent satellite-linked telemetry studies of harbour seals in Prince William Sound (PWS), a region where seal numbers have been declining steadily since surveys began in 1984, found that few tagged seals left the Sound during the period they were tracked (Frost *et al.*, 1995). The majority of movements were within 20km of the point of capture, and seals exhibited a high degree of fidelity to a haulout site. Studies on harbour seal movements elsewhere in Alaska and the western U.S. show a similar pattern of strong fidelity to haulout site, with occasional long distance movements (Pitcher and McAllister, 1981; Stewart *et al.*, 1989).

## ACKNOWLEDGEMENTS

Thanks to Lloyd Lowry for helpful advice and suggestions at the inception of this research and for his continuing support. I gratefully acknowledge Robin Westlake, Cristi Lux and Monica DeAngelis for their valued assistance in the lab. Samples were provided by the Alaska Department of Fish and Game and the University of Alaska Museum, Fairbanks.

## LITERATURE CITED

Allen P.J., W. Amos, P.P. Pomeroy, and S.D. Twiss. 1995. Microsatellite variation in grey seals (*Halichoerus grypus*) shows evidence of genetic differentiation between two British breeding colonies. Molecular Ecology, 4: 653-662.

Amos, B., S. Twiss, P. Pomeroy and S. Anderson . 1995. Evidence of mate fidelity in the grey seal. Science, 268: 1897-1899.

Árnason, Ú., K. Bodin, A. Gullberg, C. Ledje, and S. Mouchaty. 1995. A molecular view of pinniped relationships with particular emphasis on the true seals. J. Mol. Evol. 40: 78-85.

Avise, J.C. 1994. Molecular markers, natural history and evolution. Chapman and Hall. New York.

Avise, J.C. 1995. Mitochondrial DNA polymorphism and the connection between genetics and demography of relevance to conservation. Conserv. Biol. 9: 686-690.

Bruford, M. W. And R. K. Wayne. 1993. Microsatellites and their application to population genetic studies. Current Opinion in Genetics and Development, 3: 939-943.

Caro, T.M. and M.K. Laurenson. 1994. Ecological and genetic factors in conservation: a cautionary tale. Science, 263: 485-486.

Coltman, D.W., W.D. Bowen, and J.M. Wright. 1996. PCR primers for harbour seals (*Phoca vitulina concolour*) microsatellites amplify polymorphic loci in other pinniped species. Molecular Ecology, 5: 161-163.

Dizon, A.E., C. Lockyer, W.F. Perrin, D.P. DeMaster and J. Sisson. 1992. Rethinking the stock concept: a phylogeographic approach. Conserv. Biol. 6: 24-36.

Engel, S.R., R.A. Linn, J.F. Taylor, and S.K. Davis. 1996. Conservation of microsatellite loci across species of artiodactyls: implications for population studies. Journal of Mammalogy, 77: 504-518.

Franklin, I.R. 1980. Evolutionary change in small populations. In Conservation Biology: An evolutionary-ecological perspective, M. Soule and B. A Wilcox, Eds. Sinauer, Sunderland, MA. pp.135-149.

Frost, K.J. and L.F. Lowry. 1993. Assessment of injury to harbor seals in Prince William Sound, Alaska, and adjacent areas following the *Exxon Valdez* oil spill. State-federal natural resource Damage Assessment, Marine Mammals Study No.5. 95 pp.

Frost, K.J., L.F. Lowry, and J. Ver Hoef. 1995. Habitat use, behavior and monitoring of harbor seals in Prince William Sound, Alaska, *Exxon Valdez* Oil Spill Restoration Project Annual Report (Restoration Projects 94064 and 94320-F), Alaska Department of Fish and Game, Wildlife Conservation Division, Anchorage, Alaska.

Hoover-Miller, A.A. 1994. Harbor seal (*Phoca vitulina*) biology and management in Alaska. Marine Mammal Commision, Washington, D.C., 45 pp.

Kappe, A.L., L. Van De Zande, E.J. Vedder, R. Bijlsma, and W. Van Delden. 1995. Genetic variation in *Phoca vitulina* (the harbour seal) revealed by DNA fingerprinting and RAPDs. Heredity, 74: 647-653.

Kappe, A.L., R. Bijlsma, A.D.M.E. Osterhaus, W. Van Delden and L. Van De Zande. In press. Structure and amount of genetic variation at minisatellite loci within the subspecies complex of *Phoca vitulina* (the harbour seal). Heredity.

Lehman, N, R.K. Wayne, B.S. Stewart. 1993. Comparitive levels of genetic variability in harbour seals and northern elephant seals as determined by genetic fingerprinting. Symp. Zool. Soc. Lond. 66: 49-60.

Loughlin, T.R. 1993. Abundance and Distribution of harbor seals (*Phoca vitulina richardsi*) in the Gulf of Alaska and Prince William Sound in 1992. Annual rep. for 1992 to the MMPA Assessment Program, Office of Protected Resources, National Marine Fisheries Service, NOAA, Silver Spring, Md. 25pp.

O'Brien, S.J. and J.F. Evermann. 1988 Interactive influence of infectious disease and genetic diversity in natural populations. TREE, 3: 254-259.

O'Corry-Crowe, G.M., and R.L. Westlake. 1997. Molecular investigations of spotted seals (*Phoca largha*) and harbor seals (*P.vitulina*), and their relationship in areas of sympatry. In: Molecular Genetics of Marine Mammals (eds Dizon A.E., Chivers S.J., Perrin W.F.), pp. 325-338. Special Publication Number 3. The Society for Marine Mammalogy.

O'Corry-Crowe, G.M., R.S. Suydam, A. Rosenberg, K.J. Frost, and A.E. Dizon. In press. Phylogeography, population structure, and dispersal patterns of the beluga whale, *Delphinapterus leucas*, in the western Nearctic revealed by mitochondrial DNA. Molecular Ecology, 6..

Pimm, S.L., J. L. Gittleman, G.F. McCracken and M. Gilpin. 1989. Plausible alternatives to bottlenecks to explain reduced genetic diversity. TREE, 4: 176-177.

Pitcher, K.W. 1990. Major decline in number of harbor seals, *Phoca vitulina richardsi*, on Tugidak Island, Gulf of Alaska. Marine Mammal Science, 6: 121-134.

Pitcher, K.W. and D.C. McAllister. 1981. Movements and haulout behavior of radio-tagged harbor seals, *Phoca vitulina*. Canadian Field-Naturalist 95: 292-297.

Queller, D.C., J.E. Strassman and C.R. Hughes. 1993. Microsatellites and kinship. TREE. 8: 285-288.

Sambrook J., E.F. Fritsch, and T. Maniatis. 1989. Molecular Cloning: A laboratory Manual, 2nd Ed., Cold Spring Harbor Laboratory Press.

Saiki, R.K., S. Scharf, F. Faloona, K.B. Mullis, G.T. Horu, H.A. Erlich, and N. Arnheim. 1985. Enzymatic amplification of β-globin genomic sequences and restriction site analysis for diagnosis of sickle cell anemia. Science 230: 1350-1354.

Saiki, R.K., D.G. Gelfand, S. Stoffel, S.J. Scark, R. Higuchi, G. Horn, K.B. Mullis, and H.A. Erlich. 1988. Primer-directed enzymatic amplification of DNA with thermostable DNA polymerase. Science 239: 487-491.

Schlötterer, C., W. Amos, and D. Tautz. 1991. Conservation of polymorphic simple sequence loci in cetacean species. Nature, 354: 63-65.

Shaughnessy, P.D. 1975. Biochemical comparison of the harbour seals *Phoca vitulina richardsi* and *P. v. largha*. Rapp. P.-v. Réun. Cons. Int. Explor. Mer, 169: 70-73

Stewart, B.S., S. Leatherwood, P.K. Yochem, and M.-P. Heide-Jørgensen. 1989. Harbor seal tracking and telemetry by satellite. Marine Mammal Science, 5: 361-375.

Swart, J.A.A., P.J.H. Reijnders, and W. Van Delden. 1996. Absence of genetic variation in harbor seals (*Phoca vitulina*) in the Dutch Wadden Sea and the British Wash. Conserv. Biol. 10: 289-293.

Westlake, R.L. and G.M. O'Corry-Crowe. 1996. Progress in the genetic definition of Alaskan harbor seal populations using mtDNA techniques. Progress Report, Southwest Fisheries Science Center, P.O. Box 271, La Jolla, CA 92037.

Westlake, R.L. and G.M. O'Corry-Crowe. 1997. Genetic investigation of Alaskan harbor seal stock structure using mtDNA techniques. Final Report, Southwest Fisheries Science Center, P.O. Box 271, La Jolla, CA 92037.

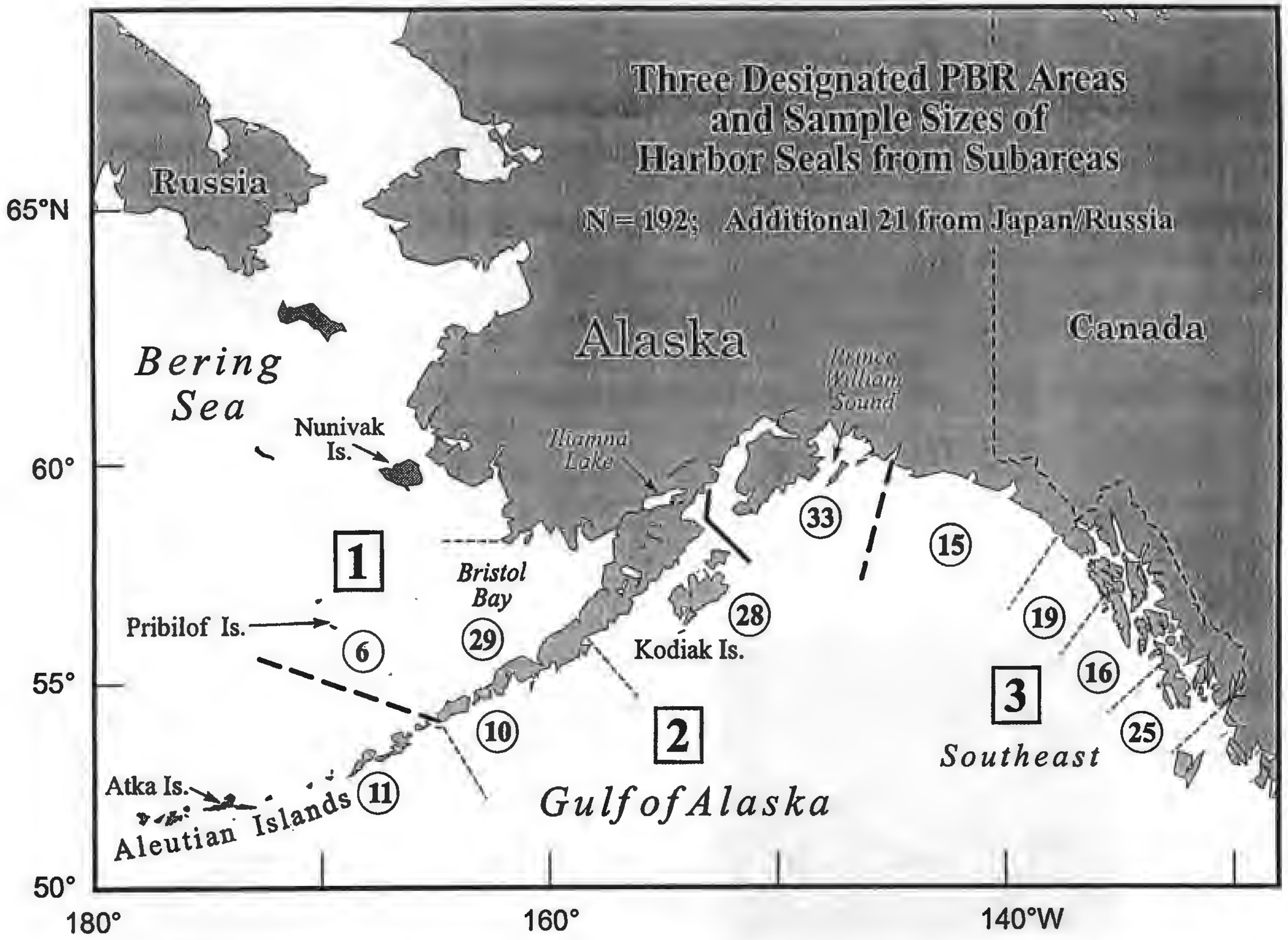


Figure 1. Map of Alaska indicating the 3 currently proposed PBR areas (bold, dashed lines), the "new" boundary suggested by Westlake and O'Corry-Crowe (bold, solid line), and 10 subpopulations showing sample sizes. The microsatellite analysis (this study) will focus on Kodiak and Prince William Sound harbor seals, which are found on either side of the proposed "new" boundary.

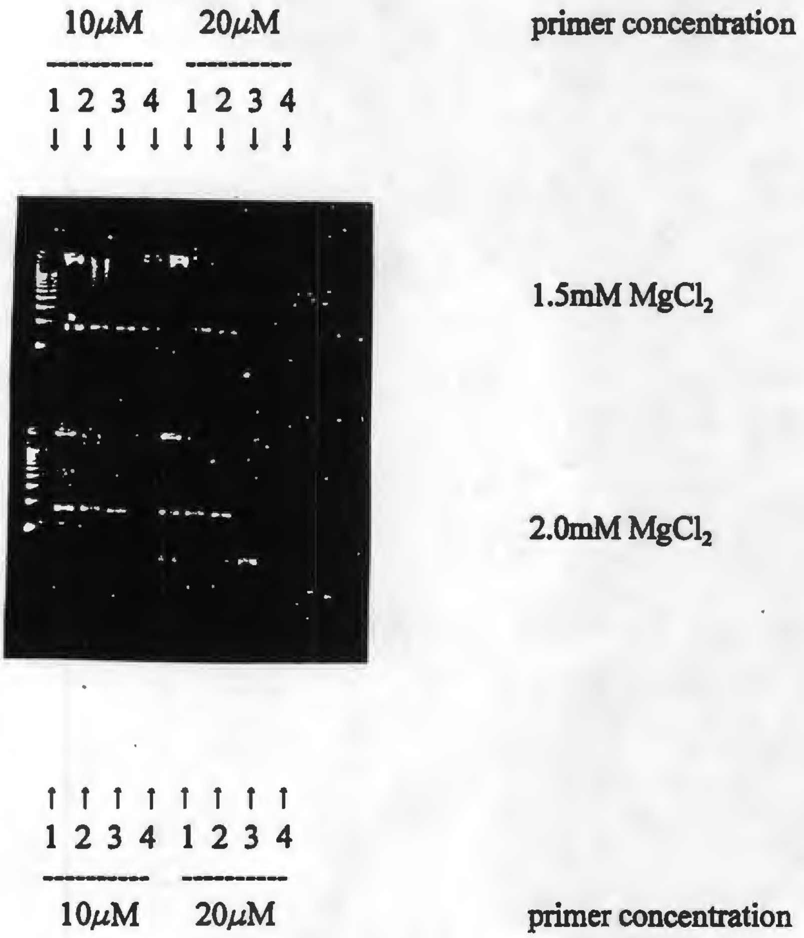


Figure 2. A 1% Agarose gel of PCR optimization for harbor seal microsatellite SGPv9. In this gel four samples were amplified for 10µM and 20µM primer concentration and 1.5mM and 2.0 mM $MgCl_2$ concentration. Tm = 50°C. At least some samples amplified under all four PCR conditions. However, only under conditions: [MgC12] = 1.5 and [primer] = 10µM did all samples amplify.

# CHAPTER FIVE

# PREY UTILIZATION AND TROPHIC STUDIES OF ALASKAN HARBOR SEALS

## OBJECTIVE 8

Provide support to studies by other investigators that will examine the nutritional status, energetic requirements, and food habits of harbor seals

## OBJECTIVE 10 (*Supplemental Proposal*)

Determine prey utilization of harbor seals through identification of fatty acids in blubber samples

## OBJECTIVE 11 (*Supplemental Proposal*)

Determine prey utilization of harbor seals through analyses of scats and stomach contents

# SUMMARY OF DIET DATA COLLECTED FROM HARBOR SEALS IN SOUTHEAST ALASKA, KODIAK ISLAND, AND THE BERING SEA, 1990 – 1996

Gay Sheffield[1], Jon Lewis[2], and Lauri Jemison[2]

[1] Alaska Department of Fish and Game, Division of Wildlife Conservation
1300 College Road, Fairbanks, Alaska 99701

[2] Alaska Department of Fish and Game, Division of Wildlife Conservation
P.O. Box 240020, Douglas, Alaska 99824-0020

## INTRODUCTION

Harbor seals (*Phoca vitulina richardsi*) eat a wide variety of fish and invertebrate prey, their diet varying seasonally, regionally, and probably annually (Imler and Sarber 1947, Fisher 1952, Wilke 1957, Pitcher and Calkins 1979, Pitcher 1980), but data on these variations are largely incomplete (Hoover-Miller 1994). The most recent and comprehensive food habits study in Alaska was conducted from 1973 through 1978 in the Gulf of Alaska where 548 seals were collected, 269 of which had food remains in the stomach (Pitcher 1980). Few historical diet data are available from the Bering Sea and Aleutian Islands regions, and limited information is available from Southeast Alaska.

In the 1990s, a renewed interest in the food habits of harbor seals developed, and collections of both scats and stomachs were initiated. This report describes the date and location of collection and the number of scats and stomachs that have been processed (cleaned and diagnostic parts identified) during the 1990s. The percent occurrence of prey identified from scats and stomachs are summarized by region.

## METHODS

In Southeast Alaska, scats were collected, primarily in the Fredrick Sound and Stephens Passage area, by Alaska Department of Fish and Game (ADFG) biologists in conjunction with harbor seal and sea lion field studies during 1995 and 1996. Biologists from Togiak National Wildlife Refuge collected scats during summer months from 1990 – 1992 at Nanvak Bay in northern Bristol Bay. In the Kodiak region, scats were collected opportunistically during ADFG seal tagging operations in spring and fall of 1995. Scats were put through an elutrification process at the University of British Columbia which separated the skeletal parts from the rest of the feces. The skeletal remains were identified by Pacific Identifications.

Harbor seal stomachs were provided by Native subsistence hunters in cooperation with the biological monitoring program funded by the National Marine Fisheries Service (NMFS) and implemented by the ADFG Subsistence Division. Additional scats and stomachs have been collected but have not yet been processed and thus are not discussed in this report.

Diet data were organized into three geographic regions (Southeast Alaska, Kodiak, and the Bering Sea). For each region, the year, month, sample size, and location of collection are summarized (Table 1). The frequency of occurrence of each prey type was determined for each region. The three or four most frequently occurring prey items in each region were considered top ranked prey. Diet data from stomachs are presented separately from the scat data.

## RESULTS

Two hundred and sixty-two scats and 8 stomachs were processed. A minimum of 32 genera of fish from 14 families, polychaete worms (Polychaeta), and cephalopods (Cephalopoda) were identified as prey (Table 2). Polychaete worms, herring (*Clupea*), smelts (*Osmerus*), pollock (*Theragra*), eelpouts (Zoarchidae), pricklebacks (Stichaeidae), sandlance (*Ammodytes*), sculpins (Cottidae), and flounders (Pleuronectidae) were identified as prey in all three regions (Table 3).

One hundred and twenty-five scats were analyzed from Southeast Alaska. Based on percent occurrence, the top ranked prey identified were pollock (68%), arrowtooth flounder (*Atheresthes*--35%), and herring (25%) (Table 4). The top ranked prey in the stomachs of eight seals from Southeast Alaska were pollock (63%), squid/octopus (Cephalopoda--38%), herring (25%), salmon (*Oncorhynchus*--25%), codfish (*Microgadus*--25%), and sculpins (25%) (Table 5).

Top ranking prey identified from 29 scats from the Kodiak area were similar to scats from Southeast Alaska and included: pollock (66%), arrowtooth flounder (62%), and herring (24%).

One hundred and eight scats collected from the Bering Sea were analyzed. Top ranked prey from these scats were flounders (56%), sandlance (44%), tomcod (*Microgadus*--44%), and smelts (35%). In the Bering Sea scats, herring (19%) and pollock (5%) did not occur frequently.

## DISCUSSION

Results from the Kodiak and Southeast Alaska scat and stomach collections revealed that pollock, herring, and arrowtooth flounder were the most frequently occurring prey items. Pollock was ranked third in importance in 102 stomach samples collected from the Kodiak region during the mid to late 1970s (Pitcher 1980). Herring and arrowtooth flounder were top ranked prey in the 1995/1996 Kodiak samples but both were infrequently identified in the samples from the 1970s. Top ranked prey in the 1970s such as smelt and octopus were low ranked prey items in the recent diet samples. The limited sample sizes and months of collection in 1995 weaken these comparisons.

Results from Southeast Alaska were similar to results from earlier harbor seal stomachs collected in the same region between 1975 and 1977 (n = 43) when the top ranked prey was also pollock (Pitcher 1980, Sheffield 1996). Interestingly, arrowtooth flounder, a low ranked prey in the late 1970s, was a top ranked prey in the 1995/1996 scat and stomach collections.

The top ranked prey items were the same for both Kodiak and Southeast Alaska scat samples (pollock, herring, arrowtooth flounder). Results from the Bering Sea scats were quite different, with pollock and herring infrequently identified as prey items. Unfortunately, few historical diet data exist for harbor seals from this region. Diet data from 3 harbor seal stomachs, however, collected at Nanvak Bay in 1981 (Lowry *et al.* 1982) resembled the 1990-1992 scat results.

Because the majority of these data were from scat contents, the interpretation of these results must take into consideration the unknown effects digestion and/or retention has on the different prey items. The effects of digestion upon different prey types has likely biased the results to an unknown degree. Additional information on prey selection and availability from individual harbor seals is needed to better understand their diet. However, the 1990-1996 diet data provide not only new information with which to describe the diet of seals in Southeast Alaska and Kodiak, but also the first detailed diet information for harbor seals in the Bering Sea.

## ACKNOWLEDGMENTS

A number of people and various agencies were involved in scat and stomach collections. We thank the Native hunters for providing stomach samples for our analyses, and the NMFS and ADFG Subsistence Division for coordinating these efforts. We appreciate the support of the staff at Togiak National Wildlife Refuge (USFWS) for assistance in scat collection, transportation, and storage. Thanks to the seal and sea lion tagging crews in the Kodiak area and Southeast Alaska for their time spent collecting scats. Lloyd Lowry saw the value in the food data and provided a means for it to be summarized. Analysis of data and preparation of this report were supported by the Alaska Department of Fish and Game.

## LITERATURE CITED

Fisher, H. D. 1952. The status of the harbour seal in British Columbia, with particular reference to the Skeena River. Fish. Res. Board Can. Bull. 93. 58pp.

Hoover-Miller, A. 1994. The harbor seal (*Phoca vitulina*) biology and management in Alaska. Marine Mammal Commission, 1825 Connecticut Avenue, NW, Washington, D.C. 20009.(Updated account from Selected Marine Mammals of Alaska: Species accounts with research and management recommendations; Marine Mammal Commission. Washington, D.C.; 1-67; 2nd; Lentfer, J. W.).

Imler, R. H., and H. R. Sarber. 1947. Harbor seals and sea lions in Alaska. U.S. Fish and Wildl. Serv. Spec. Sci. Rep. 28. 22pp.

Lowry, L. F., K. J. Frost, D. G. Calkins, G. L. Swartzman, and S. Hills. 1982. Feeding habits, food requirements, and status of Bering Sea marine mammals. North Pacific Fishery Management Council, Final Report. Contract No. 81-4. 292 pp.

Pitcher, K., 1980. Food of the harbor seal, *Phoca vitulina richardsi*, in the Gulf of Alaska. Fishery Bulletin 78(2):544-549.

Pitcher, K. W., and D. G. Calkins. 1979. Biology of the harbor seal, *Phoca vitulina richardsi*, in the Gulf of Alaska. Final report to OCSEAP, U.S. Department of Interior, BLM. Res. Unit 229 Contract 03-5-002-69. 72pp.

Sheffield, G., 1996. Harbor seal, *Phoca vitulina*, diet data collected in the Gulf of Alaska (1973-1978) by region. Alaska Department of Fish and Game report, Fairbanks, Alaska. 58 pp.

Wilke, F. 1957. Foods of sea otters and harbor seals at Amchitka Island. J. Wildl. Manage. 21:241-242.

Table 1. Year, region, month, sample size, and location of harbor seal scats and stomachs collected between 1990 and 1996.

| Year | Region | Month | N | Location |
|---|---|---|---|---|
| | **SCATS** | | | |
| 1990 | Bering Sea (19) | August | 4 | Nanvak Bay |
| | | September | 15 | Nanvak Bay |
| 1991 | Bering Sea (22) | July | 3 | Nanvak Bay |
| | | August | 19 | Nanvak Bay |
| 1992 | Bering Sea (67) | July | 23 | Nanvak Bay |
| | | August | 35 | Nanvak Bay |
| | | September | 9 | Nanvak Bay |
| 1995 | Kodiak (29) | March | 3 | Uganik Passage |
| | | October | 21 | Kiliuda Bay |
| | | | 5 | Ugak Bay |
| 1995 | Southeast (115) | March | 6 | Pybus Reef |
| | | September | 25 | Price Island |
| | | | 16 | SW Brothers |
| | | | 2 | Inner Krugoloi |
| | | | 2 | Long Bay |
| | | | 1 | Pybus Reef |
| | | | 1 | Vixen Island |
| | | October | 13 | SW Brothers |
| | | December | 26 | Price Island |
| | | | 9 | Circle Point |
| | | | 5 | W. Brothers |
| | | | 4 | Sunset Island |
| | | | 3 | Sail Island |
| | | | 2 | SW Brothers |
| 1996 | Southeast (10) | March | 2 | Price Island |
| | | September | 8 | Price Island |
| | **STOMACHS** | | | |
| 1995 | Southeast (6) | October | 3 | Sitka - Big Rose Island |
| | | | 1 | Sitka - Sergius Narrows |
| | | December | 2 | Sitka - Deep Bay |
| 1996 | Southeast (2) | January | 1 | Sitka - Silver Bay |
| | | | 1 | Sitka - Gavinski Rocks |

Table 2. A taxonomic key to harbor seal prey identified from scats collected in Southeast Alaska, the Bering Sea, and the Kodiak Island region between 1990 - 1996.

| | |
|---|---|
| | **JAWLESS FISH** |
| Class | Agnatha |
| Order | Petromyzontiformes |
| Family | Petromyzontidae |
| Genus | *Lampetra* |
| | **CARTILAGINOUS FISH** |
| Class | Chondrichthyes |
| Order | Rajiformes |
| | **cat sharks** |
| Family | Scyliorhinidae |
| | **skates** |
| Family | Rajidae |
| Genus | *Raja* |
| | **BONY FISH** |
| Class | Osteichthyes |
| Order | Anguilliformes |
| | **wolffish** |
| Family | Xenocongridae |
| Genus | *Anarchias* |
| Order | Clupeiformes |
| | **herring** |
| Family | Clupeidae |
| Genus | *Clupea* |
| Order | Salmoniformes |
| | **trouts** |
| Family | Salmonidae |
| Genus | *Oncorhynchus* |
| | **deep sea smelts** |
| Family | Bathylagidae |
| Genus | *Bathylagus* |
| | **smelts** |
| Family | Osmeridae |
| Genus | *Mallotus* |
| Genus | *Osmerus* |
| Genus | *Thaleichthys* |
| Order | Myctophiformes |
| | **lanternfishes** |
| Family | Myctophidae |
| Order | Gadiformes |
| | **codfishes** |
| Family | Gadidae |
| Genus | *Gadus* |
| Genus | *Microgadus* |
| Genus | *Theragra* |
| Genus | *Merluccius* |
| | **eelpouts** |
| Family | Zoarchidae |
| Order | Perciformes |
| | **sand fishes** |
| Genus | *Trichodon* |
| | **ronquils** |
| Family | Bathymasteridae |
| | **pricklebacks** |
| Family | Stichaeidae |
| | **gunnels** |
| Family | Pholidae |
| | **sand lances** |
| Family | Ammodytidae |
| Genus | *Ammodytes* |
| | **scorpionfishes** |
| Family | Scorpaenidae |
| Genus | *Sebastes* |
| Genus | *Sebastolobus* |
| | **sablefishes** |
| Family | Anoplopomatidae |
| Genus | *Anoplopoma* |
| | **greenlings** |
| | Hexagrammidae |
| Genus | *Hexagrammos* |
| Genus | *Pleurogrammus* |
| | **sculpin** |
| | Cottidae |
| Genus | *Artedius* |
| Genus | *Enophrys* |
| Genus | *Hemilepidotus* |
| Genus | *Myoxocephalus* |
| Genus | *Mallacottus* |
| Genus | *Oligocottus* |
| Genus | *Triglops* |
| | **poachers** |
| Family | Agonidae |
| | **snailfishes** |
| Family | Cyclopteridae |
| Order | Pleuronectiformes |
| | **righteye flounders** |
| Family | Pleuronectidae |
| Genus | *Atheresthes* |
| Genus | *Lepidopsetta* |
| Genus | *Limanda* |
| Genus | *Microstomus* |
| Genus | *Platichthys* |
| Genus | *Pleuronectes* |
| | **INVERTEBRATES** |
| | **worms** |
| Class | Polychaeta |
| | **squid/octopus** |
| Class | Cephalopoda |

Table 3. Harbor seal prey identified in scat from the Bering Sea (n = 108), Southeast Alaska (SE) (n = 125), and Kodiak (n = 29) regions between 1990 and 1996.

| | Bering | SE | Kodiak | | Bering | SE | Kodiak |
|---|---|---|---|---|---|---|---|
| **unid. fish** | X | X | X | **ronquils** | X | | |
| **worms** | X | X | X | **pricklebacks** | X | X | X |
| **octopus/squid** | | X | X | **gunnels** | | | X |
| **lampreys** | | | | **sand lance** | | | |
| *Lampetra* | X | | | *Ammodytes* | X | X | X |
| **sharks** | | | | **scorpionfishes** | | | |
| Scyliorhinidae | | X | | *Sebastes* | X | X | |
| *Raja* | X | X | | *Sebastolobus* | | X | |
| **wolffish** | | | | **sablefishes** | | | |
| *Anarchias* | X | | | *Anoplopoma* | X | | |
| **herring** | | | | **greenlings** | | | |
| *Clupea* | X | X | X | *Hexagrammos* | X | | |
| **salmon** | | | | *Pleurogrammus* | X | | |
| *Oncorhynchus* | X | X | | **sculpins** | X | X | X |
| **smelts** | X | X | X | *Artedius* | X | | X |
| *Bathylagus* | | X | | *Enophrys* | X | X | |
| *Mallotus* | X | | | *Hemilepidotus* | X | X | |
| *Osmerus* | X | | | *Myoxocephalus* | | X | |
| *Thaleichthys* | | X | X | *Oligocottus* | | X | |
| **lantern fish** | | | | *Triglops* | X | X | |
| Myctophidae | | X | | **poachers** | X | | |
| **codfish** | | | | **snailfishes** | X | | |
| Gadidae | X | X | X | **flounders** | X | X | X |
| *Gadus* | X | | | *Atheresthes* | X | X | X |
| *Merluccius* | | | X | *Lepidopsetta* | X | | |
| *Microgadus* | X | X | | *Limanda* | X | | |
| *Theragra* | X | X | X | *Microstomus* | | X | |
| **eelpouts** | X | X | X | *Platichthys* | X | | |
| **sand fish** | X | X | | *Pleuronectes* | X | | |
| *Trichodon* | X | X | | | | | |

Table 4. Percent occurrence of prey identified from harbor seal scats collected in the Southeast Alaska (SE; n = 125), Kodiak (KOD; n = 29), and Bering Sea (BS; n = 108) regions between 1990 and 1996.

| | SE | KOD | BS |
|---|---|---|---|
| *Theragra* | 68 | 66 | 5 |
| *Atheresthes* | 35 | 62 | 6 |
| *Clupea* | 25 | 24 | 19 |
| Gadidae | 13 | 21 | 15 |
| Cephalopoda | 12 | 7 | - |
| *Raja* | 12 | - | 1 |
| Unidentified fish | 6 | 3 | 14 |
| Pleuronectiformes | 6 | 14 | 56 |
| *Microstomus* | 6 | - | - |
| Cottidae | 5 | 7 | 9 |
| *Oncorhynchus* | 4 | - | 6 |
| Scyliorhinidae | 2 | - | - |
| *Bathylagus* | 2 | - | - |
| Osmeridae | 2 | 7 | 6 |
| Myctophidae | 2 | - | - |
| Zoarchidae | 2 | 7 | 6 |
| *Ammodytes* | 2 | 10 | 44 |
| *Sebastolobus* | 2 | - | - |
| *Myoxocephalus* | 2 | - | - |
| Polychaeta | 2 | 3 | 9 |
| *Thaleichthys* | 1 | 3 | - |
| *Microgadus* | 1 | - | 44 |
| Perciformes | 1 | - | 2 |
| *Trichodon* | 1 | - | 6 |
| Stichaeidae | 1 | 3 | 5 |
| *Sebastes* | 1 | - | 1 |
| *Enophrys* | 1 | - | 1 |
| *Hemilepidotus* | 1 | - | 1 |
| *Oligocottus* | 1 | - | - |
| *Triglops* | 1 | - | 1 |
| Pholidae | - | 3 | - |
| *Artedius* | - | 3 | 28 |
| *Merluccius* | - | 3 | - |
| *Osmerus* | - | - | 35 |
| *Hexagrammos* | - | - | 34 |
| *Lepidopsetta* | - | - | 17 |
| *Limanda* | - | - | 11 |
| *Gadus* | - | - | 7 |
| *Lampetra* | - | - | 6 |
| *Platichthys* | - | - | 3 |
| Bathymasteridae | - | - | 2 |
| *Anarchias* | - | - | 1 |
| *Mallotus* | - | - | 1 |
| *Anoplopoma* | - | - | 1 |
| *Pleurogrammus* | - | - | 1 |
| Agonidae | - | - | 1 |
| Cyclopteridae | - | - | 1 |
| *Pleuronectes* | - | - | 1 |

Table 5. Percent occurrence of prey identified from harbor seal stomachs collected in Southeast Alaska in 1995 and 1996.

| Southeast (n = 8) | % |
|---|---|
| *Theragra* | 63 |
| Cephalopoda | 38 |
| *Clupea* | 25 |
| *Oncorhynchus* | 25 |
| *Microgadus* | 25 |
| *Hemilepidotus* | 25 |
| *Sebastes* | 13 |
| Cottidae | 13 |
| *Enophrys* | 13 |

# FATTY ACID SIGNATURES AS INDICATORS OF FORAGING ECOLOGY AND DISTRIBUTION OF HARBOR SEALS IN THE GULF OF ALASKA

Sara J. Iverson[1] and Kathryn J. Frost[2]

[1]Department of Biology, Dalhousie University
Halifax, Nova Scotia B3H 4J1 Canada

[2]Alaska Department of Fish and Game, Division of Wildlife Conservation
1300 College Road, Fairbanks, Alaska 99701

## INTRODUCTION

In many parts of the world pinniped populations have increased as predicted after protection from over-exploitation (e.g., Olesiuk, Bigg & Ellis 1990; Shelton *et al.* 1995). However, large declines in populations of harbor seals (*Phoca vitulina richardsi*), as well as other apex predators such as Steller sea lions (*Eumetopias jubatus*), have been documented in the Gulf of Alaska (Pitcher 1990; Loughlin, Perlov & Vladimirov 1992; Loughlin 1993). Since the late 1970's, large declines (by as much as 90%; Pitcher 1990) have occurred in harbor seals in the Kodiak Archipelago and Prince William Sound (PWS), with only part of the decline in PWS attributable to the 1989 *Exxon Valdez* oil spill (Frost & Lowry 1994). In contrast, harbor seal numbers appear to have remained stable or have increased slightly in areas of Southeast Alaska (SEA). The cause or causes of these decreases are not known. However, a change in the trophic structure of the ecosystem, and hence the availability of prey, is among the hypothesized causes for the observed declines in harbor seals, as well as that of other apex predators. Thus, an understanding of the diet of harbor seals, particularly over time and in areas of stable versus decreasing populations, is needed to begin to evaluate whether food is limiting. In this regard it will be important to assess how individuals may depend on seasonal or area-specific concentrations of prey, and whether differences between juveniles and adults may be indicative of pressures on recruitment.

Methods of stomach content and fecal analysis, which are routinely used to determine diets in free-ranging pinnipeds, are useful tools but suffer from a number of inherent limitations and potential biases which may affect conclusions about the diets of a population (e.g., Jobling & Brieby 1986; Olesiuk 1993; Bowen & Harrison 1996). Rapid passage of food, differential retention of hard parts, extensive degradation of fragile otoliths from certain species, and the ability to evaluate only the last meal consumed near the haul-out site, limit conclusions that can be made. Thus, the use of fatty acid signature analysis (Iverson 1993) has been advanced as an alternative or complementary method to study marine food webs and pinniped diets (Iverson 1995). Fatty acids are the largest constituent of lipids and those of carbon chain length 14 or greater are often deposited in animal tissue with minimal modification from diet. Lipids in the marine food web are exceptionally complex and diverse and, owing to various restrictions and specificities in the biosynthesis and modification of fatty acids among different taxonomic groups (e.g., Paradis & Ackman 1976; Ackman 1980; Cook 1985; Fraser *et al.* 1989), many components appear which can be traced to a general or even specific ecological origin. In seals, ingested fatty acids are often deposited directly into adipose tissue, such that blubber may be a mirror of diet when a seals is rapidly fattening on a high fat diet (Iverson *et al.* 1995), or may reflect an integration of diet over a period of time when not rapidly fattening (Kirsch, Iverson & Bowen 1995). By sampling a core of blubber from a free-ranging seal, one may relatively non-invasively obtain information about diet that is not dependent on prey with hard parts, nor limited to nearshore influences. Similarly, these patterns extend to fish as predators, in that body lipids strongly reflect the influences of their dietary lipids (Kirsch *et al.*, in press). Fatty acids have been used successfully to identify general trophic level of diets and to detect major and minor shifts in diet within populations (Iverson, Arnould & Boyd 1997a; Smith, Iverson & Bowen 1997). In studies conducted in PWS Alaska, fatty acid signatures have also indicated that fine-scale structure of foraging distribution of harbor seals can be discerned, and that this is likely due not only to localized feeding patterns in seals, but also to specific differences in prey species with size and location or habitat within PWS (Iverson, Frost & Lowry 1997b).

The present study was undertaken on harbor seals in the GOA to compliment more extensive studies being conducted in PWS (Frost *et al.* 1997). The goal of the present study was to examine the fatty acid composition of blubber samples collected from harbor seals at Kodiak Island, Yakutat and SEA in 1995 and 1996. Our main objectives were to describe the fatty acid patterns of harbor seals from these areas in GOA, to assess the degree to which diets may differ between juveniles (subadults) and adults, and to evaluate the degree to which diets of seals likely differ among the areas sampled and in comparison to data on harbor seals from PWS in the same years.

## METHODS

### Sample Collection

Blubber samples were collected from harbor seals at Kodiak Island (Uganik Passage), Yakutat (Disenchantment Bay), and in SEA at Sitka, in Peril Straight (Vixen Island and Outer Krugoli Island), and in Stephens Passage (Price Island, Pybus Reef and Sail Island). Blubber samples were collected from a total of 66 harbor seals sampled in 1995 and 1996 by biopsy from live seals caught by entanglement in nets or obtained from Alaska Native subsistence hunters. Additionally, data on age-class and sex were available for most animals sampled. In some cases where age-class was not noted but measurements were available, an equation using body length and mass was used to estimate age-class. A summary of collection data and of the demographic groups sampled is presented in Table 1.

At collection, blubber samples were either stored frozen or first placed in chloroform containing BHT (butylated hydroxytoluene) as an antioxidant at collection and stored frozen (-20°C) until analysis.

### Sample Analysis

Lipid was extracted from harbor seal blubber samples according to the method of Folch, Lees & Sloane-Stanley (1957) with some modifications (Iverson 1988; Smith *et al.* 1997). Fatty acid methyl esters were prepared directly from 100 mg of the pure extracted lipid (filtered and dried over anhydrous sodium sulfate), using 1.5 ml 8% boron trifluoride in methanol (w/w) and 1.5 ml hexane, capped under nitrogen, and heated at 100°C for 1 hour. Fatty acid methyl esters were extracted into hexane, concentrated, and brought up to volume (50 mg/ml) with high purity hexane. This method of transesterification, as employed in our lab with fresh reagents, was routinely tested and found to produce identical results to that using Hilditch reagent (0.5 N $H_2SO_4$ in methanol).

Duplicate analyses of fatty acid methyl esters were performed on samples using temperature-programmed gas liquid chromatography according to Iverson (1988) and Iverson, Sampugna & Oftedal (1992), on a Perkin Elmer Autosystem II Capillary FID gas chromatograph fitted with a 30m x 0.25 mm id. column coated with 50% cyanopropyl polysiloxane (0.25μ film thickness; J&W DB-23; Folsom, CA) and linked to a computerized integration system (Turbochrom 4 software, PE Nelson). Identifications of fatty acids and isomers were determined from the following sources: known standard mixtures (Nu Check Prep., Elysian, MN), silver-nitrate (argentation) chromatography (Iverson 1988), and several secondary external reference standard mixtures composed of natural mixtures of fatty acids from several fish and seal oils which had been identified by chemical degradative and spectroscopic procedures including hydrogenation and GC-mass spectrometry performed in the laboratory of R. G. Ackman (Iverson *et al.* 1997b). Individual fatty acids are expressed as weight percent of total fatty acids after employing mass response factors relative to 18:0. Theoretical relative response factors were used for this purpose, with minor adjustments made after tests with accurate quantitative standard mixtures (Nu Check Prep., Elysian, MN). GC columns were kept in good condition throughout the study by changing septa daily, cleaning the injector liner regularly, and by use of a guard column. All sample chromatograms and identifications were individually checked daily and freshly made quantitative standard mixtures were rerun several times weekly to determine any column deterioration or re-programming of GC necessary. Fatty acids are expressed as weight percent of total fatty acids and are designated by shorthand IUPAC nomenclature of carbon chain length:number of double bonds and location (n-x) of the double bond nearest the terminal methyl group. All data are presented as mean ± SEM, unless otherwise indicated.

### Data analysis and interpretation

Fatty acid data were analyzed using both analysis of variance (ANOVA) and methods of classification and regression trees (CART) in S-plus according to methods described in Iverson *et al.* (1997a) and Smith, *et al.* (1997). In overview, CART uses an algorithm which automatically selects the "best" variable to split data into two named groups ("nodes") that are as different as possible. The deviance of a node is then a measure of the homogeneity of the observations which fall into each side of that node. The CART algorithm begins at the root node by considering all possible ways to split the data, i.e. all variables (fatty acids) and all possible splitting points within each variable, and chooses that split which maximizes the difference at that node. The observations (seals) in that split are then sent down one of two branches. Alternative fatty acids for this split can also be selected based upon similar deviances and dietary importance. This splitting is continued in a tree-like form and occurs until one of two stopping criteria (based on a minimum number of observations in a node or a minimum deviance of a node relative to the root node) is met. Tree growth (splitting) ends at a terminal node where a classification is made and the associated misclassification rate (number of observations not correctly classified in the node) is given. A restriction on CART analyses is that group sizes of less than 4 cannot be classified, thus groups with sample sizes of 3 or less were individually located in the CART analyses or omitted from analyses. Application of the SPLUS software is described in Clark & Pregibon (1992) and Venables & Ripley (1994).

## RESULTS

Approximately 70 fatty acids and isomers were routinely identified in all harbor seal samples (Table 2). Two additional components were formed from the ratio of two sets of important isomers as suggested by Iverson *et al.* (1997b): ratio of 20:1n-11 to 20:1n-9 (R20:1) and ratio of 22:1n-11 to 22:1n-9 (R22:1). Initial CART analysis of all seals (adults, subadults and pups combined) indicated differences in blubber fatty acid patterns among seals from the different areas of GOA (Fig. 1). Using the ratio of 20:1 at the first node, CART correctly identified 89.4% of seals to location using fatty acids. The results of these analyses indicated a relatively large difference between the SEA animals versus those from Kodiak and Yakutat, and within SEA suggested further differences among areas of Stephens Passage (SP), Sitka, and Peril Straight (Fig. 1).

Differences in diet, and thus blubber fatty acid signatures, are likely to occur with age and size in seals, hence demographic groups need to be considered in evaluations of dietary differences with location. Because the fatty acids from pups sampled (n = 4 total) are likely to reflect a combination of fetal biosynthesis and mother's milk, the pups sampled were excluded from further comparisons and analyses. Additionally, three other blubber samples for which the seal's age was unknown, were excluded for the same reason. Even so, when pups and unknown-aged animals were removed, CART analysis (adults and subadults combined) produced a classification tree almost identical to the initial one, further illustrating the differences among locations and with the exact same misclassifications (n = 7; Fig. 2).

To examine demographic effects, although age-classes could be divided into adult males, adult females, and subadults, adult males and adult females were combined since sample sizes among locations were small and predominantly male (Table 1). Variations between groups of seals by location alone were apparent, as well as among demographic groups, in components such as 16:1n-7 and 18:1n-9, which differed substantially (by 10-15 percentage points) between Kodiak and Yakutat animals (Table 2), as well as in indicator fatty acids (generally those starting with 20:1n-11, Table 2). This can be illustrated by using several of the important indicator/dietary fatty acids and ratios among age groups by location across GOA (Fig. 3). Across GOA as a whole, ANOVA revealed significant differences ($P < 0.001$) among locations. Differences were also apparent between adults and subadults, although this could not always be fully tested due to small sample sizes, especially for subadults. In general, patterns of SEA seals (particularly adults) were most different from those of Kodiak and Yakutat seals. Yakutat animals were also unique from all other groups in some selected components. As a group, SEA animals appeared to be relatively similar to one another, both in overall signatures and in the relative pattern of differences between adults and subadults, although minor variations were suggested between locations within SEA (Fig. 3). The differences found between adults and subadults, while generally consistent within SEA, tended to differ in pattern between SEA, Kodiak and Yakutat. For instance, the ratio20:1 and the fatty acid 22:6n-3 were both consistently lower in subadults than in adults in areas of SEA, whereas they were the same or higher in subadults in both Kodiak and Yakutat. In contrast, the ratio22:1 was usually higher in subadults in SEA areas compared to adults, which was similar to Yakutat but opposite to that found in Kodiak (Fig. 3).

CART analyses, with the inclusion of age groups and all locations, produced a tree (Fig. 4), again, nearly identical to the initial classifications defined (Figs. 1, 2), suggesting that despite apparent differences between subadault and adults (Fig. 3), seals still tended to be identified to a location based on their fatty acid signature. Since sample sizes for subadults were generally small (<4, and thus not able to be classified) for individual areas within SEA, all SEA animals were then combined for further analysis. Table 3 presents a summary of these analyses by major GOA region. In the initial tree, the same root node and same value (ratio20:1 at 1.725) was chosen and correctly identified 52 of 56 seals (93%) to their location and age class using the fatty acid signature of blubber. An alternative indicator component, the ratio22:1 was substituted for the root node and with similar accuracy (93%), indicated that the fatty acid composition of harbor seal blubber differed among, and tended to characterize, areas of GOA as well as age groups (Table 3).

Data from harbor seals sampled in GOA could then be compared to animals sampled in PWS (Fig. 5). For this comparison, we used only adult and subadult harbor seals from PWS sampled in the same years (1995 and 1996) and those from the largest area sampled (southcentral PWS). Full data for these PWS animals can be found in Frost *et al.* 1997. CART analysis used the ratio20:1 (at level 2.18) to begin the classification of seals to location based upon fatty acid signature. CART correctly identified 93% of harbor seals to major region (Kodiak, PWS, Yakutat, and SEA) within the GOA (Fig. 5). Characteristics of seal groups for some of the fatty acids at major splits can then be viewed in the form of box plots (Fig. 6). In general, SEA appeared to differ most from the other groups of Kodiak, PWS and Yakutat. However, Yakutat also differed from the other groups in some selected components (Fig. 6, Table 2).

## DISCUSSION

Pinniped species exhibit a diversity of distributional patterns, with some species being highly migratory and generally offshore, while other species, such as the harbor seal being relatively more sedentary and generally remaining nearshore. Recent information gained from satellite telemetry of harbor seals in the GOA and PWS has demonstrated the tendency of this species to exhibit not only site-fidelity but also to remain resident at a single central place throughout much of the year (Frost *et al.* 1996, 1997; Swain *et al.* 1996). Since fatty acid signatures are significantly affected by spatial or temporal heterogeneity in habitats and food webs (Sargent *et al.* 1988; Iverson 1993; St. John & Lund 1996), analyses of fatty acids in harbor seals and their prey should provide an opportunity to conduct complementary studies of the spatial scales of foraging and habitat use (Iverson *et al.* 1997b).

Data from the analysis of fatty acid signatures of harbor seal blubber appear to confirm the findings of central residency and foraging habits (Iverson *et al.* 1997b; Frost *et al.* 1997). Previous data from fatty acid signatures of harbor seals within PWS suggested that seals not only haul out site-specifically, but also forage and feed site-specifically. These conclusions were supported by PWS prey fatty acid patterns, which also differ on similarly small spatial scales and with size and age class (Iverson *et al.* 1997b). The same appears to hold true for harbor seals located across broader regions within the GOA. Unfortunately, at present all conclusions must be drawn from the patterns observed in harbor seals themselves, as information on the prey base and its variability across regions within GOA is currently not available.

On a large geographical scale of 400-800 km, harbor seals differed in fatty acid patterns between areas of the Kodiak Archipelago, Yakutat and SEA (Table 2; Figs. 1-3), suggesting differences in diets between these general areas. Ten of 11 Yakutat animals and 17 of 18 Kodiak animals were clearly distinguished from SEA animals (Fig. 1). Additionally, on finer scale resolutions of areas within SEA, harbor seals differed between areas and could be accurately classified to locations such as Sitka, Peril Straight and Stephens Passage. These differences within SEA may have been confounded somewhat by year influences in that all Peril Straight animals were collected in 1996, while the others were collected mostly in 1995 (Table 1). Likewise, all Yakutat animals were sampled in 1996, whereas Kodiak animals were sampled in both years. Although differences have been suggested between years 1994, 1995 and 1996 within PWS, possibly as a result of changes in prey structure (Frost *et al.* 1997), locations still remained a larger influence on blubber fatty acid differences and this is likely to be the case in SEA. Nevertheless, it will be important in the future to examine samples from all locations within the same year and in relation to available prey.

Our results suggest that seals sampled at a general haulout location had foraged and fed nearby or at least on the same general prey sources, as was found previously for seals within PWS. Misclassifications in the CART trees could represent those seals which were simply more wide-ranging in their foraging patterns or that had more individual feeding habits. These conclusions are supported by data on movements of satellite-tagged seals in GOA. Swain *et al.* (1996) found that harbor seals in the Kodiak archipelago or SEA tended to reside in the immediate vicinity of their initial capture site or made relatively brief round-trip movements. As found for harbor seals in PWS (Frost *et al.* 1997; Iverson et al 1997b), overall findings from fatty acid signature analysis and satellite telemetry suggest that harbor seals in the GOA may depend on a very localized prey base.

Differences in diet, and thus blubber fatty acid signatures, were also apparent with age and size in GOA seals. Adults differed from subadults in most components in most locations (Table 2; Figs. 3, 4). The direction of the differences also appeared to be a location-specific characteristic. Since data on the fatty acid signatures of the prey base is currently unavailable, it is not possible to examine what the differences are specifically attributable to, other than that the diets of subadults do differ from that of adults. The way in which the patterns differed between subadults and adults within the three areas of SEA were all quite similar, and different to that found in the Kodiak and Yakutat animals (Fig. 3). Since the population of harbor seals in SEA appears to be stable or increasing in comparison to the other locations, it would be important to examine the sources of these differences. In pinniped populations, juveniles in particular are thought to be significantly affected by reduced prey availability at relevant scales to the nutrition of individuals (NRC 1996). Thus, there could be several indications about stresses on juveniles through understanding diets. Small forage fish species such as capelin and sandlance have long been an important part of pinniped diets and a decline in these prey species may have affected the seal populations which depend upon them. If a reduction in these prey are apparent in the diets of adult seals in areas of decline, this would suggest a lower abundance of these prey in general. If indeed juveniles are found to be dependent on and limited to smaller size prey, this would coincide with the above finding. If juveniles are feeding on smaller but different prey than the small prey in adult diets, this might indicate competition with large animals for available food and further indication of low abundance of important forage fish species.

Since harbor seals are likely to adjust their foraging patterns to changes in abundance of local prey (Olesiuk 1993; Tollit & Thompson 1996), this suggests that determining diets or changes in diets of harbor seals over time using fatty acid signatures may provide clues not only to changes in foraging patterns, but also to differences in local prey availability, predominant species size classes, and species abundance at the spatial and temporal scales that are essential to the nutrition of individual animals.

## ACKNOWLEDGMENTS

We thank C. Beck, A. Bowen, J. Lassner, J. Marcus, and L. Smith for laboratory assistance. We also thank J. Smith for computing and statistical assistance. Funding was provided by the Alaska Department of Fish and Game and NOAA, as well the *Exxon Valdez* oil spill Trustee Council. This study was also supported in part by a Natural Sciences and Engineering Research Council (NSERC) operating and equipment grant to S.J.I.

## LITERATURE CITED

Ackman, R. G. (1980). Fish lipids, part 1. In "Advances in Fish Science and Technology" (Connell, J. J.,ed.), pp. 86-103. Fishing News Books Ltd., Surrey, England.

Ackman, R. G. (1976). Fish oil composition. In "Objective Methods for Food Evaluation" pp. 103-128. National Academy of Sciences, Washington D.C.

Bowen, W. D., and Harrison, G. D. (1996). Comparison of harbour seal diets in two inshore habitats of Atlantic Canada. Can. J. Zool. 74, 125-135.

Clark, L. A., and Pregibon, D. (1992). Tree-based models. in "Statistical Models in S" (Chambers, J. M.,Hastie, T. J., eds.), pp. 377-419. Wadsworth & Brooks/Cole Advanced Books & Software,

Cook, H. W. (1985). Fatty acid desaturation and chain elongation in eucaryotes. In "Biochemistry of Lipids and Membranes" (Vance, D. E.,Vance, J. E.,eds.), pp. 181-211. The Benjamin/Cummings Publishing Co., Inc., Menlo Park, CA.

Fraser A J, Sargent J R, Gamble J C, Seaton D D (1989) Formation and transfer of fatty acids in an enclosed marine food chain comprising phytoplankton, zooplankton and herring (*Clupea harengus* L.) larvae. Marine Chem 27: 1-18

Folch, J., Lees, M., and Sloane-Stanly, G. H. (1957). A simple method for the isolation and purification of total lipids from animal tissues. J. Biol. Chem. 226, 497-509.

Frost K J, Lowry L F (1994) Assessment of injury to harbor seals in Prince William Sound, Alaska, and adjacent areas following the *Exxon Valdez* oil spill. Final Rep. Marine Mammal Study No. 5, State-Federal Resource Damage Assessment, 154 p.

Frost K J, Lowry L F, Small R J, Iverson S J (1996) Monitoring habitat use and trophic interactions of harbor seals in Prince William Sound, Alaska. *Exxon Valdez* Oil Spill Restoration Project Annual Report (Restoration Projects 95064), Alaska Deptartment of Fish and Game, Division of Wildlife Conservation, Fairbanks.

Frost K J, Lowry L F, Small R J, Iverson S J (1997) Monitoring habitat use and trophic interactions of harbor seals in Prince William Sound, Alaska. *Exxon Valdez* Oil Spill Restoration Project Annual Report (Restoration Projects 96064), Alaska Deptartment of Fish and Game, Division of Wildlife Conservation, Fairbanks.

Iverson, S. J. (1988). "Composition, Intake and Gastric Digestion of Milk Lipids in Pinnipeds." Ph.D. Thesis. Univ. of Maryland, College Park.

Iverson, S. J. (1993). Milk secretion in marine mammals in relation to foraging: Can milk fatty acids predict diet? Symp. Zool. Soc. Lond. 66, 263-291.

Iverson, S. (1995). Principles of fatty acid signature analysis and its use in studying foraging ecology and diets of marine mammals. ICES/NAFO Symp., Role of Marine Mammals in the Ecosystem Halifax, 1995.

Iverson, S. J., Arnould, J. P. Y., and Boyd, I. L. (1997a). Milk fatty acid signatures indicate both major and minor shifts in the foraging ecology of lactating fur seals. Can. J. Zool. 75:188-197.

Iverson S J, Frost, K J, Lowry, L F (1997b) Fatty acids signatures reveal fine scale structure of foraging distribution of harbor seals and their prey in Prince William Sound, Alaska. Mar Ecol Prog Ser 151: 255-271.

Iverson, S. J., Oftedal, O. T., Bowen, W. D., Boness, D. J., and Sampugna, J. (1995). Prenatal and postnatal transfer of fatty acids from mother to pup in the hooded seal (*Cystophora cristata*). J. Comp. Physiol. 165, 1-12.

Iverson, S. J., Sampugna, J., and Oftedal, O. T. (1992). Positional specificity of gastric hydrolysis of long-chain n-3 polyunsaturated fatty acids of seal milk triglycerides. Lipids 27, 870-878.

Jobling, M., and Brieby, A. (1986). The use and abuse of fish otoliths in studies of feeding habits of marine piscivores. Sarsia 71, 265-274.

Kirsch, P. E., Iverson, S. J., and Bowen, W. D. (1995). Diet composition based on fatty acid signatures: captive feeding experiments on harp seals and grey seals. Abstr., Eleventh Bien. Conf. Biol. Mar. Mamm. p. 62.

Kirsch, P. E., Iverson, S. J., Bowen, W. D., Kerr, S. R. and Ackman, R. G. (in press) Dietary effects on the fatty acid signature of whole Atlantic cod (*Gadus morhua*). Can. J. Fish. Aquat. Sci.

Loughlin T R. 1993. Abundance and distribution of harbor seals (*Phoca vitulina richardsi*) in the Gulf of Alaska and Prince William Sound in 1992. Annual rep. for 1992 to the MMPA Assessment Program, Office of Protected Resources, National Marine Fisheries Service, NOAA, Silver Spring, MD. 25pp.

Loughlin T R, Perlov A S, Vladimirov VA (1992) Range-wide survey and estimation of total numbers of Steller sea lions in 1989. Mar Mamm Sci 8: 220-239.

NRC (National Research Council) (1996) The Bering Sea Ecosystem. Committee on the Bering Sea, National Academic Press, Washington, DC

Olesiuk, P. F. (1993). Annual prey consumption by harbor seals (*Phoca vitulina*) in the Straight of Georgia, British Columbia. Fishery Bulletin 91, 491-515.

Olesiuk P F, Bigg M A, Ellis G M (1990) Recent trends in the abundance of harbour seals, *Phoca vitulina*, in British Columbia. Can J Fish Aquatic Sci 47: 992-1003

Paradis, M., and Ackman, R. G. (1976). Localization of a source of marine odd chain length fatty acids. I. The amphipod Pontoporeia femorata (Kroyer). Lipids 11, 863-870.

Pitcher K W (1990) Major decline in number of harbor seals, *Phoca vitulina richardsi*, on Tugidak Island, Gulf of Alaska. Mar Mamm Sci 6: 121-134

Sargent J R, Parkes R J, Mueller-Harvey I, Henderson R J (1988) Lipid biomarkers in marine ecology. In: Sleigh M A (ed.) Microbes in the sea. Ellis Horwood, Ltd., Chichester, U.K., p 119-138

Shelton P A, Stenson G B, Sjare B, Warren W G (1995) Model estimates of harp seal numbers at age for the northwest Atlantic. DFO Atlantic Fisheries Res. Doc. 95/21

Smith, S. J., Iverson, S. J., and Bowen, W. D. (1997). Fatty acid signatures and classification tress: new tools for investigating the foraging ecology of seals. Can. J. Fish. Aquat. Sci.

St. John M A, Lund T (1996) Lipid biomarkers: linking the utilization of frontal plankton biomass to enhanced condition of juvenile North Sea cod. Mar Ecol Prog Ser 131: 75-85

Swain U, Lewis J, Pendleton G, Pitcher K (1996) Movements, haulout, and diving behavior of harbor seals in Southeast Alaska and Kodiak Island. *In* Lewis J P *et al.* (compiler) Harbor Seal Investigations in Alaska Annual Report.. NOAA Grant NA57FX0367.

Tollitt D J, Thompson P M (1996) Seasonal and between-year variations in the diet of harbour seals in the Moray Firth, Scotland. Can J Zool 74: 1110-1121

Venables, W., and Ripley, B. (1994). "Modern Applied Statistics with S-Plus." Springer Verlag, Heidleberg.

Table 1. Collection Data for Harbor Seal Blubber (n = 66) from the Gulf of Alaska

| | 1995 | 1996 | AdultM | AdultF | Subadult | Pup | unk |
|---|---|---|---|---|---|---|---|
| Kodiak Isl. | 8 | 10 | 11 | 1 | 3 | 3 | |
| Yakutat | | 11 | 3 | 3 | 5 | | |
| SEA-Sitka | 9 | 3 | 2 | 2 | 4 | 1 | 3 |
| SEA-Peril Straight | | 11 | 7 | 1 | 3 | | |
| SEA-Stephens Passage | 14 | | 9 | 3 | 2 | | |
| Total | 31 | 35 | 32 | 10 | 17 | 4 | 3 |

SEA, Southeast Alaska; AdultM, adult males; AdultF, adult females; unk, age not available.

Table 2. Fatty Acid Composition of GOA Harbor Seal Blubber (n = 66)

| | KODIAK ISLAND | | | YAKUTAT | |
|---|---|---|---|---|---|
| | Adult n = 12 | Subadult n = 3 | Pup n = 3 | Adult n = 6 | Subadult n = 5 |
| 12:0 | 0.08 ± 0.01 | 0.10 ± 0.00 | 0.11 ± 0.05 | 0.08 ± 0.01 | 0.10 ± 0.01 |
| 13:0 | 0.02 ± 0.00 | 0.01 ± 0.00 | 0.01 ± 0.00 | 0.02 ± 0.00 | 0.02 ± 0.00 |
| Iso14 | 0.02 ± 0.00 | 0.02 ± 0.00 | 0.02 ± 0.00 | 0.02 ± 0.00 | 0.02 ± 0.00 |
| 14:0 | 4.22 ± 0.10 | 3.53 ± 0.23 | 4.60 ± 0.24 | 5.45 ± 0.31 | 5.94 ± 0.58 |
| 14:1n-9 | 0.14 ± 0.01 | 0.10 ± 0.02 | 0.10 ± 0.02 | 0.13 ± 0.01 | 0.13 ± 0.01 |
| 14:1n-7 | 0.08 ± 0.00 | 0.08 ± 0.01 | 0.13 ± 0.02 | 0.05 ± 0.00 | 0.06 ± 0.00 |
| 14:1n-5 | 1.39 ± 0.12 | 1.77 ± 0.41 | 3.24 ± 0.58 | 0.91 ± 0.10 | 1.14 ± 0.10 |
| Iso15 | 0.14 ± 0.01 | 0.11 ± 0.01 | 0.11 ± 0.01 | 0.12 ± 0.01 | 0.15 ± 0.01 |
| Anti15 | 0.06 ± 0.01 | 0.04 ± 0.01 | 0.05 ± 0.00 | 0.05 ± 0.00 | 0.06 ± 0.00 |
| 15:0 | 0.27 ± 0.02 | 0.23 ± 0.03 | 0.24 ± 0.02 | 0.23 ± 0.00 | 0.25 ± 0.01 |
| 15:1n-8 | 0.01 ± 0.00 | 0.01 ± 0.00 | 0.01 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 |
| 15:1n-6 | 0.08 ± 0.01 | 0.08 ± 0.01 | 0.12 ± 0.02 | 0.03 ± 0.00 | 0.04 ± 0.01 |
| Iso16 | 0.10 ± 0.02 | 0.06 ± 0.01 | 0.08 ± 0.02 | 0.05 ± 0.01 | 0.06 ± 0.01 |
| 16:0 | 8.23 ± 0.29 | 7.71 ± 0.40 | 9.35 ± 0.79 | 8.84 ± 0.38 | 8.59 ± 0.20 |
| 16:1n-11 | 0.71 ± 0.04 | 0.71 ± 0.03 | 0.53 ± 0.07 | 0.47 ± 0.04 | 0.56 ± 0.04 |
| 16:1n-9 | 0.44 ± 0.02 | 0.42 ± 0.02 | 0.50 ± 0.05 | 0.51 ± 0.03 | 0.41 ± 0.02 |
| 16:1n-7 | 15.68 ± 0.63 | 19.39 ± 2.59 | 26.67 ± 3.14 | 9.58 ± 0.38 | 10.72 ± 0.99 |
| 7Me16:0 | 0.28 ± 0.03 | 0.26 ± 0.03 | 0.27 ± 0.02 | 0.22 ± 0.01 | 0.27 ± 0.02 |
| 16:1n-5 | 0.17 ± 0.03 | 0.09 ± 0.03 | 0.09 ± 0.03 | 0.18 ± 0.01 | 0.19 ± 0.02 |
| 16:2n-6 | 0.09 ± 0.02 | 0.10 ± 0.04 | 0.15 ± 0.04 | 0.04 ± 0.00 | 0.04 ± 0.01 |
| Iso17 | 0.12 ± 0.03 | 0.05 ± 0.01 | 0.05 ± 0.02 | 0.09 ± 0.01 | 0.09 ± 0.01 |
| 16:2n-4 | 0.23 ± 0.04 | 0.13 ± 0.04 | 0.12 ± 0.03 | 0.30 ± 0.01 | 0.32 ± 0.02 |
| 16:3n-6 | 0.52 ± 0.03 | 0.48 ± 0.12 | 0.44 ± 0.11 | 0.25 ± 0.02 | 0.29 ± 0.03 |
| 17:0 | 0.16 ± 0.02 | 0.11 ± 0.02 | 0.11 ± 0.03 | 0.16 ± 0.05 | 0.14 ± 0.03 |
| 16:3n-4 | 0.41 ± 0.04 | 0.37 ± 0.10 | 0.29 ± 0.04 | 0.44 ± 0.01 | 0.45 ± 0.03 |
| 17:1 | 0.16 ± 0.06 | 0.27 ± 0.12 | 0.30 ± 0.14 | 0.00 ± 0.00 | 0.01 ± 0.01 |
| 16:3n-1 | 0.05 ± 0.01 | 0.07 ± 0.02 | 0.05 ± 0.01 | 0.07 ± 0.02 | 0.08 ± 0.01 |
| 16:4n-1 | 0.30 ± 0.03 | 0.25 ± 0.08 | 0.23 ± 0.07 | 0.09 ± 0.02 | 0.13 ± 0.06 |
| 18:0 | 1.00 ± 0.06 | 0.88 ± 0.15 | 0.87 ± 0.15 | 1.31 ± 0.06 | 1.23 ± 0.09 |
| 18:1n-13 | 0.28 ± 0.04 | 0.25 ± 0.03 | 0.19 ± 0.10 | 0.28 ± 0.01 | 0.34 ± 0.02 |
| 18:1n-11 | 1.59 ± 0.12 | 1.43 ± 0.19 | 1.21 ± 0.17 | 1.60 ± 0.22 | 2.05 ± 0.28 |
| 18:1n-9 | 24.88 ± 1.34 | 22.85 ± 0.59 | 21.48 ± 4.25 | 38.46 ± 1.48 | 31.50 ± 4.15 |
| 18:1n-7 | 4.82 ± 0.30 | 4.11 ± 0.18 | 4.62 ± 0.55 | 4.12 ± 0.18 | 3.43 ± 0.25 |
| 18:1n-5 | 0.40 ± 0.02 | 0.41 ± 0.01 | 0.45 ± 0.03 | 0.40 ± 0.01 | 0.50 ± 0.03 |
| 18:2d5,7 | 0.05 ± 0.01 | 0.05 ± 0.03 | 0.13 ± 0.03 | 0.11 ± 0.02 | 0.04 ± 0.02 |
| 18:2n-7 | 0.07 ± 0.01 | 0.10 ± 0.03 | 0.17 ± 0.01 | 0.04 ± 0.00 | 0.03 ± 0.00 |
| 18:2n-6 | 1.04 ± 0.04 | 1.12 ± 0.10 | 0.81 ± 0.08 | 1.01 ± 0.04 | 1.16 ± 0.06 |
| 18:2n-4 | 0.13 ± 0.01 | 0.11 ± 0.02 | 0.14 ± 0.05 | 0.06 ± 0.01 | 0.08 ± 0.02 |
| 18:3n-6 | 0.05 ± 0.01 | 0.04 ± 0.01 | 0.07 ± 0.01 | 0.03 ± 0.01 | 0.03 ± 0.01 |
| 18:3n-4 | 0.13 ± 0.01 | 0.12 ± 0.02 | 0.10 ± 0.02 | 0.11 ± 0.01 | 0.13 ± 0.01 |
| 18:3n-3 | 0.61 ± 0.04 | 0.71 ± 0.09 | 0.44 ± 0.04 | 0.44 ± 0.04 | 0.65 ± 0.10 |
| 18:3n-1 | 0.05 ± 0.00 | 0.04 ± 0.00 | 0.04 ± 0.02 | 0.04 ± 0.00 | 0.05 ± 0.00 |
| 18:4n-3 | 0.88 ± 0.06 | 0.89 ± 0.05 | 0.67 ± 0.01 | 0.50 ± 0.04 | 0.91 ± 0.25 |
| 18:4n-1 | 0.18 ± 0.02 | 0.18 ± 0.03 | 0.15 ± 0.03 | 0.05 ± 0.01 | 0.08 ± 0.03 |

Table 2. Fatty Acid Composition of GOA Harbor Seal Blubber (n = 66)

| | KODIAK ISLAND | | | YAKUTAT | |
|---|---|---|---|---|---|
| | Adult n = 12 | Subadult n = 3 | Pup n = 3 | Adult n = 6 | Subadult n = 5 |
| 20:0 | 0.06 ± 0.00 | 0.04 ± 0.01 | 0.05 ± 0.01 | 0.08 ± 0.01 | 0.09 ± 0.02 |
| 20:1n-11 | 4.35 ± 0.49 | 3.31 ± 0.33 | 2.91 ± 0.62 | 5.55 ± 0.33 | 6.94 ± 1.33 |
| 20:1n-9 | 1.74 ± 0.12 | 1.47 ± 0.27 | 1.03 ± 0.21 | 1.95 ± 0.13 | 2.26 ± 0.10 |
| R20:1 | 2.47 ± 0.21 | 2.45 ± 0.56 | 2.82 ± 0.12 | 2.86 ± 0.07 | 2.98 ± 0.50 |
| 20:1n-7 | 0.35 ± 0.07 | 0.21 ± 0.02 | 0.27 ± 0.14 | 0.21 ± 0.02 | 0.17 ± 0.02 |
| 20:1n-5 | 0.04 ± 0.00 | 0.03 ± 0.01 | 0.02 ± 0.01 | 0.07 ± 0.01 | 0.09 ± 0.01 |
| 20:2n-6 | 0.21 ± 0.02 | 0.15 ± 0.04 | 0.16 ± 0.05 | 0.17 ± 0.02 | 0.16 ± 0.02 |
| 20:3n-6 | 0.06 ± 0.00 | 0.08 ± 0.01 | 0.08 ± 0.01 | 0.05 ± 0.00 | 0.05 ± 0.01 |
| 20:4n-6 | 0.59 ± 0.07 | 0.61 ± 0.04 | 0.77 ± 0.19 | 0.39 ± 0.04 | 0.47 ± 0.15 |
| 20:3n-3 | 0.07 ± 0.01 | 0.07 ± 0.01 | 0.06 ± 0.01 | 0.04 ± 0.01 | 0.05 ± 0.01 |
| 20:4n-3 | 0.55 ± 0.05 | 0.69 ± 0.18 | 0.35 ± 0.04 | 0.32 ± 0.04 | 0.47 ± 0.15 |
| 20:5n-3 | 6.25 ± 0.41 | 6.56 ± 0.23 | 4.21 ± 1.16 | 2.51 ± 0.38 | 3.52 ± 1.30 |
| 22:1n-11 | 1.08 ± 0.14 | 0.62 ± 0.14 | 0.55 ± 0.21 | 2.34 ± 0.13 | 3.11 ± 0.56 |
| 22:1n-9 | 0.14 ± 0.01 | 0.12 ± 0.06 | 0.14 ± 0.10 | 0.23 ± 0.02 | 0.26 ± 0.03 |
| R22:1 | 7.99 ± 0.93 | 6.63 ± 1.51 | 6.68 ± 2.16 | 10.45 ± 0.84 | 11.37 ± 1.47 |
| 22:1n-7 | 0.02 ± 0.00 | 0.00 ± 0.00 | 0.01 ± 0.01 | 0.02 ± 0.01 | 0.02 ± 0.01 |
| 22:2n-6 | 0.03 ± 0.01 | 0.03 ± 0.02 | 0.02 ± 0.01 | 0.01 ± 0.01 | 0.01 ± 0.01 |
| 21:5n-3 | 0.34 ± 0.02 | 0.32 ± 0.01 | 0.24 ± 0.11 | 0.17 ± 0.02 | 0.20 ± 0.06 |
| 22:4n-6 | 0.14 ± 0.03 | 0.10 ± 0.01 | 0.15 ± 0.07 | 0.09 ± 0.02 | 0.09 ± 0.03 |
| 22:5n-6 | 0.12 ± 0.01 | 0.16 ± 0.03 | 0.12 ± 0.04 | 0.09 ± 0.01 | 0.09 ± 0.02 |
| 22:4n-3 | 0.06 ± 0.01 | 0.07 ± 0.01 | 0.05 ± 0.01 | 0.05 ± 0.01 | 0.06 ± 0.01 |
| 22:5n-3 | 4.59 ± 0.33 | 4.80 ± 0.97 | 3.14 ± 1.08 | 2.64 ± 0.41 | 2.71 ± 0.99 |
| 22:6n-3 | 8.62 ± 0.56 | 10.59 ± 1.52 | 6.05 ± 1.26 | 5.80 ± 0.69 | 6.38 ± 1.75 |
| 24:1n-11 | 0.01 ± 0.01 | 0.02 ± 0.01 | 0.02 ± 0.01 | 0.03 ± 0.01 | 0.06 ± 0.02 |
| 24:1n-9 | 0.07 ± 0.01 | 0.06 ± 0.02 | 0.03 ± 0.01 | 0.13 ± 0.01 | 0.16 ± 0.02 |

Table 2. Fatty Acid Composition of GOA Harbor Seal Blubber (n = 66)

| | SEA<br>Peril Straight | | SEA<br>Sitka | | | |
|---|---|---|---|---|---|---|
| | Adult<br>n = 8 | Subadult<br>n = 3 | Adult<br>n = 4 | Subadult<br>n = 4 | Pup<br>n = 1 | unk.<br>n = 3 |
| 12:0 | 0.09 ± 0.01 | 0.09 ± 0.01 | 0.12 ± 0.01 | 0.11 ± 0.01 | 0.13 | 0.10 ± 0.03 |
| 13:0 | 0.02 ± 0.00 | 0.01 ± 0.00 | 0.02 ± 0.00 | 0.02 ± 0.00 | 0.01 | 0.02 ± 0.01 |
| Iso14 | 0.02 ± 0.00 | 0.01 ± 0.00 | 0.02 ± 0.00 | 0.02 ± 0.00 | 0.02 | 0.01 ± 0.00 |
| 14:0 | 3.18 ± 0.09 | 3.89 ± 0.64 | 3.59 ± 0.10 | 4.09 ± 0.40 | 4.46 | 3.11 ± 0.53 |
| 14:1n-9 | 0.12 ± 0.01 | 0.17 ± 0.01 | 0.06 ± 0.03 | 0.13 ± 0.05 | 0.17 | 0.10 ± 0.03 |
| 14:1n-7 | 0.06 ± 0.00 | 0.08 ± 0.01 | 0.05 ± 0.01 | 0.06 ± 0.01 | 0.11 | 0.08 ± 0.02 |
| 14:1n-5 | 1.05 ± 0.05 | 1.32 ± 0.22 | 0.68 ± 0.05 | 1.02 ± 0.26 | 1.84 | 1.10 ± 0.20 |
| Iso15 | 0.12 ± 0.01 | 0.11 ± 0.01 | 0.15 ± 0.01 | 0.15 ± 0.01 | 0.10 | 0.13 ± 0.01 |
| Anti15 | 0.05 ± 0.01 | 0.04 ± 0.01 | 0.05 ± 0.01 | 0.05 ± 0.00 | 0.03 | 0.04 ± 0.01 |
| 15:0 | 0.25 ± 0.02 | 0.22 ± 0.02 | 0.36 ± 0.01 | 0.31 ± 0.03 | 0.21 | 0.30 ± 0.04 |
| 15:1n-8 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 | 0.00 ± 0.00 |
| 15:1n-6 | 0.08 ± 0.00 | 0.07 ± 0.00 | 0.05 ± 0.00 | 0.05 ± 0.00 | 0.05 | 0.08 ± 0.01 |
| Iso16 | 0.08 ± 0.01 | 0.05 ± 0.00 | 0.09 ± 0.02 | 0.09 ± 0.01 | 0.06 | 0.07 ± 0.00 |
| 16:0 | 7.98 ± 0.25 | 8.85 ± 0.95 | 9.83 ± 0.86 | 9.59 ± 0.58 | 10.88 | 6.78 ± 1.65 |
| 16:1n-11 | 0.53 ± 0.04 | 0.47 ± 0.04 | 0.78 ± 0.06 | 0.61 ± 0.09 | 0.34 | 0.82 ± 0.09 |
| 16:1n-9 | 0.45 ± 0.01 | 0.43 ± 0.02 | 0.45 ± 0.03 | 0.41 ± 0.04 | 0.59 | 0.55 ± 0.09 |
| 16:1n-7 | 14.66 ± 0.60 | 17.48 ± 1.35 | 11.74 ± 0.39 | 14.54 ± 1.57 | 17.89 | 14.67 ± 1.72 |
| 7Me16:0 | 0.23 ± 0.01 | 0.23 ± 0.01 | 0.32 ± 0.03 | 0.27 ± 0.03 | 0.22 | 0.35 ± 0.04 |
| 16:1n-5 | 0.20 ± 0.01 | 0.14 ± 0.01 | 0.26 ± 0.01 | 0.22 ± 0.03 | 0.13 | 0.21 ± 0.02 |
| 16:2n-6 | 0.06 ± 0.00 | 0.06 ± 0.01 | 0.04 ± 0.01 | 0.09 ± 0.01 | 0.07 | 0.06 ± 0.01 |
| Iso17 | 0.12 ± 0.01 | 0.07 ± 0.00 | 0.14 ± 0.03 | 0.13 ± 0.03 | 0.07 | 0.10 ± 0.00 |
| 16:2n-4 | 0.24 ± 0.02 | 0.21 ± 0.03 | 0.31 ± 0.04 | 0.20 ± 0.06 | 0.10 | 0.26 ± 0.02 |
| 16:3n-6 | 0.34 ± 0.02 | 0.49 ± 0.09 | 0.27 ± 0.07 | 0.56 ± 0.12 | 0.48 | 0.30 ± 0.02 |
| 17:0 | 0.24 ± 0.05 | 0.09 ± 0.01 | 0.21 ± 0.02 | 0.18 ± 0.05 | 0.10 | 0.11 ± 0.03 |
| 16:3n-4 | 0.50 ± 0.03 | 0.39 ± 0.04 | 0.56 ± 0.02 | 0.47 ± 0.06 | 0.34 | 0.62 ± 0.04 |
| 17:1 | 0.02 ± 0.00 | 0.02 ± 0.01 | 0.03 ± 0.00 | 0.03 ± 0.00 | 0.04 | 0.04 ± 0.00 |
| 16:3n-1 | 0.07 ± 0.01 | 0.06 ± 0.01 | 0.12 ± 0.01 | 0.09 ± 0.02 | 0.07 | 0.10 ± 0.01 |
| 16:4n-1 | 0.13 ± 0.01 | 0.29 ± 0.14 | 0.15 ± 0.06 | 0.39 ± 0.11 | 0.28 | 0.15 ± 0.05 |
| 18:0 | 1.21 ± 0.03 | 1.07 ± 0.01 | 1.54 ± 0.17 | 1.44 ± 0.26 | 1.64 | 0.97 ± 0.23 |
| 18:1n-13 | 0.23 ± 0.03 | 0.14 ± 0.03 | 0.38 ± 0.03 | 0.15 ± 0.06 | 0.11 | 0.33 ± 0.03 |
| 18:1n-11 | 1.65 ± 0.27 | 1.28 ± 0.18 | 1.94 ± 0.33 | 1.36 ± 0.30 | 0.63 | 2.26 ± 0.15 |
| 18:1n-9 | 25.31 ± 1.21 | 26.28 ± 3.47 | 19.82 ± 0.87 | 21.42 ± 2.05 | 32.76 | 24.32 ± 3.02 |
| 18:1n-7 | 5.24 ± 0.47 | 5.47 ± 0.76 | 4.25 ± 0.42 | 5.06 ± 0.43 | 4.80 | 4.61 ± 0.50 |
| 18:1n-5 | 0.37 ± 0.02 | 0.35 ± 0.04 | 0.43 ± 0.02 | 0.29 ± 0.04 | 0.30 | 0.40 ± 0.03 |
| 18:2d5,7 | 0.03 ± 0.01 | 0.01 ± 0.01 | 0.01 ± 0.00 | 0.01 ± 0.01 | 0.17 | 0.02 ± 0.01 |
| 18:2n-7 | 0.06 ± 0.00 | 0.07 ± 0.01 | 0.04 ± 0.00 | 0.06 ± 0.01 | 0.10 | 0.05 ± 0.00 |
| 18:2n-6 | 1.26 ± 0.05 | 1.11 ± 0.13 | 1.30 ± 0.14 | 1.31 ± 0.13 | 1.03 | 1.50 ± 0.03 |
| 18:2n-4 | 0.13 ± 0.01 | 0.16 ± 0.02 | 0.12 ± 0.02 | 0.16 ± 0.02 | 0.12 | 0.12 ± 0.02 |
| 18:3n-6 | 0.05 ± 0.01 | 0.05 ± 0.01 | 0.03 ± 0.01 | 0.07 ± 0.02 | 0.07 | 0.03 ± 0.00 |
| 18:3n-4 | 0.16 ± 0.01 | 0.17 ± 0.01 | 0.15 ± 0.02 | 0.18 ± 0.02 | 0.14 | 0.17 ± 0.01 |
| 18:3n-3 | 0.68 ± 0.05 | 0.60 ± 0.13 | 0.88 ± 0.09 | 0.87 ± 0.16 | 0.58 | 0.90 ± 0.10 |
| 18:3n-1 | 0.04 ± 0.00 | 0.03 ± 0.00 | 0.05 ± 0.01 | 0.03 ± 0.02 | 0.00 | 0.04 ± 0.00 |
| 18:4n-3 | 0.80 ± 0.07 | 0.85 ± 0.17 | 1.19 ± 0.19 | 1.66 ± 0.65 | 1.37 | 1.06 ± 0.19 |
| 18:4n-1 | 0.13 ± 0.01 | 0.20 ± 0.05 | 0.12 ± 0.02 | 0.19 ± 0.04 | 0.13 | 0.13 ± 0.03 |

Table 2. Fatty Acid Composition of GOA Harbor Seal Blubber (n = 66)

| | SEA<br>Peril Straight | | SEA<br>Sitka | | | |
|---|---|---|---|---|---|---|
| | Adult<br>n = 8 | Subadult<br>n = 3 | Adult<br>n = 4 | Subadult<br>n = 4 | Pup<br>n = 1 | unk.<br>n = 3 |
| 20:0 | 0.05 ± 0.00 | 0.04 ± 0.01 | 0.04 ± 0.01 | 0.05 ± 0.01 | 0.04 | 0.03 ± 0.00 |
| 20:1n-11 | 3.07 ± 0.51 | 2.39 ± 0.62 | 3.42 ± 0.36 | 1.71 ± 0.40 | 0.79 | 2.85 ± 0.23 |
| 20:1n-9 | 2.09 ± 0.23 | 2.09 ± 0.54 | 2.26 ± 0.21 | 2.16 ± 0.72 | 1.13 | 1.89 ± 0.14 |
| R20:1 | 1.49 ± 0.23 | 1.17 ± 0.25 | 1.51 ± 0.08 | 0.93 ± 0.25 | 0.70 | 1.51 ± 0.10 |
| 20:1n-7 | 0.32 ± 0.03 | 0.28 ± 0.06 | 0.40 ± 0.04 | 0.25 ± 0.06 | 0.16 | 0.26 ± 0.03 |
| 20:1n-5 | 0.05 ± 0.00 | 0.04 ± 0.01 | 0.07 ± 0.01 | 0.06 ± 0.01 | 0.04 | 0.06 ± 0.00 |
| 20:2n-6 | 0.25 ± 0.01 | 0.21 ± 0.02 | 0.32 ± 0.02 | 0.21 ± 0.03 | 0.24 | 0.27 ± 0.02 |
| 20:3n-6 | 0.08 ± 0.00 | 0.06 ± 0.01 | 0.08 ± 0.00 | 0.07 ± 0.01 | 0.10 | 0.08 ± 0.01 |
| 20:4n-6 | 0.70 ± 0.03 | 0.54 ± 0.07 | 0.78 ± 0.07 | 0.85 ± 0.13 | 0.57 | 0.67 ± 0.03 |
| 20:3n-3 | 0.09 ± 0.00 | 0.07 ± 0.02 | 0.12 ± 0.01 | 0.08 ± 0.02 | 0.05 | 0.11 ± 0.02 |
| 20:4n-3 | 0.70 ± 0.07 | 0.52 ± 0.08 | 0.97 ± 0.11 | 0.75 ± 0.13 | 0.34 | 1.01 ± 0.22 |
| 20:5n-3 | 6.13 ± 0.33 | 6.43 ± 0.85 | 6.82 ± 1.00 | 8.70 ± 1.36 | 4.84 | 6.12 ± 0.61 |
| 22:1n-11 | 0.81 ± 0.16 | 0.82 ± 0.34 | 1.30 ± 0.19 | 0.91 ± 0.32 | 0.23 | 0.87 ± 0.34 |
| 22:1n-9 | 0.21 ± 0.01 | 0.16 ± 0.03 | 0.28 ± 0.03 | 0.13 ± 0.05 | 0.07 | 0.17 ± 0.05 |
| R22:1 | 3.69 ± 0.56 | 5.53 ± 2.86 | 4.68 ± 0.25 | 8.62 ± 1.89 | 3.46 | 4.78 ± 0.51 |
| 22:1n-7 | 0.04 ± 0.02 | 0.01 ± 0.01 | 0.02 ± 0.01 | 0.02 ± 0.01 | 0.00 | 0.01 ± 0.00 |
| 22:2n-6 | 0.05 ± 0.01 | 0.01 ± 0.01 | 0.06 ± 0.01 | 0.01 ± 0.01 | 0.00 | 0.08 ± 0.04 |
| 21:5n-3 | 0.37 ± 0.01 | 0.38 ± 0.02 | 0.38 ± 0.05 | 0.43 ± 0.07 | 0.32 | 0.37 ± 0.04 |
| 22:4n-6 | 0.14 ± 0.02 | 0.08 ± 0.02 | 0.21 ± 0.05 | 0.12 ± 0.03 | 0.09 | 0.12 ± 0.02 |
| 22:5n-6 | 0.14 ± 0.01 | 0.11 ± 0.02 | 0.19 ± 0.02 | 0.14 ± 0.03 | 0.07 | 0.16 ± 0.00 |
| 22:4n-3 | 0.08 ± 0.00 | 0.07 ± 0.01 | 0.08 ± 0.01 | 0.07 ± 0.01 | 0.04 | 0.09 ± 0.03 |
| 22:5n-3 | 6.11 ± 0.31 | 4.37 ± 0.36 | 6.85 ± 0.36 | 4.42 ± 0.67 | 2.19 | 6.14 ± 0.76 |
| 22:6n-3 | 9.99 ± 0.82 | 7.88 ± 1.06 | 12.43 ± 0.76 | 10.33 ± 1.72 | 5.83 | 11.36 ± 0.62 |
| 24:1n-11 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 | 0.01 ± 0.01 |
| 24:1n-9 | 0.10 ± 0.01 | 0.09 ± 0.01 | 0.11 ± 0.01 | 0.06 ± 0.01 | 0.03 | 0.06 ± 0.03 |

Table 2. Fatty Acid Composition of GOA Harbor Seal Blubber (n = 66)

| | SEA<br>Stephens Passage | |
|---|---|---|
| | Adult<br>n = 12 | Subadult<br>n = 2 |
| 12:0 | 0.07 ± 0.00 | 0.14 ± 0.03 |
| 13:0 | 0.02 ± 0.00 | 0.02 ± 0.01 |
| Iso14 | 0.02 ± 0.00 | 0.03 ± 0.01 |
| 14:0 | 2.94 ± 0.15 | 3.95 ± 0.31 |
| 14:1n-9 | 0.12 ± 0.01 | 0.11 ± 0.04 |
| 14:1n-7 | 0.08 ± 0.00 | 0.12 ± 0.01 |
| 14:1n-5 | 1.55 ± 0.16 | 2.55 ± 0.10 |
| Iso15 | 0.09 ± 0.00 | 0.10 ± 0.02 |
| Anti15 | 0.05 ± 0.00 | 0.07 ± 0.02 |
| 15:0 | 0.21 ± 0.01 | 0.23 ± 0.03 |
| 15:1n-8 | 0.00 ± 0.00 | 0.01 ± 0.00 |
| 15:1n-6 | 0.08 ± 0.01 | 0.10 ± 0.00 |
| Iso16 | 0.06 ± 0.00 | 0.08 ± 0.02 |
| 16:0 | 6.22 ± 0.28 | 9.67 ± 1.68 |
| 16:1n-11 | 0.54 ± 0.04 | 0.26 ± 0.05 |
| 16:1n-9 | 0.51 ± 0.02 | 0.46 ± 0.02 |
| 16:1n-7 | 17.58 ± 0.94 | 27.34 ± 1.09 |
| 7Me16:0 | 0.22 ± 0.01 | 0.21 ± 0.00 |
| 16:1n-5 | 0.04 ± 0.00 | 0.05 ± 0.01 |
| 16:2n-6 | 0.16 ± 0.02 | 0.13 ± 0.02 |
| Iso17 | 0.03 ± 0.00 | 0.04 ± 0.01 |
| 16:2n-4 | 0.09 ± 0.01 | 0.09 ± 0.02 |
| 16:3n-6 | 0.61 ± 0.05 | 0.65 ± 0.09 |
| 17:0 | 0.09 ± 0.01 | 0.09 ± 0.03 |
| 16:3n-4 | 0.51 ± 0.05 | 0.41 ± 0.13 |
| 17:1 | 0.51 ± 0.05 | 0.40 ± 0.01 |
| 16:3n-1 | 0.03 ± 0.00 | 0.03 ± 0.00 |
| 16:4n-1 | 0.27 ± 0.03 | 0.38 ± 0.02 |
| 18:0 | 0.78 ± 0.04 | 0.88 ± 0.16 |
| 18:1n-13 | 0.02 ± 0.01 | 0.03 ± 0.03 |
| 18:1n-11 | 1.46 ± 0.12 | 0.67 ± 0.20 |
| 18:1n-9 | 30.02 ± 1.38 | 21.69 ± 2.47 |
| 18:1n-7 | 4.95 ± 0.23 | 5.06 ± 0.41 |
| 18:1n-5 | 0.35 ± 0.02 | 0.30 ± 0.02 |
| 18:2d5,7 | 0.06 ± 0.00 | 0.08 ± 0.02 |
| 18:2n-7 | 0.11 ± 0.01 | 0.16 ± 0.02 |
| 18:2n-6 | 1.10 ± 0.09 | 0.75 ± 0.00 |
| 18:2n-4 | 0.14 ± 0.01 | 0.16 ± 0.00 |
| 18:3n-6 | 0.05 ± 0.00 | 0.06 ± 0.00 |
| 18:3n-4 | 0.13 ± 0.01 | 0.14 ± 0.02 |
| 18:3n-3 | 0.56 ± 0.06 | 0.40 ± 0.04 |
| 18:3n-1 | 0.05 ± 0.01 | 0.04 ± 0.00 |
| 18:4n-3 | 0.69 ± 0.05 | 0.65 ± 0.03 |
| 18:4n-1 | 0.18 ± 0.01 | 0.21 ± 0.01 |

Table 2. Fatty Acid Composition of GOA Harbor Seal Blubber (n = 66)

| | SEA<br>Stephens Passage<br>Adult<br>n = 12 | <br><br>Subadult<br>n = 2 |
|---|---|---|
| 20:0 | 0.05 ± 0.00 | 0.04 ± 0.01 |
| 20:1n-11 | 2.84 ± 0.29 | 0.45 ± 0.15 |
| 20:1n-9 | 2.17 ± 0.17 | 0.79 ± 0.29 |
| R20:1 | 1.34 ± 0.12 | 0.58 ± 0.02 |
| 20:1n-7 | 0.26 ± 0.02 | 0.18 ± 0.01 |
| 20:1n-5 | 0.02 ± 0.00 | 0.03 ± 0.01 |
| 20:2n-6 | 0.16 ± 0.02 | 0.09 ± 0.01 |
| 20:3n-6 | 0.10 ± 0.01 | 0.07 ± 0.01 |
| 20:4n-6 | 0.48 ± 0.03 | 0.56 ± 0.08 |
| 20:3n-3 | 0.08 ± 0.01 | 0.04 ± 0.00 |
| 20:4n-3 | 0.59 ± 0.08 | 0.34 ± 0.04 |
| 20:5n-3 | 5.58 ± 0.33 | 6.89 ± 0.75 |
| 22:1n-11 | 0.36 ± 0.04 | 0.08 ± 0.03 |
| 22:1n-9 | 0.14 ± 0.03 | 0.03 ± 0.01 |
| R22:1 | 2.99 ± 0.32 | 2.38 ± 0.38 |
| 22:1n-7 | 0.02 ± 0.01 | 0.00 ± 0.00 |
| 22:2n-6 | 0.03 ± 0.01 | 0.04 ± 0.01 |
| 21:5n-3 | 0.36 ± 0.01 | 0.36 ± 0.01 |
| 22:4n-6 | 0.09 ± 0.01 | 0.08 ± 0.01 |
| 22:5n-6 | 0.10 ± 0.01 | 0.08 ± 0.00 |
| 22:4n-3 | 0.06 ± 0.01 | 0.04 ± 0.01 |
| 22:5n-3 | 4.72 ± 0.35 | 3.30 ± 0.28 |
| 22:6n-3 | 8.39 ± 0.83 | 7.54 ± 0.74 |
| 24:1n-11 | 0.02 ± 0.00 | 0.01 ± 0.01 |
| 24:1n-9 | 0.04 ± 0.00 | 0.02 ± 0.01 |

Values are mean weight percent of total fatty acids ± SEM.
See Table 1 for collection data.

Table 3. Summary of CART Analyses of Demographic Groups by Major GOA Region

Tree 1. Root node: Ratio 20:1n-11/20:1n-9 at < 1.725 >

| groups | | correct/total |
|---|---|---|
| Kodiak[1] | Adult | 12/12 |
| Yakutat | Adult | 5/6 |
| | Subadult | 4/5 |
| SEA | Adult | 23/24 |
| | Subadult | 8/9 |
| Total | | 52/56 |

Tree 2. Root node: Ratio 22:1n-11/20:1n-9 at < 1.845 >

| groups | | correct/total |
|---|---|---|
| Kodiak[1] | Adult | 11/12 |
| Yakutat | Adult | 6/6 |
| | Subadult | 4/5 |
| SEA | Adult | 23/24 |
| | Subadult | 8/9 |
| Total | | 52/56 |

[1] Subadults from Kodiak could not be included in classification because of small sample size (n = 3).

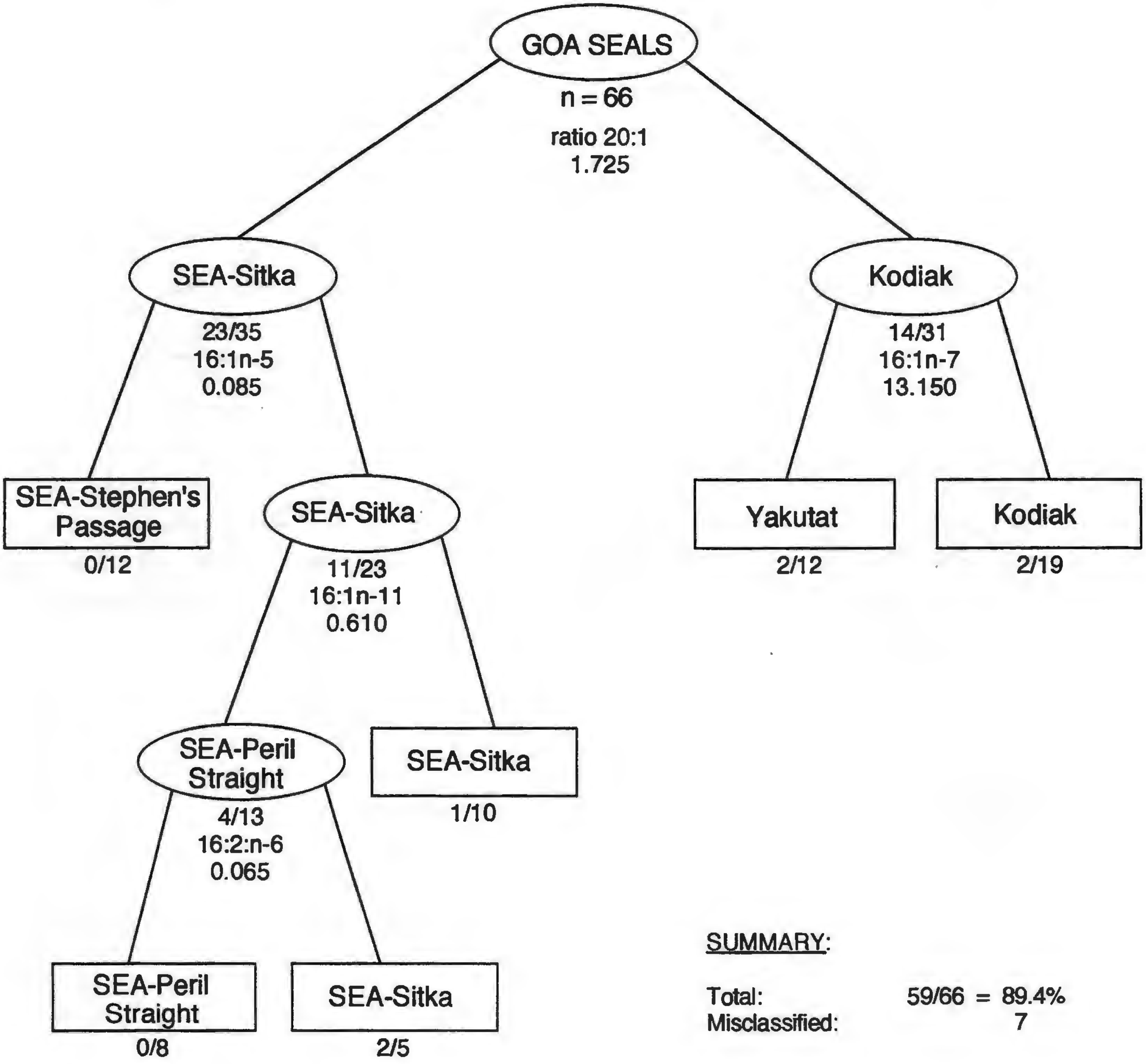
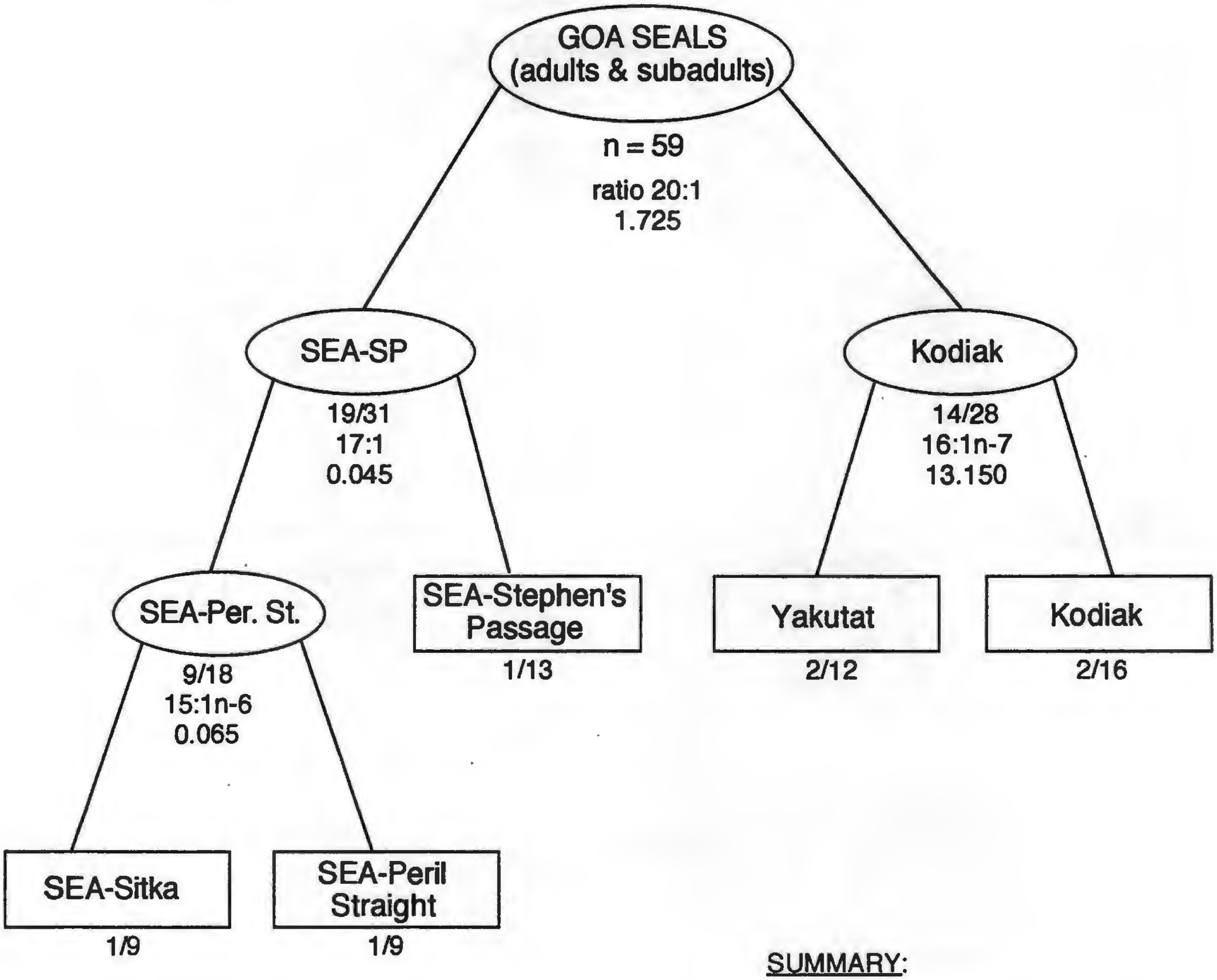


Figure. 1. Classification tree of harbor seals among areas in the GOA (adults, subadults and pups combined). Ellipses represent intermediate nodes and rectangle boxes represent terminal nodes; lables within an ellipse or rectangle indicate the classification at that node as represented by the largest number of observations in that node. The fatty acid listed at each node is the variable chosen to split; the value listed is the optimal splitting value for that fatty acid (> down right node and < down left node). Fractions under each node indicate the number of misclassifications over the total number of observations in that node.



SUMMARY:

Total: 52/59 = 88.1%
Misclassified: 7

Figure 2. Classification tree of harbor seals (adults and subadults only, pups excluded) among areas in the GOA. See Fig. 1. legend for explanation of tree.

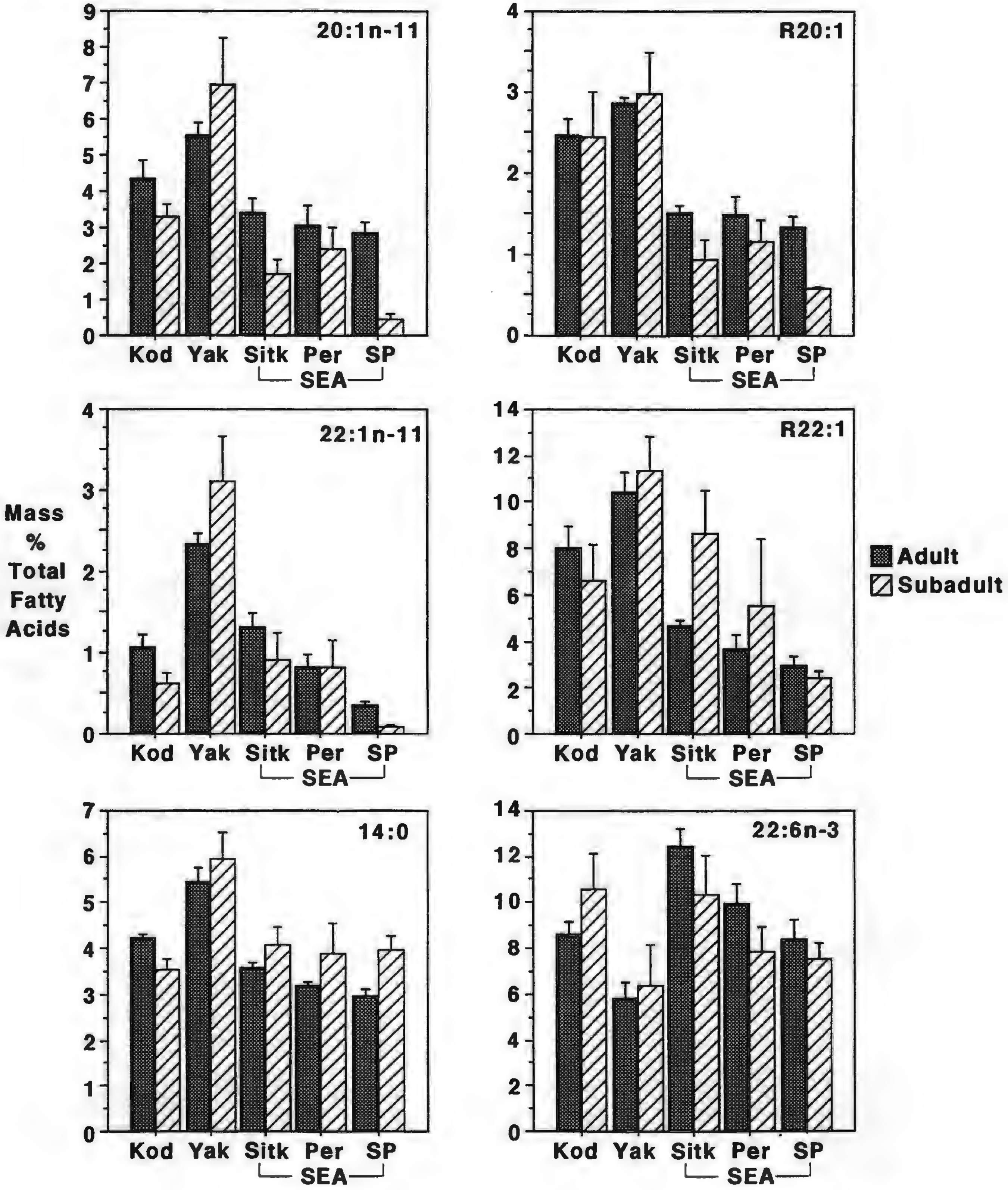


Figure 3. Selected fatty acids and isomer ratios (mean ± SEM) in harbor seal blubber across areas of GOA and within SEA as a function of age-class. See Tables 1, 2 for sample sizes. Significant differences were found by area for all components ($P < 0.001$) and by age-class within each area for most components ($P < 0.05$, ANOVA).

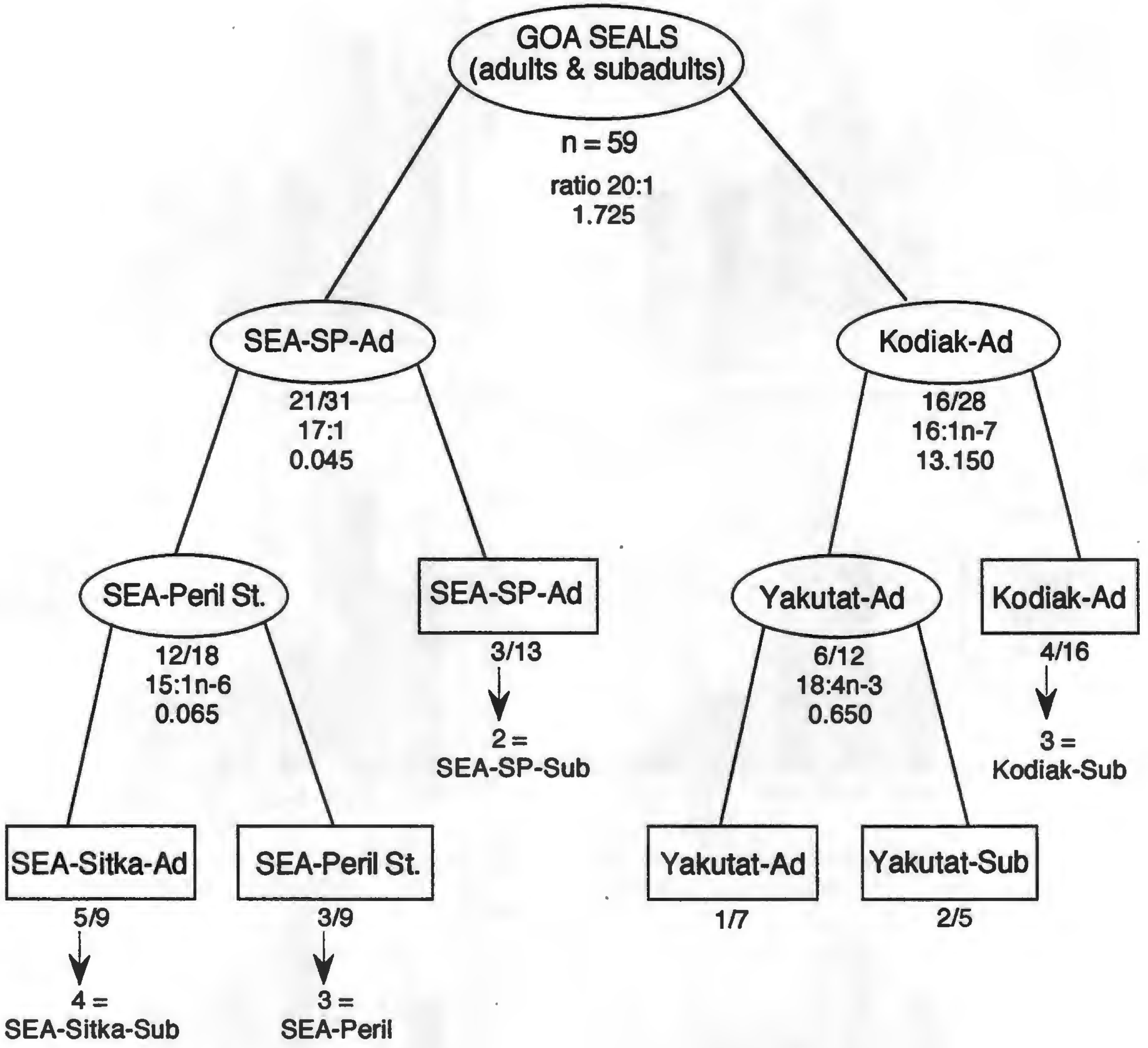


Figure 4. Classification tree of harbor seals among areas in the GOA and by adults (Ad) versus subadults (Sub). SP = Stephens Passage. See Fig. 1. legend for explanation of tree. Because of generally small sample sizes for subadults and the fact that CART cannot classify groups with sample sizes < 4, subadults were individually identified within the classification tree.

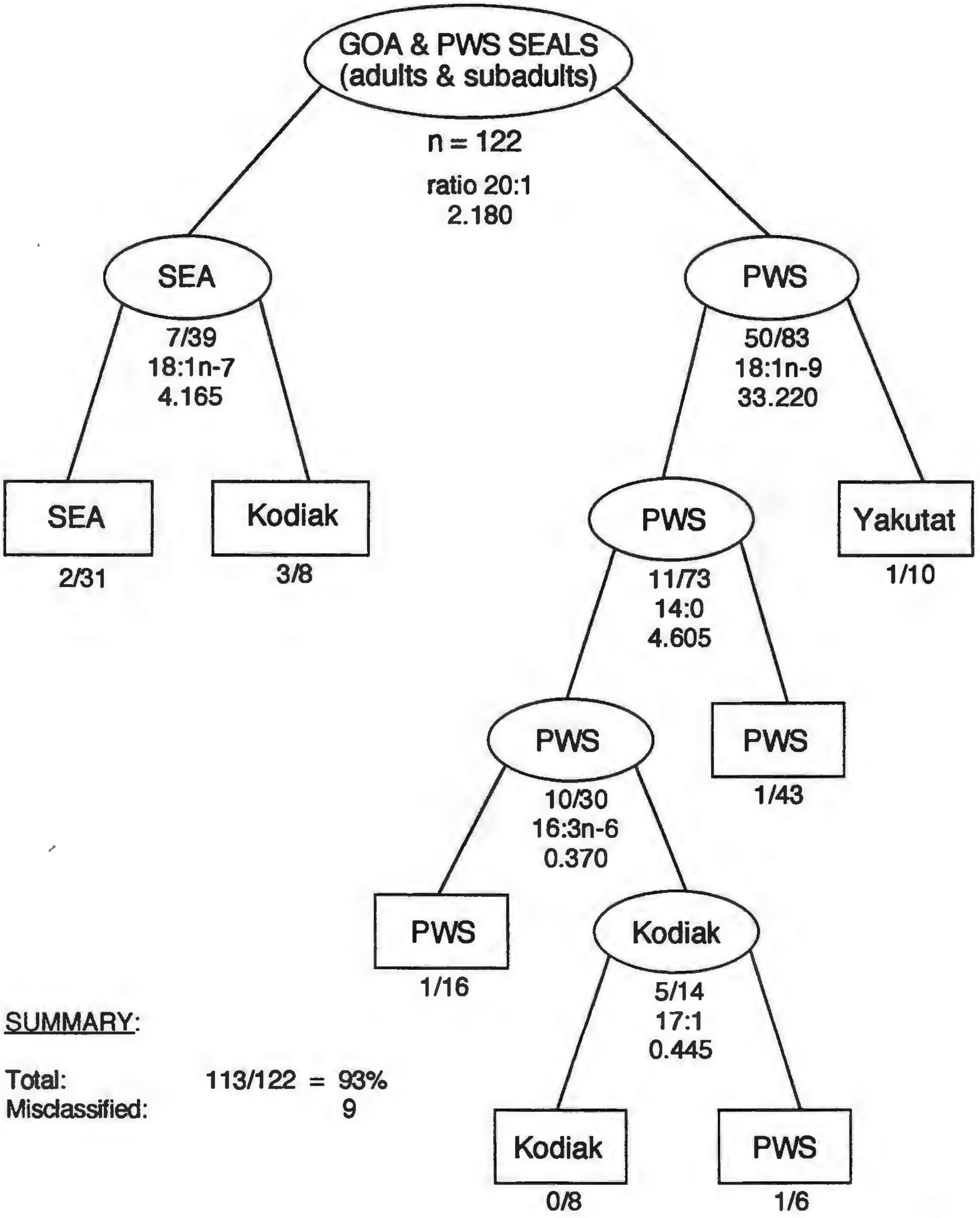


Figure 5. Classification tree of harbor seals (adults and subadults combined) among areas of the GOA (n = 59) and in southcentral PWS (n = 63) in the years 1995 and 1996. See Fig. 1. legend for explanation of tree.

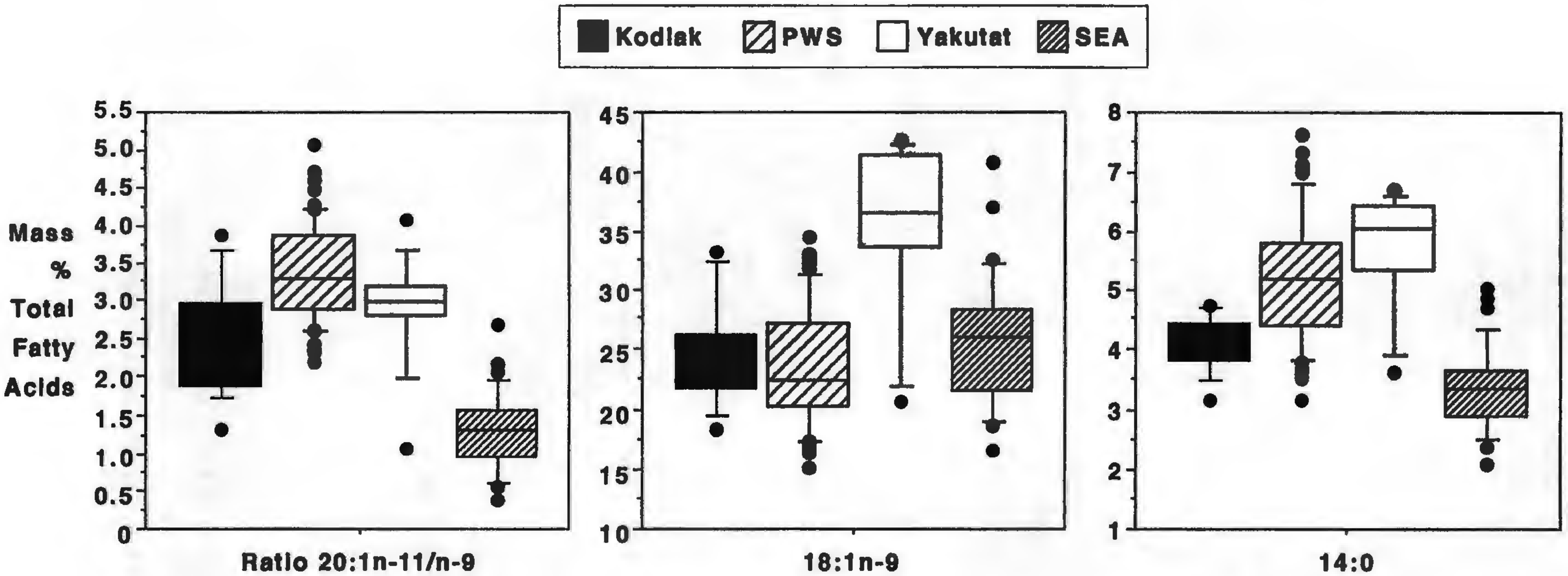


Figure 6. Box plots of the major CART splits for 1995 and 1996 GOA and PWS harbor seals in classification tree Fig. 5, illustrating the distribution of the data at right-hand nodes. The notched area of each box is the 95% confidence interval on the mean; dots represent outliers. See Tables 1 and 2 for GOA sample sizes; PWS, n = 63.

# SUMMARY AND RECOMMENDATIONS

# SUMMARY

Monitoring harbor seal population trends in selected areas of Alaska is the first overall objective of this research project. Population trend routes in the Ketchikan and Sitka areas of Southeast Alaska (SE) and in the Kodiak Island area were surveyed again in 1996, and significant increasing trends were estimated for all three routes. For Ketchikan, the 9.3% annual trend (1983-1996) is consistent with previous increasing trend estimates for that area of SE. The precision of the trend estimate has increased such that the range of the 95% confidence interval (7.5 to 11.0%) is quite narrow, and in the future the route may be monitored on a biennial basis. The 3.0% increasing trend (1983-1996) for Sitka is the first significant trend estimate for that area of SE. However, because this estimate is based on counts from only four years, two of which were in the early 1980s, at least two additional annual surveys are necessary before a current (i.e., 1990s) trend can be estimated. The estimate of a 7.2% annual rate of increase for Kodiak is further evidence that the population decline in that area has ceased. However, population levels in the Kodiak region are still severely reduced from those recorded in the 1970s and 1980s. Monitoring of the seal population in the Kodiak Island area should continue, ensuring that the population trend is documented after the severe decline. The increasing trend in Glacier Bay provides additional support for increasing seal numbers in SE, including John Hopkins Inlet, a tide-water glacier haulout that currently represents the largest breeding aggregation of harbor seals in Alaska. The need to better understand how seals may move between such large glacial sites and nearby terrestrial haulouts was also demonstrated by the Glacier Bay results. A population survey of the northeastern Gulf of Alaska in 1996 recorded higher seal numbers than counted in 1993, yet survey coverage and timing was different and thus data are not appropriate for trend analysis.

The investigation of factors that affect harbor seal populations is the second overall objective of this project. Such factors may include reduced prey availability, either by environmental changes or through commercial exploitation, human caused mortality through harvest or incidental take in fisheries, diseases, pollutants, and predation. In 1993, available data indicated a stable or increasing population in SE compared to declining seal numbers in Prince William Sound and Tugidak Island. Similar geographic differences in Steller sea lion populations had been recorded, adding support to the hypothesis that some factor(s) influences the two pinniped species differently in SE as opposed to the Gulf of Alaska. Comparative research studies were thus initiated, with the goal of determining whether certain factors differed between the two geographic regions.

The current status of harbor seals in the Gulf of Alaska is unknown. Since 1993, the population in the Kodiak region has increased whereas the population decline continued in Prince William Sound (Frost *et al.* 1997). Thus, the comparison between the Kodiak region and SE does not currently represent a direct comparison between declining and increasing seal populations. However, determining what factors affect seal populations in different regions of the state must continue to be a research priority for this project. Due to the dramatic population decline in the Kodiak region, it remains a key area for such research, whether or not the current trend continues to increase. SE presents the opportunity to study an increasing population. In Prince William Sound, the long-term research investigation of a decreasing population continues (Frost *et al.* 1997).

Research efforts should expand to include the relatively large number of seals along the north side of the Alaska Peninsula in the Bering Sea. Overall, these investigations will provide a greater understanding of the proximate and ultimate factors that regulate harbor seal populations throughout their range in Alaska, which is required to develop effective management and conservation strategies. The results of the various research projects presented in this report, and summarized below, represent progress towards such an understanding.

Tugidak Island research comparing pupping phenology from declining (1970s) to stable or increasing populations (1990s) indicates that the onset and peak of pupping was 7-18 days earlier in recent years. In addition, the ratio of seals ashore during pupping to the number ashore during molting increased from 0.3 to 1.1. These results raise questions relative to changes in demography and haulout behavior that need further investigation.

Based on preliminary results, two new research techniques need further development. Examination of fine structure in teeth has potential for estimating age of sexual maturity, but refinements in tooth preparation are required before the potential to determine growth indices can be realized. The results of pregnancy determination techniques are currently equivocal, thus additional research is needed.

The analysis of an additional year of satellite tag data confirmed general movement and diving patterns reported previously (Swain *et al.* 1996). Specifically, seals exhibit a strong fidelity to their capture area, and subadults make more extensive movements than adults. Breeding dispersal appears uncommon, and natal dispersal patterns remain unknown. The majority of dives are relatively short (<4 min) and shallow (<50m), with dives >150 m very rare; seasonal and diurnal patterns are also present. The data from 16 seals tagged in the fall of 1996 are now available, and a more detailed and complete analysis will be conducted. With a sample size of 64 individual seals, diving patterns as well as the spatial and temporal use of haulouts will be compared between males and females, adults and subadults, and SE and the Kodiak region. In addition, the movement data will be integrated with the results of dive data analyses to provide insight on the foraging behavior of seals.

Currently, there is no support for the hypothesis that disease has been an important factor in the decline of Alaskan harbor seal populations, based on samples from more than 300 harbor seals collected from 1978-1995. Although seals have apparently been exposed to five of the eight potential disease causing agents tested for, symptoms of disease have not been documented and no obvious differences in antibody prevalence exist between SE and other parts of the state.

A detailed review that describes what is known about environmental contaminants in harbor seals and their potential effects will be completed in November 1997. The review will include recommendations for additional research to better define the potential effect of contaminants, the identification of pertinent research activities that are either ongoing or planned, and an annotated bibliography.

The first stage of genetic research on Alaskan harbor seals is complete. The primary result of this research, based on mitochondrial DNA, indicates a clinal genetic structure along a coastal continuum from SE to Bristol Bay. Significant substructure was found between animals on either side of lower Cook Inlet in the Gulf of Alaska, with additional microgeographic structure apparent in several smaller subpopulations. Additional samples need to be analyzed to increase the level of statistical power to detect discrete populations. A DNA microsatellite study has been initiated to examine the consequences of population declines on spatial and temporal patterns of genetic variation. Samples from Kodiak Island and Prince William Sound are being used, because of recent population declines in those areas. This project will be expanded to parallel the mtDNA study as a second type of molecular marker in determining identification of stocks.

Available diet information from the 1990s, based on scats and stomach contents, revealed distinct differences in prey composition between northern Bristol Bay versus the Kodiak and SE areas. Based on frequency of occurrence, flounders, sandlance, tomcod, and smelts were the primary prey in Bristol Bay, whereas pollock, arrowtooth flounder, and herring were the primary prey in Kodiak and SE. Seasonal collections of scats and stomach contents will be expanded in all areas beginning in 1997. Fatty acid signatures found in blubber samples indicated differences in diet among seals from the Kodiak region, Yakutat Bay, and SE. As sample sizes increase for both types of research, an overall synthesis will provide a better understanding of the harbor seal diet.

Providing the National Marine Fisheries Service with information that can be used in the management and conservation of Alaskan harbor seals is the final overall objective of this research project. The results and discussion from the various subprojects presented herein can be used to further develop a management strategy. Trends in population abundance may be used in conjunction with NMFS statewide population size estimates to evaluate stock status. The scientific basis for stock delineation has strengthened due to the completion of a mtDNA analysis. Information on movement patterns, diving behavior, and diet are now available, which can be integrated to provide a better understanding of foraging ecology and habitat utilization needed for management.

## RECOMMENDATIONS

1. Annual trend count surveys should continue in the Sitka and Kodiak regions. The Ketchikan route should be surveyed on a biennial basis, with the next survey conducted in 1998. The area between Icy Bay and Icy Strait in the northeastern Gulf of Alaska was surveyed in 1996 (and 1997), but future surveys should be modified with improved techniques for monitoring the large concentrations of seals in Icy Bay and Disenchantment Bay. The north side of the Alaska Peninsula should be considered as an area for a new trend route.

2. Methods for the statistical analysis of population trend should be further developed. Specifically, a Bayesian approach to estimate trends should be investigated, and a quantitative criterion to determine the appropriate interval for monitoring counts should be developed.

3. Movement and dive data from all satellite tagged seals from 1993-1996 should be synthesized to determine the strength of such data in the description of harbor seal foraging ecology. Available bathymetry data should be integrated in the analysis to examine spatial and temporal differences among seals. The results of this analysis should be used to: (1) investigate which aspects of foraging behavior are

most likely to indicate differences in foraging effort and prey availability; and (2) determine the most appropriate method to detect such behaviors for future research. Time-depth-recorders (TDRs) should be considered to measure finer details of foraging behavior.

4. Satellite tags should be deployed on pups to examine their movement patterns and dive behavior, which can then be compared to non-pups. Physiological studies should continue in conjunction with captures.

5. Harbor seal sera should continue to be archived for future disease testing. Relationships of ages of animals and exposure rates should be investigated when adequate samples are available.

6. Tissue samples for genetic analyses should be routinely collected from all capture efforts and sent to the SWFSC of NMFS to be archived. Samples from those areas which are most needed to increase the statistical power necessary for further refinement of stock identification should be collected and analyzed.

7. Develop a stronger relationship with the Alaska Native Harbor Seal Commission, including discussion of future research objectives and cooperative projects. Attaining appropriate specimens in cooperation with Alaska Native subsistence hunters should continue and be expanded to assist in studies of diet, fine tooth structure, and genetics.

8. Methods to study harbor seal survival rates should be investigated, including radio telemetry (VHF and satellite transmitters) and mark-recapture techniques.

9. There is a need to further develop capture methods for seals on glacial ice, with subsequently tagged seals to be used for studies of haulout behavior, movements, and censusing on glacial haulouts.

10. Expand research on the diet of harbor seals to examine seasonal and geographical differences in major prey species.

## LITERATURE CITED

Frost, K. J., L. F. Lowry, J. M. Ver Hoef, and S. J. Iverson. 1997. Monitoring, habitat use, and trophic interactions of harbor seals in Prince William Sound, Alaska. *Exxon Valdez* Oil Spill Restoration Project Annual Report (Restoration Project

Lewis, J. P., G. W. Pendleton, K. W. Pitcher, and K. M. Wynne. 1996. Harbor seal population trends in Southeast Alaska and the Gulf of Alaska. Pages 8-57 *in* Annual report of harbor seal investigations in Alaska. Alaska Department of Fish and Game Final Report for NOAA Award NA57FX0367, 203 pages.

Pitcher, K. W. 1990. Major decline in number of harbor seals, *Phoca vitulina richardsi*, on Tugidak Island, Gulf of Alaska. Marine Mammal Science 6:121-134.

Swain, U.G., J.P. Lewis, and G.W. Pendleton. 1996. Movements, haulout, and diving behavior of harbor seals in Southeast Alaska and Kodiak Island. Pages 59-144 *in* Harbor seal investigations in Alaska. Annual rep. for NOAA award NA57FX0367, Alaska Dept. of Fish and Game, Anchorage, AK. 203pp.

(NOTE: This literature was cited in the introduction and summary.)