Exxon Valdez Oil Spill
Restoration Project Annual Report

Monitoring, Habitat Use, and Trophic Interactions of Harbor Seals in Prince William Sound, Alaska

Restoration Project 95064
Annual Report

This annual report has been prepared for peer review as part of the *Exxon Valdez* Oil Spill Trustee Council restoration program for the purpose of assessing project progress. Peer review comments have not been addressed in this annual report.

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Study History: Restoration Project 95064 continues the study effort initiated under Marine Mammal Study Number 5 (Assessment of Injury to Harbor Seals in Prince William Sound, Alaska, and Adjacent Areas) in 1989 through 1991. The project was reclassified as Restoration Study Number 73 (Harbor Seal Restoration Study) in 1992, and continued as 93046 (Habitat Use, Behavior, and Monitoring of Harbor Seals in Prince William Sound) in 1993, and as 94064 (same title) in 1994. A final report was issued in 1994 for the combined Marine Mammal Study Number 5 and Restoration Study Number 73, entitled Assessment of Injury to Harbor Seals in Prince William Sound, Alaska, and Adjacent Areas Following the *Exxon Valdez* Oil Spill. Subsequently, annual reports were submitted entitled Habitat Use, Behavior, and Monitoring of Harbor Seals in Prince William Sound (Restoration Project 93046) and Habitat Use, Behavior, and Monitoring of Harbor Seals in Prince William Sound (Restoration Project 94064). Fatty acid studies funded under Restoration Project 94320F (Trophic Interactions of Harbor Seals in Prince William Sound) were included in the 94064 annual report.

Abstract: Aerial surveys of harbor seals, *Phoca vitulina richardsi*, at 25 trend sites in Prince William Sound (PWS) during 1989-1995, showed significant declines in counts during the molt (19%) and during pupping (31%) when corrected for effects of date, time of day, and time relative to low tide. A Leslie matrix population model indicated large changes in vital parameters must have occurred to cause the 1984-1989 decline. Preliminary results indicate that projections for population recovery will depend on the carrying capacity level and pattern of density dependence assumed in the model. Forty-two seals were sampled in 1995, and satellite-linked depth recorders were attached to 14. Tagged seals were tracked for up to 267 days. Most stayed within PWS near the capture site; one moved to Middleton Island, one to Yakutat Bay. Data analyses indicate that seals show considerable fidelity to haulout sites and haul out more regularly during May-July. Diving behavior was variable among individuals. Seals that moved out of PWS made longer feeding trips than those within PWS. Fatty acid analyses found differences in seal prey by species, area, and season. Fatty acid signatures indicated differences in seal diets between southeast Alaska, Kodiak and PWS, and between areas within PWS.

Key Words: Behavior, diving, *Exxon Valdez* oil spill, fatty acids, habitat use, harbor seal, movements, *Phoca vitulina richardsi*, population modeling, population monitoring, Prince William Sound, recovery, satellite telemetry.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES--Continued.

LIST OF FIGURES

LIST OF FIGURES--Continued.

Page

EXECUTIVE SUMMARY

Harbor seals (*Phoca vitulina richardsi*) and their habitats in Prince William Sound (PWS) were impacted by the *Exxon Valdez* oil spill. Natural resource damage assessment (NRDA) studies estimated that about 300 harbor seals died in oiled areas of PWS. The impacts of the spill on harbor seals are of particular concern since the number of harbor seals in PWS had declined by over 40% from 1984 to 1988, and similar declines have been noted in other parts of the northern Gulf of Alaska. Because of concerns for harbor seals, a restoration science study was designed to monitor their trend in numbers, and to gather data on their habitat use and behavior.

Results of harbor seal restoration studies conducted from 1991 through October 1994 were reported previously. This report describes work done under Restoration Science Study No. 95064 from October 1994 through September 1995. Emphasis is on analysis of the trend in seal numbers during 1989-1995, and on presentation of data collected from satellite tagged seals during September 1994-July 1995. Some preliminary analyses are presented incorporating data from all 30 seals satellite tagged in 1992, 1993, 1994, and spring 1995. Preliminary results of fatty acid signature analysis of seals and seal prey, and from development of a population projection model, are also reported.

In 1995, aerial surveys were again flown during pupping and molting at 25 trend count haulout sites that have been used for NRDA and other studies. Unadjusted counts were lower during pupping and higher during molting. For trend analysis, counts were adjusted using parameter estimates from a generalized linear model that took into account effects of date, time of day, and time relative to low tide. Adjusted molting period counts were 19% lower in 1995 than in 1989 while adjusted counts of non-pups during pupping were 31% lower. Both molting period and pupping period declines were statistically significant. Compared with 1994, adjusted molting period counts were 16% higher in 1995 while pupping counts were 12% lower. The mean pup count in 1995 was the lowest ever recorded, and was 26% lower than the 1989 count. These results show that harbor seal numbers in PWS have not yet recovered. The apparent increase in numbers seen in 1995 molting counts may be the beginning of a recovery, a short-term variation, or a survey artifact. The decline of pupping period counts from 1994 to 1995 indicates that it would be premature to conclude that an increasing trend has begun.

The model showed that meteorological conditions (wind speed, cloud cover, and air temperature) also have statistically significant effects on seal counts. Weather parameters will be incorporated into the model and trend analysis after 1996 surveys.

A power analysis using revised adjusted counts and variances confirmed that adjusted molting counts provide a reasonable method for correctly detecting a population increase of 5% per year over a 5 year period. Pupping counts, even after adjustment, have very little power to detect trend, and therefore pupping surveys will be discontinued as a monitoring tool.

A new life table was developed based on information from Alaskan harbor seals collected in the 1970s. Age-specific survival and reproductive rates derived from the life table were used in a Leslie matrix population projection model. Sensitivity analyses showed that changes in survival, especially for the younger age cohorts, had the greatest effect on population growth. Simulations of the decline in seal numbers documented for 1984-1988 and 1988-1989 showed that large changes in vital parameters (survival, reproduction, or both) must have occurred during these time periods.

Preliminary results from 10 year population projections varied depending on the carrying capacity level assumed and the pattern of density dependent response incorporated in the model.

Forty-two seals were captured, sampled, and tagged in 1995. Eight satellite-linked depth recorders (SDRs) attached in September 1994 transmitted for 40-267 days, and six SDRs attached to seals in May 1995 transmitted for 48-77 days. For all 30 SDRs, the average duration of operation was 64 days for those attached in spring and 153 days for fall. On average the 30 seals were located on 80% of the days transmitters were operating, with an average of 3.1 locations received per day.

Six of the eight seals tagged in September 1994 stayed within PWS; movements of five were confined to near where they were captured while the sixth made trips to glaciers in the northern Sound. One seal moved to Middleton Island where it spent the period from late September through mid May. The other moved about 400 km to the east, and spent October through February using Yakutat Bay and an area 90-150 km offshore in the Gulf of Alaska. All six seals tagged in May 1995 mostly stayed in PWS during the tracking period. These results are similar to the movements of the other 16 seals tracked in 1992 and 1993. The majority have stayed within PWS spending most of their time near the location where they were captured. A few have made trips to tidewater glaciers in northern PWS, or moved out into the Gulf of Alaska.

Most seals hauled out principally at the capture location and adjacent haulout sites. An analysis of haulout site use of all tagged seals showed that within each month seals on average used only a few sites (1.4-3.6) and that they used a "preferred" site 65%-87% of the time. There was a strong seasonal difference with more haulouts used during May-July (mean 3.8) than September-March (mean 2.3), but only relatively small age- or sex-related differences. Eleven of the 14 seals tracked in 1994-1995 were at the tagging location or an adjacent haulout when the transmitters failed, 2 were at sea in PWS, and 1 was offshore from Yakutat. Of the 30 total tagged seals, 29 were in PWS at the time they were last located; 24 were at the tagging location or an adjacent haulout and the other 5 were 5-30 km away. An analysis of land-sea sensor data from the 30 seals indicated that individuals hauled out on 44%-69% of the days they were tracked during September-April and 74%-80% of days during May-July.

Preliminary analysis of dive data showed considerable seasonal and diurnal variability among individual seals. Two seals that moved out of PWS into the Gulf of Alaska showed a pattern of occasional haulouts alternating with extended feeding trips lasting up to 20 days. Seals that stayed within PWS showed shorter feeding trips (less than 8 days) and hauled out more frequently. To date, individual variability has made it difficult to analyze dive data for patterns due to factors such as age and sex of the seal, location, and time of year. Statistical methods need to be developed so that dive data can be fully analyzed and interpreted.

Fatty acid types have been analyzed from 84 seal blubber samples and from 163 potential seal prey. Preliminary analysis of fatty acid signatures indicated differences in the diets of seals from PWS, southeast Alaska, and the Kodiak area. Within PWS there were differences between seals sampled near Montague Island and those from the northern and eastern Sound. Fatty acid signatures of prey such as pollock and herring differed by species, collection area, and season. Additional sampling and fatty acid analyses should provide detailed information on the current diet of seals. Results from stable isotope studies, prey availability studies, seal satellite-tagging, and historical information on food habits from stomach contents will be evaluated in conjunction with results from fatty acids to describe the feeding behavior and trophic relationships of harbor seals in PWS.

It is essential to continue to monitor the trend in abundance of PWS harbor seals, using adjusted counts from replicate aerial surveys conducted during the molt. Additional population modeling should be done to explore the potential importance of factors that may be limiting harbor seal recovery. Satellite-tagging studies should be continued until there are sufficient data to describe the movements, diving behavior, and haulout use of harbor seals in PWS. Samples should be taken from seals captured for tagging for use in studies of physiology, genetics, stable isotopes, and fatty acids.

INTRODUCTION

Harbor seals, *Phoca vitulina richardsi*, are one of the most common marine mammal species in Prince William Sound (PWS), where they occur throughout the year. Harbor seals are seen primarily in the coastal zone where they feed, haul out to rest, give birth, care for their young, and molt (Pitcher and Calkins 1979). Hauling out areas include intertidal reefs, rocky shores, mud bars, floating glacial ice, and gravel and sand beaches. Pups are born at the same general locations that are used as haulouts at other times of year.

The exact number of harbor seals inhabiting PWS is unknown. Beginning in 1983, the Alaska Department of Fish and Game (ADF&G) began conducting repetitive aerial counts at selected haulouts to monitor population trend. Between 1984 and 1988, for unknown reasons, the number of seals at the 25 trend count sites in eastern and central PWS declined by 40% (Pitcher 1986, 1989).

On 24 March 1989, the *T/V Exxon Valdez* ran aground on Bligh Reef in northeastern PWS, spilling approximately 11 million gallons of crude oil. Studies conducted as part of the Natural Resources Damage Assessment (NRDA) program documented a substantial impact of the spill on harbor seals (Frost and Lowry 1994*a*). The decline in seal numbers from 1988 to 1989 was significantly greater at oiled than at unoiled sites, and pup production was reduced at oiled sites in 1989 (Frost et al. 1994). Calculations indicated that about 300 seals died due to the spill, and that pup production was about 26% lower than normal.

Because of the decline in harbor seals, which was exacerbated in the area impacted by the spill, it is particularly important to try to determine what factors are limiting the population. Because seal numbers were declining before the spill, it cannot be assumed that the number of seals in oiled areas will return naturally to pre-spill levels. Therefore, continued monitoring of the population trend is needed to determine if recovery is occurring.

To facilitate recovery of seals in PWS it will also be necessary to identify and appropriately manage areas of particular biological significance. Most of the information available on harbor seals in PWS prior to the spill consisted of counts of animals on haulouts during molting. As part of NRDA studies additional counts were made during pupping. While those data are useful for monitoring changes in overall abundance, they provide little insight into the causes for the ongoing decline, nor are they adequate for designing conservation and management measures. Information is needed on site fidelity, movements between haulout sites, seasonal changes in hauling out patterns, habitats used for feeding, and feeding behavior.

Satellite-linked telemetry can be used to gather information on these important aspects of harbor seal biology (e.g., Stewart et al. 1989, Boveng et al. 1989). Beginning in 1991, the oil spill harbor seal restoration studies included attachment of satellite-linked depth recorders (SDRs) to seals to examine their behavior and habitat use (Frost and Lowry 1994*b*, Frost et al. 1995).

As top level predators, harbor seals are likely to affect, and be affected by, other components of the ecosystem in PWS. Because of the need to understand how harbor seals function in the ecosystem, this restoration study has increasingly emphasized a broad approach to research on the nutrition, energetics, and health of harbor seals. Working in conjunction with researchers at the University of Alaska, Fairbanks, (Dr. Michael Castellini and Brian Fadely) all seals captured have been measured, weighed, and blood-sampled. Blood has been analyzed for a variety of hematological and chemical parameters. These results have been reported separately in preliminary reports (Fadely et al. 1994*a*,*b*), and in the annual report for project 95001. Vibrissae have been collected for a study of stable isotope ratios and supplied to researchers at the University of Alaska, Fairbanks (Dr. Don Schell and Amy Hirons, Project 96170). Stable isotope results will be reported separately. Blood serum samples have been screened for disease as part of an ongoing investigation being conducted by ADF&G. Results were summarized in the 1995 annual report for this project (Frost et al. 1995) and are currently being prepared for publication.

Recently, a new method has been developed for investigating marine food webs through the use of fatty acid signatures (Iverson 1993). Fatty acids are essentially the building blocks of lipids. Organisms are able to biosynthesize and modify fatty acids, but there are biochemical limitations and differences in these processes depending on the organism. Some fatty acids cannot be synthesized by certain animals and therefore can only originate from diet. Because of this, some fatty acids in the food chain can be attributed to specific origins (Cook 1985). Lipids from marine organisms are characterized by a complex array of fatty acids. There are substantial differences in fatty acid composition among species and prey types, as well as within species by geographic region (e.g., Ackman et al. 1975, Iverson 1993). In marine mammals, dietary fatty acids are often deposited in body tissue without modification (Iverson et al. 1992, Iverson et al. 1995). Consequently, it is possible to trace fatty acids obtained from the diet and to compare arrays in the tissues of the predator to those in the prey consumed. Starting in 1994 and continuing in 1995, we collected and analyzed samples needed to investigate fatty acids in PWS harbor seals and their prey.

Restoration studies of harbor seals in PWS are continuing, and therefore some of the results presented in this report are preliminary. This report contains a detailed analysis of the recent trend in numbers of harbor seals based on pupping and molting surveys, and a final revision of the model that was developed to adjust survey counts. The behavior of 30 satellite tagged seals is described in some detail. However, some tags attached in September 1995 are still operational and more SDRs will be attached in the future, so full statistical analysis of movements and diving will be presented in later reports. A newly developed harbor seal population model is described and some initial simulations are presented. Results of fatty acid studies to date are described and included in this report as Appendix A.

OBJECTIVES

The objectives of this restoration study for 1995 were:

1) to monitor and assess the trend in numbers of harbor seals in PWS:
   a) conduct aerial surveys of harbor seals at 25 trend count sites in PWS during pupping and molting;
   b) conduct a multivariate analysis of aerial survey data to evaluate the effects date, time of day, time and height of low tide, and weather on survey counts;
   c) compare data from 1995 surveys to data collected during 1989-1994 to determine whether seal numbers are recovering;

2) to describe habitat use by harbor seals in PWS:
   a) describe hauling out and diving behavior, and by inference, feeding behavior of satellite tagged seals in PWS relative to date and time of day;

b) describe use of haulouts and frequency of movements between haulouts;
c) to determine movement patterns within PWS and between PWS and adjacent areas;

3) to investigate the trophic relationships of harbor seals in PWS:
a) determine fatty acid composition of blubber from PWS harbor seals;
b) determine fatty acid composition of prey species;
c) use statistical analysis of fatty acid signatures in blubber and prey to determine harbor seal prey and to compare diets of harbor seals;

4) to develop a model that can be used to evaluate the effects of age-specific reproduction, predation, subsistence harvesting, and other sources of mortality on harbor seal trend; and

5) to provide samples to and assist other researchers who are investigating genetics, stable isotopes, blood chemistry, morphometrics, disease, and other factors that may be affecting harbor seals.

METHODS

Aerial Surveys

Aerial surveys were conducted in PWS along a previously established trend count route (Calkins and Pitcher 1984; Pitcher 1986, 1989). The trend count route covered 25 haulout sites, and included 7 sites that were substantially impacted by the spill and 18 unoiled sites that were north, east, and south of the primary area impacted by oil (Table 1, Figure 1).

Survey methods were identical to those used during the NRDA harbor seal study (Frost and Lowry 1994*a*, Frost et al. 1994) and harbor seal restoration studies in 1992-1994 (Frost and Lowry 1994*b*, Frost et al. 1995). Surveys were conducted from a single engine fixed-wing aircraft (Cessna 185). Visual counts of seals were made at altitudes of 200-300 m, usually with the aid of 7-power binoculars. Each site was circled until the observer was confident that an accurate count had been made. For larger groups of seals (generally those of 40 or more) photographs were taken using a hand-held 35-mm camera with a 70-210 mm zoom lens and high speed film (ASA 400). Color slides were commercially developed, and seals were counted from images projected on a white surface. During June surveys, separate counts were made of pups and non-pups. Replicate counts (usually 7-8) were made at each site. Counts were usually done within two hours before and after low tide.

For each survey the date, time and height of low tide, and time of sunrise and sunset were recorded. As each site was counted the observer recorded time of the count, air temperature, sky conditions, and wind speed according to the categories shown in Table 2. Air temperature, of necessity, was measured at survey altitude.

Analysis of Factors Affecting when Seals are Hauled Out

Complete methods for the analysis of factors affecting the counts of seals were described in Frost et al. (1995) and will not be repeated here. In brief, a Poisson regression was used to analyze the factors that may affect the number of seals hauled out and available to be counted during surveys. This is a generalized linear model (McCullagh and Nelder 1989) with a log link function and a Poisson distribution. To assign an average count to each site in any given year, a model was first used which considered site, year, and the interaction of site by year. Other factors (Table 2) were subsequently added into the model one at a time.

For all surveys, data were complete for time of day, time of low tide, date, and tide height. Each of these factors was first entered into the model one at a time. The factor with the most significant χ^2-value was retained in the model, and then other factors were again entered into the model one at a time until any remaining factors were insignificant. Time of day and time relative to low tide were analyzed as categorical data. Initially, time increments before and after midday and before and after low tide were placed in six and eight separate categories (Table 2). Some categories were combined when preliminary analysis indicated that it could be done without changing the fit. Date was centered to 15 June for pupping counts and to 15 August for molt period counts, and scaled so that each day was equal to 0.1. This latter technique is a modification and an improvement of the analysis described in Frost et al. (1995) in which date was neither centered nor scaled.

Using the parameter estimates from the model for time of day, date, and time relative to low tide, the daily count for each site for each year was adjusted to an expected count, for both pupping and molting period data. These adjusted counts should be more comparable across years when, for example, survey dates or the distribution of counts relative to time and tide were not the same.

Additional factors that were not available for all counts were considered separately. These included wind speed, air temperature, and sky conditions. The full model containing site, year, and site by year interactions, along with time of day, date, and time relative to low tide was always fit. An additional factor such as wind speed was then added to see if it significantly improved the fit. Because the number of records with complete data for all three of these meteorological factors was relatively small, no attempt was made to see if, for example, sky conditions significantly improved the fit after including wind speed in the model. Each of these factors was considered separately, and independent of the other. Sky condition was analyzed as five categories and wind speed as four. Because complete meteorological data were not available for all years, the final counts used in trend analysis were not adjusted to account for weather conditions. When complete data are available for five years counts used in trend analyses will be adjusted for weather, if appropriate.

Trend Analysis of Adjusted Aerial Survey Counts

Data were analyzed to determine whether there was an identifiable trend in the counts of harbor seals in PWS since 1989. For each year, adjusted daily counts were averaged for each site and then sites were summed to produce adjusted yearly estimates for the total trend count area.

A linear regression model was fitted to the adjusted 1989-1995 mean count data for the 25 trend count sites combined (see Frost et al. 1995). This was done separately for pupping and molting counts. The significance of regression coefficients was tested using analysis of variance (Snedecor and Cochran 1969).

Population Modeling

A Leslie matrix (i.e., projection model) approach (Taylor and Carley 1988, Caswell 1989, Noon and Sauer 1992) was used to examine the population dynamics of harbor seals in PWS. The model was designed to be used to simulate the response of the PWS harbor seal population to things such as oil spill related mortality, subsistence hunting, or take due to fisheries. Such models examine what would happen to a population if specific environmental conditions were held constant. The model should not be interpreted as a tool to predict what will happen to the population, but rather as a source of information about present conditions. Results of the model should be interpreted on an ecological basis, which requires a clear understanding of the model construction, particularly the manner in which the demographic data were collected and the subsequent assumptions about those data.

The Leslie matrix approach is best suited for "birth-pulse" populations (Caughley 1977). These are populations where the large majority of young are born in a relatively short time period, as is the case with harbor seals. The model is indexed by time intervals that are of equal length for each age class. Model simulations assume that individuals first survive at a specified rate over the defined time interval and then reproduce immediately prior to the beginning of the subsequent time interval. In the present application, the population census occurs immediately after the birth-pulse.

The Leslie matrix requires survival and reproduction rates for each age-class, data that are difficult to obtain. In addition, the model assumes that the population has a stable age distribution, which will result when vital rates (i.e., survival and reproduction) are held constant over time. Finally, a "closed" population is assumed, where immigration equals emigration.

There is a paucity of information on age-specific survival and reproduction of harbor seals in Alaska. The most comprehensive dataset was collected in the Gulf of Alaska during the mid 1970s, and was presented as life tables by Pitcher and Calkins (1979). The method to estimate survival from such data has developed further since these early life tables were published (see Siler 1979, Eberhardt 1985, Barlow and Boveng 1991, and York 1994 for examples). Thus, we used the mid-1970s data to construct a new life table of age-specific survival and reproduction rates.

We selected the Weibull model to derive our estimates of harbor seal age-specific survival rates. This is the same statistical technique that was utilized to estimate the survival of Steller sea lions (*Eumetopias jubatus*) (York 1994). The Weibull model is a simple extension of the exponential model (constant survival model) and allows for a decreasing or increasing mortality rate as age increases (Lawless 1982). Age-specific reproduction rates were estimated directly from the percentage of pregnant females in the sample, except for ages 8-25 which were assumed to have a constant reproduction rate equal to the mean for those ages. The following sex ratios were derived from the number of males and females within the sample: ages 0-4, 50:50; ages 5-20, 47:53; and ages 21-30, 22:78.

We assumed the harbor seal population from which the sample was collected was stationary (i.e., population growth rate of zero) with a stable age distribution. Survival during the first 4 years after birth was adjusted to achieve such conditions, due to the lack of a representative sample for those age-classes in the dataset. Basically, we assumed survival for ages 1-3 was slightly lower than survival estimate for 4 year-olds, with pup survival approximately half that of 1 year-olds. A new life table of age-specific survival and reproduction estimates, and subsequent stable age distribution, was calculated using the Weibull model (Table 3). Those values were used in the baseline model for simulations.

We derived annual estimates of the total number of seals in PWS for each year since 1988 based on counts at ADF&G trend sites and other sites in northern and western PWS. Adjusted molt counts for each year were used for trend sites surveyed by this project. For 1992 and 1993, unadjusted mean counts were used for sites counted in northern and western PWS (Burns, unpublished data; Loughlin 1992). For years when northern and western PWS was not counted we made the assumption that the relationship between seal numbers in that region and in the ADF&G trend route had remained constant over time. We used the 1992 and 1993 counts in the two areas to establish a ratio (1.877) and applied that factor to the yearly count from the trend route to estimate seal numbers in the uncounted region. A correction factor for seals that were in the water and not available to be counted during surveys (1.61; Small and DeMaster 1995) was applied to the total uncorrected count to derive the total yearly population estimates. These estimates do not include seals in the Copper River delta.

To run simulations with the model an estimate of the carrying capacity (K) of the PWS environment is required. There are no direct estimates of K for harbor seals in PWS under present conditions, or in previous years when higher population levels were recorded. For model simulations we first set K to 8,662 which was the estimated total population size in 1988, the model year including the *Exxon Valdez* oil spill. We later set K to 5,281 which was the estimated total population size in 1995.

Simulation modeling requires information on how vital parameters respond to changes in population density. Information on density dependent responses of harbor seals is currently not available, but evidence for other seal species does exist (Eberhardt and Siniff 1977, Siniff 1984, Fowler 1987). Using this information, we developed density dependent functions to simulate how specific vital parameters would change with density. Theoretically, survival and reproduction rates fluctuate such that a population remains at K. For example, when population size (N) is less than K, enhanced survival and reproduction should result in a positive growth rate and the population should increase toward K. Survival and reproduction reach their maximum levels at densities near zero, when the maximum possible population growth rate, R_{MAX}, occurs.

We used a standard density dependent function which is comprised of three main components: (1) $Surv_K$, the survival at K; (2) $Surv_{MAX}$, the maximum possible survival rate; and (3) *z*, a 'shape' parameter, which determines how quick the response is from $Surv_K$ to $Surv_{MAX}$. A linear density dependent response results when *z* is set to one, whereas values of *z* greater than one result in a non-linear response. Using these three components, survival at any population size N (i.e., $Surv_N$) can be determined according to the following equation:

$$Surv_N = Surv_K + (Surv_{MAX} - Surv_K) * [1 - (N/K)^Z]$$

An identical function using $Repro_K$ and $Repro_{MAX}$ was used for applying density dependence to reproduction.

We assumed an R_{MAX} of 12%, based on empirical (Olesiuk et al. 1990) and theoretical (Barlow et al. 1995) evidence. The other major assumptions were to determine which vital parameters would be density dependent, their respective shape parameters, and the values of $Surv_{MAX}$ and $Repro_{MAX}$ needed to achieve an R_{MAX} of 12%. Eberhardt and Siniff (1977) proposed the following hierarchy of density dependent responses: (1) juvenile survival, (2) age of sexual maturity, (3) reproduction of adult females, and (4) adult survival. Using this proposed hierarchy as a guide, and our baseline vital parameters values, we generated the following sequence of density dependent responses: (1) survival of seals aged 0-3, $z = 4$, (2) reproduction of seals aged 4-7, $z = 3$, and (3) survival of seals aged 4-10, $z = 2$. We did not decrease the age of sexual maturity to below 4 years, as there is no empirical evidence that 3 year old harbor seals are capable of giving birth, even at very low population levels. We considered the z values above as 'strong' density dependence, and then decreased the z values by 50% to simulate a 'weak' density dependent response.

Because there are no data from Alaskan harbor seals on density dependent changes in survival and reproductive rates, it was necessary to estimate the kinds of changes of that would bring a reduced population back to a stable state. Specifically, we had to assume that survival and reproduction for certain age-classes would increase with a decrease in population density, and also assume values of maximum survival and maximum reproduction for those age classes that would result in a maximum growth rate of 12% when the population was near zero. Table 4 shows which age classes we assumed to exhibit density dependent survival and/or reproduction, and the values of those vital parameters at both K and near zero. The resulting non-linear 'strong' density dependent responses for a few of these selected parameters are shown in Figure 2.

The baseline model discussed above assumes age-specific survival and reproduction schedules that result in a stationary population; i.e., population growth equals zero. Changes in either of these vital parameters, in any age class, results in a non-zero population growth rate. However, based on model structure, such changes would be in effect for the entire simulation period. We also wanted to conduct population projections with age-specific levels of additional mortality that could vary from one year to the next. Additional mortality could include such things as the death of seals in 1989 from the spill, subsistence harvest by Alaska Natives, or mortality due to disease or killer whale predation. Thus, we allowed age-specific 'additional mortality' to be incorporated into any year of model simulation. Such mortality was considered completely additive to the mortality derived from the baseline survival parameters. The only compensatory function was the density dependent response described above. Data for the subsistence harvest were obtained from Wolfe and Mischler (1995) and Mischler (unpublished data). For some pre-spill years when the subsistence harvest at Chenega and Tatitlek was not monitored, we assumed that the annual harvest level was equal to the mean harvest documented during pre-spill years.

Capture and Tagging of Seals

Field work was conducted at locations throughout PWS during May and September 1995. Personnel were transported from Whittier to the study sites aboard the chartered vessels *Provider* or *Pacific Star*.

Seals were caught by entanglement in nets deployed near their haulouts. Nets were approximately 100 m long and 7.4 m deep with a float-core line and lead line. The size of openings was 15 cm (30 cm stretch mesh). Nets were set from a 6-m Boston Whaler, as close as possible to areas where seals were hauled out and where they were likely to become entangled as they went in the water in response to the presence of people and boats. A 5-m Whaler and a 4-m Zodiac raft were used to help set and tend the net. When seals became entangled they were brought into the boats, cut free from the tangle net, and put into hoop nets (large stockings made of 1 cm mesh soft nylon webbing). Seals were either taken to shore to be worked on, or were processed on the support vessel.

Some seals could be physically restrained during handling and tagging. Larger animals were sedated with a mixture of ketamine and diazepam administered intramuscularly at standard doses (Geraci et al. 1981). Each seal was weighed, measured, and tagged in the hindflippers with individually numbered plastic tags. Approximately 50 cc of blood was drawn from the extradural intervertebral vein and the following samples were collected: whiskers for stable isotope analysis (Project 96170), flipper-punch skin samples for genetic analysis (G. O'Corry-Crowe and R. Westlake, Southwest Fisheries Science Center, La Jolla, CA), blubber biopsies for analyses of fatty acids (S. Iverson, Dalhousie University) and energy content (M. Castellini, University of Alaska Fairbanks, Project 96001), and muscle biopsies for a study of mitochondrial density in locomotor and non-locomotor muscles (S. Kanatous, Texas A & M University).

SDRs were glued to the mid-dorsal surface of the seal using Devcon quick setting epoxy (Fedak et al. 1984, Stewart et al. 1989). The SDRs were manufactured by Wildlife Computers (Redmond, WA), and produced 0.5 watts of power. Six of the units deployed in 1995 measured 14.8 x 10.0 x 3.8 cm, weighed about 750 g, and were powered by four lithium C cells. They were attached only to larger seals, generally those weighing more than 40 kg. A smaller version which measured 11.9 cm x 5.1 cm x 4.5 cm, weighed 385 g, and was powered by six lithium 2/3 A cells was attached to smaller seals, weighing as little as 28 kg. All 0.5 watt SDRs used version 3.10 software. In addition, in fall 1995 we attached one test unit of a 0.25 watt transmitter with timeline software (version 3.13).

SDRs were equipped with conductivity and pressure sensors, and programmable microprocessors that collected and summarized data for periods when animals were diving and stored it for later transmission, as has been done for spotted seals (*Phoca largha*), crabeater seals (*Lobodon carcinophagus*), and Steller sea lions (Lowry et al. 1994*a*,*b*; Hill et al. 1987; Bengtson et al. 1993; Merrick et al. 1994). Dive depths, dive durations, and the amount of time spend at depth were stored in six hour blocks (0300-0900 hrs, 0900-1500 hrs, 1500-2100 hrs, and 2100-0300 hrs local time) and transmitted to the satellite once the six hour period was complete. Data from four periods were stored in memory providing at least a 24-hour window for transmission before the data were lost. Data were accumulated in 10 bins as follows: 4-20 m, 21-50 m, 51-75 m, 76-100 m, 101-150 m, 151-200 m, 201-250 m, 251-300 m, 301-350 m, and over 350 m; and 0-2 minutes, >2-4 minutes, >4-6 minutes, >6-8 minutes, >8-10 minutes, >10-12 minutes, >12-14 minutes, >14-16 minutes, >16-18 minutes, and greater than 18 minutes.

Each SDR transmitted information to a National Oceanic and Atmospheric Administration polar-orbiting satellite whenever the antenna broke the surface and a satellite was positioned such that it could receive the signal. As described above, two sizes of SDRs were used with different battery capacities. The larger units had a projected capacity of about 100,000 transmissions, while the smaller units were rated for approximately 30,000 transmissions. Based on voltages reported on status messages, the larger units we have attached have very rarely gone off the air because the batteries were drained. Therefore, we program all of those units to transmit 24 hours every day. The smaller SDRs have less initial battery power, and if allowed to run constantly they would likely stop transmitting after approximately two months. Therefore, all the small units were programmed to transmit only during periods with good satellite coverage of the PWS region (0300 to 2300 hours local time). Also, those deployed in September were duty-cycled: SDRs attached in September 1994 were set to transmit for one day followed by one day of no transmissions, and those attached in September 1995 were set for a transmission cycle of one day on and two days off. The duty cycle setting in the SDRs is based on Greenwich mean time, and therefore based on local time the transmission cycles were: in fall 1994 units transmitted from 1400-2300 on one day and 0300-1400 on the next day, while in fall 1995 they transmitted from 1400-2300 on day 1, 0300-1400 on the day 2, and not at all on the day 3.

Satellite Tag Data Analysis

Data from satellite tagged seals were obtained from Service Argos. The Argos system recorded the date and time of each uplink and calculated a location for the SDR based on Doppler shift whenever sufficient signals were received during a satellite pass. When only one uplink occurred during a satellite pass, sensor data were recorded but no location was calculated. Fancy et al. (1988), Stewart et al. (1989), and Mate (1987) provide additional description and analysis of the Argos system and its application to marine mammal tracking.

For analysis and presentation of data, dates and times reported by Service Argos were converted to true local time from Greenwich mean time by subtracting 10 hours. The correction we used for true local time is not equivalent to the corrections normally used for Alaska standard time (-9 GMT) or Alaska daylight savings time (-8 GMT). However, the minus 10 correction accounts for the actual position of the sun, and makes mid-day occur at approximately 1200 hours.

The accuracy of location calculations varies based in part on the number of uplinks that occur during a satellite pass. Service Argos assigns a quality ranking to each location. On June 15, 1994 Service Argos changed the methods used for evaluating and categorizing location qualities. Prior to June 1994 locations resulting from standard data processing were ranked as 1, 2, or 3, with quality 3 the best. Special data processing provided locations from satellite passes with few uplinks or other potential problems. Such locations were assigned a quality of 0 and given a location indicator value of 0 to -10. After June 15, 1994 standard data processing produced location qualities 0, 1, 2, and 3, while locations from special processing were assigned a letter designation (A, B, or Z).

For previous reports we started with all location records obtained from Argos and screened them for erroneous data based on an error index and the distance and speed between adjacent locations (Frost and Lowry 1994, Frost et al. 1995). Inspection of the resulting datasets indicated that many erroneous locations remained (e.g., locations that plotted far from the water in mountainous terrain), and for that reason we generally used only quality 1-3 records for describing seal distribution and movements. However, further detailed examination of those datasets indicated that this procedure resulted in the elimination of many potentially useful location records, especially when the animals were at sea. Therefore, not using the lower quality records would result in an underestimation of seal movements and habitat use.

For this report a modified system was used for eliminating erroneous location records, as follows. First, records that failed validation tests performed by Argos (given location indicators -10 to -6 prior to June 1994 and assigned class Z after June 1994) were deleted from the database. Then, an error index value (KEI) was calculated for each remaining record according to the equation described in Keating (1994). This value takes into account the distances and relative directions between sequential location fixes, and is used to identify erroneous locations based on the assumption that records indicating a single, relatively large movement followed immediately by a return to a point near the origin are likely to be in error. All location records that had a KEI value greater than 25 were removed from the database. The next step in screening records was to locate and remove erroneous locations based on the apparent movement speeds of the seals. Time, distance, and speed between each sequential pair of fixes were calculated for all location records remaining in the database. A three-stage process was used to flag records that produced improbable movements: 1) apparent speeds of greater than 10 km/hr for a period of greater than 5 minutes; 2) apparent speeds of greater than 100 km/hr for a period of greater than 1 minute; and 3) apparent speeds of greater than 500 km/hr for any length of time. The parameters in 1) are based on the likely sustained swim speeds of harbor seals (Williams and Kooyman 1985), while the latter two identify records that may be erroneous but were too close together in time to be flagged by the first set of criteria. Flagged records were inspected visually, and the locations that were most distant from adjacent records were removed from the database. As a final step, the KEI values were recalculated for the remaining records, and any records with a KEI greater than 25 were deleted. Numbers of location records referred to in this report include only those records that remained after the complete screening process.

With each transmission, SDRs reported the seals as hauled out or at sea based on the status of conductivity sensors. A datafile was created that included the times when sensors indicated that haulouts began and ended. The land-sea sensor data were merged with location records to produce a datafile that included SDR number, date, time, latitude, longitude, location quality, and whether sensors indicated that the seal was on land or at sea. A computer program calculated from this datafile the average location of the seal during each haulout bout and the average daily position for at sea locations. The program also calculated the distance between each sequential pair of average positions. The result was saved as an average position datafile.

The all-location and average-position datafiles were used to produce geographic information system coverages in ArcInfo, and datasets were selected and displayed using ArcView. Figures shown in this report are from the average position datafiles. Average position datafiles were used to determine the locations where seals hauled out and where they were when at sea. The average locations of haulout bouts were displayed in ArcView on a map of PWS, and each location record was assigned to the nearest known seal haulout site. If a location plotted more than 5 km from any known haulout, or if it was approximately equidistant between haulouts, the location of that haulout bout was categorized as unknown. In some cases where nearby haulouts are very close together it was not practical to distinguish which location was actually used. In those instances, if one of the haulouts was where the seal was captured and tagged the positions were assigned to that haulout.

All location data obtained since 1992 were reprocessed using the new methods, and all analyses used all records remaining in the final databases. Results presented here therefore differ somewhat from those presented in previous reports.

Two measures were used in an analysis of site fidelity of seals. The first was the number of separate haulout locations used. The second was an index based on the proportional use of separate haulouts. For each seal in each month it was observed, the proportion of average daily locations was calculated for each haulout used by that seal. The index was the largest of these proportions. The means of these two indices were compared in a mixed model analysis-of-covariance with factors age, sex, and period (period 1 = September-March, period 2 = May-July) and month as a linear covariates (months were numbered from September = 1 to July = 11). The data were divided into periods because only two seals, both adults, had data in both periods; these two seals also had the only data in April, which was not used. We used procedures appropriate for unbalanced samples (SAS Type III, Milliken and Johnson 1984). Individual seals were also included as a nested random factor which was used as the error term for testing hypotheses about age, sex, and period. Satterthwaite's approximation (Milliken and Johnson 1984) was used to adjust these tests for unbalanced samples. Observations in the analyses were weighted by the number of days each seal was located. The maximum proportional use was analyzed untransformed and with an arcsine-square root transformation; the results were the same for both analyses so only those from the untransformed variable are presented. The analyses started with all factors, covariates, and their interactions included. Unimportant factors ($P > 0.05$) were deleted sequentially beginning with the slopes and higher order interactions and continued until all terms left had $P < 0.05$ or were contained in interactions still in the model.

Dive data from SDRs were extracted using software provided by the manufacturer. An error-checking algorithm was used to validate messages. Histogram messages were sorted by date, period, and type, and duplicate messages were removed. In addition, this software extracted status messages which provided information about battery voltage and maximum depth of dive. Custom software was developed to sum dive information by month or a specified range of dates, and within months (or date range) by bin and by period.

Dive data from individual seals were graphed and visually examined for patterns relating to date, time of day, and location. In this report, we present some examples of the dive data that are available. However, these examples only describe the behavior of individual seals, and are of limited use in investigating more general patterns that may be related to age, sex, or geographic location. Statistical methods for the analysis of dive data are currently being developed. Conceptual approaches and accompanying methods for describing and analyzing patterns of seal diving behavior will be described in future reports.

RESULTS

Aerial Surveys

Molting period surveys of trend count sites were conducted in 1984 and 1988 (Pitcher 1986, 1989), and have been done annually since the spill (Frost and Lowry 1994*a*, *b*; Frost et al. 1995). In 1995, the trend sites were surveyed during 17-25 August, and up to eight replicate counts were made at each site (Table 5). The mean count for the trend count area as a whole was 852 seals, which was 26% greater than the mean count in August-September 1994 (678).

Pupping period surveys have also been conducted in PWS during every year since 1989. Pupping period surveys were conducted during 9-16 June 1995, with seven replicate counts at most of the trend count sites (Table 6). The mean count for the trend count route was 485 non-pups and 125 pups. The non-pup count was 17% less than in June 1994 (586) and the pup count was 5% lower than 1994 (132).

Because modeling and power analysis have indicated that unadjusted counts have little likelihood of reliably detecting a trend (Frost et al. 1995), no further analyses of the unadjusted 1995 survey counts were done.

Factors Affecting when Seals are Hauled Out - Molting Period

The multivariate analysis developed in 1995 to model the effects of time of day, date, and time of low tide on seal counts during the molting period was redone including 1995 data.

Parameter estimates changed slightly with the incorporation of new data, but the general results remained the same. Time of day, date, and time relative to low tide all significantly affected the counts. Time of day entered the model first as the most significant factor, followed by date, and finally the time of counts relative to low tide ($P < 0.0001$ for all three). Tide height was not significant. Time of day was collapsed into five categories and time relative to low tide into four. Categories used in the model and parameter estimates are shown in Table 7.

The analysis for time of day indicated that during molting the highest counts would be expected in the period 2-4 hours before midday, and the lowest counts 2-4 hours after midday (Figure 3a). The model indicated that 25% fewer seals would be counted 2-4 hours after midday than in the period 2-4 hours before midday. During late August, sunrise occurs at about 6:30 am local time and sunset at about 9:00 pm, placing midday at approximately 1:40 pm. Therefore, the highest counts would be expected before 11:40 am, intermediate counts between 11:40 am and 3:40 pm, and the lowest counts between 3:40 pm and 5:40 pm.

The highest survey counts relative to tidal stage were from 1.0 hour before to 1.5 hours after low tide (Figure 3b). Maximum counts were for the periods 1.0 to 0.5 hour before low tide and from low tide to 0.5 hour after the tide. The model indicated that about 30% fewer seals would be counted more than 1.5 hour after the low tide than during peak times.

Dates for molting surveys during 1984-1994 ranged from 22 August to 16 September. Because the model developed from the 1984-1994 count data predicted that maximum counts would occur before 22 August, the 1995 surveys began on 17 August, five days earlier than any previous molting surveys. When 1995 data were incorporated, the model again indicated that more seals would be counted during the earliest surveys, and that in fact the maximum number of seals would be expected in early August (Figure 4a). Counts on 31 August are predicted to be 17% lower than counts made on 17 August, while counts on 16 September would be 30% lower than counts on 31 August and 42% lower than those on 17 August.

Wind speed had a significant effect on the number of seals counted during surveys ($P < 0.001$). The four categories used in field data collection were collapsed into two categories for the final analysis. The categories "calm" and "light breeze" were combined, as were "light wind" and "windy". Using these two categories, the model predicted that about 14% more seals would be counted on calm days than on windy days. Sky conditions had a highly significant effect on the number of seals counted ($P < 0.001$). Clear, cloudy, and overcast conditions resulted in counts that were about 27% higher than when it was raining. Air temperature was also significant for molting period surveys ($P = 0.01$). However, temperature increases from 50° to 60° Fahrenheit would be expected to increase counts by only about 1%.

Factors Affecting when Seals are Hauled Out - Pupping Period

As was found for molting period surveys, the primary factors affecting counts of seals during pupping were time of day, date, and the time of counts relative to low tide ($P < 0.001$ for all three). Tide height was not significant. Time of day and time relative to low tide were collapsed into four categories. Categories used in the model and parameter estimates are shown in Table 8.

The analysis for time of day indicated that counts during pupping were highest during the 2 hours before midday and lowest more than 4 hours after midday, when about 17% fewer non-pup seals were counted (Figure 5a). During mid-June, sunrise occurs at approximately 4:10 am and sunset at about 11:15 pm, placing midday at 1:40 pm. Therefore, the highest counts would be expected between 11:40 am and 1:40 pm. Surveys made during the period from 9:40 am to 5:40 pm would yield counts within 4% of each other.

The highest survey counts relative to tidal stage were within 1.5 to 0.5 hour before low tide (Figure 5b). Counts in this period were 8% to 10% higher than other counts made within 1.5 hour before or after low tide.

Dates for pupping surveys during 1989-1995 ranged from 7-27 June. The model indicated 20% more non-pup seals were counted on 27 June than on 7 June (Figure 4b). Counts were relatively consistent (within 3%) from 7 June through 17 June, with a relatively rapid increase thereafter. To examine the effect of date on counts of harbor seal pups, the full model with time of day, date up to a third order polynomial, and time relative to low tide was fit. Based on the adjusted data, it appears that the number of pups counted increases until about 17 June and then declines (Figure 4b). However, none of the polynomial terms for date in the model were significant, even with $\alpha = 0.1$.

Wind speed had a significant effect ($P < 0.001$) on the number of non-pup seals counted during pupping surveys. The four categories used in field data collection were collapsed into two categories for the final analysis. As for molting surveys, the categories "calm" and "light breeze" were combined, as were "light wind" and "windy". Using these two categories, the model predicted that about 17% fewer seals would be counted on windy days than on calm days. Sky conditions also had a highly significant effect on the number of seals counted ($P < 0.001$). High overcast or partly cloudy skies resulted in counts that were about 9% higher than for low overcast conditions and 17% higher than when there was fog, rain, or drizzle, or when it was clear. Air temperature had a relatively small effect on counts, with 1%-3% fewer seals expected at temperatures of 40° or 60° F than at 50° F ($P = 0.02$).

Trend Analysis of Adjusted Counts

Using the model parameter estimates for time of day, date, and time relative to low tide, the expected counts for each site were calculated for the molting and pupping periods. Because incorporation of the 1995 data caused minor changes in all parameter estimates, new adjusted counts were produced for all years.

For molting period surveys, all counts were corrected to 15 August, 2-4 hours before midday, and 1.0 to 0.5 hour before low tide (Table 9). Once adjusted, the molting-period counts for the 25 trend sites combined indicated a very clear overall decrease in numbers from 1989-1995 ($P = 0.02$; Figure 6a). Adjusted counts in 1995 were 19% lower than counts in 1989 and 65% lower than those in 1984 (Table 10). The adjusted counts in 1995 were approximately 16% higher than counts in 1994.

For pupping period surveys, the adjusted counts of non-pup seals were corrected to 15 June, 0-2 hours before midday, and 1.0 to 0.5 hour before low tide (Table 11). As for the molting period, the 1989-1995 pupping period counts also indicated a significant decline ($P = 0.02$; Figure 6b). Unlike 1995 molt-period counts which were higher than in 1994, the 1995 pupping counts declined by an additional 12% (Table 12). Overall, pupping period counts were 31% lower in 1995 than in 1989. Because polynomial terms in the model were not significant no correction was made to the annual counts of pups. Unadjusted pup counts were also lower in 1995 than in 1994 (Figure 6b), and overall there were 26% fewer seal pups counted in 1995 than in 1989.

Model Simulations

The actual age-specific changes in mortality or fecundity that have occurred since harbor seals were collected and sampled in the mid-1970s are unknown; all that is known is that the population has had a negative growth rate. Thus, there is no known change in a specific demographic parameter (e.g., increased mortality of pups or lower fecundity in juvenile females) for which we can modify the base-line model. However, because it is important to know what kinds of changes in the parameter values might result in the observed decline, we conducted analyses to determine how sensitive population growth was to changes in the vital demographic parameters. The results of these sensitivity analyses (Figure 7) indicate the relative change in the growth rate with a change in survival or reproduction. As expected for a long-lived species, changes in survival had a substantially greater impact on population growth than did changes in reproduction. For changes in survival, the influence of the youngest cohorts (pups to 4 year-olds) was greatest, followed by a general decrease in sensitivity with increasing age. For changes in reproduction, the sensitivity curve is slightly different, because reproduction doesn't occur in pups to 3 year-olds, and is minimal for 4 year-olds. Thus, population growth is most sensitive to changes in reproduction for seals between 5 and 10 years old, and then a similar decrease in sensitivity with increasing age is observed.

Based on the results of the sensitivity analysis and the density dependent functions described above, we selected the following groups of age classes for the model simulations: for survival (1) pups, (2) 1-3 year-olds, (3) 4-10 year-olds, and (4) 11-30 year-olds; and for reproduction (1) 4-7 year-olds and (2) 8-10 year-olds. We then used these cohorts to examine the magnitude of changes in vital parameters that would result in the observed population decline, assuming the absence of any density dependent response. Recorded estimates of the subsistence harvest were entered directly as additional mortality to that simulated by age-specific survival rates.

Simulations of the 1984-1988 estimated population decline from 14,937 to 8,662 seals showed that large changes in vital population parameters (age-specific reproduction, survival, or both) would have been required for such a decline to occur. Obviously, there are many different combinations of parameters that would result in a negative growth rate equal to the observed rate of decline. We examined 15 different scenarios to determine the level of changes in survival and/or reproduction that would result in this decrease (Table 13). The results demonstrate that substantial decreases in survival would have had to occur for the population to decline at 12.7%/year. For example, pup survival would have to decrease 37% (i.e., 42% to 5%), or a similar decrease of 36% would have to occur among 1-3 year-olds. Among prime aged adults (4-10 year-olds), a decrease of 15% would cause the decline, whereas among the remaining older cohorts (11-30 year-olds) a 45% decrease would cause the decline. If all cohorts were to suffer a decrease in survival of 5.9%, the population decline of 12.7% per year would occur due to the decreased number of pups born from a smaller population.

As expected from the sensitivity analysis, much larger decreases in reproduction would have to occur to result in a decrease of 12.7%/year; e.g., a 53% decrease among all reproducing females, or an 83% decrease among 8-30 year-olds. Even if all 4-7 year-olds did not reproduce the decrease would not be as severe as that observed from 1984-1988. Decreases in survival of about 15-30% were still required when reproduction was decreased 50% for either 4-7 year-olds or 8-30 year-olds.

The estimated population of seals in PWS declined from 8,662 to 6,512 between 1988 and 1989, a one year decrease of 24.8%. The largest annual subsistence harvest (699 animals) was recorded that year, along with an estimated 300 deaths attributed to the oil spill. We examined the same combinations of reductions in survival and reproduction described above that could result in such a decline (Table 14). The changes in vital parameters that would result in the 1988-1989 decline varied greatly depending on the cohorts considered. For example, an 86% decrease over baseline in reproduction among 8-30 year-olds or a 48% decrease in survival among 11-30 year-olds would be required. Although the actual rate of population decline was almost double for 1988-1989, the simulated decreases in vital rates are just 3% more than modeled rates required to simulate the 1984-1988 decline. In contrast, the simulations required substantially greater decreases for survival among 4-10 year-olds (27% compared to 15%) and for survival of all age cohorts combined (10.3% compared to 5.9%) to achieve the observed decline in 1988-1989.

Following the spill the population decline continued, but at a much slower rate. From 1989 to 1995, the population declined from 6,512 to 5,281, or about 3.4%/year. If subsistence harvest was considered as mortality that was completely additional to natural mortality, the harvest alone would result in a 4.0%/year decline. Thus, an analysis similar to the ones presented above was not possible, unless we assumed that the vital parameters had increased from their baseline values.

We conducted 10-year population projections starting with the estimated 1995 population of 5,281 to examine the interrelationships between K, additional mortality, and density dependence. We ran simulations with two levels of K (corresponding to the 1988 and 1995 population levels) and both the 'strong' and 'weak' density dependent functions desc..bed above, along with three levels of additional mortality (300, 200, 100).

The population level achieved after a 10-year simulation was most dependent on the assumed level of K. The strength of the density dependent response ('strong' or 'weak') determined how quickly that level was achieved. Specifically, when K was set at the 1988 population level of 8,662 all projections increased from the 1995 level of 5,281 towards K, but the population growth rate was higher under a strong density dependent response (Figure 8) than a weak response (Figure 9). Under a strong response with additional mortality set at 100, the population level after 10 years was 8,395 whereas it was 7,450 under a weak response, a difference of 945. The difference in population size after 10 years between a strong and weak density dependent response increased to 1,222 and 1,423 for additional mortality levels of 200 and 300, respectively.

The effect of additional mortality on the achieved population level and the population growth rate was slightly less pronounced under a strong density dependent response. Population growth rates after 10 years were slightly higher under a strong response than under a weak one, except for the simulation with additional mortality set at 100. For this simulation, K had almost been reached after 10 years under the strong response and the growth rate was 1.7%, the lowest for all simulations with K = 8,662.

When K was set to the population level at the start of simulations (i.e., 5,281) all projections began with a negative growth rate due to additional mortality. Under strong density dependence, all projections had reached a positive growth rate after 7 or 8 years and were stabilizing at levels slightly lower than K minus the amount of additional mortality. Under a weak response, all projections still exhibited a negative growth rate, albeit minimal (0.2 to 1.1%), after 10 years. Overall, population levels predicted by the weak density dependent response were about 250 to 750 less, depending on the level of additional mortality, than projections with a strong response.

Capture and Tagging of Seals

In 1995 we captured 42 seals, and attached 14 SDRs, 6 in spring and 8 in fall (Table 15). SDRs were attached to seals at Port Chalmers (2 in spring and 4 in fall), Stockdale Harbor (2 in spring), Dutch Group (1 in spring), Olsen Bay (1 in spring), Gravina Island (2 in fall), and Little Green Island (2 in fall).

Satellite-linked Depth Recorder Performance

As discussed in a previous report (Frost and Lowry 1994*b*), the prototype 1.0 watt SDRs attached to harbor seals in 1991 produced little in the way of useful results, but the 0.5 watt tags we began using in 1992 usually worked well. In spring and fall of 1994 we attached ten 0.5 watt tags that had a new version of software (version 3.11), all of which failed after transmitting for a very short time (Frost et al. 1995). SDRs with version 3.10 software attached in fall 1994 operated for 40-267 days, while those attached in spring 1995 worked for 48-77 days (Table 16).

The performance of the other 30 SDRs attached from spring 1992 through spring 1995 is summarized in Table 16. For 16 tags attached in May the average duration of operation was 64 days (range 39-87 days). Fourteen tags attached in September operated for an average of 153 days (range 40-312 days). On average, seals were located on 80% of the days that SDRs were operational (range 36%-100%), with the number of locations per operational day averaging 3.1 (range 0.9-8.6).

In fall of 1994, the four small SDRs we attached were duty-cycled to operate one day on and one day off, while the four large SDRs transmitted constantly. The average total operational period for the two types was similar (126 days for duty-cycled and 136 days for not duty cycled), as was the percent of days on which locations were obtained (82% versus 88%). Based on the total operational period, duty-cycled transmitters on average provided substantially fewer locations per day (2.2 versus 3.6).

Although the data have not yet been fully analyzed, it appears that most of the SDRs attached to seals in fall 1995 have worked properly. The exception is one experimental 0.25 watt transmitter with new software that stopped providing locations after 13 days.

Movements and Haulout Behavior

The movements of seals tagged in September 1994 are shown in Figure 10 and are summarized in Table 17. One of the fall 1994 seals (94-4) was tagged at Gravina Island and its movements were confined to the eastern portion of PWS. The other seven were caught at Channel Island and Port Chalmers. Four of those (94-3, 94-5, 94-6, and 94-8) moved little and all relocations were between Green Island and the north part of Montague Island in the general vicinity of the capture location. One seal (94-2) moved from Channel Island to Middleton Island in late September, and spent from then until late May in the area between Middleton and the south tip of Montague Island. It then returned to Little Green Island, near the tagging site. Seal 94-7 spent most of its time near Port Chalmers where it was tagged, but made two short trips to glaciers in northern PWS. Seal 94-1 left PWS in early October and traveled eastward to Icy Bay then to Yakutat Bay, a distance of over 400 km. It then alternated periods of 3-10 days in Yakutat Bay with feeding trips of 11-20 days offshore in the Gulf of Alaska. When their transmitters failed six of the tagged seals were near the tagging location or an adjacent haulout, one was at sea in PWS about 25 km away from the tagging site, and one was in the Gulf of Alaska 450 km to the east.

In May 1995 seals were tagged in three parts of PWS (Figure 11 and Table 17). A seal tagged in the Dutch Group (95-1) and one tagged in Olsen Bay (95-2) both stayed in the general vicinity of where they were captured. Movements of seals tagged at Port Chalmers (95-3 and 95-6) and at Stockdale Harbor (95-4 and 95-5) were also mostly local, except for some short trips into the Gulf of Alaska outside Hinchinbrook Entrance. Five of the six tagged seals were near the tagging location or an adjacent haulout when transmissions ended, and one was at a haulout 22 km away.

Of three seals tagged at Channel Island in fall 1994, only one (94-3) hauled out mostly at the tagging location and adjacent haulouts (Table 18). One (94-2) used mostly Middleton Island while the other (94-1) hauled out mostly in Yakutat Bay. Seal 94-4 hauled out almost exclusively at Gravina Island where it was captured. Three of four seals tagged at Port Chalmers (94-5, 94-6, and 94-8) used only haulouts near the capture area between Little Green Island and northern Montague Island, while seal 94-7 also hauled out at the Columbia Glacier and in Unakwik Inlet.

Of the seals tagged in spring 1995, the animals tagged in the Dutch Group (95-1) and Olsen Bay (95-2) hauled out principally at the sites were they were captured (Table 19). Two seals captured in Port Chalmers (95-3 and 95-6) and one in Stockdale Harbor (95-4) used the capture sites and adjacent haulouts. One tagged in Stockdale Harbor (95-5) did not return there to haul out but rather used primarily Little Green Island.

Data from all 30 seals tracked during 1992-1995 were combined for an analysis of patterns of haulout site use by season, sex, and age (Table 20). For different age/sex categories, the average number of haulouts used in a single month ranged from 1.4 to 3.6, and seals on average used a single haulout 65.4%-87.1% of the time. There were no differences between sexes in the number of haulouts used or the maximum proportional use ($P > 0.05$). For all seals combined, significantly fewer haulouts were used in September-March (mean 2.3) compared to May-July (mean 3.8; $P = 0.002$), and the maximum proportional use was greater during fall-winter (85.2%) than spring-summer (73.8%; $P = 0.008$). Adult seals had a significantly greater maximum proportional use of haulouts than juveniles ($P = 0.019$), but the difference in the number of haulouts used was not significant ($P = 0.790$).

When data were examined on a monthly basis, the change in maximum proportional use of haulouts through time differed among age classes ($P = 0.019$) with adults showing differences between periods ($P = 0.014$) but not within periods ($P = 0.965$), and juveniles showing a change in maximum proportional use within periods ($P = 0.009$) as well as between periods ($P = 0.014$) (Figure 12).

We examined seasonal differences in hauling out behavior by comparing the percent of days per month that each seal hauled out based on land-sea sensor data reported by the SDRs (Table 21). During September through April, seals hauled out on 44%-69% of the days, compared to 74%-80% in May through July when pupping, breeding, and molting occur. The same general pattern was seen in adult males, adult females, and subadults (Figure 13). One pregnant female (95-6) hauled out every day she was tagged during May-July.

Behavior at Sea

Depth of dive histogram information was received summarizing 144,412 dives made by eight seals tagged in September 1994 and 62,990 dives made by six seals tagged in May 1995. For the fall 1994 seals combined, 56% of the total dives were to depths of 20 m or less, and 76% to 50 m or less. Fewer than 3% of the total dives were deeper than 150 m. For individual seals, 34%-99% of the total dives were shallower than 20 m, and 0%-9% were deeper than 150 m (Figure 14). For the spring 1995 seals combined, 76% of the total dives were shallower than 20 m and 94% were shallower than 50 m. None of the dives were deeper than 150 m. For individual seals, 52% to 100% of their dives in May-July were shallower than 20 m (Figure 15).

There was no consistent seasonal pattern apparent in how deep seals dove. Some seals dove deeper than 150 m in all months that they were tagged. Others never dove deeper than 20 m or 50 m. Three adult females (94-5, 94-6, and 94-8) tagged at Port Chalmers in September 1994 spent the 2-4 months they were tagged in the Port Chalmers-Stockdale-Channel Island area diving entirely in water shallower than 50 m (Figure 14). Four other seals tagged at Port Chalmers or Stockdale Harbor in spring 1995 also stayed in the Port Chalmers-Stockdale-Channel-Little Green area and spent almost all of their time diving shallower than 50 m (Figure 15). A subadult male (94-4) that spent September-February in eastern PWS dove to a variety of depths, with 7%-34% of the dives deeper than 100 m. In contrast, a subadult female tagged in eastern PWS in May (95-2) spent all of her time diving to less than 20 m.

There was also considerable variability in the time of day or night during which seals did most of their diving. Of the eight seals tagged in September 1994, three adults (seals 94-3, 94-6, and 94-8) spent a higher proportion of their time diving during the day (9 am-9 pm) than during the night (9 pm-9 am) (Figure 16). Two subadults (94-1 and 94-4) spent the greatest proportion of time diving from 3 am-3 pm. Others differed from month to month. Three of six seals tagged in May 1995 spent a higher proportion of their time diving between 3 pm and 3 am than during the rest of the day (Figure 17). One dove mostly from 9 pm-9 am, and the other two were quite variable.

Seal 94-1, a subadult female tagged at Channel Island in September 1994 moved to Yakutat Bay about a month after it was tagged (Figure 10). It left PWS on about 6 October, hauled out at Icy Bay over 300 km to the east on 16 October, then on 21 October it was at Yakutat Bay another 100 km to the east. During the next four months, this seal made five trips between Yakutat Bay and a feeding area 90-150 km southeast of the mouth of the bay. It spent an average of 15 days per trip at sea (range 11-20 days) with no haulouts. On trips to Yakutat Bay, it hauled out on an average of six consecutive days before returning to sea. On the days when this seal was at sea (presumably feeding), most dives were deeper than 20 m (Figure 18). When it was in Yakutat Bay and hauling out daily, over 50% of the dives were shallower than 20 m. A high proportion of shallow dives also occurred on the days preceding and following haulouts in Yakutat Bay.

Another seal tagged at Channel Island in September 1994 (94-2) also left PWS to feed and haul out in the Gulf of Alaska (Figure 10). This adult male moved to Middleton Island one week after it was tagged and remained in the Gulf of Alaska from late September through mid-May. During this period it made nine extended feeding trips lasting six or more days. Seven of those were to an area about 120 km west of Middleton and 60 km off the southern end of Montague Island, and no locations were available for the other two trips. Mean duration of these trips was 8 days (range 5-11). While the seal was at sea on these extended trips, it made very few dives shallower than 20 m (Figure 19). When the seal was near Middleton, it usually hauled out each day and made many shallow dives. It sometimes remained at sea for a full day, and rarely for 2-3, when apparently feeding in the Middleton area.

Multiple-day trips to sea also occurred for seals that stayed within PWS, but they were usually shorter and less frequent (Figure 20). Adult male 94-3 stayed in the Chalmers-Channel-

Little Green Island area from September-February. It remained at sea for four or more days (range 4-8 days) on five occasions. Adult female 94-5, which stayed in the Chalmers-Channel-Stockdale Harbor area, was at sea continuously for four or more days on five occasions during September to early December. The longest trip was eight days, and most were four days.

DISCUSSION

Aerial Survey Methods

As part of this project we have constructed a model that considered the effects of various factors on the counts of seals in PWS (Frost et al. 1995). Primary factors included in the model that influenced seal counts included time of day, date, and time relative to low tide. The model generated parameter estimates for each of these factors, and the estimates were then used to adjust the actual counts of seals to optimal conditions. These adjusted data were used for annual comparisons and analyses of trend.

Parameter estimates are derived by modeling the entire data set for all years, and each survey provides additional data about the effects of survey variables. Consequently, it is necessary to update parameter estimates each year, and it would not be appropriate to apply parameter estimates developed for 1984-1994 data to the 1984-1995 data set. Because we expect the behavior of seals to be generally similar from one year to the next, there should be only small annual differences in parameter estimates once an adequate number of samples is included in the model. This was in fact the case. A comparison of estimates derived from 1984-1994 data (8 survey years) and 1984-1995 data (9 survey years) indicated no major between-year differences in the modeled relationship between seal counts and the variables we included in the analysis (Figure 21).

There were, however, some consistent within-year differences between the modeled behavior of counts during pupping and molting. A higher and more constant proportion of seals was counted during the late morning and early afternoon for pupping period surveys (Figure 21). Proportions counted earlier and later in the day were similar. A comparison of counts relative to low tide indicated that counts during the molting period fell off sharply when they occurred more than 1.5 hrs after low tide. In contrast, counts during pupping stayed relatively stable in relation to tide. This may be in part because adult females with pups are likely to spend more total time hauled out during pupping than they do at other times of year.

Each time new data are added and parameter estimates are recalculated, the new estimates must be used to adjust both the current year's survey data as well as the counts for previous years. Normally, this should result in adjusted count data that are only slightly different than data reported for previous years. However, adjusted counts based on 1995 parameter estimates (Tables 8 and 10) are quite different than values previously reported (Tables 9 and 10 in Frost et al. 1995). This is due mostly to a change in the way date was scaled in the model, not to annual differences in parameter estimates.

If identical methods are used to calculate parameter estimates for 1994 and 1995, adjusted counts would in fact be quite similar (Table 22). For example, the adjusted total molt-period count for 1994, based on 1994 parameter estimates, was 959. This compares to 984 when updated parameter estimates incorporating 1995 data were used. For 1989-1994, annual differences between counts adjusted using 1994 versus 1995 parameter estimates were 25-58 seals (less than

4%) for the molting period and 0-18 seals for pupping (less than 3%). Thus, the model produces adjusted count estimates that are quite consistent over time. We would expect these differences to become smaller as the data set becomes larger and more representative, and the impact of a single year's data becomes less.

In addition to the parameters considered above, wind speed, cloud cover, and air temperature were all found to have a significant effect on counts. The data for those factors were not systematically recorded until 1992 and the sample sizes available for use in the model have been small. For that reason, we decided not to incorporate meteorological factors into the full model until there were five years of data that included complete information. Weather parameters will be added to the model and analyses after completion of 1996 surveys.

In the 1995 annual report for this project, we presented a power analysis of the aerial survey data, using unadjusted and adjusted counts for both molting and pupping (Frost et al. 1995). The adjusted counts were developed using model parameters for the effects of time of day, date, and time relative to low tide. It was assumed that the goal of PWS harbor seal monitoring is to be able to detect an increase of 5% per year over a five year period with a high degree of confidence that a conclusion of increasing population trend would be correct ($\alpha = 0.05$).

Because of the changes in the adjusted counts resulting from our most recent analyses, it was necessary to rerun the power analysis using the revised adjusted counts and calculated variances (Table 23). Consistent with our previous conclusions, the revised analysis also demonstrated that unadjusted counts during both pupping and molting had very little power to detect trend, regardless of the number of replicates (Figure 22a). Adjusting pupping counts did not improve the situation, but adjusted molting counts were much better. With seven replicate surveys, the analysis predicts a 67% chance that a 5% per year increasing trend will be correctly detected by adjusted molting counts. The power increases to 89% for detecting a 7% rate of increase (Figure 22b).

It is clear from these analyses that adjusting counts to take into account variation in survey conditions greatly improves our ability to detect trend, and that power analysis is a valuable tool in evaluating the utility of particular data sets for monitoring purposes. Using these two techniques, multivariate analysis of the effects of survey variables and power analysis, we have determined that counts of the PWS trend route made during pupping are too variable to use for monitoring trend, even if they are adjusted to account for the influence of measurable factors. In contrast, counts made during the molting period, after adjustment, provide a reasonable monitoring tool.

In many situations, analyses of this kind are not possible because the data have been collected intermittently, inconsistently, or for only a few years. In the case of PWS harbor seals these analyses were possible, and useful, because there was a consistent, relatively long-term data set from which to develop models for use in adjusting data. The PWS example demonstrates the importance of long-term, cost-effective monitoring programs that will allow the evaluation of population trends, and will also provide a way to measure the impacts of human activities or accidents such as the *Exxon Valdez* oil spill.

Trends in Numbers of Seals

The number of harbor seals counted on 25 trend count sites in PWS declined over 40% between 1984 and 1988. That decline was exacerbated by the *Exxon Valdez* oil spill in 1989, when about 300 seals were estimated to have died (Frost et al. 1994). Since then, the number of seals on the trend count route in PWS has continued to show an overall decline based on data collected both during pupping and molting (Table 22). Comparisons of adjusted trend count data from 1989 and 1995 indicate a 19% decline during the molt period and a 31% decline of non-pups during pupping. The 1995 mean pup count was the lowest of any year for which we have data, and was 26% lower than in 1989.

Although the overall trend was similar for pupping and molting period surveys, the annual change from 1994 to 1995 was not. Adjusted pupping period counts declined by 12% in 1995, in contrast to molting period counts which increased by 16%. Such apparently contradictory trends have occurred in other years, for example 1990 when pupping counts increased and molting counts decreased (Table 22). Despite this between-year variation, linear regressions of the data indicate that the declining trends are highly significant for both pupping and molting. If at some point the declining trend reverses, linear regression may no longer be the most appropriate method for examining trend, and statistical methods for evaluating trend will need to be modified.

It is still unclear whether molting period or pupping period surveys provide the most realistic picture of population trend in PWS. However, because within and between-year variances are substantially higher during pupping, those surveys have very limited statistical power. Consequently, we have recommended that only molting period surveys be used for future monitoring of population trend in PWS. No pupping period surveys will be conducted by this project in 1996.

Without additional years of survey data, it is not possible to know whether the 16% increase in the adjusted 1995 molting period counts represents the start of an increasing trend, between-year variation, or is an survey artifact. Modeling efforts using 1984-1994 data predicted that higher counts would occur early in August. Therefore, we intentionally began the 1995 surveys five days earlier than in any previous year (17 August versus 22 August) in part to confirm the relationship between date and counts. However, when the 1995 data were analyzed, the difference in counts was greater than the model predicted based on date alone. Surveys conducted during 17-25 August 1995 resulted in a mean actual count of 854 seals for the trend route, while counts made during 22 August-9 September 1994 averaged only 678. Either the effect of date was greater than the model had predicted using mostly data from later in August and September, or some other factor was responsible for the increased counts. Perhaps 1995 was good year for PWS seals, with unusually high productivity and survival due to short-term changes in their environment. If so and good conditions do not persist, counts may drop in 1996 and fall closer to the overall trend line. Alternatively, it is possible that 1995 may mark the beginning of some change that makes PWS more favorable to seals, and seal numbers may continue to increase. It is important to note that the number of pups counted on the trend route was lower in 1995 than in previous years, which is not consistent with a scenario of higher productivity resulting in population increase.

Power analysis of survey data shows that it will not be possible to reliably determine an increasing trend in seal numbers in PWS until there have been at least five surveys after the trend changes. This means that if a change occurred in 1995, monitoring surveys will have to continue until at least 1999, and perhaps longer, if we are to correctly conclude that the change is real.

Satellite-linked Depth Recorder Performance

In general, we have had very good performance from the 0.5 watt SDRs with versions 3.05 and 3.10 software that we attached to seals during 1992-1995. Tags attached in May usually transmitted until July, and the number of days operational was relatively consistent, ranging from 39-87 (Table 16). The range of operational time for tags attached in September was much greater, 40-312 days. Four of the tags that operated for relatively short periods (40-94 days) were all attached to seals captured on the same day in Port Chalmers. Not counting those SDRs, the performance of fall tags was more consistent (operating for 102-312 days), and the average duration of performance was nearly three times greater than for spring tags (185 days versus 64 days).

Shedding of transmitters during the molt probably explains the loss of most SDRs attached in spring, and perhaps also the two tags attached during the fall that transmitted into the following June or July (93-8 and 94-2). Based on the voltages and the number of transmissions reported in status messages it is possible to evaluate the amount of power remaining in SDR batteries. The SDR on seal 93-8 which transmitted for 312 days indicated low voltage, and if it was not lost due to molting it would not have operated much longer. That was the only large SDR that may have stopped transmitting due to a loss of battery power. Of the four small SDRs attached in fall 1994, one clearly lost power after 167 days operating while the other three showed somewhat reduced power after 78-119 days, even though the units were duty-cycled and transmitted one day on and one day off. To extend the operational period of small SDRs, the units we attached to seals in fall 1995 were duty-cycled to transmit one day on and two days off.

Other than battery failure and molting, reasons why transmissions from an SDR may cease include: 1) breakdowns of hardware or software; 2) the transmitter becomes detached from the seal and sinks; or 3) death of the seal results in loss of the transmitter. It is very difficult to evaluate these other possible causes of SDR failure. We definitely encountered problems with SDRs equipped with versions 3.11 and 3.13 software, but otherwise have no reason to think hardware or software problems caused failures. While identical procedures are used in attaching all SDRs, it is possible that differences in pelage among individual seals may affect how well they stay attached. Certainly some seals die each year from natural causes and some are taken by subsistence hunters. Hunters have reported to us flipper tags from two seals that we had captured, both of which had previously been carrying SDRs. We have heard no reports of seals taken by hunters with SDRs attached.

Movements and Haulout Behavior

In order to begin combining results from tagging efforts in different years, we have grouped location data by tagging location and season. Ten seals have been tagged with SDRs in central PWS (Seal Island and Applegate Rocks) in spring (Figure 23). With the exception of one trip to the Gulf of Alaska south of Montague Island, adult female seals stayed quite close to the capture location. Adult males moved more, with trips made to glaciers in northern PWS and to Middleton Island. Juvenile seals moved to the Copper River Delta and back, and to Danger Island at the southwestern extremity of the Sound.

Movements of five seals tagged in central PWS (Seal Island and Bay of Isles) in fall were restricted to within PWS (Figure 24). A juvenile seal moved the most, using land and ice haulouts in northern PWS as well as the tagging site at Seal Island.

Four seals tagged in southern PWS (Port Chalmers and Stockdale Harbor) in spring moved very little (Figure 25). Three of the eight seals tagged in that area (Port Chalmers and Channel Island) in fall moved considerably more (Figure 26). An adult male spent much of its time near

Middleton Island and in the Gulf of Alaska south of Montague Island. One juvenile used glaciers in northern PWS, while the other moved eastward to Yakutat Bay.

Only two seals have been equipped with SDRs in eastern PWS (Figure 27), one in spring and one in fall. Both stayed mostly in Port Gravina where they were captured, with occasional movements into adjacent bays. The one seal captured in western PWS stayed in that general area (Figure 27).

The frequency with which SDRs indicated that seals were hauled out at the location where they were captured ranged widely, from 0% to 98% both for animals tagged in fall 1994 and spring 1995 (Tables 18 and 19). Seals tagged at the Dutch Group, Olsen Bay, and Gravina Island usually hauled out where they were tagged. Some seals tagged at Channel Island, Port Chalmers, and Stockdale Harbor mostly used the tagging site and adjacent haulouts, but two spent most of their time outside of PWS. There are several seal haulouts in close proximity in the 20 km distance between Little Green Island and Stockdale Harbor, and it appears that some seals move considerably among the haulouts. Alternatively, with haulouts so close together it is possible that some haulout bouts were assigned wrongly because of errors in location fixes. These patterns of haulout site use are similar to those described for seals tagged in 1992 and 1993 (Frost and Lowry 1994*b*, Frost et al. 1995).

An analysis of haulout site use of all 30 seals tracked during 1992-1995 showed that within each month seals on average used only a few sites and that they used a "preferred" site more than two-thirds of the time. There was a strong seasonal difference with more haulouts used during May-July than September-March, but only relatively small age- or sex-related differences. Results of this analysis should be considered preliminary as sample sizes within most separate age/sex/month categories are still relatively small (e.g., see Table 21).

Of the seals tagged with SDRs in fall 1994 and spring 1995, 13 of 14 were in PWS when the last location was received and the other was off Yakutat (Table 17). Combining those results with seals tagged in 1992 and 1993 (Frost and Lowry 1994*b*, Frost et al. 1995), 29 of 30 seals were in PWS at the time they were last located. Of those 29, 24 were at or near the capture site or an adjacent haulout, while the other 5 were located 5-30 km away.

These results suggest a pattern in PWS seals of relatively strong site fidelity with occasional exceptions. Clearly seals do not always use only a single haulout, and the degree of fidelity to a specific primary site may vary considerably among individual animals. At a slightly larger scale it appears that there are strong patterns of regional use. Of 12 seals tagged at Channel Island, Port Chalmers, and Stockdale Harbor none were recorded as hauling out at Seal Island or Applegate Rocks, which are less than 20 km away. Conversely, 14 seals tagged at Applegate Rocks and Seal Island only very rarely were recorded as hauled out at Channel Island, Port Chalmers, or Stockdale Harbor.

Prior to oil spill restoration studies, only one study of harbor seal movements had been done in Alaska by Pitcher and McAllister (1981) who attached very high frequency (VHF) radiotags to 35 animals captured on Tugidak Island in 1988. Tags were monitored daily from land at the haulout where seals were captured, and occasional aerial tracking was done in adjacent areas. Most individual animals showed considerable fidelity to one or two specific haulout sites. The longest documented movement was 194 km, and one seal moved across 74 km of open ocean to a haulout on an adjacent island.

Similar results have been obtained in studies conducted on harbor seals in other areas. Suryan (1995) used VHF radio telemetry to study use of three haulouts in the northern San Juan

Islands, Washington. Haulout site fidelity for 13 male seals ranged from 33% to 100%. The greatest recorded movement was 28 km, and movements and site use were similar for adults and subadults. Harvey (1987) attached VHF radiotags to 26 seals along the Oregon coast. Radiotagged seals moved as much as 280 km from the release site, but 92% of the time were located within 8 km. There were no apparent movement differences by sex, but only four males were tagged. Working in the Channel Islands off southern California, Stewart and Yochem (1994) found that individual radiotagged seals used only a fraction of total haulouts on an island (not more than 4 of 15 at San Nicholas Island and 3 of 15 at San Miguel Island). During any one year seals used a single site 83% of the time, and they used the same site 81% of the time in subsequent years. Some subadults moved further to other islands or the mainland, while satellite tagged adults mostly stayed near the island where they were tagged. Working in Orkney, Scotland, Thompson (1989) found that individual VHF tagged seals used several haulout sites, but sometimes only one for extended periods within a season. Several marked juveniles were seen at haulouts beyond the study area and some were not resighted. Adults that moved to distant sites were later seen back in study area. In most VHF radiotagging studies there is a pattern of many local sightings with few indications of long distance movements, which may be at least partly because the probability of recording animals away from the main study area is low. However, such a bias does not exist with satellite tagging as is being done in this oil spill restoration study, and the same general pattern is evident.

Because they are shed during the annual molt, SDRs can only give information on site fidelity over periods of a few months. We also attach flipper tags to seals that we capture, and these tags should be retained for relatively long periods. To date, we have had two tag returns. One was from an adult male tagged at Applegate Rocks on May 8, 1993 and taken by a hunter at Applegate Rocks in August 1993. The second was an adult female tagged April 28, 1994 in Stockdale Harbor and taken by a hunter at Stockdale on December 15, 1995. This latter recovery suggests that at least some seals show site fidelity for periods longer than covered by tracking the SDRs.

Land-sea sensor data for seals tagged since 1992 show that PWS harbor seals haul out on a higher percentage of days during May-July than they do at other times of year (Figure 13). This was true for both males and females. This pattern is consistent with our aerial survey data, which also suggests that the number of seals hauled out is highest from late June through mid-August and decreases steadily in September (Figure 4). Harbor seal investigators in other areas also report that seals spend a greater percentage of their time hauled out in spring/summer when they pup, breed and molt, than they do in winter (Harvey 1987, Thompson et al. 1989, Moss 1992, Stewart and Yochem 1994). The percentage of days hauled out by PWS seals in summer is considerably higher than was found on Sable Island, Nova Scotia (52%-57%; Godsell 1988).

Behavior at Sea

Seals tagged in 1994-1995, like those tagged previously (Frost et al. 1995), showed considerable individual variability in how deep they dove. Sample sizes by age, sex, or haulout location are still too small to allow meaningful statistical comparisons. However, it appears that PWS harbor seals spend little of their time deeper than 150 m. Of the 14 seals presented in this report, only three spent any significant amount of time deeper than 150 m. Two of those were tagged at Channel Island and spent much of the winter in the Gulf of Alaska, and the other seal was tagged in northern PWS and stayed in that area. In Norway, Bjørge (1995) found that seals fed near the bottom at 15-200 m in a diversity of habitats. Stewart and Yochem (1994) reported that seals in the California Channel Islands dove as deep as 446 m.

With few exceptions, the seals tagged in September 1994 did not show a seasonal pattern in how deep they dove. The amount of time one subadult from Port Chalmers spent in deeper water increased from September-December. An adult male from Channel Island spend less time deeper than 50 m in winter than in fall. An adult male for which we had a nine month record spent most of the time near Middleton Island, and did not show any seasonal pattern in dive depth. This is in contrast to an adult male tagged at Seal Island in September 1993, with a similarly long record, which spent far more time in deeper water during November-February than it did in March-May (Frost et al. 1995). Based on our preliminary analysis of diving data from the 30 seals we have tagged to date, it appears possible that each seal has an individual strategy that is determined by a combination of age, geographic location, prey availability, and perhaps other factors.

Of the 30 seals we have tagged since 1992, only five have left PWS and spent time in the Gulf of Alaska. One of the most interesting things to emerge from these data was the long periods at sea (presumably feeding trips) that two of those seals made. The adult male hauling out at Middleton sometimes traveled 120 km to the west to feed, and spent an average of eight days at sea without hauling out. The subadult female that wintered near Yakutat traveled 90-150 km offshore to feed, and remained at sea for an average of 15 days. When seals stayed within PWS, they appeared to make fewer extended trips to sea, and the trips were of shorter average duration. Other investigators have found that harbor seals make repeated feeding trips to the same areas, and report that seals feed within 20-50 km of their haulouts (Bjørge 1995, Thompson and Miller 1990, Stewart and Yochem 1994).

Seals tagged in September 1994 and May 1995 were quite variable with respect to how much time they spent diving during different periods of the day. This was also true for seals tagged in September 1993 (Frost et al. 1995). Some seals appear to dive consistently more at night, others during the day, and still others are quite variable. Similar behavior was observed by Stewart and Yochem (1994) in southern California. Some seals dove predominantly during the day and hauled out at night, while others dove at night and hauled out during the day.

Foods and Trophic Relationships

In 1994 we began a study in cooperation with Dr. Sara Iverson of Dalhousie University to use fatty acid analyses to investigate food web relationships of harbor seals in PWS. To date, we have been able to analyze the fatty acid composition of blubber from 84 seals sampled in PWS, near Kodiak Island, and in southeast Alaska. Most of the PWS seals were from the southcentral region, although smaller samples were available from the northern and eastern Sound. In addition, we have analyzed the fatty acid composition of 163 prey collected in PWS. These initial samples, representing 10 species, have allowed us to make some very preliminary seasonal, annual, and geographic comparisons of seal diet, which are described in Appendix A.

Based on initial results of fatty acid analysis, it is clear that the fatty acid signatures of prey differ by species, area, and season. To date, only samples of pollock (*Theragra chalcogramma*) and herring (*Clupea harengus*) are available from more than one location, in more than one season, and for more than one size class. These two species differ remarkably between locations and seasons. Furthermore, the fatty acid composition of both species was directly related to body size, indicating that the diets of these fish change with size and age. However, they are still identifiable to species. The major significance of these findings is that, given the fatty acid composition of an unknown herring or pollock, it may be possible to put the data through the various prey trees and determine its size class and collection location with reasonable certainty. Using these data we may eventually be able to estimate not only the species composition of harbor seal diets, but also size class and location of the species fed upon. In future sampling, it will be important to obtain better seasonal, geographic, and size-class coverage for other prey species as well.

Analyses of harbor seal blubber collected in 1994 and spring 1995 suggest that seals not only haul out site-specifically, but also forage and feed site-specifically. The large differences observed in fatty acid patterns between harbor seals sampled near Montague Island (Stockdale Harbor, Port Chalmers, and Channel Island) and in other areas of PWS (northern and eastern) indicated that seals in these areas were feeding upon prey with different dietary levels of fatty acids. These differences might reflect different species composition (i.e., largely of one fish species versus another fish species, or largely fish versus cephalopod, etc.), or it could mean that they were feeding on different stocks of the same species.

Seals differed in fatty acid signatures, and hence likely feeding habits, even within small areas such as in the different bays and islands in the Montague area. This suggests that seals from a given haulout location may be expected to feed nearby, or at least on the same general prey resources. This conclusion is supported by data from satellite tagged seals, which suggests that most seals remained near the same haulout for most of the time they were tagged. The "misclassifications" of seals by location based on fatty acid signatures may correspond with the few seals that travel longer distances, such as the two that went to the Gulf of Alaska in winter 1994.

Fatty acid signatures also indicated that seals from southeast Alaska, and to a lesser extent the Kodiak area, fed upon different diets than did seals in PWS. The southeast Alaska animals were easily distinguishable from PWS and Kodiak area seals. Kodiak seals shared more characteristics with Montague area seals, suggesting a more common diet. This may be because, as demonstrated by satellite tagged seals, some seals travel from PWS to the Gulf of Alaska to feed.

The use of fatty acids to elucidate diet and trophic relationships is not a stand-alone method, and we will also use other available methods for examining harbor seal diets. Stable isotopes studies using seal whiskers (EVOS Project 96170) may indicate the trophic level at which seals feed and may show geographical or temporal variations in prey type. Studies of prey availability such as are being done by the SEA plan and APEX will help establish the "menu" from which seals may choose. Prey availability data will be used in conjunction with information on dive behavior to make inferences about what prey are being eaten by seals.

During 1973-1978, ADF&G collected harbor seals in PWS and elsewhere and examined their stomach contents (Pitcher and Calkins 1979, Pitcher 1980). We have recently accessed the original data from that study and have entered the information on prey into a computerized database. The database includes 119 specimens from PWS (including 4 from Middleton Island), 69 from areas to the east (Copper River Delta, Yakutat Bay, Icy Bay, and southeast Alaska), and 241 from areas to the west (Kenai Peninsula, Cook Inlet, Kodiak, and Alaska Peninsula). Those data will be reanalyzed and used to help interpret results from fatty acid, stable isotope, prey availability, and dive behavior studies. If additional stomach contents information becomes available from seals taken for subsistence, those data will be incorporated into this analysis.

Factors Affecting Population Recovery

Harbor seals have been declining in PWS since at least 1984, when the first trend count surveys were conducted there. Between 1984 and 1988, the annual rate of decline was about 12%. Then, in a single year from 1988 to 1989, the estimated population for PWS declined an additional 25%. This was the year in which the *Exxon Valdez* oil spill occurred. Since 1989, the total population has continued to decline at about 3%-5% per year. To date, other than the decrement due to the spill, the causes for the decline remain unexplained.

To better understand how the decline might be mediated we developed a harbor seal population model. The model can be used to explore what kinds of changes in reproduction and survival might result in such a decline and how long it might take the population to recover to historic levels. Using this model, it was possible to compare, for example, population growth rates with and without the estimated mortality caused by the EVOS for density dependent and independent populations (Figure 28).

It is immediately clear from this modeling exercise that the PWS harbor seal population has not behaved in the way a density dependent model would predict. If density dependence were operating the population should have declined only moderately from 1988 to 1989, and stayed relatively stable. In fact, the behavior of the actual 1989-1995 count estimates is more similar to a non-density dependent model which predicts a continuous decline in numbers.

In a normal, "healthy" environment it is generally assumed that when a species declines due to increased mortality, there will be an increase in per capita availability of resources. In such a situation, individual animals may have higher survival, grow faster, and/or reproduce at an earlier age. This results in a density dependent response that allows the population to stabilize despite the higher mortality. A non-density-dependent response indicates that for some reason the animals are unable to compensate for the factors causing their decline by either increased reproduction, survival, or both. One explanation for the apparent absence of a density dependent response in PWS harbor seals is that the carrying capacity of the environment has declined since the earlier surveys. Since there have been no major changes to the terrestrial habitats used by the seals it seems most likely that the changes must have occurred at sea. This would be consistent with the hypothesis that food has been limiting to the population.

It is also possible that the PWS seal population has experienced a higher level of mortality than is accounted for in the model. The steep decline in numbers between 1988 and 1989 is nearly 1,000 seals more than predicted by the model, even without density dependence (Figure 28). Mortality due to the spill (Frost and Lowry 1994) or to the subsistence harvest (e.g., Wolfe and Mischler 1994) may have been underestimated, or some other unaccounted for source of mortality could have affected the population.

Killer whales are important predators of harbor seals in PWS and elsewhere (Saulitis 1993, Baird and Dill 1995). A preliminary estimate suggests that the transient killer whales using PWS in 1995 could have eaten at least 377 adult-sized harbor seals (C. Matkin, personal communication). While such a number may not have been enough to explain the population decline, it is possible that killer whale predation could now have an effect on recovery of the reduced harbor seal population. Similar conclusions were reached in a study of the effects of killer whale predation on Steller sea lions (Barrett-Lennard et al. 1995). Predation estimates should be refined and incorporated into the population model to further explore the possible influence of predation on population recovery of seals in PWS.

The simulations presented in this report represent only the initial modeling efforts. Additional population modeling is ongoing and will be presented in a separate report.

CONCLUSIONS

1. Trend count surveys showed that the number of harbor seals in PWS has not recovered since the EVOS. Statistically significant declines occurred in both molting period and pupping period counts from 1989 through 1995. Adjusted molting period counts were 19% lower in 1995 than in 1989 while adjusted counts of non-pups during pupping were 31% lower. The mean pup count in 1995 was the lowest ever recorded, and was 26% lower than the 1989 count.

2. Compared with 1994, molting period counts were 16% higher in 1995 while pupping counts were 12% lower. The apparent increase in numbers in 1995 molting counts may be the beginning of a recovery, a short-term variation, or a survey artifact. The decline of pupping period counts from 1994 to 1995 indicates that it would be premature to conclude that an increasing trend has begun.

3. The generalized linear model used to adjust counts reduces variation due to date, time of day, and time relative to low tide. Analyses showed that meteorological conditions (wind speed, cloud cover, and air temperature) also have statistically significant effects on seal counts. Weather parameters should be incorporated into the model and trend analysis after the 1996 surveys.

4. Power analysis using revised adjusted counts and variances confirmed that adjusted molting counts provide a reasonable method for correctly detecting a population increase of 5% per year over a 5 year period. Pupping counts, even after adjustment, have very little power to detect trend, and therefore pupping surveys should be discontinued as a monitoring tool.

5. A newly developed Leslie matrix population projection model provides a useful tool for investigating factors that may be affecting harbor seal recovery. Sensitivity analysis showed that changes in survival of the younger age cohorts are likely to have the greatest effect on population growth. Simulations suggest that large changes in vital parameters must have occurred to cause the declines in seal numbers documented for 1984-1988 and 1988-1989. Preliminary results from 10 year population projections varied depending on the carrying capacity level assumed and the pattern of density dependent response incorporated in the model.

6. Ongoing studies using satellite-linked time-depth recorders (SDRs) continue to provide a wealth of information on harbor seal movements and behavior. During 1992-1995, the average duration of operation was 64 days for 16 SDRs attached in May and 153 days for 14 SDRs attached in September. On average tagged seals were located on 80% of the days transmitters were operating. The majority of seals tracked have stayed within PWS and hauled out principally at the capture location and adjacent haulout sites. A few individuals have made trips to tidewater glaciers in northern PWS, or moved out into the Gulf of Alaska. Over the time period sampled by the SDRs it appears that most harbor seals show considerable fidelity to particular haulout sites or regions within PWS.

7. Preliminary analysis of dive data showed considerable variability among individual seals. Two seals that moved out of PWS into the Gulf of Alaska showed a pattern of occasional haulouts alternating with extended feeding trips lasting up to 20 days. Seals that stayed within PWS showed shorter feeding trips (less than 8 days) and hauled out more frequently.

8. Fatty acid signature analysis of 163 potential seal prey showed differences between species, collection areas, and seasons. Preliminary analysis of fatty acid signatures from 84 seal blubber samples indicated differences in the diets of seals from PWS, southeast Alaska, and the Kodiak area. Within PWS there were differences between seals sampled near Montague Island and those from the northern and eastern Sound.

9. It is essential to continue to monitor the trend in abundance of PWS harbor seals, using adjusted counts from replicate aerial surveys conducted during the molt. Additional population modeling should be done to explore the potential importance of factors that may be limiting harbor seal recovery. Satellite-tagging studies should be continued until there are sufficient data to describe the movements, diving behavior, and haulout use of harbor seals in PWS. Additional fatty acid sampling and analysis should be conducted. Samples should continue to be taken from seals captured for tagging for use in studies of physiology, genetics, stable isotopes, and fatty acids.

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Table 1. Prince William Sound harbor seal trend count route.

Site #	Site Name	Oiling Status
1	Sheep Bay	unoiled
2	Gravina Island	unoiled
3	Gravina Rocks	unoiled
4	Olsen Bay	unoiled
5	Porcupine Point	unoiled
6	Fairmount Island	unoiled
7	Payday	unoiled
8	Olsen Island	unoiled
9	Point Pellew	unoiled
10	Little Axel Lind Island	unoiled
11	Storey Island	oiled
12	Agnes Island	oiled
13	Little Smith Island	oiled
14	Big Smith Island	oiled
15	Seal Island	oiled
16	Applegate Rocks	oiled
17	Green Island	oiled
18	Channel Island	unoiled
19	Little Green Island	unoiled
20	Port Chalmers	unoiled
21	Stockdale Harbor	unoiled
22	Montague Point	unoiled
23	Rocky Bay	unoiled
24	Schooner Rocks	unoiled
25	Canoe Passage	unoiled

Table 2. Factors considered in Poisson regression analysis of the number of seals hauled out during aerial surveys.

Factor	Type	Description
Location	categorical	25 sites
Year	categorical	7 years, 1989-1995 for pupping surveys
		9 years, 1984 and 1988-1995 for molting surveys
Time of day	categorical	before (midday - 4 hours)
		(midday - 4 hours) to (midday - 2 hours)
		(midday - 2 hours) to (midday)
		(midday) to (midday +2 hours)
		(midday + 2) to (midday + 4 hours)
		after (midday + 4 hours)
Date	continuous, scaled	day/10 since June 15 or August 15
Time relative to low tide	categorical	before (lowtide - 1.5 hours)
		(lowtide - 1.5 hours) to (lowtide - 1 hour)
		(lowtide - 1 hour) to (lowtide - 0.5 hour)
		(lowtide - 0.5 hour) to (lowtide)
		(lowtide) to (lowtide + 0.5 hour)
		(lowtide + 0.5 hour) to (lowtide + 1 hour)
		(lowtide + 1 hour) to (lowtide + 1.5 hours)
		after (lowtide + 1.5 hours)
Tide height	continuous	deviations from low tide, in feet
Wind	categorical	CA = calm
		LB = light breeze
		LW = light wind
		WI - windy
Air temperature	continuous, scaled	in degrees Fahrenheit, (airtemp-50)/10
Sky conditions	categorical	CL = cloudy
		HO = high overcast
		LO = low overcast or fog
		PC = partly cloudy
		RN = rain or drizzle

Table 3. Survival, reproduction, and fecundity estimates used in the Leslie matrix population model. These estimates resulted in a population growth rate of zero and the stable age distribution shown.

Age	Survival	Reproduction	Fecundity	Age Distribution %	Age Distribution Cumulative %
0	0.418	0.000	0.000	22.1	22.1
1	0.800	0.000	0.000	9.2	31.3
2	0.850	0.000	0.000	7.4	38.7
3	0.900	0.000	0.000	6.3	45.0
4	0.955	0.170	0.077	5.7	50.7
5	0.943	0.630	0.319	5.4	56.1
6	0.931	0.880	0.440	5.1	61.1
7	0.921	0.880	0.434	4.7	65.9
8	0.912	0.950	0.464	4.4	70.3
9	0.904	0.950	0.459	4.0	74.2
10	0.896	0.950	0.455	3.6	77.8
11	0.888	0.950	0.451	3.2	81.1
12	0.881	0.950	0.447	2.9	83.9
13	0.874	0.950	0.444	2.5	86.5
14	0.867	0.950	0.440	2.2	88.7
15	0.861	0.950	0.437	1.9	90.6
16	0.855	0.950	0.433	1.6	92.2
17	0.849	0.950	0.430	1.4	93.6
18	0.843	0.950	0.427	1.2	94.8
19	0.837	0.950	0.424	1.0	95.8
20	0.832	0.950	0.422	0.8	96.7
21	0.827	0.950	0.617	0.7	97.4
22	0.822	0.950	0.613	0.6	98.0
23	0.816	0.950	0.609	0.5	98.4
24	0.812	0.950	0.605	0.4	98.8
25	0.807	0.950	0.601	0.3	99.1
26	0.802	0.660	0.415	0.3	99.4
27	0.797	0.660	0.413	0.2	99.6
28	0.793	0.660	0.410	0.2	99.8
29	0.788	0.660	0.408	0.1	99.9
30	0.000	0.660	0.406	0.1	100.0

Table 4. Age specific vital parameters which were assumed to be density dependent, and their values for populations at both carrying capacity (K) and at near zero when the maximum rate of growth (R_{MAX}) is achieved. The density dependent (DD) shape parameters determine how quickly these vital parameters increase with increasing density (see text and Figure 2).

	Vital	Estimate of Vital Parameter		DD Shape Parameters	
Age	Parameter	K	R_{MAX}	Strong	Weak
0	Survival	41.8	77.5	4	2
1	Survival	80.0	94.5	4	2
2	Survival	85.0	95.0	4	2
3	Survival	90.0	96.0	4	2
4	Survival	95.5	98.0	2	1
5	Survival	94.3	97.5	2	1
6	Survival	93.1	97.0	2	1
7	Survival	92.1	96.5	2	1
8	Survival	91.2	96.0	2	1
9	Survival	90.4	95.0	2	1
10	Survival	89.6	92.0	2	1
4	Reproduction	17.0	50.0	3	1.5
5	Reproduction	63.0	75.0	3	1.5
6	Reproduction	88.0	90.0	3	1.5
7	Reproduction	88.0	95.0	3	1.5

Table 5. Repetitive counts of harbor seals on selected haulout sites in Prince William Sound, August 1995. Dashes indicate that no count was made.

	Date (August)								
	17	18	19	29	21	22	23	25	mean
Sheep Point	1	0	0	0	0	0	2	0	0.4
Gravina Island	17	21	16	14	13	4	15	24	15.5
Gravina Rocks	57	58	55	52	--	26	30	77	50.7
Olsen Bay	109	124	106	107	--	87	79	77	98.4
Porcupine	0	0	0	0	0	0	0	0	0
Fairmount	2	17	--	22	24	18	17	--	16.7
Payday	0	--	--	0	--	0	--	--	0
Olsen Island	0	0	0	0	0	0	0	--	0
Point Pellew	2	2	3	0	4	4	8	--	3.3
Little Axel Lind	0	0	0	0	0	0	0	--	0
Storey Island	0	1	--	1	0	0	0	--	0.3
Agnes Island	61	61	54	47	47	46	45	48	51.1
Little Smith Island	42	47	45	35	42	40	37	29	39.6
Big Smith Island	36	29	25	25	23	25	19	26	26.0
Seal Island	44	28	23	31	16	31	35	38	30.8
Applegate Rocks	159	170	152	143	139	148	125	91	140.9
Green Island	13	10	10	12	0	5	11	30	11.4
Channel Island	170	174	71	71	69	51	--	97	100.4
Little Green Island	27	26	39	47	49	37	33	50	38.5
Port Chalmers	88	90	80	86	45	102	94	102	85.9
Stockdale Harbor	51	38	11	2	11	10	36	25	23.0
Montague Point	0	4	0	2	0	0	0	0	0.8
Rocky Bay	90	84	49	62	26	62	57	59	61.1
Schooner Rocks	36	37	32	24	24	20	22	--	27.8
Canoe Passage	18	21	32	23	14	38	23	84	31.6

Table 6. Repetitive counts of harbor seals and harbor seal pups (#/#) on selected haulout sites in Prince William Sound, June 1995. Dashes indicate that no count was made.

	Date (June)							
Site	9	10	11	12	13	15	16	mean
Sheep Point	0/0	0/0	0/0	--	0/0	0/0	0/0	0/0
Gravina Island	0/0	0/0	0/0	8/0	15/0	36/1	20/0	11.3/0.1
Gravina Rocks	3/0	3/0	0/0	6/0	2/0	0/0	5/0	2.7/0
Olsen Bay	38/12	40/17	62/16	44/11	31/10	72/25	75/24	51.7/16.4
Porcupine	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Fairmount	10/2	16/1	18/3	9/2	17/3	25/3	19/1	16.3/2.1
Payday	0/0	0/0	0/0	0/0	0/0	0/0	4/0	0.6/0
Olsen Island	0/0	0/0	0/0	0/0	8/0	6/1	6/1	2.9/0.3
Point Pellew	6/0	1/1	7/0	5/0	6/0	0/0	5/0	4.3/0.1
Little Axel Lind	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Storey Island	2/0	0/0	0/0	1/0	0/0	2/1	4/1	1.3/0.3
Agnes Island	40/12	39/12	34/11	38/19	41/12	32/7	23/12	35.3/12.1
Little Smith Island	18/6	21/6	12/4	12/4	10/6	14/3	16/6	14.7/5.0
Big Smith Island	20/8	22/10	19/6	17/6	19/7	21/7	23/8	20.1/7/4
Seal Island	24/10	25/7	38/16	35/13	28/17	29/12	37/16	30.9/13.0
Applegate Rocks	101/21	98/25	121/34	131/32	106/34	103/32	88/34	106.9/30.3
Green Island	26/9	22/6	12/3	19/6	23/7	38/7	25/5	23.6/6.1
Channel Island	17/2	26/1	34/2	20/3	16/3	15/2	26/6	22.0/3.0
Little Green Island	43/4	54/8	42/6	38/4	45/3	59/4	62/7	49.0/5.1
Port Chalmers	67/20	50/15	62/20	53/13	44/11	42/10	63/17	54.4/15.1
Stockdale Harbor	8/0	2/0	1/0	0/0	1/0	0/0	0/0	1.7/0
Montague Point	4/0	3/0	3/0	1/0	2/0	1/1	0/0	2.0/0.1
Rocky Bay	14/4	8/2	10/2	4/1	10/1	32/4	16/4	13.4/2.6
Schooner Rocks	23/8	25/8	23/4	26/5	21/7	7/2	13/6	19.7/5.7
Canoe Passage	0/0	0/0	0/0	1/0	0/0	--	--	0.2/0

Table 7. Parameter estimates for factors affecting molt period counts of hauled out seals made during aerial surveys of Prince William Sound, August-September 1984-1995.

Factor	Category	Parameter estimate
Tide of day	before (midday - 4 hr)	0.2319
	(midday - 4 hr) to (midday - 2 hr)	0.2886
	(midday - 2 hr) to midday	0.1902
	midday to (midday + 2 hr)	0.1223
	(midday + 2 hr) to (midday + 4 hr)	0.0000
	after (midday + 4 hr)	0.1223
Date	day/10 since August 15	-0.0787
	$(\text{day}/10)^2$ since August 15	-0.0305
Time of tide	before -1.5 hr and -1.5 hr to -0.5 hr from low tide	0.2161
	-1 hr to -0.5 hr from low tide, and low tide to 0.5 hr after	0.3563
	-0.5 hr to low tide, and 0.5 hr to 1.5 hr after after low tide	0.2912
	> 1.5 hr after low tide	0.0000
Wind speed	calm/light breeze	0.1453
	light wind/windy	0.0000
Air temperature	airtemp-50/10	-0.0033
	$((\text{airtemp}-50)/10)^2$	0.0166
Sky conditions	Precipitation	0.0000
	all others	0.2413

Table 8. Parameter estimates for factors affecting pupping period counts of hauled out non-pup seals made during aerial surveys of Prince William Sound, June 1989-1995.

Factor	Category	Parameter estimate
Tide of day	before (midday - 4 hr)	0.0579
	(midday - 4 hr) to (midday - 2 hr)	0.1337
	(midday - 2 hr) to (midday)	0.1752
	(midday) to (midday + 4 hr)	0.1337
	after (midday + 4 hr)	0.0000
Date	day/10 since June 15	0.0675
	$(\text{day}/10)^2$ since June 15	0.0636
Time of tide	before -1.5 hr from low tide	0.0000
	-1.5 hr to -0.5 hr from low tide	0.1234
	-0.5 hr to +0.5 hr from low tide	0.0406
	+0.5 hr to +1.5 hr from low tide	0.0201
	after +1.5 hr from low tide	0.0000
Wind speed	calm/light breeze	0.1864
	light wind/windy	0.0000
Air temperature	(airtemp-50)/10	0.0048
	$((\text{airtemp}-50)/10)^2$	-0.0188
Sky conditions	clear, precipitation	0.0000
	low overcast	0.0641
	high overcast, partly cloudy	0.1543

Table 9. Adjusted counts of harbor seals on selected haulout sites in Prince William Sound, August-September 1984-1995.

	Year								
	1984	1988	1989	1990	1991	1992	1993	1994	1995
Sheep Point	83	23	0	<1	1	1	6	0	<1
Gravina Island	48	23	35	9	19	35	23	15	22
Gravina Rocks	81	78	60	36	37	46	60	85	73
Olsen Bay	274	139	76	120	111	61	107	71	141
Porcupine	55	6	12	1	19	11	4	1	0
Fairmount	176	69	59	36	23	17	27	3	23
Payday	21	3	3	6	6	<1	<1	<1	0
Olsen Island	72	20	13	16	13	6	3	7	0
Point Pellew	42	33	42	36	29	18	14	<1	4
Little Axel Lind	51	31	40	24	13	10	4	0	0
Storey Island	21	8	5	4	1	<1	<1	0	<1
Agnes Island	148	64	60	58	50	63	31	54	70
Little Smith Island	142	53	37	47	32	46	35	40	51
Big Smith Island	177	133	69	47	43	62	50	62	34
Seal Island	205	123	62	62	82	73	57	61	39
Applegate Rocks	411	262	154	188	136	90	77	89	178
Green Island	112	76	31	40	32	54	40	37	14
Channel Island	501	153	164	60	132	118	168	92	126
Little Green Island	108	91	55	49	20	82	68	40	49
Port Chalmers	129	130	116	160	137	94	165	105	111
Stockdale Harbor	63	84	78	78	59	65	21	48	44
Montague Point	84	59	62	60	35	15	2	9	1
Rocky Bay	66	20	33	18	26	36	31	58	80
Schooner Rocks	130	119	105	74	71	87	96	49	37
Canoe Passage	25	70	37	39	68	39	32	58	42

Table 10. Adjusted mean counts and annual percent change for harbor seals at oiled and unoiled trend count sites in Prince William Sound, based on surveys during August-September 1984-1995.

	Oiled (n=7)		Unoiled (n=18)		All (n=25)	
Year	mean	annual % change	mean	annual % change	mean	annual % change
1984	1215		2008		3224	
1988	719	-41	1151	-43	1870	-42
1989	417	-42	989	-14	1406	-25
1990	445	+ 7	820	-17	1266	-10
1991	375	-16	818	0	1194	- 6
1992	388	+ 3	738	-10	1126	- 6
1993	291	-25	829	+12	1120	- 1
1994	342	+18	641	-23	984	-12
1995	385	+13	754	+18	1140	+16
Overall changes						
1984-1995		-68		-62		-65
1988-1995		-46		-34		-39
1989-1995		-8		-24		- 19

Table 11. Adjusted counts of non-pup harbor seals on selected haulout sites in Prince William Sound, June 1989-1995.

	Year						
	1989	1990	1991	1992	1993	1994	1995
Sheep Point	0	3	<1	4	11	<1	0
Gravina Island	3	13	3	3	7	13	15
Gravina Rocks	5	6	1	10	10	3	3
Olsen Bay	78	63	26	27	40	38	65
Porcupine	10	2	7	2	3	<1	0
Fairmount	17	11	13	18	16	11	20
Payday	4	<1	4	4	4	<1	1
Olsen Island	10	4	3	1	6	2	3
Point Pellew	11	9	4	6	7	7	5
Little Axel Lind	3	1	3	1	0	0	0
Storey Island	3	6	1	1	1	1	2
Agnes Island	31	50	46	46	38	33	43
Little Smith Island	11	22	17	15	13	12	18
Big Smith Island	19	22	29	17	22	22	24
Seal Island	51	56	82	52	47	61	36
Applegate Rocks	159	164	161	93	124	134	123
Green Island	24	33	30	54	55	55	27
Channel Island	102	86	69	75	59	64	24
Little Green Island	98	82	48	40	45	44	55
Port Chalmers	85	112	76	43	89	78	61
Stockdale Harbor	23	34	15	7	1	2	2
Montague Point	18	27	18	14	5	17	2
Rocky Bay	28	25	22	11	20	23	15
Schooner Rocks	33	31	29	34	21	24	23
Canoe Passage	<1	1	1	<1	0	<1	<1

Table 12. Adjusted mean counts and annual percent change for non-pup harbor seals at oiled and unoiled trend count sites in Prince William Sound, based on surveys during June 1989-1995.

	Oiled (n=7)		Unoiled (n=18)		All (n=25)	
Year	mean	annual % change	mean	annual % change	mean	annual % change
1989	298		528		826	
1990	354	+19	509	-4	863	+4
1991	367	+4	342	-33	709	-18
1992	277	-25	297	-13	575	-19
1993	300	+8	344	+16	644	+12
1994	318	+6	329	-4	648	-1
1995	273	-14	296	-11	569	-12
Overall change						
1989-1995		-8		-44		-31

Table 13. Percent decrease in vital parameters that would cause a decline similar to that observed from 1984-88, when the Prince William Sound harbor seal population declined from 14,937 to 8,662 (-12.7% per year) in 4 years. Harvest mortality was considered as either additive or compensatory. When a decrease is greater than the baseline, value was taken to zero.

Vital Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Additive															
Survival															
Pups	37				19.5	25		5.9				29		20	
1-3 Years		36			19.5	14		5.9					26		13
4-10 Years			15				9	5.9							
11-30 Years				45			9	5.9							
Reproduction															
4-7 Years									88		53	50	50		
8-30 Years										83	53			50	50
Simulated 88 pop	8,648	8,653	8,648	8,661	8,669	8,669	8,698	8,657	10,826	8,666	8,653	8,651	8,634	8,691	8,673
Compensatory															
Survival															
Pups	42				42	25		10.5				42		42	
1-3 Years		90			42	69		10.5					90		44
4-10 Years			30				16	10.5							
11-30 Years				89			16	10.5							
Reproduction															
4-7 Years									88		86	50	50		
8-30 Years										95	86			50	50
Simulated 88 pop	10,670	8,984	8,682	9,468	8,677	8,615	8,709	8,650	12,973	10,180	8,686	10,036	8,657	9,429	8,681

Table 14. Percent decrease in vital parameters that would cause a decline similar to that observed from 1988-89, when the Prince William Sound harbor seal population declined from 8,662 to 6,512 (-24.8%). Harvest mortality was considered as either additive or compensatory. When a decrease is greater than the baseline, value was taken to zero.

Vital Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
<u>Additive</u>															
Survival															
Pups	42				26	25		10.3				39		22	
1-3 Year-olds		52			26	27		10.3					40		22
4-10 Year-olds			27				17	10.3							
11-30 Year-olds				48			17	10.3							
Reproduction															
4-7 Year-olds									88		57	50	50		
8-30 Year-olds										86	57			50	50
Simulated 89 pop	6,701	6,515	6,527	6,510	6,513	6,513	6,517	6,513	6,973	6,517	6,515	6,511	6,510	6,508	6,510
<u>Compensatory</u>															
Survival															
Pups	42				67	25		20				42		42	
1-3 Years		90			67	84		20					90		70
4-10 Years			53				31	20							
11-30 Years				77			31	20							
Reproduction															
4-7 Years									88		88	50	50		
8-30 Years										95	95			50	50
Simulated 89 pop	7,862	6,950	6,510	6,515	6,504	6,514	6,539	6,504	8,103	7,308	6,749	7,464	6,590	7,142	6,524

Table 15. Harbor seals captured, sampled, and tagged with satellite-linked depth recorders in Prince William Sound, May and September 1995.

Specimen Number	Capture Date	Capture Location	Sex	Age Class	SDR Number	Standard Length (cm)	Axillary Girth (cm)	Weight (kg)
PWSHS-1-95	05/09/95	Dutch Group	M	subadult	11041	96.0	81.0	33.1
PWSHS-2-95	05/09/95	Lone Island	M	subadult	none	107.0	90.0	40.4
PWSHS-3-95	05/09/95	Dutch Group	M	subadult	none	106.0	91.0	37.1
PWSHS-4-95	05/09/95	Dutch Group	M	subadult	none	124.0	79.0	38.1
PWSHS-5-95	05/09/95	Dutch Group	M	subadult	none	116.0	91.0	45.6
PWSHS-6-95	05/11/95	Olsen Bay	F	subadult	11043	114.0	84.0	38.0
PWSHS-7-95	05/11/95	Olsen Bay	M	subadult	none	107.0	90.0	42.4
PWSHS-8-95	05/11/95	Port Chalmers	F	adult	11039	134.0	105.0	90.0
PWSHS-9-95	05/11/95	Channel Island	F	subadult	none	98.0	81.0	31.7
PWSHS-10-95	05/11/95	Channel Island	M	subadult	none	120.0	83.0	34.9
PWSHS-11-95	05/11/95	Channel Island	F	subadult	none	126.0	94.0	52.1
PWSHS-12-95	05/11/95	Channel Island	M	adult	none	131.0	100.0	54.8
PWSHS-13-95	05/11/95	Channel Island	F	subadult	none	120.0	87.0	43.2
PWSHS-14-95	05/11/95	Channel Island	M	adult	none	137.0	96.0	58.1
PWSHS-15-95	05/12/95	Stockdale Harbor	M	adult	11040	147.0	101.0	80.5
PWSHS-16-95	05/12/95	Stockdale Harbor	M	adult	none	126.0	94.0	56.6
PWSHS-17-95	05/12/95	Stockdale Harbor	F	subadult	none	109.0	84.0	37.4
PWSHS-18-95	05/12/95	Stockdale Harbor	M	subadult	none	124.0	94.0	46.8
PWSHS-19-95	05/12/95	Stockdale Harbor	F	subadult	11044	109.0	91.0	42.8
PWSHS-20-95	05/14/95	Port Chalmers	F	adult	11038	135.0	111.0	105.0

Table 15. Continued.

Specimen Number	Capture Date	Capture Location	Sex	Age Class	SDR Number	Standard Length (cm)	Axillary Girth (cm)	Weight (kg)
PWSHS-21-95	05/14/95	Port Chalmers	F	subadult	none	98.0	71.0	28.6
PWSHS-22-95	05/14/95	Port Chalmers	M	subadult	none	107.0	80.0	36.1
PWSHS-23-95	09/25/95	Gravina Island	F	subadult	2283	105.0	82.0	36.6
PWSHS-24-95	09/25/95	Gravina Island	F	pup	2286	99.0	74.0	29.8
PWSHS-25-95	09/26/95	Port Chalmers	F	subadult	failed	114.0	88.0	41.0
PWSHS-26-95	09/26/95	Port Chalmers	F	adult	2285	125.0	102.0	69.5
PWSHS-27-95	09/26/95	Port Chalmers	F	adult	2280	136.0	105.0	77.1
PWSHS-28-95	09/26/95	Little Green Island	M	subadult	none	98.0	82.0	31.9
PWSHS-29-95	09/26/95	Little Green Island	M	subadult	2287	120.0	90.0	48.4
PWSHS-30-95	09/26/95	Little Green Island	F	adult	2281	129.0	94.0	61.2
PWSHS-31-95	09/26/95	Little Green Island	M	adult	none	121.0	94.0	45.0
PWSHS-32-95	09/26/95	Little Green Island	M	adult	none	151.0	108.0	84.5
PWSHS-33-95	09/26/95	Little Green Island	F	subadult	none	117.0	84.0	40.3
PWSHS-34-95	09/26/95	Little Green Island	F	subadult	none	109.0	80.0	32.6
PWSHS-35-95	09/26/95	Little Green Island	F	pup	none	108.0	69.0	28.6
PWSHS-36-95	09/26/95	Little Green Island	F	subadult	none	124.0	82.0	40.9
PWSHS-37-95	09/27/95	Channel Island	M	adult	none	147.0	115.0	81.4
PWSHS-38-95	09/27/95	Port Chalmers	F	adult	none	133.0	107.0	68.2
PWSHS-39-95	09/27/95	Port Chalmers	F	subadult	2284	127.0	83.0	41.8
PWSHS-40-95	09/27/95	Port Chalmers	M	adult	none	130.0	105.0	58.3
PWSHS-41-95	09/28/95	Applegate Rocks	M	subadult	none	121.0	86.0	42.0
PWSHS-42-95	09/28/95	Applegate Rocks	M	subadult	none	99.0	83.0	33.3

Table 16. Performance of satellite-linked depth recorders attached to harbor seals in Prince William Sound, 1992-1995. Does not include units with versions 3.11 or 3.13 software.

SDR	ID Number	Age\ Sex[a]	Date Attached	Date of Last Transmission	Total Days Operational	No. Days w/ Locations[b]	Total No. Locations[b]
1992 - spring							
3089	92-1	JM	5/17/92	7/24/92	69	25	63
3086	92-2	JM	5/17/92	7/7/92	52	36	83
3088	92-3	AF	5/17/92	7/19/92	64	39	183
3087	92-4	JM	5/17/92	7/11/92	56	37	109
1993 - spring							
2287	93-1	AM	5/7/93	6/14/93	39	36	139
2282	93-2	AM	5/7/93	7/28/93	83	70	234
2283	93-3	AM	5/7/93	7/21/93	76	65	186
11040	93-4	AF	5/8/93	7/8/93	62	43	164
2240	93-5	AM	5/8/93	8/2/93	87	53	181
11042	93-6	AM	5/9/93	7/25/93	78	59	163
1993 - fall							
2282	93-7	AF	9/15/93	12/25/93	102	92	353
2287	93-8	AM	9/15/93	7/23/94	312	256	852
2284	93-9	JM	9/15/93	3/17/94	184	122	312
5039	93-10	AM	9/16/93	3/11/94	177	116	297
2280	93-11	AM	9/18/93	3/10/94	174	140	499
2283	93-12	AM	9/18/93	2/11/94	147	125	375

[a] AF = adult female; AM = adult male; JF = juvenile female; JM = juvenile male

[b] Figures for may vary slightly from those reported in Frost and Lowry (1994*b*) due to changes in procedures for screening records (see methods).

Table 16. Continued.

SDR	ID Number	Age\ Sex[a]	Date Attached	Date of Last Transmission	Total Days Operational	No. Days w/ Locations	Total No. Locations
1994 - fall							
2286[b]	94-1	JF	9/18/94	3/3/95	167	126	392
2282	94-2	AM	9/18/94	6/11/95	267	182	748
2280	94-3	AM	9/18/94	2/27/95	163	155	601
11042[b]	94-4	JM	9/19/94	2/18/95	153	119	254
2281	94-5	AF	9/22/94	12/6/94	76	72	261
11039	94-6	AF	9/22/94	10/31/94	40	38	183
2283[b]	94-7	JF	9/22/94	12/21/94	91	84	250
2284[b]	94-8	AF	9/22/94	12/24/94	94	78	178
1995 - spring							
11041	95-1	JM	5/09/95	6/25/95	48	46	175
11043	95-2	JF	5/11/95	7/9/95	60	56	298
11039	95-3	AF	5/11/95	7/12/95	63	63	541
11040	95-4	AM	5/12/95	7/27/95	77	75	298
11044	95-5	JF	5/12/95	7/7/95	56	40	155
11038	95-6	AF	5/14/95	7/5/95	53	53	420
1995 - fall							
2283[c]	95-7	JF	9/25/95				
2286[c]	95-8	JF	9/25/95				
2285[c]	95-9	AF	9/26/95				
2280[c]	95-10	AF	9/26/95				
2287[c]	95-11	JM	9/26/95				
2281[c]	95-12	AF	9/26/95				
2284[c]	95-13	JF	9/27/95				

[a] AF = adult female; AM = adult male; JF = juvenile female; JM = juvenile male

[b] These SDRs were duty-cycled one day on and one day off (see methods)

[c] Location data for these SDRs have not yet been analyzed, and will be presented in the 1997 annual report

Table 17. Summary of movements of harbor seals satellite tagged in Prince William Sound, September 1994 and May 1995.

ID no.	Age/ sex[a]	Location and Date Tagged	Other Major Areas and Dates of Use	Location and Date of Last Location Fix
94-1	JF	Channel Island 9/18/94	Gulf of Alaska 10/6-16, 10/18-21, 11/4-19, 11/24-12/9, 12/15-30,1/9-29, 2/2-20; Yakutat Bay 10/21, 11/2-4, 11/19-23, 12/10-14, 12/30-1/8, 1/29-2/2; Icy Bay 10/16	Gulf of Alaska 2/20/95
94-2	AM	Channel Island 9/18/94	Middleton I. 9/26-10/19, 10/29-5/13 south Montague I. 10/25, 5/17-21; L. Green I. 5/25-6/11	near Little Green I. 6/11/95
94-3	AM	Channel Island 9/18/94	Pt. Chalmers 11/6-22; Hinchinbrook Entrance 1/11-23	north Montague I. 2/27/95
94-4	JM	Gravina Island 9/19/94	Port Fidalgo 10/18, 11/14, 1/23	Gravina Island 2/17/95
94-5	AF	Port Chalmers 9/22/94		Stockdale Hbr. 12/5/94
94-6	AF	Port Chalmers 9/22/94	Stockdale Hbr. 9/23-10/29	Rocky Bay 10/30/94
94-7	JF	Port Chalmers 9/22/94	Stockdale Hbr 9/26-10/23, 12/6-20; Unakwik Inlet 11/8-13; Columbia Bay 11/26-27	Port Chalmers 12/21/94
94-8	AF	Port Chalmers 9/22/94		Port Chalmers 12/24/94
95-1	JM	Dutch Group 5/9/95		near Dutch Group 6/24/95
95-2	JF	Olsen Bay 5/11/95	Port Fidalgo 5/28, 6/17, 6/26, 7/2	near Olsen Bay 7/9/95
95-3	AF	Port Chalmers 5/11//95	Channel I. 5/22-23, 6/8-7/12	Channel Island 7/12/95
95-4	AM	Stockdale Harbor 5/12/95	Pt. Chalmers 6/10-7/19; Channel I. 7/20-23 Gulf of Alaska 7/26	Channel Island 7/27/95
95-5	JF	Stockdale Harbor 5/12/95	Little Green I. 5/26-7/7; Gulf of Alaska 5/14, 5/22	Little Green Island 7/7/95
95-6	AF	Port Chalmers 5/14/95	Channel I. 6/18-19, 7/2-5	near Channel Island 7/5/95

[a] AF = adult female; AM = adult male; JF = juvenile female; JM = juvenile male

Table 18. Use of haulout sites by satellite tagged harbor seals in Prince William Sound, September 1994-June 1995. Numbers indicate the number of haulout bouts that occurred at each site based on location and land-sea sensor data.

	ID Number and Tagging Site (age/sex[a])							
Location	94-1 (JF) Channel I.	94-2 (AM) Channel I.	94-3 (AM) Channel I.	94-4 (JM) Gravina I.	94-5 (AF) Pt. Chalmers	94-6 (AF) Pt. Chalmers	94-7 (JF) Pt. Chalmers	94-8 (AF) Pt. Chalmers
Channel Island	1	1	43	--	2	--	--	--
Port Chalmers	--	1	12	--	20	--	1	19
Stockdale Harbor	--	--	1	--	5	20	14	--
Little Green Island	--	2	6	--	--	--	--	--
Green Island	--	1	--	--	1	1	--	2
Montague Point	--	--	--	--	--	2	--	--
Rocky Bay	--	--	1	--	--	2	--	--
Port Etches	--	--	3	--	--	--	--	--
Columbia Glacier	--	--	--	--	--	--	1	--
Unakwik Inlet	--	--	--	--	--	--	4	--
Middleton Island	--	148	--	--	--	--	--	--
S. Montague Island	--	5	--	--	--	--	--	--
Gravina Island	--	--	--	54	--	--	--	--
Hells Hole	--	--	--	1	--	--	--	--
Yakutat Bay	32	--	--	--	--	--	--	--
Icy Bay	1	--	--	--	--	--	--	--
TOTAL KNOWN	34	167	66	55	28	25	20	21
Unknown	1	12	11	11	7	4	0	2

[a] AF = adult female; AM = adult male; JF = juvenile female; JM = juvenile male

Table 19. Use of haulout sites by satellite tagged harbor seals in Prince William Sound, May-July 1995. Numbers indicate the number of haulout bouts that occurred at each site based on location and land-sea sensor data.

	ID Number and Tagging Site (age/sex[a])					
Location	95-1 (JM) Dutch Group	95-2 (JF) Olsen Bay	95-3 (AF) Pt. Chalmers	95-4 (AM) Stockdale Hbr.	95-5 (JF) Stockdale Hbr.	95-6 (AF) Pt. Chalmers
Dutch Group	32	--	--	--	--	--
Little Axel Lind Island	5	--	--	--	--	--
Lone Island	3	--	--	--	--	--
Perry Island	3	--	--	--	--	--
Olsen Bay	--	46	--	--	--	--
Gravina Island	--	1	--	--	--	--
Port Chalmers	--	--	32	37	--	58
Stockdale Harbor	--	--	--	21	--	1
Channel Island	--	--	45	10	1	9
Little Green Island	--	--	2	--	27	--
Green Island	--	--	--	2	--	2
TOTAL KNOWN	43	47	79	70	28	70
Unknown	4	12	6	1	5	3

[a] AF = adult female; AM = adult male; JF = juvenile female; JM = juvenile male

Table 20. Haulout site use by 30 harbor seals satellite tagged in Prince William Sound, 1992-1995. The number of haulouts used is the average number of sites used in a single month. Maximum proportional use is the average percentage of times that the primary haulout site was used in each month.

			Number of Haulouts Used		Maximum Proportional Use	
Period	Age	Sex	Mean	Approx. 95% C. I.	Mean	Approx. 95% C. I.
September-March	adult	female	2.3	1.3-3.3	82.9	70.7-95.1
		male	2.2	1.8-2.6	87.1	81.8-92.4
	juvenile	female	1.4	1.0-1.8	87.1	72.4-101.8
		male	2.2	1.7-2.6	80.6	70.5-90.8
May-July	adult	female	2.9	2.2-3.6	81.5	74.5-88.5
		male	3.8	3.0-4.6	72.4	64.4-80.5
	juvenile	female	3.2	1.9-4.4	77.9	67.2-88.7
		male	3.6	2.0-5.2	65.4	48.9-81.9

Table 21. Percent of days hauled out by month for harbor seals satellite tagged in Prince William Sound, May 1992-July 1995.

SDR	Age	Sex	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
92-1	Sub	M									33	27	25
92-2	Sub	M									80	83	71
92-3	Ad	F									87	67	26
92-4	Sub	M									20	73	44
93-1	Ad	M									96	93	
93-2	Ad	M									80	83	93
93-3	Ad	M									87	90	90
93-4	Ad	F									42	57	100
93-5	Ad	M									61	53	58
93-6	Ad	M									91	67	100
93-7	Ad	F	62	71	67	54							
93-8	Ad	M	80	81	70	81	48	29	45	53	90	93	83
93-9	Sub	M	67	74	60	42	45	39	35				
93-10	Ad	M	86	84	77	39	61	54	55				
93-11	Ad	M	62	87	63	42	65	57	60				
93-12	Ad	M	33	42	40	45	58	45					
94-2	Ad	M	67	77	33	68	55	46	58	53	61	100	
94-3	Ad	M	67	61	53	55	29	41					
94-5	Ad	F	33	61	27	50							
94-6	Ad	F	58	55									
95-1	Sub	M									96	96	
95-2	Sub	F									86	97	78
95-3	Ad	F									71	97	100
95-4	Ad	M									95	93	96
95-5	Sub	F									45	77	100
95-6	Ad	F									100	100	100
mean			61.5	69.3	54.4	52.9	51.6	44.4	50.6	53.0	73.6	80.3	77.6
std. deviation			17.23	14.29	17.45	13.81	12.16	9.41	10.45	0.0	23.95	19.88	27.06
94-1 [a]	Sub	F	25	10	27	23	35						
94-4 [a]	Sub	M	33	58	40	45	52	56					
94-7 [a]	Sub	F	44	39	20	19							
94-8 [a]	Ad	F	11	29	20	42							

[a] Duty cycled transmitters, 1 day on/ 1day off. Not included in the means and standard deviations.

Table 22. Adjusted mean counts of harbor seals on the Prince William Sound trend route during pupping and molting periods, 1984-1995. Values shown under 1994 were adjusted using 1994 parameter estimates, and those for 1995 were adjusted using 1995 parameter estimates. Pup counts are not adjusted.

Year	Pupping Period			Molting Period	
	Non-Pups		1995		
	1994	1995	Pups	1994	1995
1984	---	---	---	3168	3,224
1988	---	---	---	1812	1,870
1989	808	826	170	1363	1,406
1990	855	863	171	1216	1,266
1991	704	709	167	1157	1,194
1992	583	575	147	1085	1,126
1993	642	644	126	1082	1,120
1994	648	648	132	959	984
1995	---	569	125	---	1,140

Table 23. Summary of parameters for molting and pupping period data used in the power analysis for Prince William Sound harbor seal trend count surveys.

	Molting Period n=8.83		Pupping Period n=7.5	
	unadjusted	adjusted	unadjusted	adjusted
$\hat{V}$	14,603.8	4,229.1	7,334.3	9,155.0
$\hat{V} / \bar{n}$	1,653.9	478.9	977.9	1,220.7
$\hat{\beta}_0$	49,892	143,052	77,440	89,471
$\hat{\beta}_1$	-24.7	-71.257	-38.571	-44.571
$\hat{\sigma}^2$	5,175.5	1,501.4	4,093.4	5,107.4
$\hat{\delta}^2$	3,524.5	1,022.5	3,115.5	3,886.7

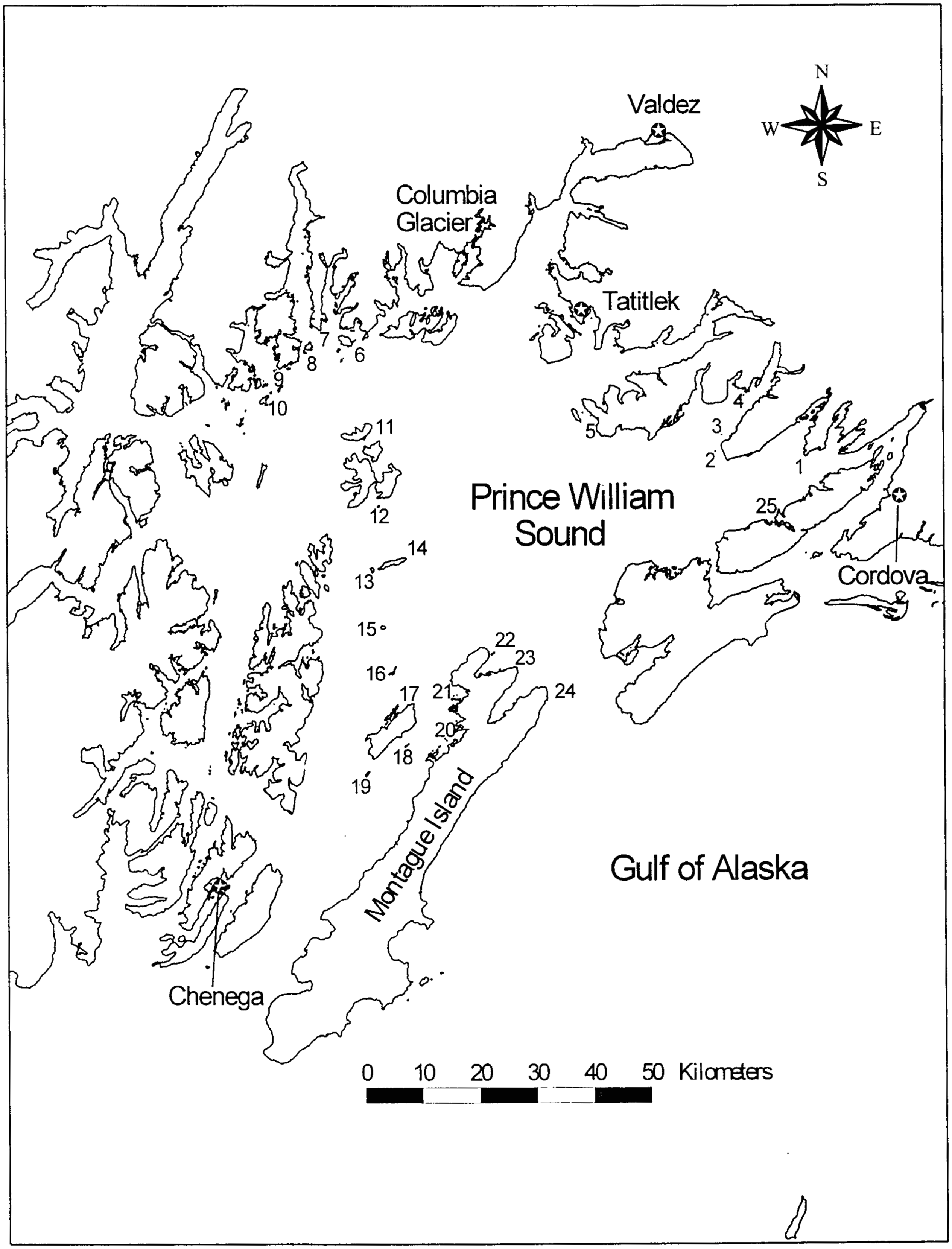


Figure 1. Map of the Prince William Sound study area showing trend count sites.

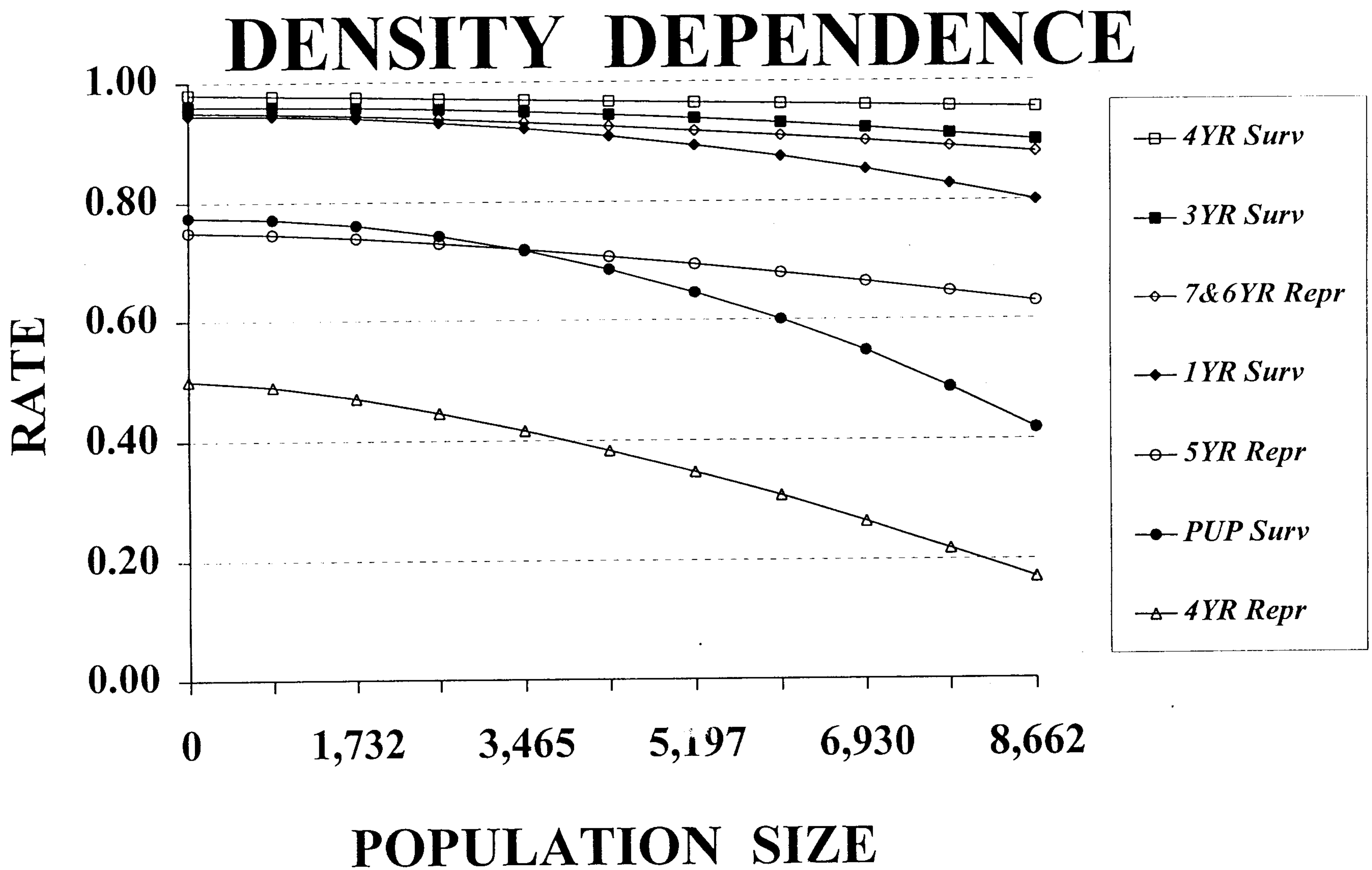


Figure 2. Density dependent functions for selected age-specific vital parameters. Each curve represents how either a survival or reproductive rate would increase as the population level decreases from the carrying capacity to zero.

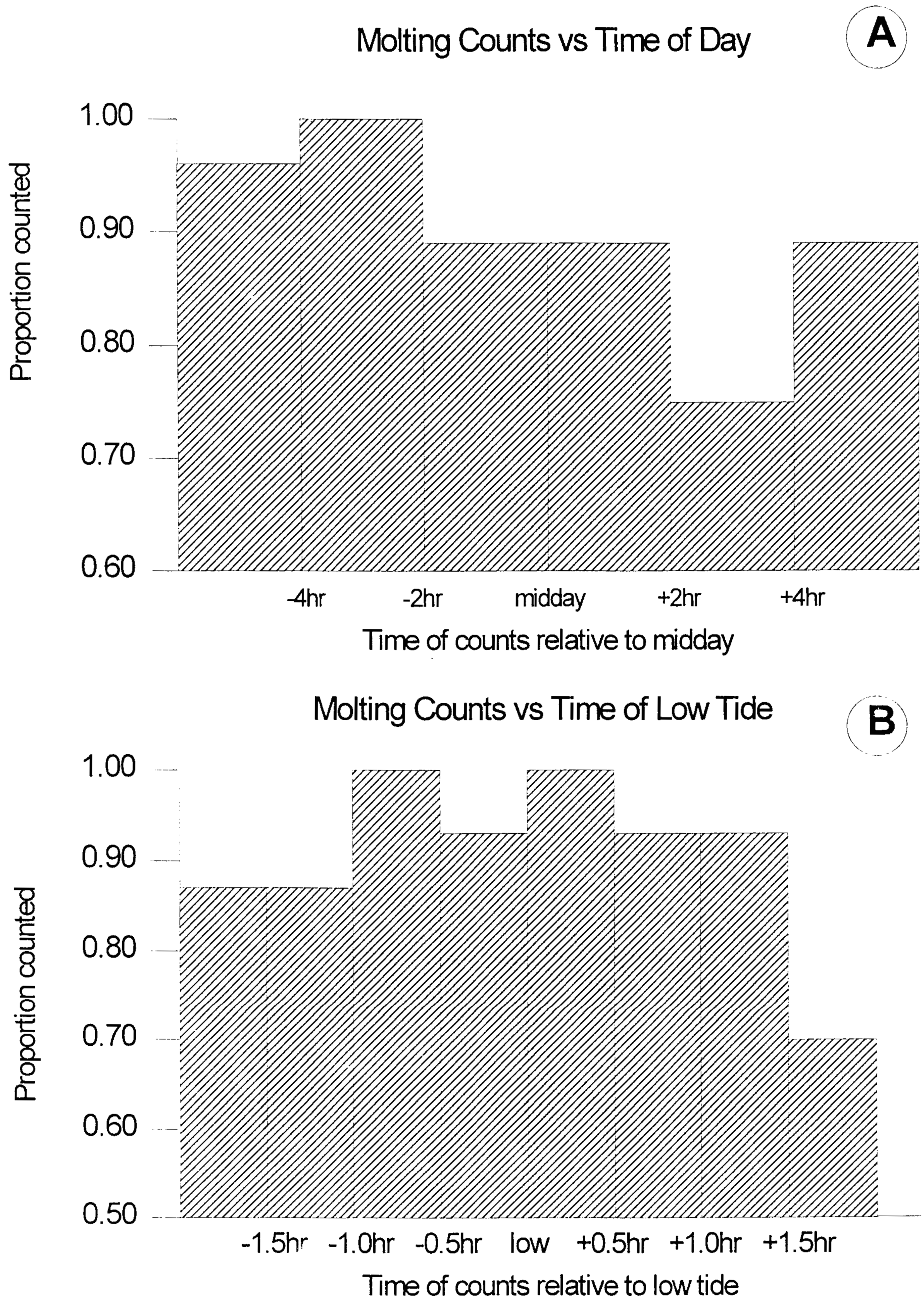
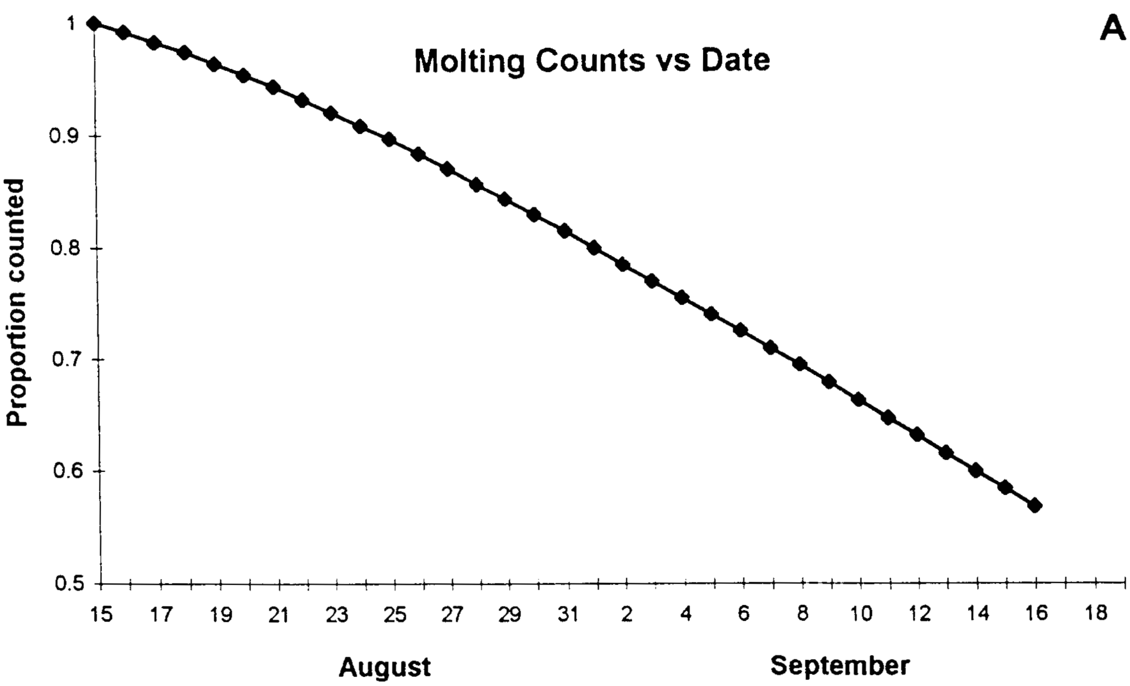


Figure 3. Effect of time of day (A) and time relative to low tide (B) on counts of harbor seals in Prince William Sound, August-September 1983-1995.



B

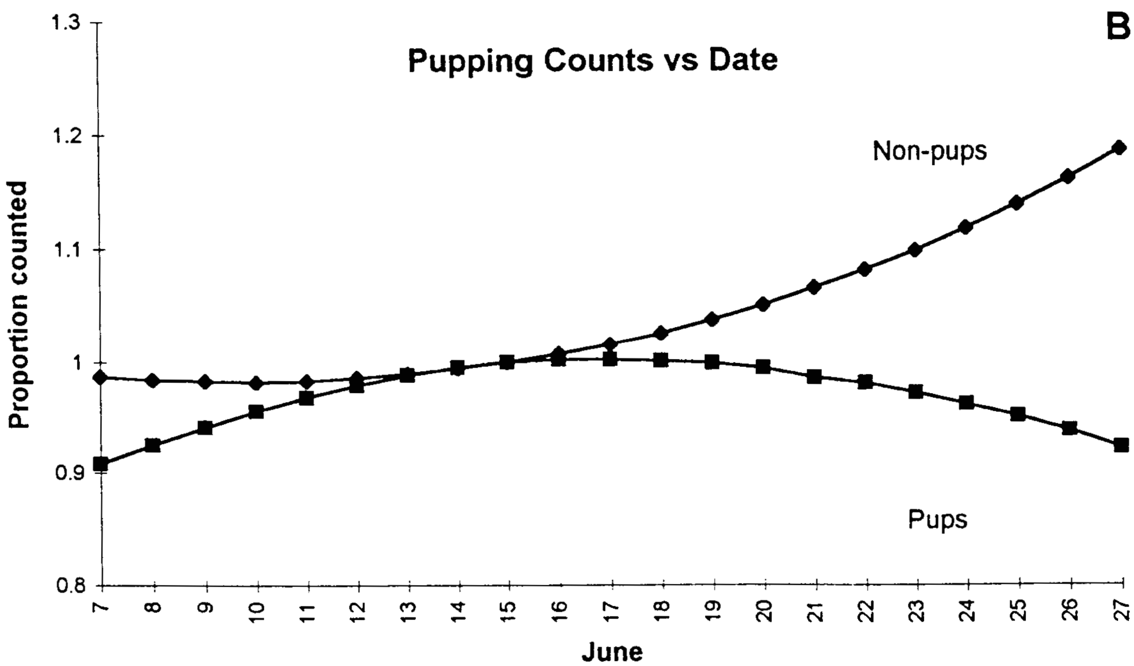


Figure 4. Effect of date on counts of harbor seals in Prince William Sound made during molting (A) and pupping (B) periods.

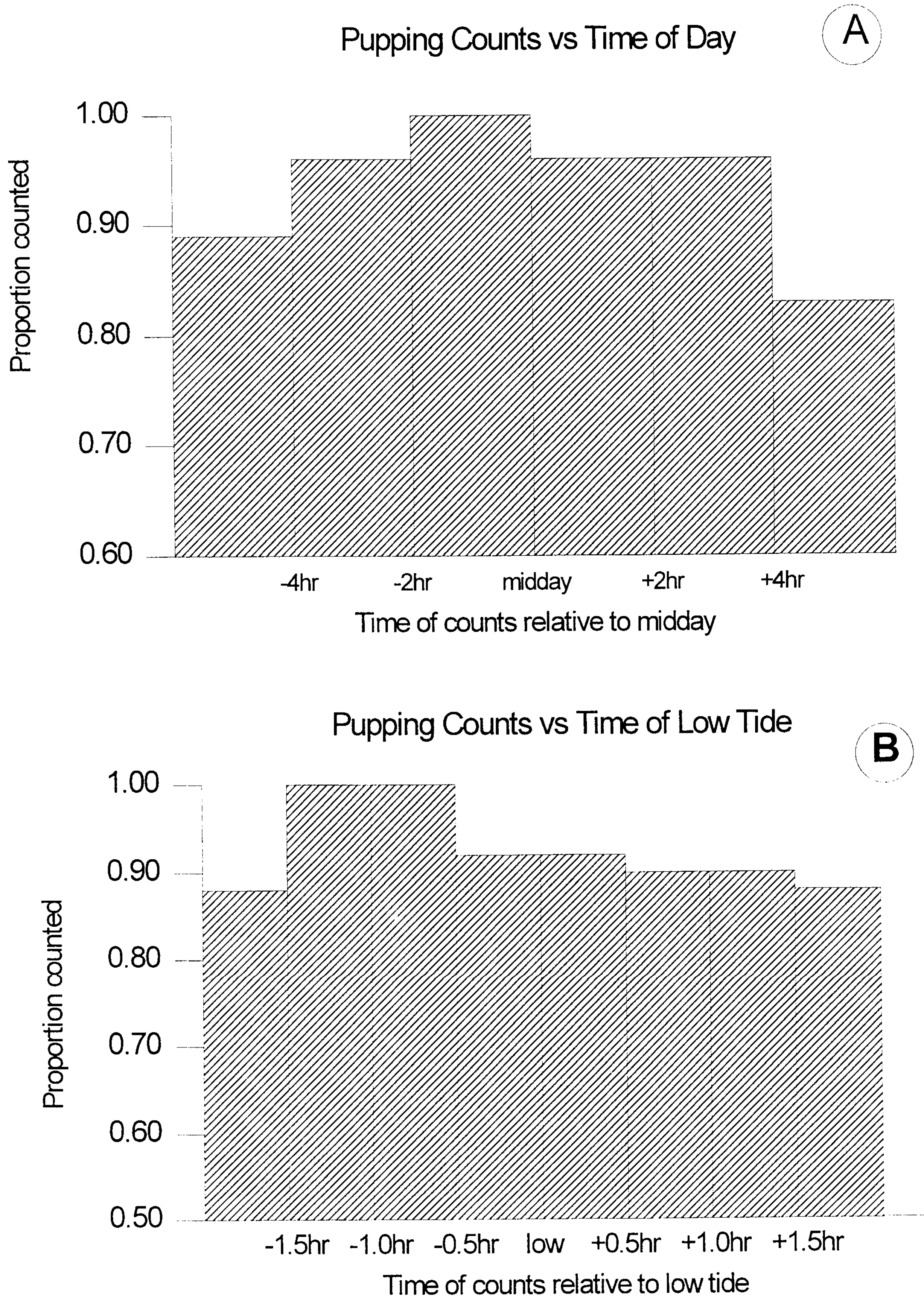
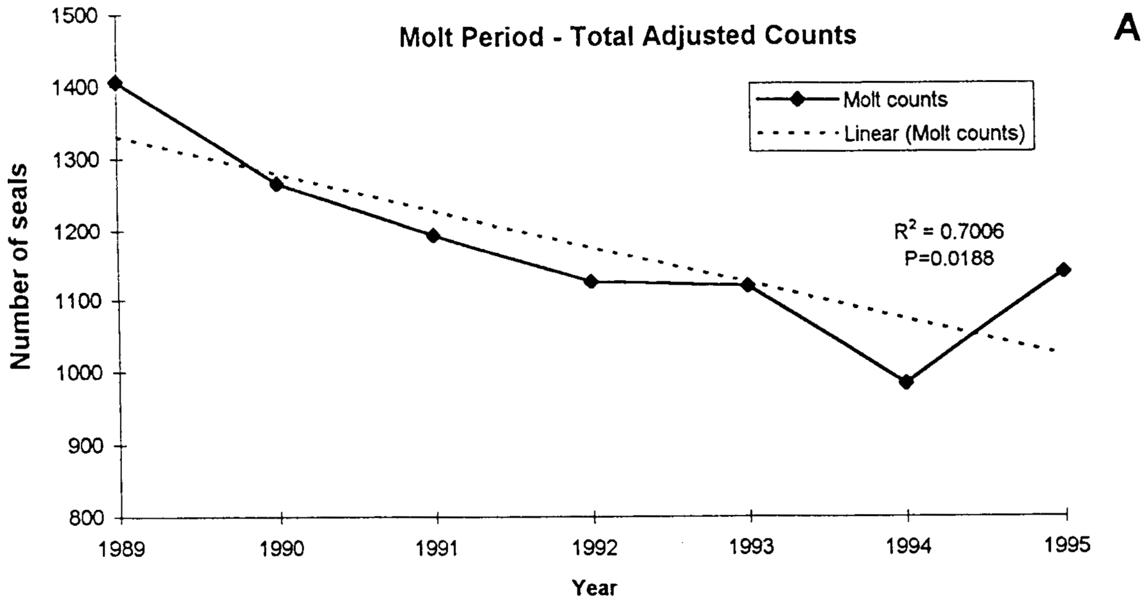


Figure 5. Effect of time of day (A) and time relative to low tide (B) on counts of harbor seals in Prince William Sound, June 1989-1995.



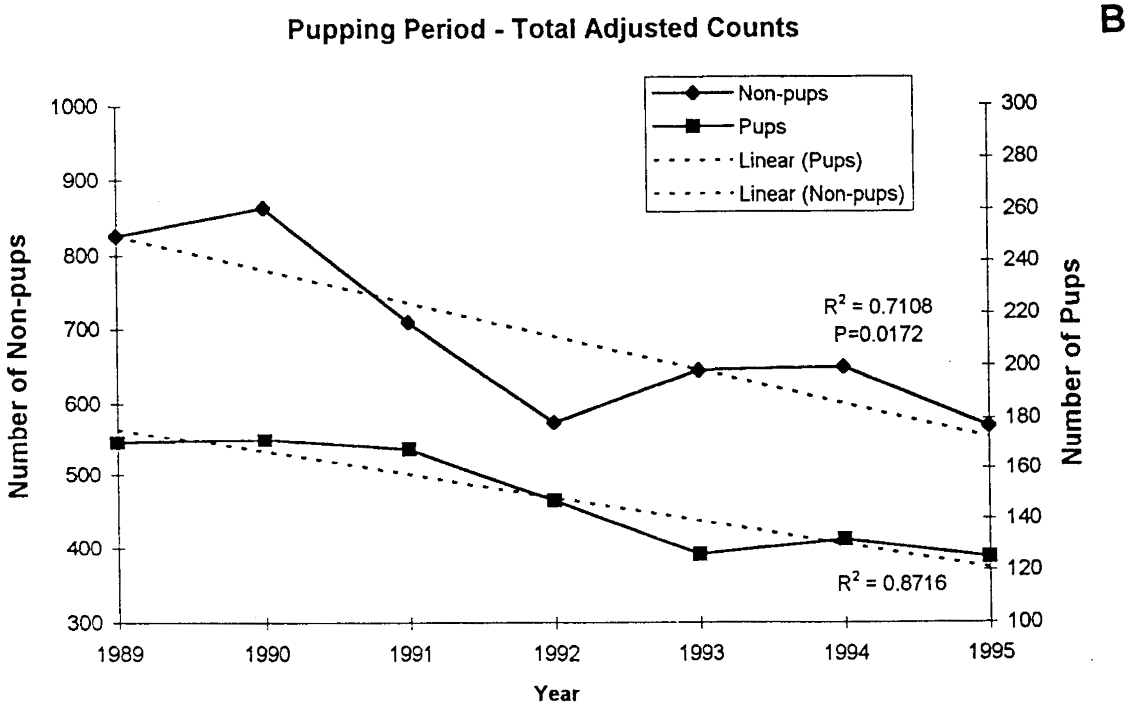


Figure 6. Trend in numbers of harbor seals in Prince William Sound based on adjusted counts made during August-September (A) and June (B) 1989-1995.

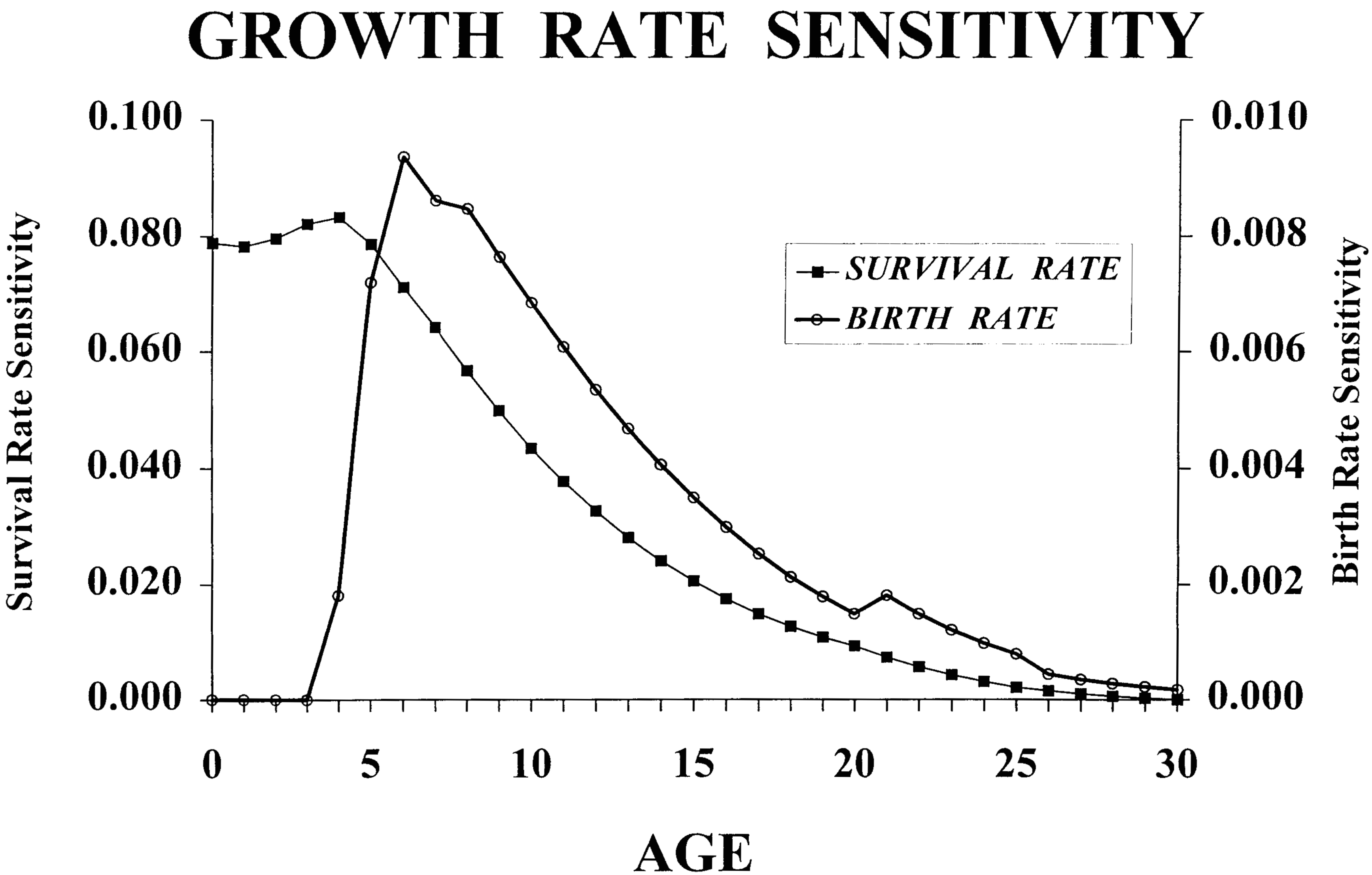


Figure 7. Sensitivity of the population growth rate to changes in survival and reproduction. Values on the y-axes indicate sensitivity and must be multiplied by age-specific survival or growth rates to estimate the amount of change which would occur.

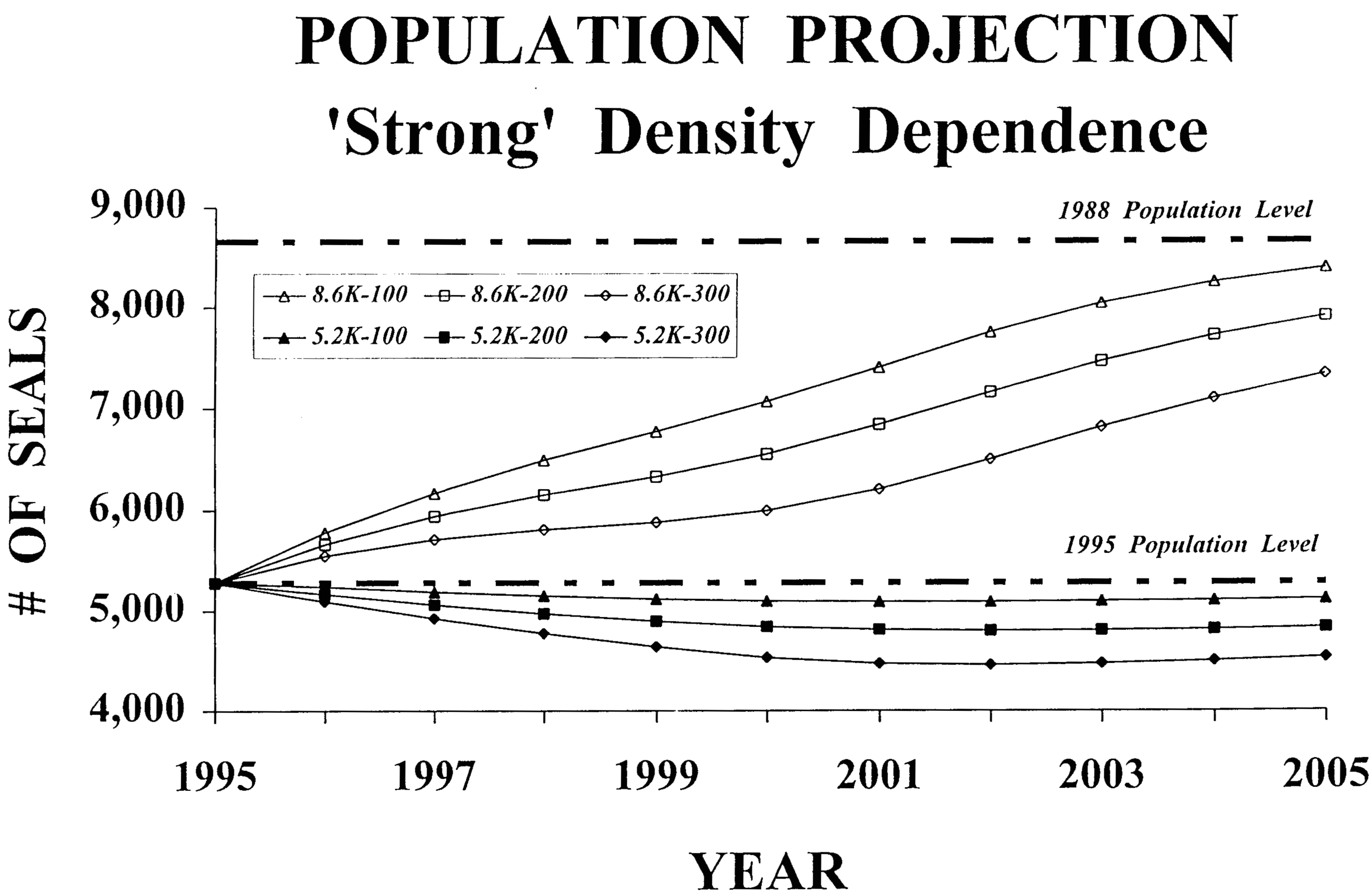


Figure 8. Ten year population projections with 'strong' density dependence. Projections begin with the estimated 1995 population, and use two levels of K corresponding to 1988 and 1995 population levels. Additional mortality was set at three levels: 300, 200, 100.

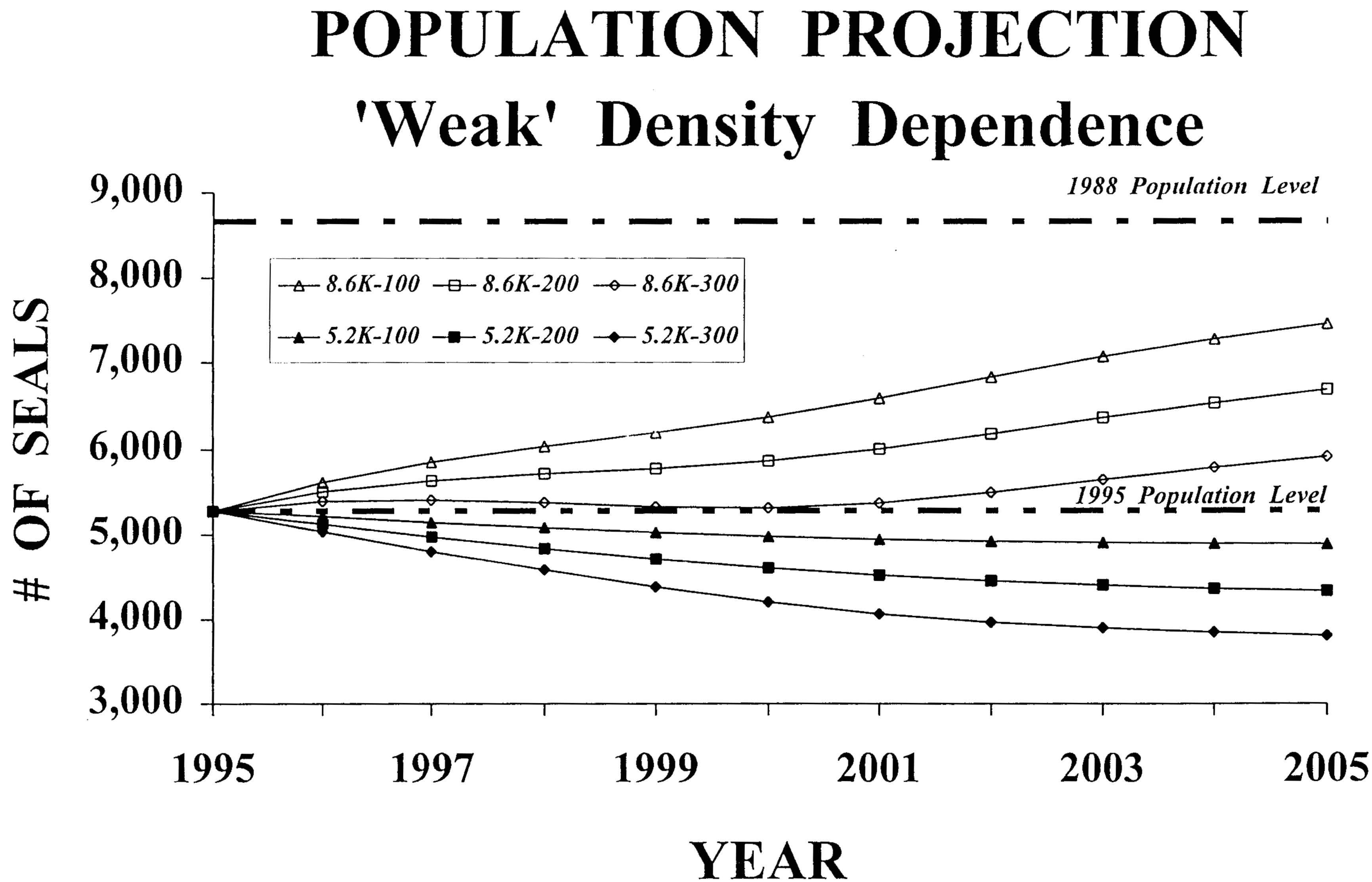


Figure 9. Ten year population projections with 'weak' density dependence. Projections begin with the estimated 1995 population, and use two levels of K corresponding to 1988 and 1995 population levels. Additional mortality was set at three levels: 300, 200, 100.

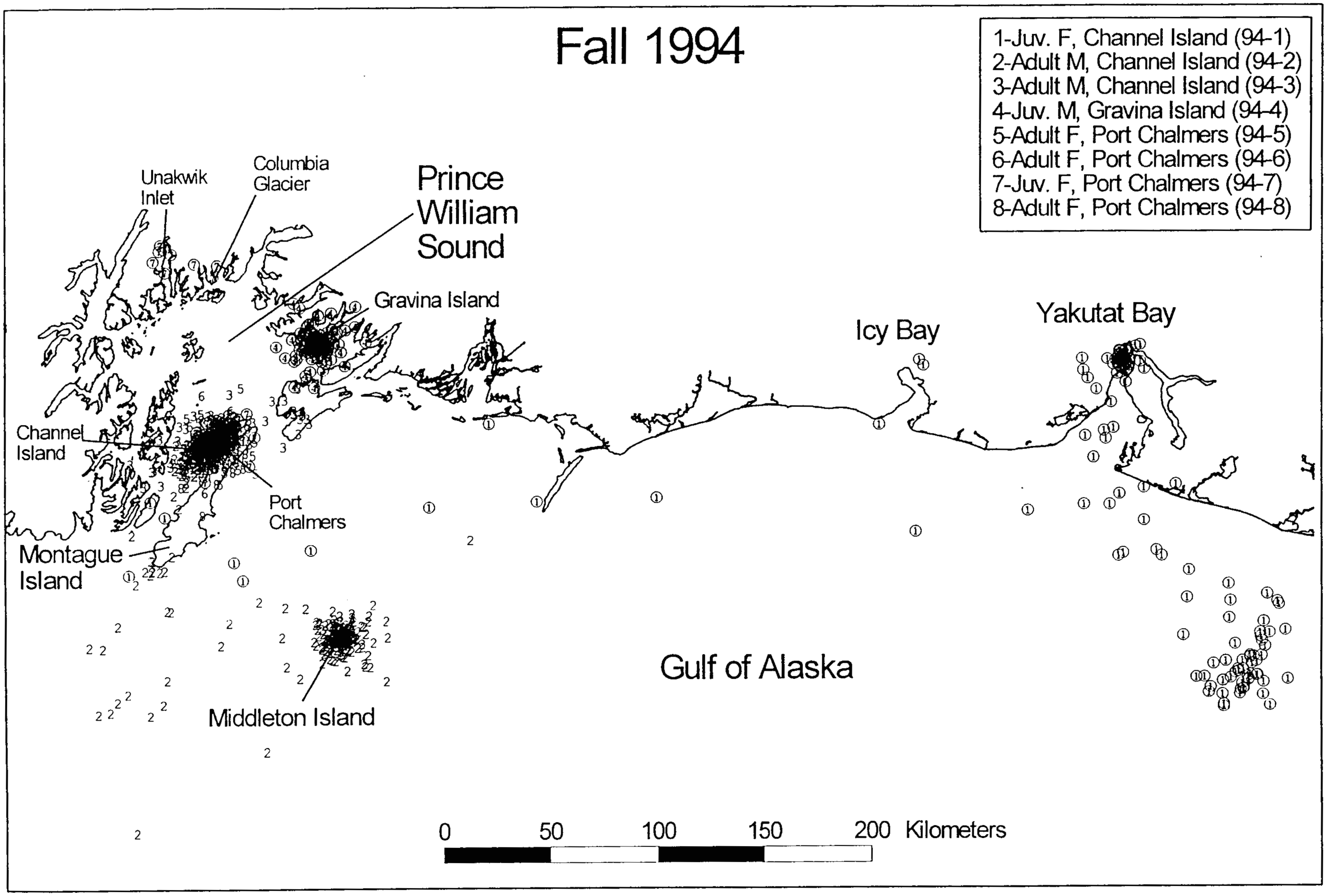


Figure 10. Map of Prince William Sound and the Gulf of Alaska showing average daily locations of satellite tagged seals during September 1994-June 1995.

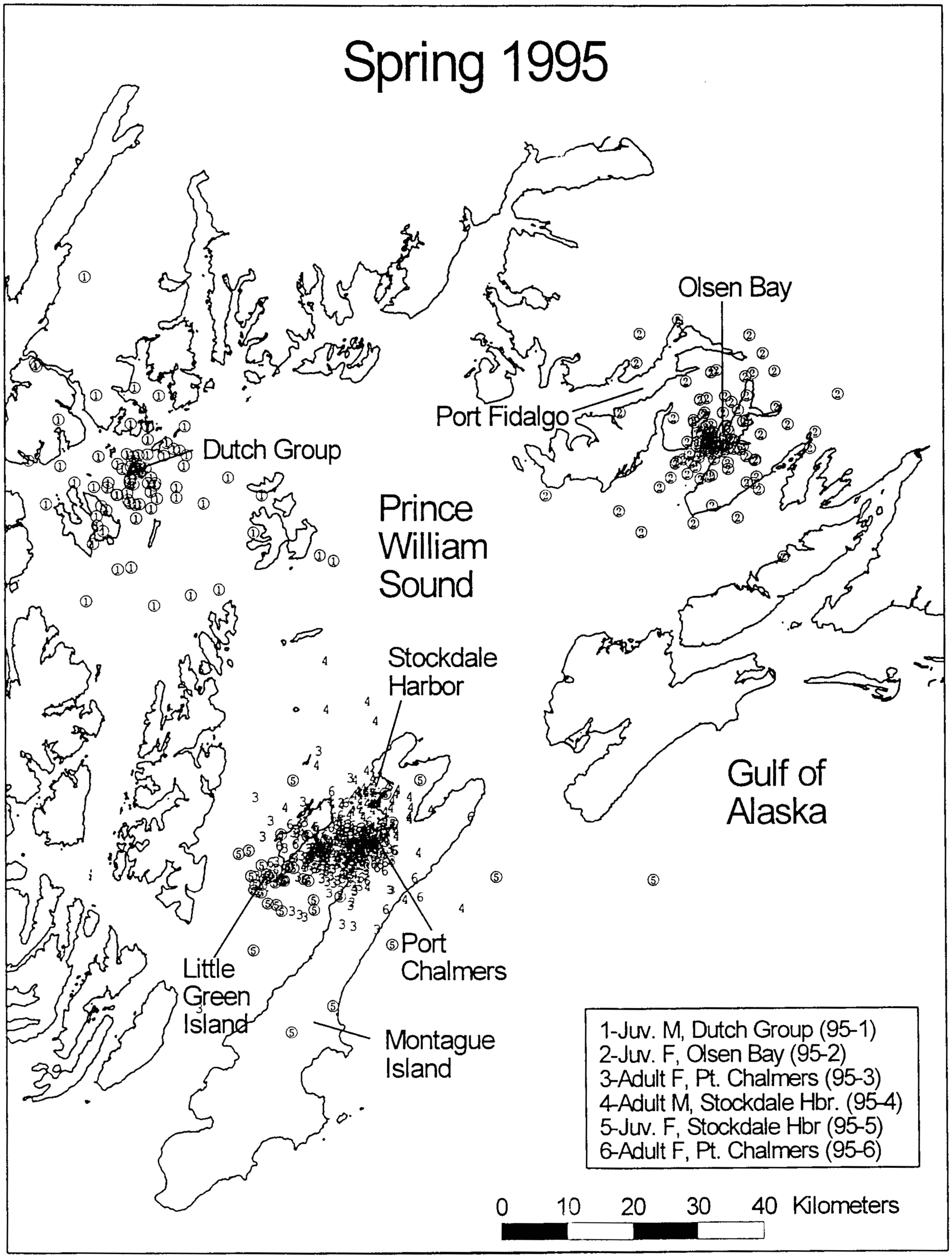


Figure 11. Map of Prince William Sound showing average daily locations of satellite tagged seals during May-July 1995.

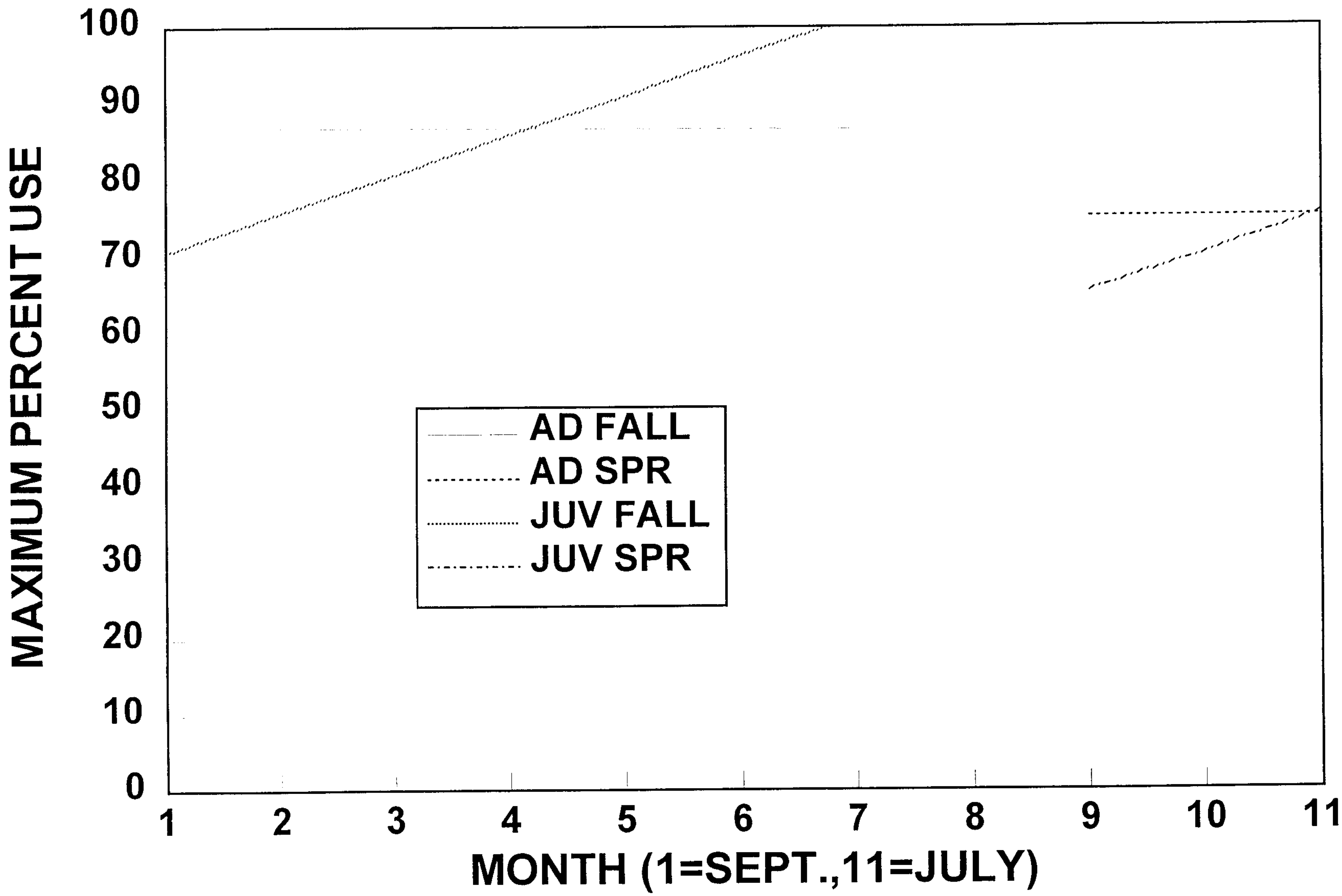


Figure 12. Monthly maximum proportional use of haulouts by harbor seals satellite tagged in Prince William Sound, 1992-1995. Lines shown are averages within age/sex classes where there are significant differences in intercepts within these groups.

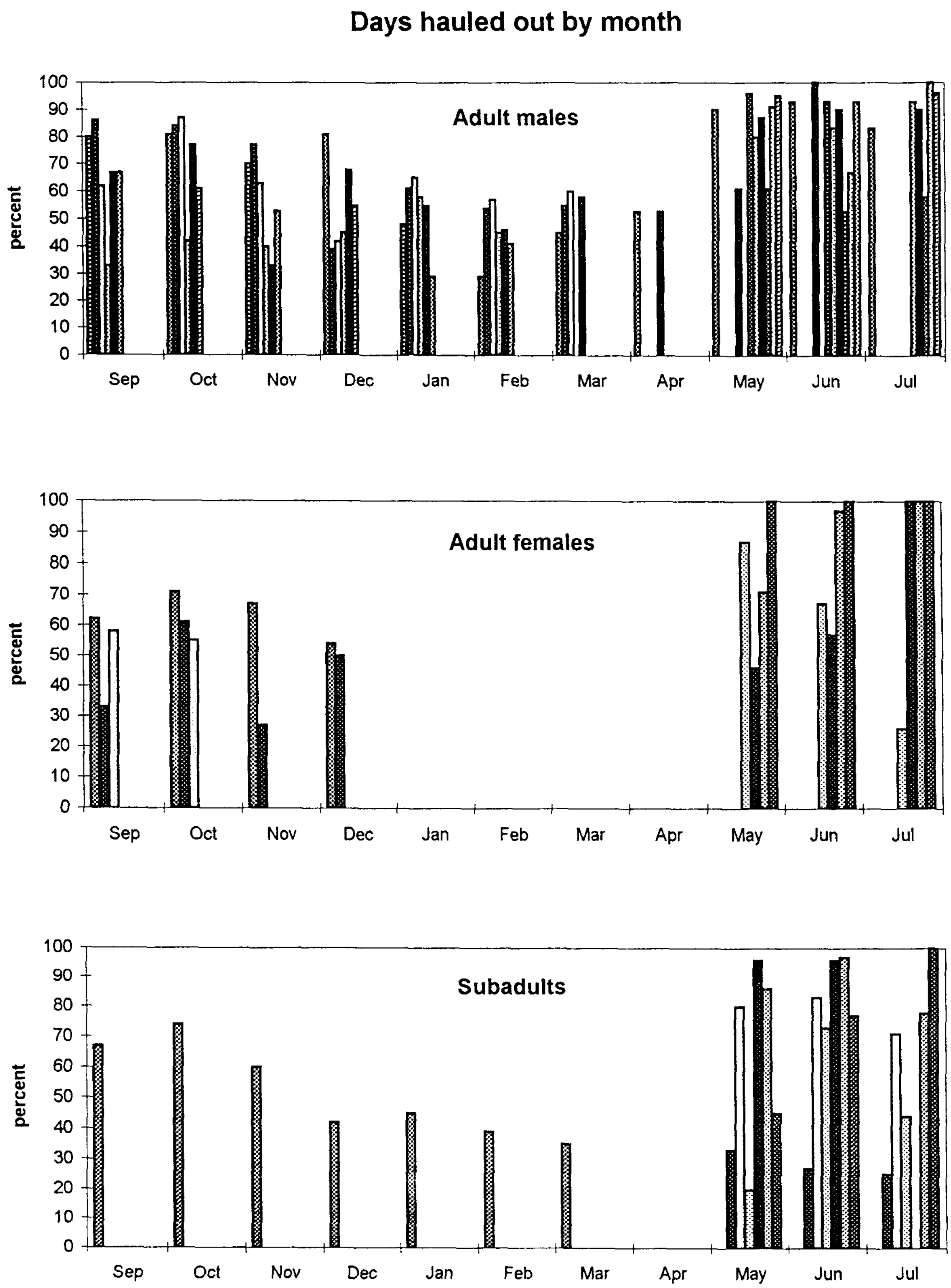


Figure 13. Percent of days hauled out each month, based on land-sea sensor data, for 26 satellite tagged harbor seals, May 1992-September 1995.

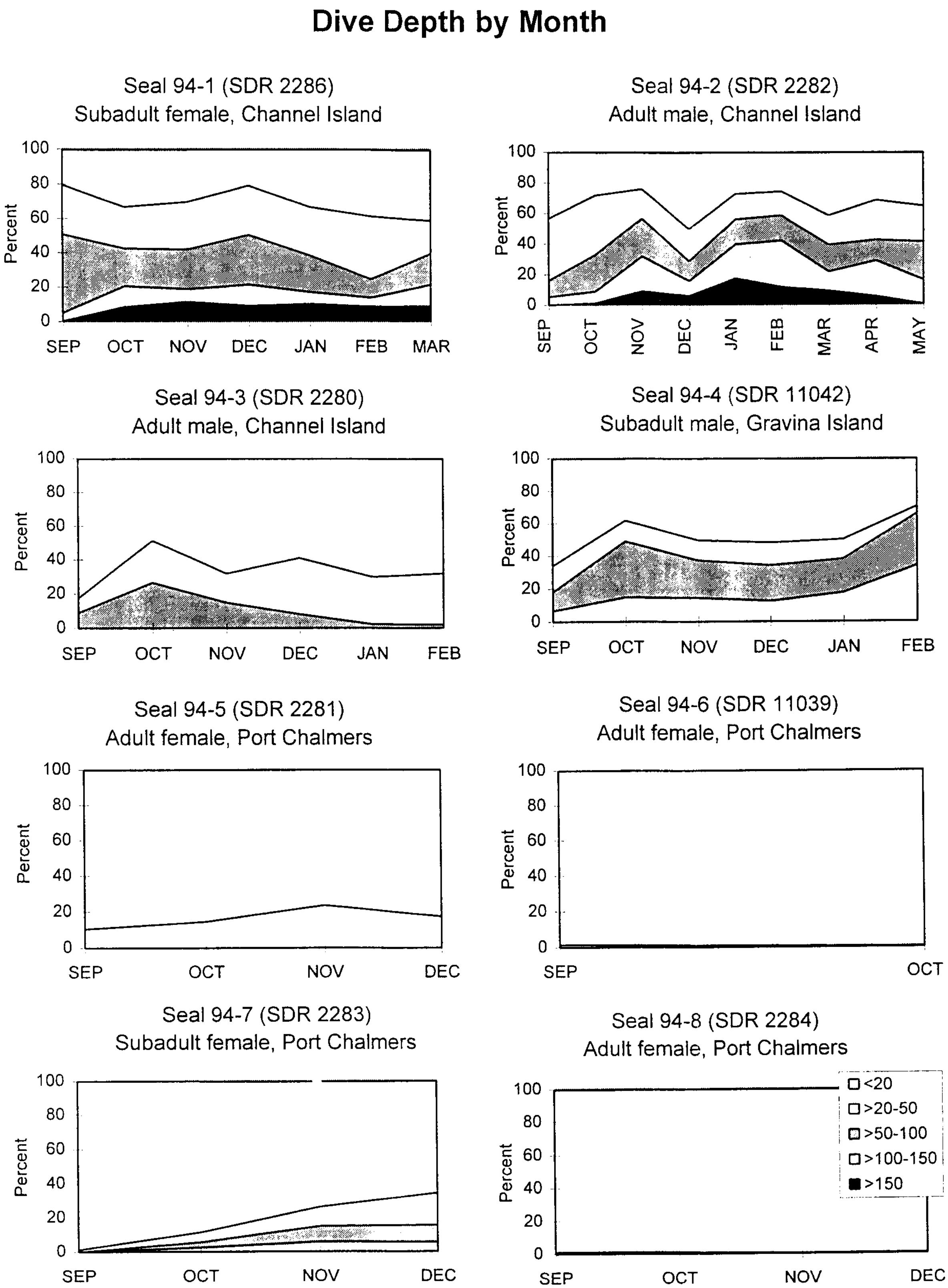


Figure 14. Monthly distribution of dives by depth (m) for eight satellite tagged harbor seals in Prince William Sound, September 1994-May 1995.

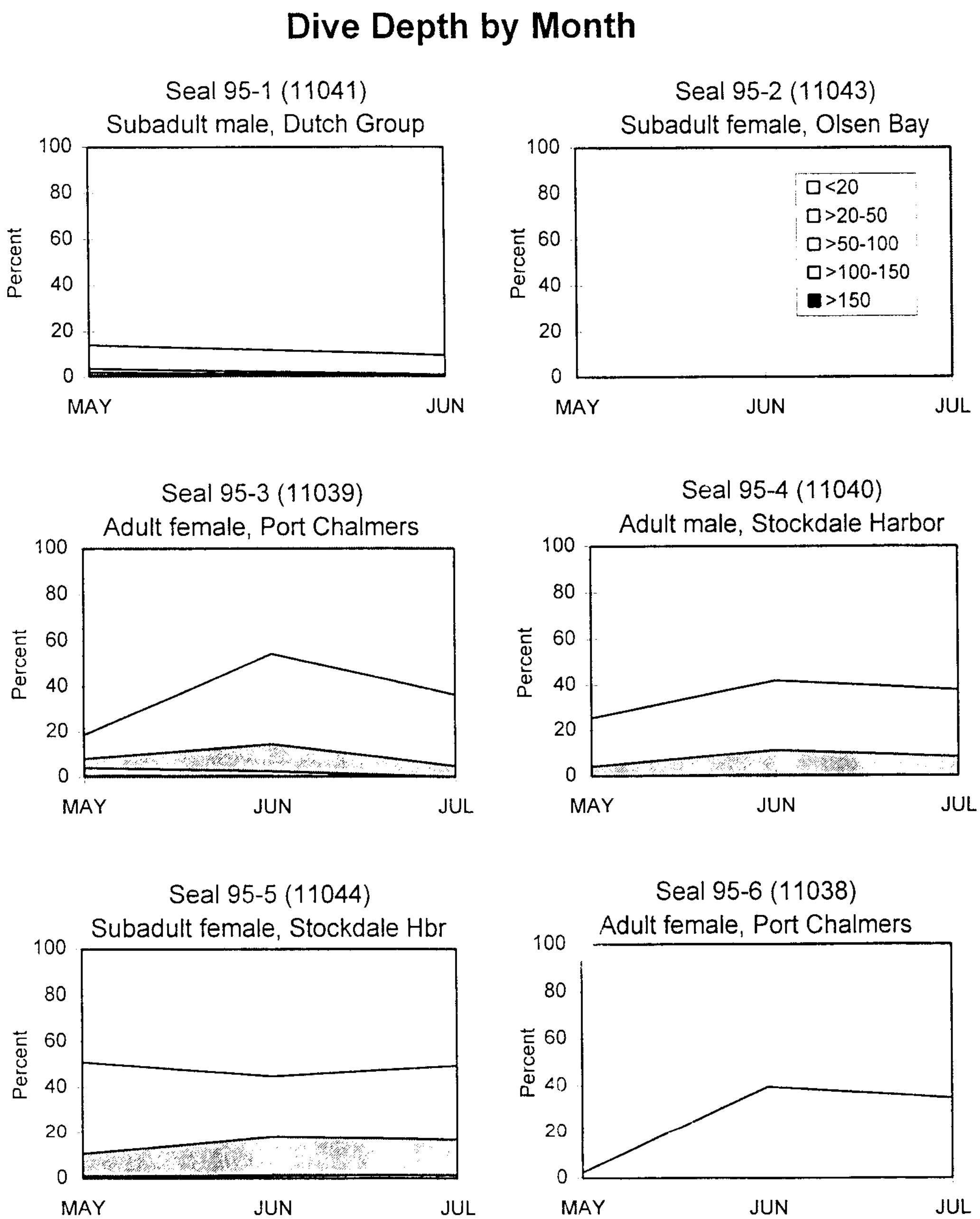


Figure 15. Monthly distribution of dives by depth (m) for six satellite tagged harbor seals in Prince William Sound, May-July 1995.

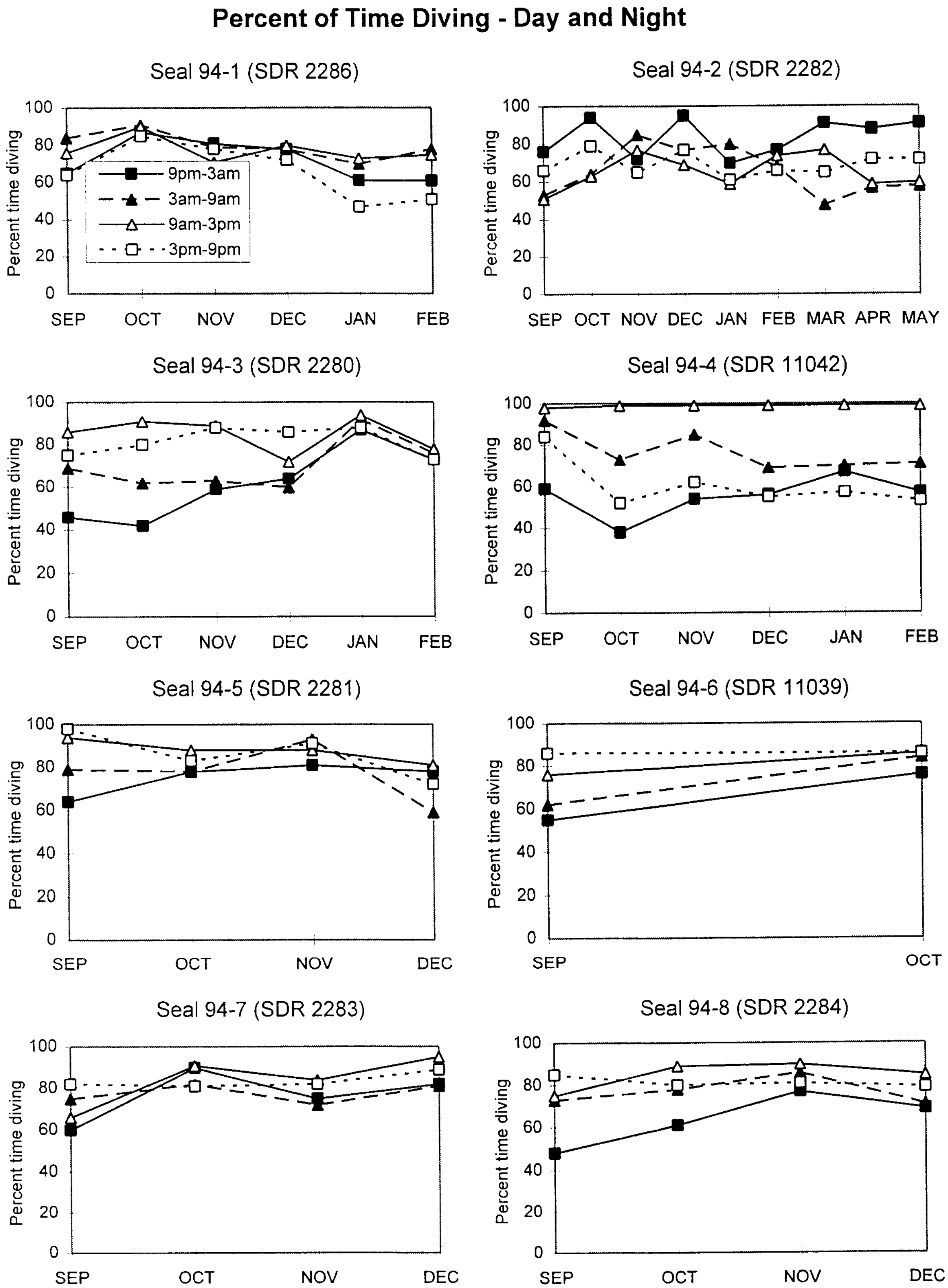


Figure 16. Monthly distribution of the percent of time diving during four periods of the day for eight satellite tagged harbor seals in Prince William Sound, September 1994-May 1995.

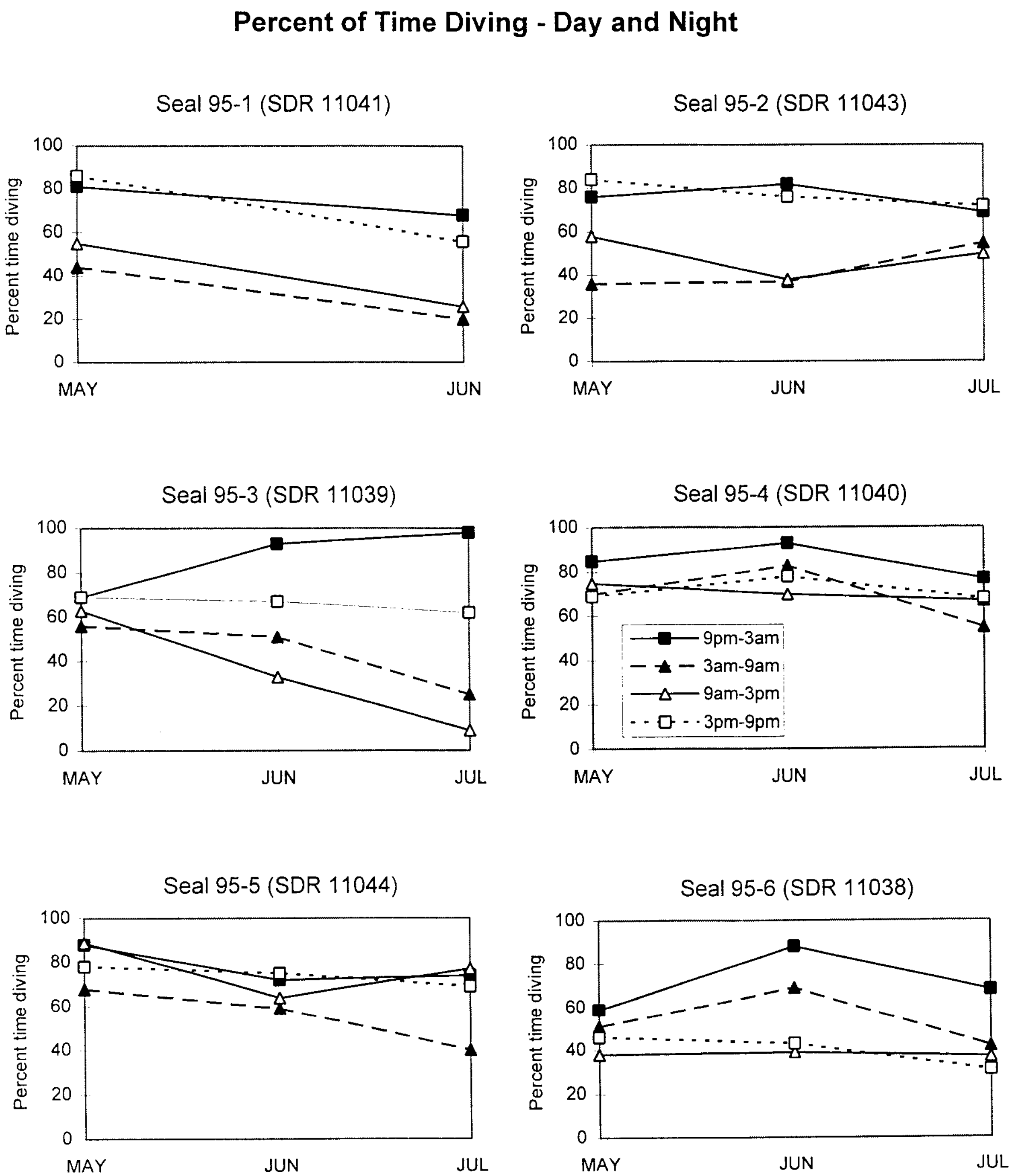


Figure 17. Monthly distribution of the percent of time diving during four periods of the day for six satellite tagged harbor seals in Prince William Sound, May-July 1995.

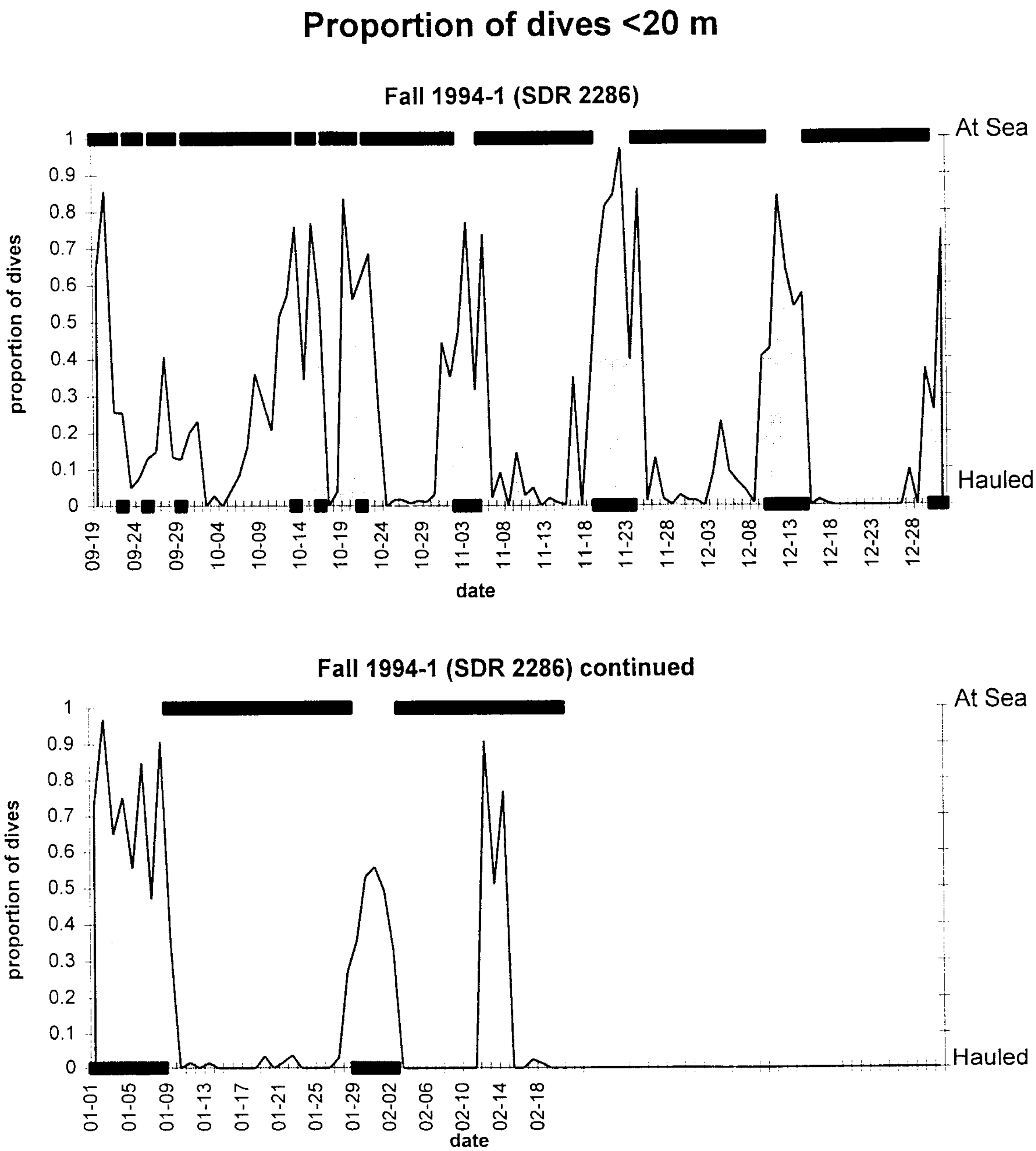


Figure 18. Proportion of dives less than 20 m, and days hauled out or at sea, for seal 94-1, a subadult female that spent the period from October 6 through February 20 in the Gulf of Alaska near Yakutat.

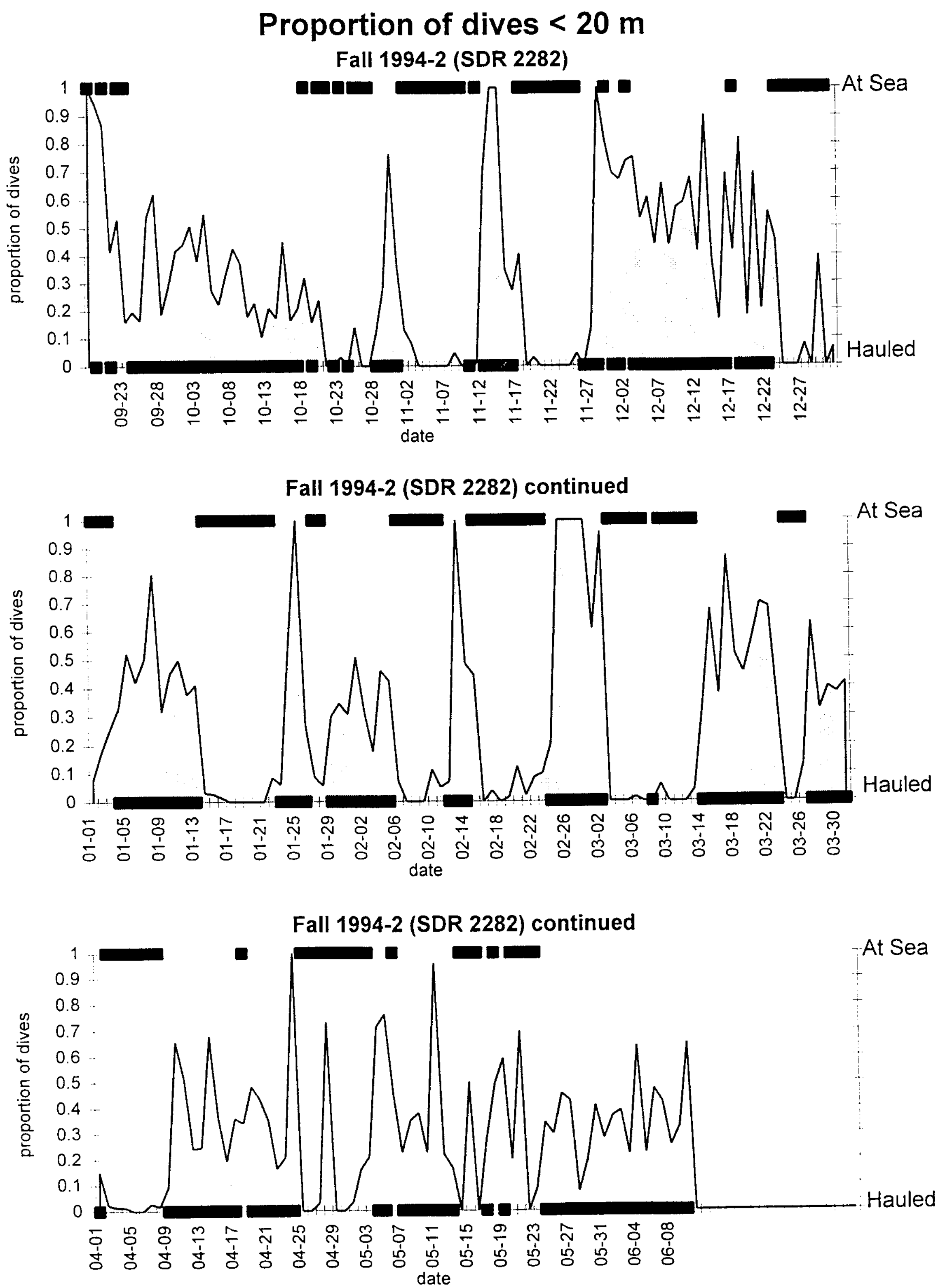


Figure 19. Proportion of dives less than 20 m, and days hauled out or at sea, for seal 94-2, an adult male that spent the period from 26 September through 21 May in the Gulf of Alaska near Middleton Island.

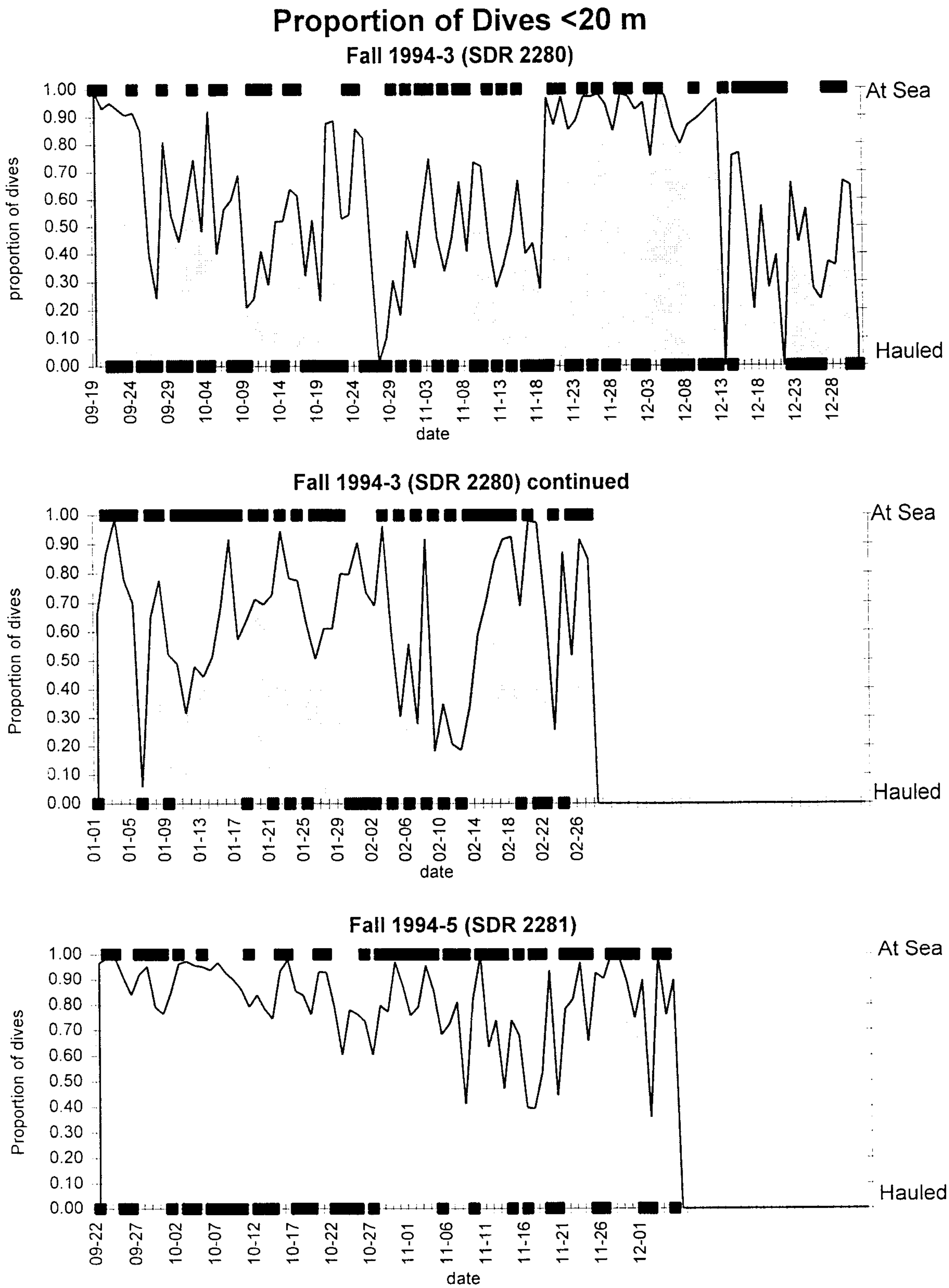
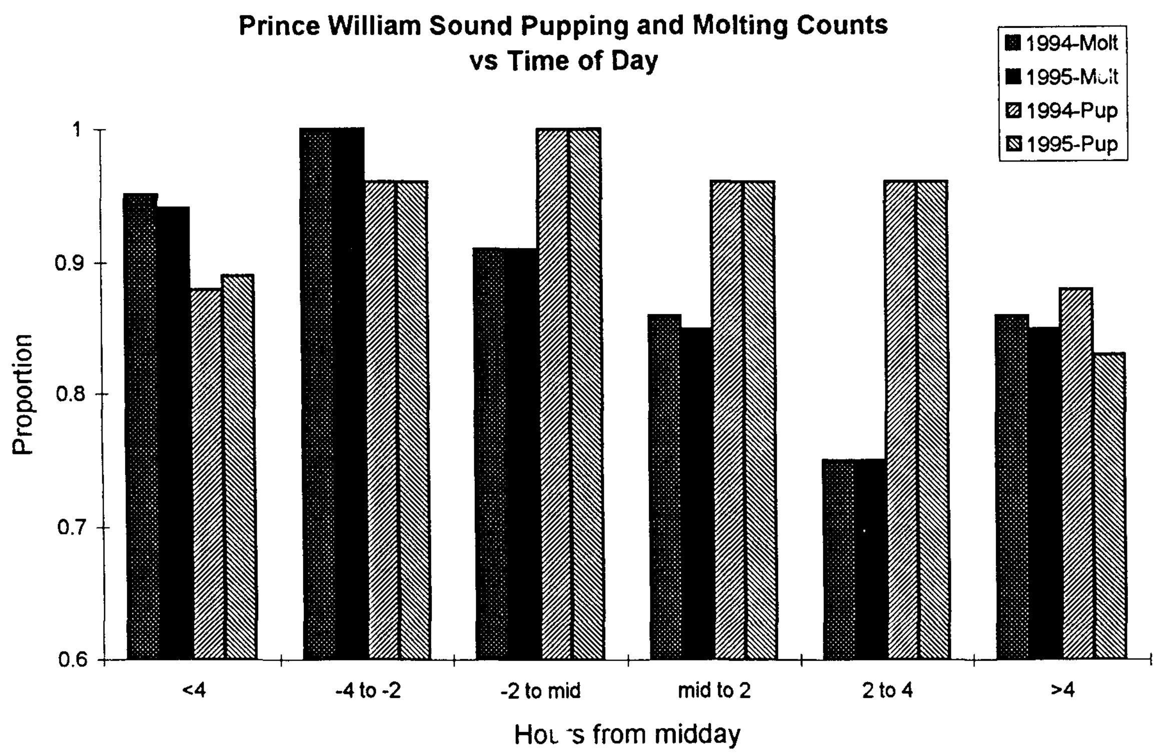


Figure 20. Proportion of dives less than 20 m, and days hauled out or at sea, for two seals (94-3 and 94-5) that spent September through February in Prince William Sound near Montague Island.



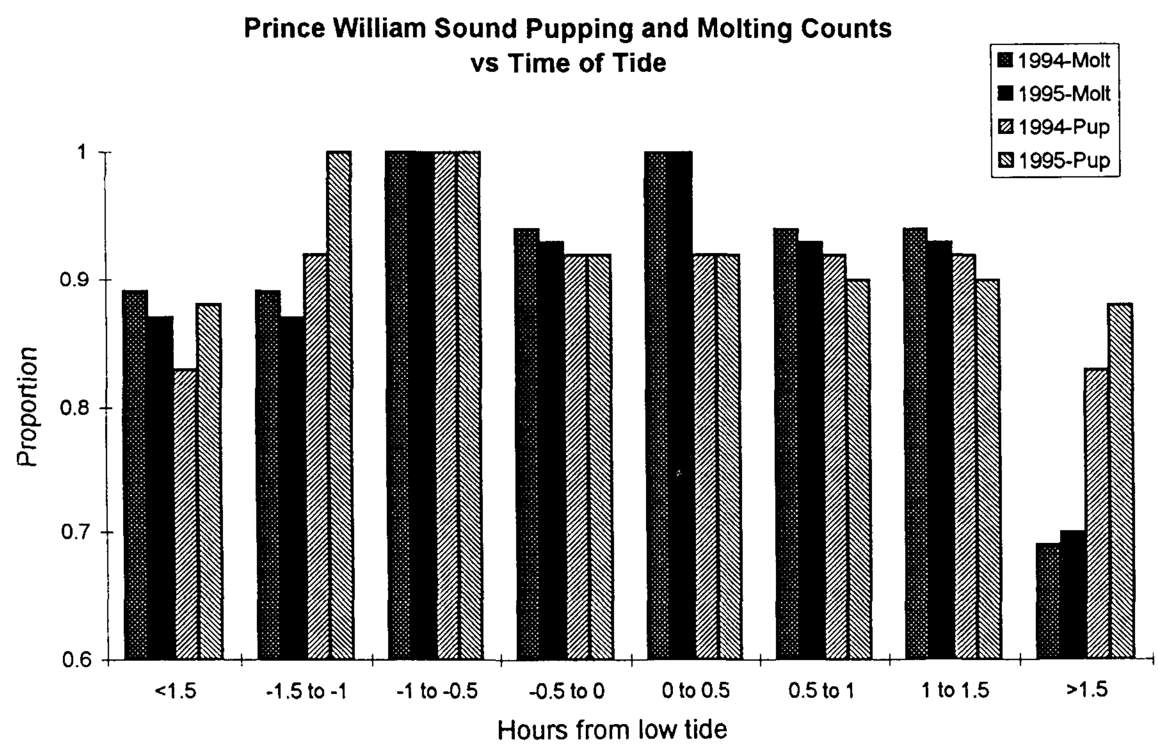


Figure 21. Effect of time of day and time relative to low tide on counts of harbor seals during pupping and molting in Prince William Sound using parameter estimates for 1994 and 1995.

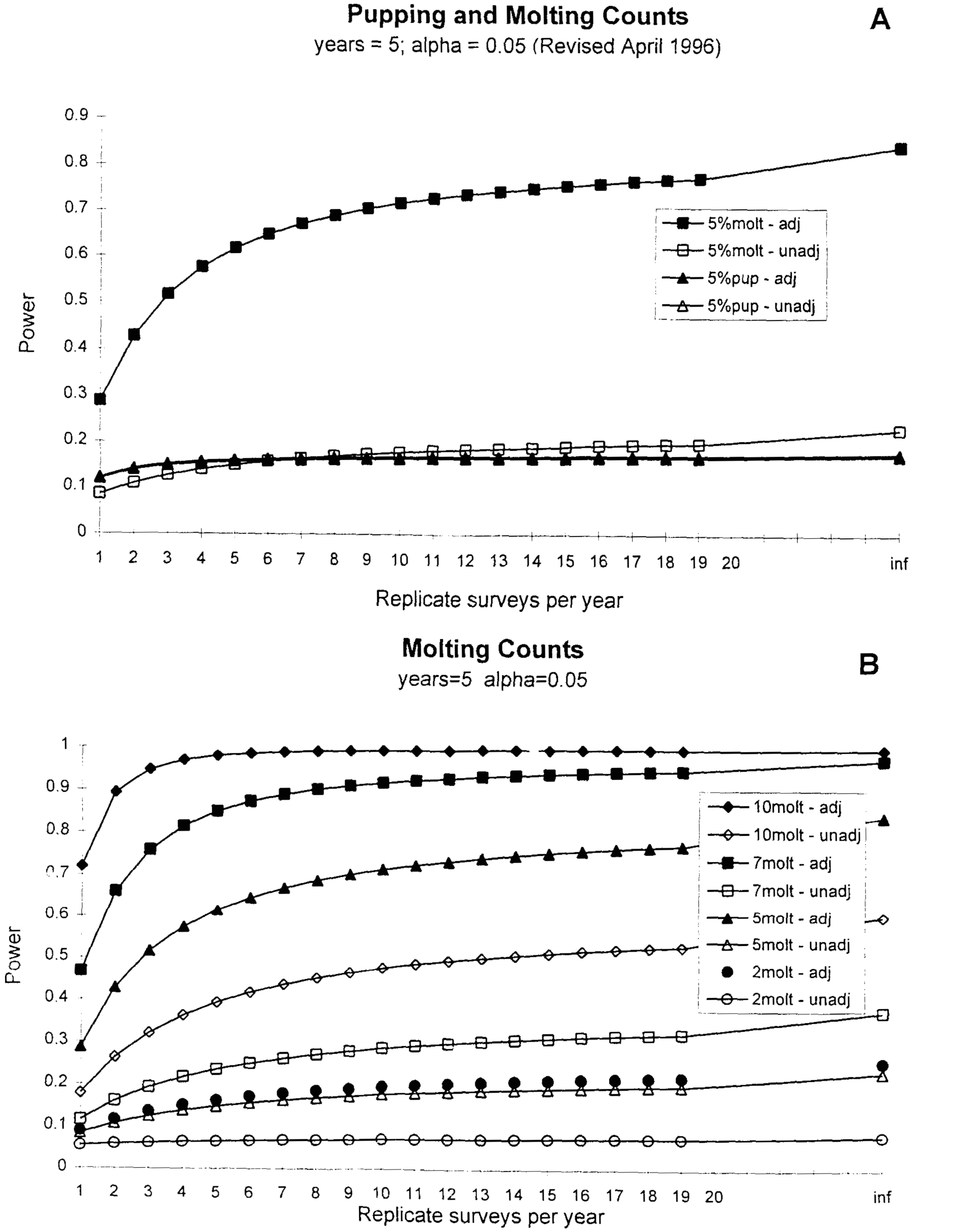


Figure 22. Power analysis for aerial surveys of harbor seals in Prince William Sound using unadjusted and adjusted counts: A. based on a 5% annual incease during molting and pupping, and B. for 2%, 5%, 7%, and 10% rates of increase during molting.

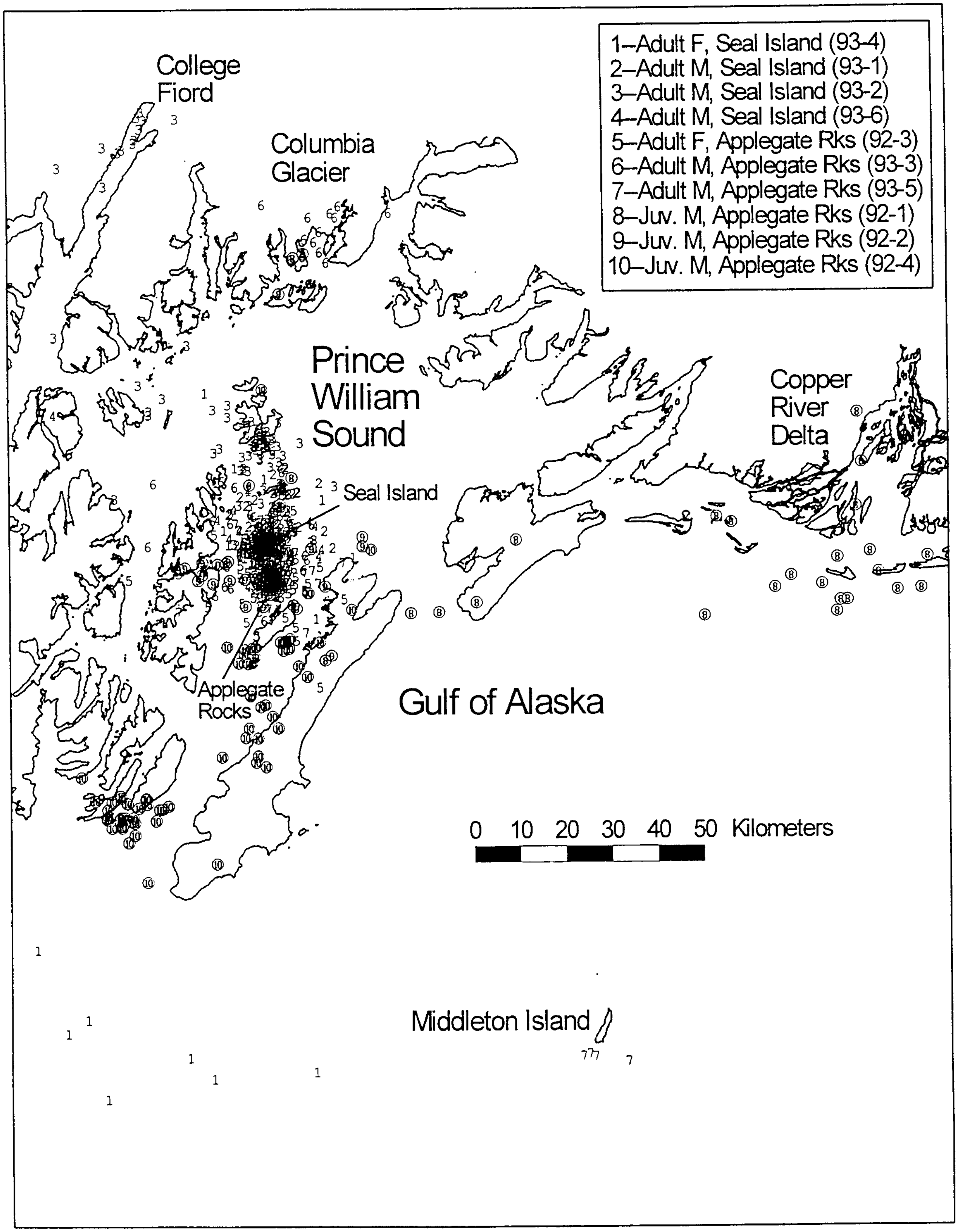


Figure 23. Map showing average daily locations of satellite tagged harbor seals in central Prince William Sound, May-July 1992-1993.

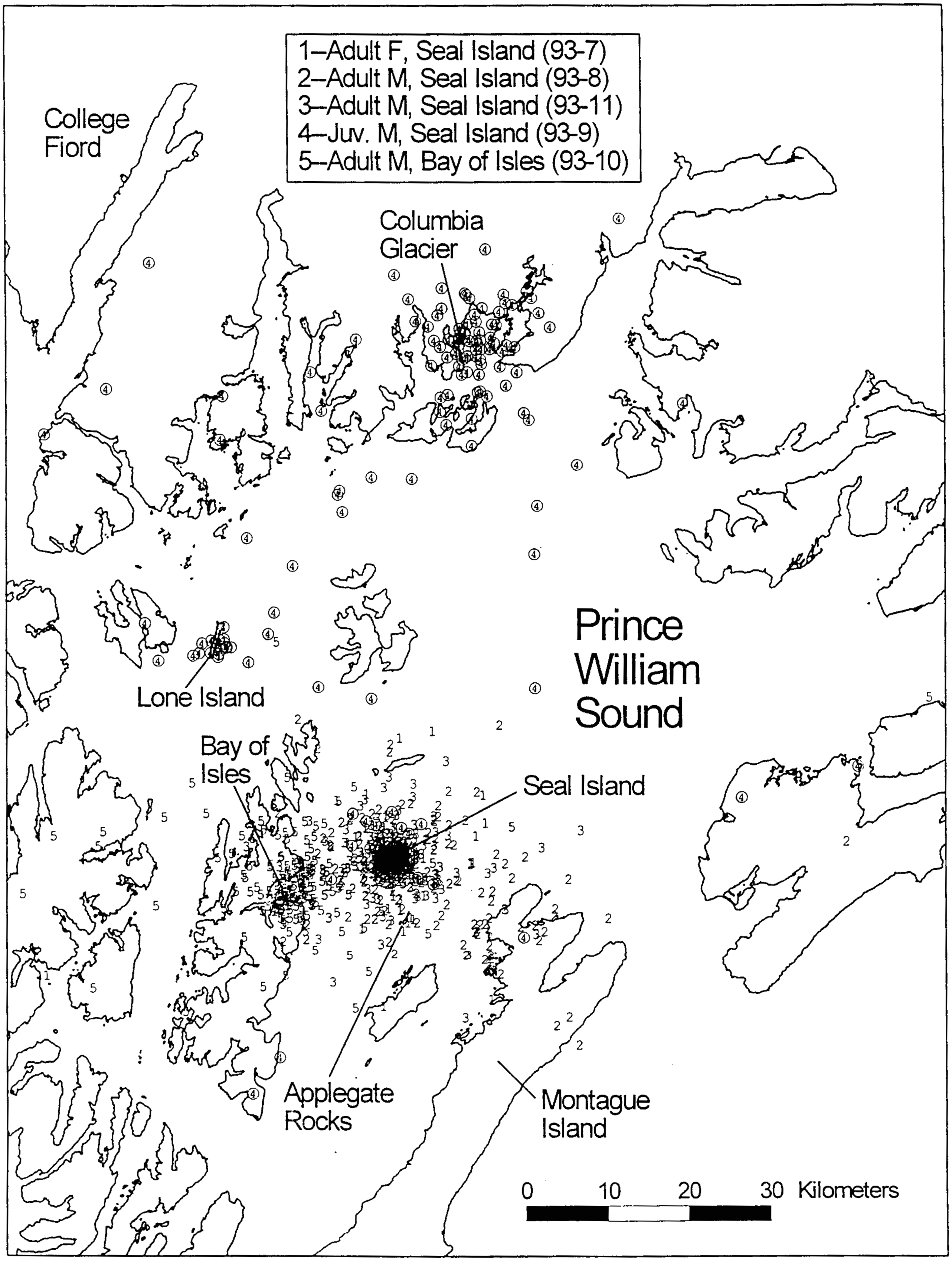


Figure 24. Map showing average daily locations of satellite tagged harbor seals in central Prince William Sound, September-July 1993-1994.

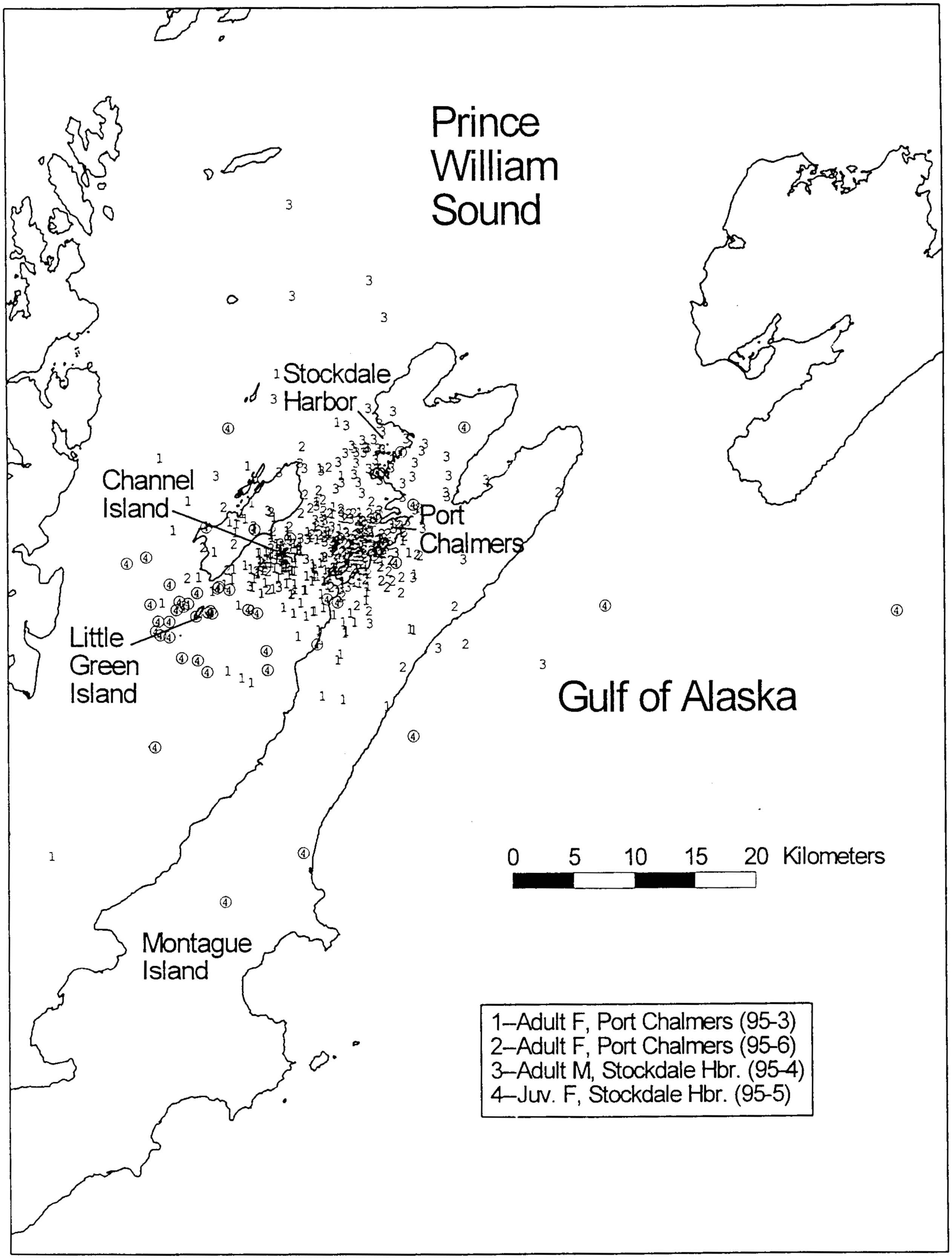


Figure 25. Map showing average daily locations of satellite tagged harbor seals in southern Prince William Sound May-July 1995.

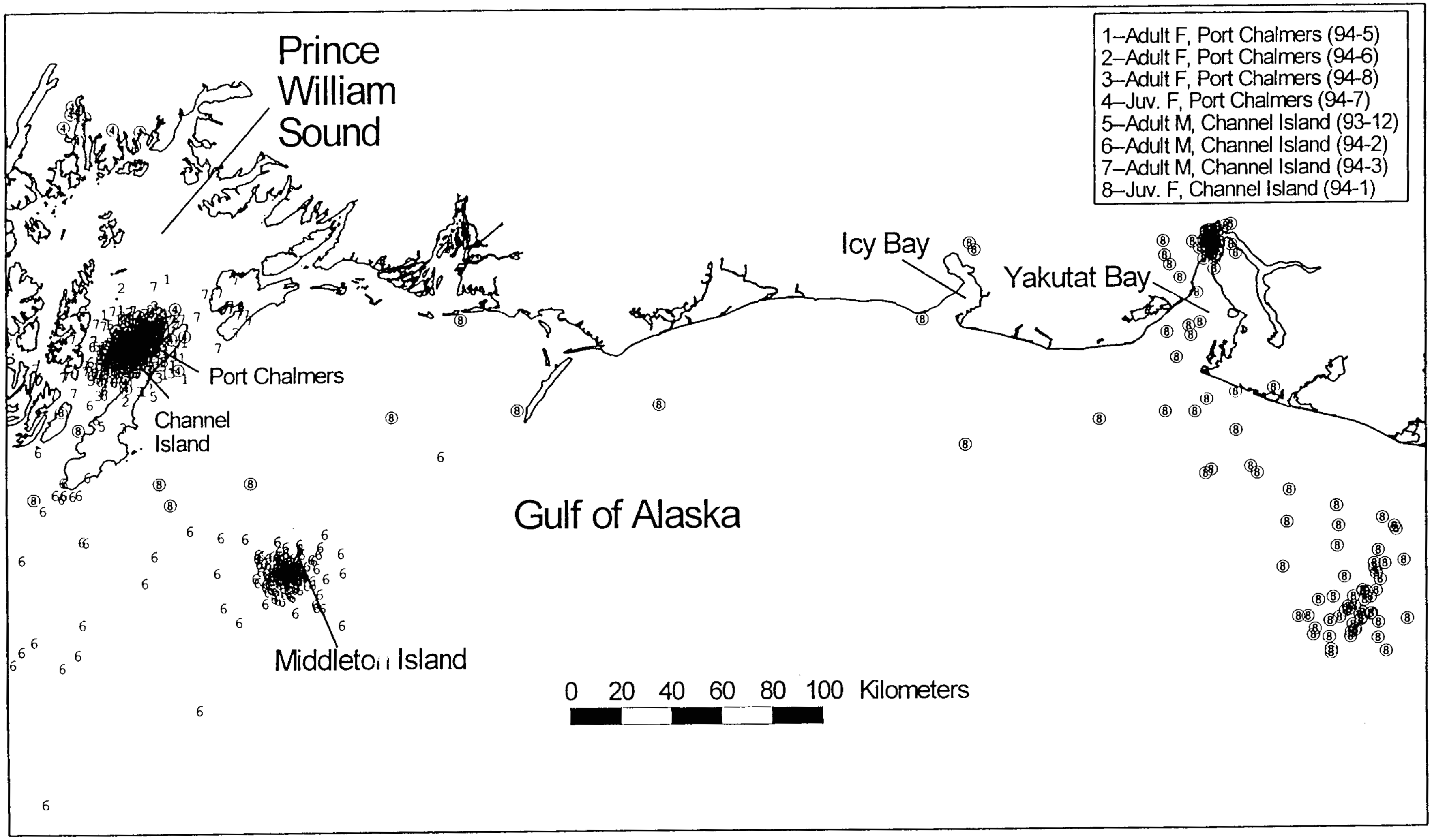


Figure 26. Map showing average daily locations of satellite tagged harbor seals in southern Prince William Sound, September-May 1993-1995.

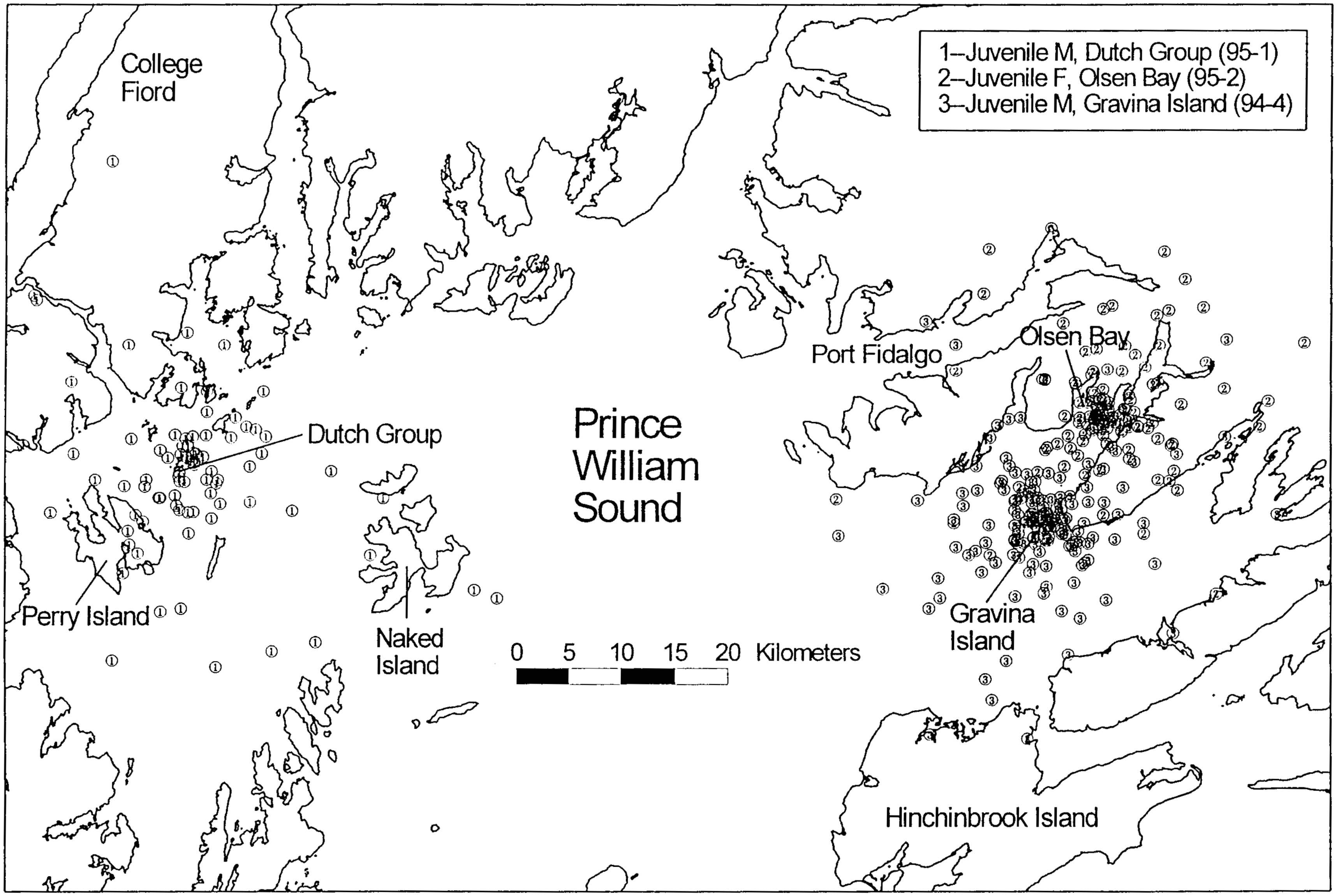


Figure 27. Map showing average daily locations of satellite tagged harbor seals in eastern and western Prince William Sound, September 1994-February 1995 and May-July 1995.

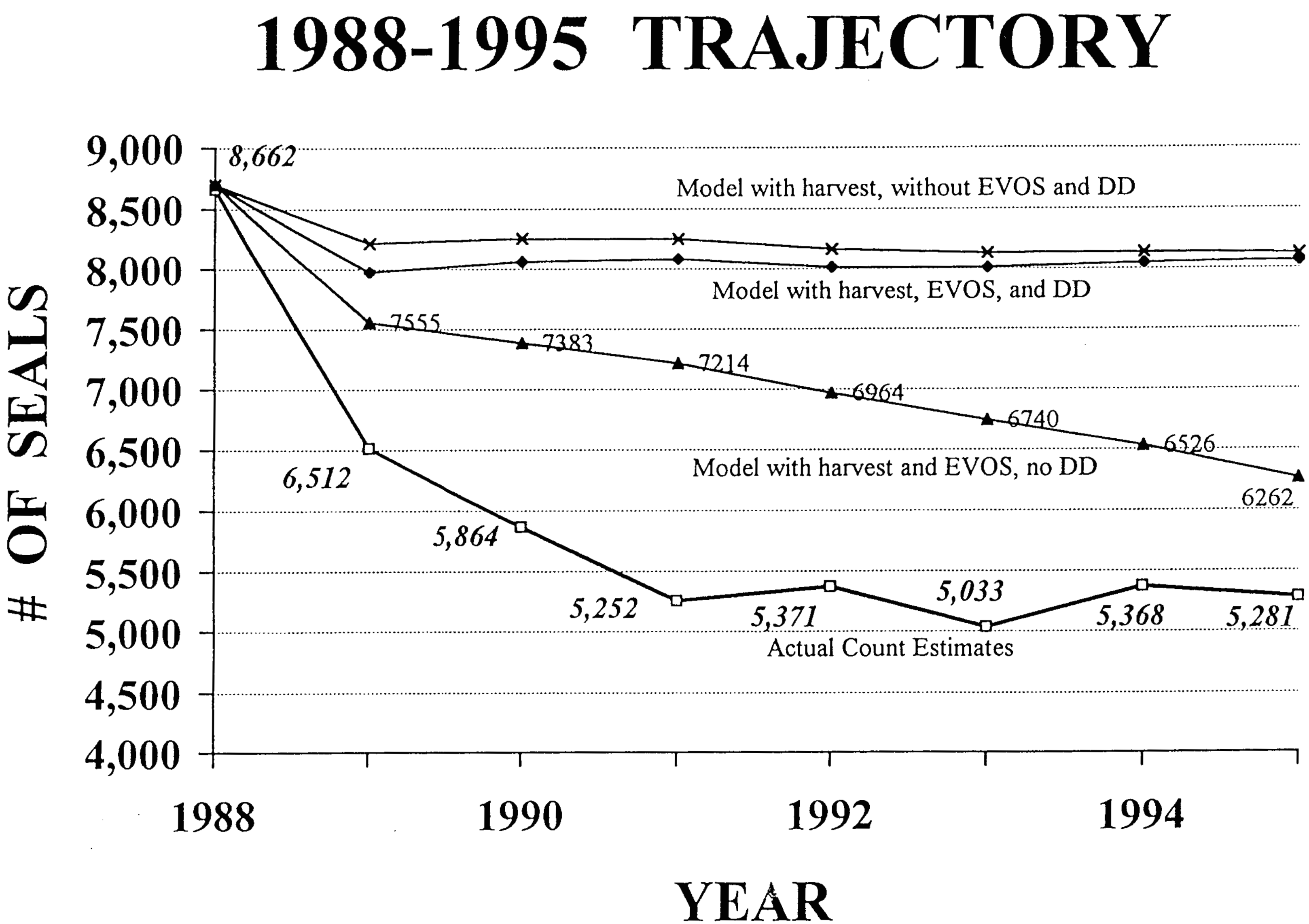


Figure 28. Trajectories of harbor seal counts from 1988-1995 showing actual estimated count data and simulated data. Simulations include subsistence harvest and estimated mortality due to the EVOS, and are done both with and without density dependence (DD).

Appendix A.

The Use of Fatty Acid Signatures to Investigate Foraging Ecology and Food Webs in Prince William Sound, Alaska: Harbor Seals and their Prey

Part of:

Monitoring, Habitat Use, and Trophic Interactions of Harbor Seals in Prince William Sound, Alaska

Exxon Valdez Oil Spill
Restoration Science Study Number 95064
1996 Annual Report

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15 April 1996

SUMMARY

The decline in harbor seal numbers in Prince William Sound (PWS), since 1984, which was exacerbated by the *Exxon Valdez* oil spill of 1989, has prompted continuing and detailed monitoring of the population. Central to this monitoring is the study of prey consumed by harbor seals. In the present study, we report on the first part of a longer term research project to investigate both harbor seals and their prey in PWS and the Gulf of Alaska using fatty acid signature analysis and demonstrate the use of classification and regression tree (CART) analysis in S-Plus. Blubber samples were collected and analyzed for fatty acid composition from a total of 84 harbor seals within various areas of PWS, as well as from the Gulf of Alaska (Kodiak Island and southeast Alaska) for comparison. A total of 163 prey representing 10 species collected in PWS, were individually analyzed for fat content and fatty acid composition. Our results indicate that fatty acid composition of harbor seal blubber varies as a function of haulout site both among areas in the Gulf and within PWS, suggesting that harbor seals in PWS depend on a very localized prey base. Prey differed notably among species in fatty acid composition, and species could be identified from signatures. Within species such as herring and pollock, the fatty acid composition varied directly as a function of body size, yet each could still be differentiated as a species. These results imply that size and age class of prey can be determined from fatty acid signatures. The fatty acid composition of prey in PWS clearly explained the signatures and occurrence of unique isomer ratios in the Alaska seals, and provide encouraging validation for fatty acids reflecting diet. Although full conclusions are restricted at this point with limited data, in general large herring, followed by large pollock, would be predicted to dominate the diets of harbor seals from southcentral PWS, while small herring, sandlance, cod, and cephalopods would be predicted to dominate the diets of seals from northwest, northcentral, and northeast PWS. The actual determination of seal diets from fatty acid signatures will require completion of an extensive prey library (including perhaps a more extensive review of fish stocks and productivity patterns in PWS) and development of a numerical pattern-matching approach. We conclude that this continued work and development will likely result in an important contribution to understanding the foraging ecology and marine food webs in PWS, which will also likely be applicable to understanding other estuarine and marine environments.

INTRODUCTION

Understanding the foraging ecology and diets of free-ranging marine mammals is clearly critical to evaluating how marine mammals function within an ecosystem. In Prince William Sound (PWS), harbor seals (*Phoca vitulina richardsi*) are one of the most abundant marine mammals. As top-level predators, harbor seals may both impact and be impacted by their environment. The decline in harbor seal numbers since 1984, which was exacerbated by the *Exxon Valdez* oil spill of 1989, has prompted continuing and detailed monitoring of the population (Frost, Lowry & Ver Hoef 1995). Central to this monitoring must be the study of prey consumed by harbor seals. Conservation and management strategies of will also require an understanding of effects of seals upon factors such as age-structure and productivity of commercial fish.

Methods of stomach content and fecal analysis, which are routinely used to determine diets in free-ranging pinnipeds, 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). Due to the rapid passage of food from the gut, stomachs collected from killed seals are often empty (Harwood & Croxall 1988; Bowen, Lawson & Beck 1993), and those which contain food may yield biased information. For instance, cephalopod beaks may be retained for long periods in stomachs and hence result in an overestimation of their importance in the diet (Bigg & Fawcett 1985). In contrast, the heads of large fish may not be consumed, precluding otolith recovery in stomachs or scats. Fragile otoliths from small fish, such as herring, may be completely digested and hence underrepresented in scat hard parts. Lastly, collections of stomachs and feces are usually restricted to nearshore haul-out sites and hence may not represent what the population feeds upon offshore. Past studies of harbor seal diets in PWS and the Gulf of Alaska have recognized these limitations (Pitcher 1980a and 1980b), nevertheless, the use of stomach content analysis may have biased conclusions towards an overestimation of octopus and an underestimation of herring.

An alternative method has been proposed ("fatty acid signature analysis", Iverson 1993) to complement existing methods and which could potentially overcome many of the inherent difficulties in determining the composition of seal diets or in simply detecting changes or differences in diets (Iverson 1995; Iverson, Arnould & Boyd, submitted). 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. 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), many components appear which can be traced to a general or even specific ecological origin. Certain "indicator" fatty acids (Iverson 1993) exist which are particularly useful in food web studies since they can arise only or mostly from the diet. In seals, ingested fatty acids appear to be deposited directly into adipose tissue, such that blubber may be a mirror of diet when a seals is rapidly fattening (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.

Although the full methods of "fatty acid signature analysis" are still in a stage of development, we now know that fatty acids can be used to detect both major and minor shifts in diet within populations and will allow the determination of general trophic level of diets to be assessed (Iverson et al. submitted; Smith, Iverson & Bowen, submitted). In the present study, we report on the first part of a longer term research project to investigate both harbor seals and their prey in PWS and the Gulf of Alaska using fatty acid signature analysis. We also demonstrate the use of classification and regression tree (CART) analysis in S-Plus in the statistical interpretation of complicated fatty acid patterns containing more than 60 variables per observation. CART is a non parametric multivariate technique for classifying data (Clark & Pregibon 1992) and has recently been applied to and modified for use specifically in fatty acid signature analysis (Iverson et al. submitted; Smith et al. submitted).

The initial goals of our analysis were 1) to determine whether there were statistical differences between the fatty acid composition of harbor seal blubber as a function of haulout site within PWS (i.e. do seals feed site-specifically or exhibit farther ranging foraging patterns), 2) to determine whether harbor seals in PWS appear to feed on similar diets as those in other parts of the Gulf of Alaska, and 3) to determine classification rules for estimating the location or habitat use of a given seal using its blubber fatty acid composition.

The next goals of our analysis were 1) to determine whether there were statistical differences between the fatty acid composition of various prey species sampled in PWS, 2) to determine whether differences occurred within a prey species as a function of size-class or region in PWS, and 3) to determine classification rules for identifying the prey species or its size or location given its total fatty acid composition. Our ultimate goal is to link the prey species to observed differences in seal fatty acids and to determine percentage composition of seal diets. However, at the current stage in this research, our last aim was to infer the probable influences and general importance of various prey species in overall diets of seals.

METHODS

Sample Collection

Figure 1 depicts a map of PWS showing most of the locations of harbor seals and prey species sampled for this study, which should be referred to throughout this report. In 1994 and 1995, blubber core samples (50-150 mg) were collected from the pelvic region of harbor seals using sterile 6 mm biopsy punches (see Frost, Lowry & Ver Hoef 1996). At the time of collection, samples were placed in chloroform containing BHT (butylated hydroxytoluene) as an antioxidant and stored frozen until analysis. A total of 84 seals were sampled and analyzed for fatty acid composition the present report. Seals were sampled in PWS (n = 62), at Kodiak Island (n = 8 from Uganik Passage), and in Stephens Passage, Southeast (SE) Alaska (n = 14). Within PWS, seals were grouped according to general region: West Montague Island (n = 45, comprising animals from Channel Island and Little Green Island n = 20, Port Chalmers, n = 15, and Stockdale Harbor, n = 10), Northwest (NW) PWS (n = 7, comprising animals from Lone Island, Dutch Group, Fairmount Island and Outpost Island), and Northcentral/Northeast (NC/NE) PWS (n = 10, comprising animals from Long Bay, Glacier Bay, Port Fidalgo, and Port Gravina).

Prey species were collected from fishing trawls in PWS at various seasons during 1994 and 1995 and stored frozen until analysis. A total of 163 individual prey representing 10 species were analyzed for total fat content and fatty acid composition for the present report. The most detailed sampling, by region within PWS and over size classes, was of herring (n = 77) and pollock (n = 44).

Sample Analysis

Lipid was extracted from harbor seal blubber samples according to the method of Folch, Lees & Sloane-Stanley (1957) as modified by Iverson (1988; Smith et al. submitted). After recording length and mass, each whole prey was ground individually and lipids were quantitatively extracted in duplicate aliquots using a modified Bligh & Dyer method (Bligh & Dyer 1959); fat content was expressed as an average of the two duplicates. In some cases when prey were too small to analyze separately, several individuals were combined for total fat content measurements.

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.

Duplicate analyses of fatty acid methyl esters and their identifications were performed using temperature-programmed gas liquid chromatography according to Iverson (1988) and Iverson, Sampugna & Oftedal (1992), but 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). Individual fatty acids are expressed as weight percent of total fatty acids and 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.

Data analysis and interpretation

Fatty acid data were analyzed using both ANOVA and methods of classification and regression trees (CART) in S-plus according to methods described in Iverson et al. (submitted) and Smith, et al. (submitted). 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 or prey) in that split are then sent down one of two branches. 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. The distribution of the data at each non-terminal node can then be viewed in the form of tree box plots, which successively remove the effect of the previous split(s) and allows examination of the splitting point at each node. Because the stopping rules in CART are conservative, an initial completed tree is typically "overfitted" (analogous to using too many parameters to fit a regression) and hence needs to be "pruned", which we did according to Smith et al. (submitted).

Since the fatty acids and splitting points in the tree are selected algorithmically by maximizing the change in deviance between the root node and subsequent nodes, we also examined which, if any, other fatty acids might have been nearly as close to being selected using charts of deviances. We then forced the algorithm to select specific major fatty acids known to be indicative of diet differences for the split. The efficiencies of the corresponding trees and competing fatty acids were then compared to the initial tree. Application of the SPLUS software is described in Clark & Pregibon (1992) and Venables & Ripley (1994).

All data are presented as mean ± SE, unless otherwise indicated.

RESULTS

Approximately 67 fatty acids and isomers were routinely identified in all harbor seal blubber samples (Table 1). Variations between groups of seals were apparent and can be illustrated by 9 of the major components comprising greater than 75% of total fatty acids (Fig. 2). Significant differences were found in levels of many major components between seals from Kodiak, PWS, and SE Alaska, as well as between groups of seals within regions of PWS (Fig. 2). Of particular note in all seals from the Gulf of Alaska was the large relative proportion of 20:1n-11 to the isomer 20:1n-9, as well as its variability among groups (Table 1). Isomers of the other long-chain monounsaturate, 22:1, were also notably variable among groups of seals. Both sets of these isomers can be considered indicator fatty acids (Iverson 1993), since they can arise only or mostly from diet. Since CART looks only for absolute levels of components to differentiate observations, which is not always the most useful interpretation, we formed two additional components to express these isomer relationships. Hence, a ratio of the n-11 and n-9 isomers was calculated for both 20:1 and 22:1 and included in the list of fatty acids (Table 1) and in the data sets used by CART. Selecting only these and other specific indicator fatty acids, differences were even more apparent between seal groups (Fig. 3). Within PWS, Montague area seals differed from NC, NE, and NW seals in most isomers and ratios of 20:1 and 22:1 and from NW seals in 14:0. Kodiak differed from most PWS and SE Alaska seals in many components, but tended to share more similarities with Montague area animals. SE Alaska seals almost always differed from PWS seals, but tended to be more similar to some of the NC, NE, and NW-PWS animals (Fig. 3).

The results of CART analysis confirmed the general observations of differences between groups of seals (Fig 4). Using the ratio of 20:1, which exhibited the greatest deviance between groups for the root node (Fig. 5), CART correctly classified most seals according to their haulout location at sampling. Most animals from NC/NE-PWS and NW-PWS, and all SE Alaska animals, were sent down the left node and were separated from each other with 0 out of 27 misclassifications (Fig. 4). On the right side of the tree, Montague-PWS seals were separated with 2 out 43 misclassifications from Kodiak and NC/NE-PWS animals, although there were more errors between these groups. The total error rate for the tree was 7 out of 84 seals misclassified to a location by their fatty acid signatures. Box plots of the algorithmically chosen variables indicate splitting values and data points missclassified at each node for the tree (Fig. 6). Deviance plots (Fig. 5) indicated that other, and mostly major, fatty acids (ratio 22:1n-11/n-9, 22:1n-11, 18:1n-

13, and 20:1n-11) could have been used as the initial splitting point. In fact, using 20:1n-11 at the root node, resulted in one less misclassification (6/84), despite the fact that its deviance was lower than the others.

CART analysis also supported the findings that within PWS, fatty acid composition of seal blubbers differed according to haulout location with a total of 6 out of 62 misclassifications (Fig. 7). Animals likely feeding in the NW of PWS could be accurately separated from animals sampled in the NE, and within the NE of PWS, there was an indication that the more northerly bay of Port Fidalgo could be separated from the Port Gravina animals, but with more error. Montague area animals were classified by fatty acids with 2 out of 45 misclassifications (Fig. 7). Lastly, there was also an indication that in the more confined area of Montague Island, seals hauled out at Channel Island, Stockdale Harbor, and Port Chalmers differed from one another in fatty acid composition, although this was associated with a misclassification rate of 8/44 (Fig. 8).

Morphometric and fat content data for prey species collected from trawls in PWS are summarized in Table 2. Species analyzed included herring, pollock, rockfish, sandlance, pacific cod, tomcod, rainbow smelt, yellowfin sole, octopus, and a small mixture of squid and shrimp. Collections, and thus analyses, of herring ($n = 77$) and pollock ($n = 44$) were far more comprehensive than for other species. Data for both herring and pollock were available over a range of sizes (length and mass) as well as seasons and locations within PWS. Herring had the highest fat content of any species analyzed (6.3% ± 4.33 SD), but this ranged widely (0.6 - 19.1%), primarily with season and also location. Herring appeared to be lowest in fat in the spring and highest in fat by the fall (Table 2). Pollock was relatively low and less variable in fat content at 1.7% ± 0.92 SD. In both herring and pollock, length and mass were highly correlated ($r \geq 0.91$, $P < 0.0001$), but fat content was not correlated with either length or mass ($r \leq 0.33$).

The same 67 fatty acids and isomers found in harbor seal blubber were routinely identified in prey, in addition to three as yet unidentified but minor components which occurred around 16- and 17-carbon fatty acids (Table 3). Despite variations within species (see below), differences between prey species were apparent and are perhaps best illustrated, although by no means exhaustively, by choosing several of the important indicator fatty acids and their ratios (Fig. 9). The levels of 20:1n-11 and its ratio with the n-9 isomer were particularly high in herring, followed by yellowfin sole and pollock. Species such as sandlance were distinguished by being notably low in 20:1n-11, but quite high in 20:1n-9, resulting in a very low ratio. Levels of these two components were nearly equal to one another in Pacific cod, tomcod, and octopus, but absolute values differed greatly between species. Levels of 22:1n-11, and its ratio with 22:1n-9, were equally variable among species and highest in species such as herring, pollock, sole, and sandlance (Fig. 9).

Comparing all 70 fatty acids across all species of prey is best accomplished using CART analysis. Although the variance dot plot deviances between groups (a plot similar to Fig. 5) indicated several appropriate choices for the variable for the root node split, the ratio of 22:1n-11/22:1n-9 resulted in the best classification tree (least misclassifications at a total of 3 out of 154, or 2% error) for identifying prey species by fatty acid signature (Fig. 10). Although pollock and herring were each variable in fatty acid composition and appeared in nodes on both sides of the tree, no herring were missclassified (0 out of 77) and only 3 out of 44 pollock were missclassified. All Pacific cod and yellowfin sole were separated and correctly classified (Fig. 10). Tomcod (n = 5) and rainbow smelt (n = 4) traveled together, which is not surprising given their similarities (Fig. 9) and small sample sizes. Samples sizes of 4 and 5 were the lowest possible that could be included in CART analysis, hence octopus, squid/shrimp, and rockfish could not be analyzed.

The CART tree (Fig. 10) clearly identified prey species, but the appearance of herring and pollock on both sides of the tree clearly pointed to their variability in fatty acid composition. These were also the only species that were sampled in enough numbers and in more than one area, such that variability by factors such as location could be addressed. Large variability within species was indeed apparent in some fatty acids. For instance averages by location of 20:1n-11 and 22:1n-11 ranged from 1.9 to 10.4% and 3.4 to 12.7%, respectively, in herring (Table 3). Selecting important indicator fatty acids and ratios in both herring and pollock and comparing groups by geographical location illustrated a number of differences (Fig. 11). Although the two species differed significantly from one another in most components, within species there were pronounced differences in some components with collection area. In order to try to explain this variation, we also had to address the confounding fact that some areas represented only certain size classes within species (Table 2). Hence size class was first addressed separately.

Selecting six important indicators and ratios and plotting levels of these in each species as a function of body length illustrates profound effects of size on fatty acid signature within each species (Figs. 12 and 13). In both species, 20:1n-11, the ratio of 20:1n-11/n-9, 22:1n-11, and the ratio of 22:1n-11/n-9 increased directly with increasing body length, while 20:5n-3 and 22:6n-3 decreased with increasing length (although 22:6n-3 was not significant for pollock, Fig. 13). In general, 50-70% of the variation in levels of these components within species was explained by their body length. Regressing these fatty acid levels against body mass resulted in similar but slightly less significant relationships. There was no relationship between fatty acid levels and fat content in either species ($r^2 < 0.05$). These size classes also occurred across different locations. However, 37 herring were available from the Montague area alone and the relationship between body length and fatty acid level for these same components (Fig. 12) resulted in P values of < 0.0001 for all components.

Arbitrarily choosing three size classes (dividing length distribution by 3) for herring and pollock and incorporating these into categories for CART analysis produced a tree (Fig. 14) that again separated species, but demonstrated why herring and pollock had occurred on both sides of the initial prey tree (Fig. 10). Although a different root node variable was chosen (ratio of 20:1n-11/n-9) and there was a somewhat higher error rate overall (15 out of 154 misclassifications), small herring and small pollock moved initially together down the left node, but eventually separated with 0 out of 27 misclassifications. Similarly medium- and large-sized herring and pollock moved initially together and eventually separated (Fig. 14). Lastly, to avoid one very large and cumbersome tree, we separated herring and pollock, and within each species incorporated both size class (as above) and general location for CART analysis. Herring could be identified by size-class and location within PWS with a total of 7 out of 77 misclassifications (Fig. 15) and likewise, pollock could be identified by size-class and location within PWS with a total of 2 out of 41 misclassifications (Fig. 16).

In summary, although herring and pollock could each be differentiated using fatty acid signatures by size-class and location within PWS (Figs. 15 and 16), and exhibited similar patterns in changes with size (Figs. 12 and 13), they could still be differentiated from one another within size (Fig. 14) and across species as a whole (Figs. 10 and 11). Other prey species were also readily separated from these two using fatty acid signatures (Fig. 10). Not all locations were represented by all size classes and vice versa in herring and pollock, and other prey species were available from only one location and in small numbers. It will clearly be necessary to assess these parameters in other potential prey species of the harbor seal.

Although, determination of species composition of seal diets cannot yet be performed at this stage, some preliminary comparisons can be made. Figure 17 illustrates box plots of selected components in prey compared to that found in seals. High levels of the ratio of 20:1n-11/n-9 found in seals from Kodiak Island and the Montague area of PWS are only found at comparable levels in herring, pollock, and yellowfin sole. The higher value in Montague seals corresponds only with herring and yellowfin sole. Lower values for this ratio are present in the other prey, as well as very small herring and pollock, and tend to match levels found in the NC, NE, and NW-PWS and SE Alaska seals. The mean for octopus, squid and shrimp most closely resembles that in SE Alaska seals. These patterns largely hold true for the other ratio (22:1n-1/n-9), although the very low averages in the NC/NE-PWS seals correspond most closely with Pacific cod, the NW-PWS seals with a mixture of prey, and SE Alaska with octopus, squid and shrimp. Similar, although varying, patterns are found for the other components illustrated (Fig. 17). It must be reiterated, that these are single point comparisons, and other fatty acids will likely be informative.

DISCUSSION

Prince William Sound is described as a large, complex estuarine system, but one which also shares characteristics with small inland seas (Niebauer, Royer & Weingartner). Although in terms of absolute size (about 60 km by 90 km) it is not a particularly large area, clearly it comprises localized habitats of perhaps differing productivities, which are variously influenced by depths and temperatures and by fresh and saltwater input. Like most estuaries, it may be expected to comprise a fairly complex ecosystem (e.g., Lalli & Parsons 1993). This may indeed set up the opportunity to study localized feeding, based on local food webs from primary producers to primary consumers and up through the food web. Fatty acid signatures would indeed be significantly affected by these differences (reviewed in Iverson 1993). Our findings using fatty acid signature analysis largely support the notion of localized habitat and feeding differences in both harbor seal and their prey in PWS and the Gulf of Alaska.

Our data from harbor seal blubber suggests strongly that animals not only haul out site-specifically, but also forage and feed site-specifically. The large differences observed in fatty acid patterns between harbor seals studied at or near Montague Island in southcentral PWS versus seals in other areas of PWS indicated that these groups were feeding upon difference dietary levels of fatty acids and hence different diets (Figs. 3-7). These diets might reflect different species composition (i.e. largely of one fish species vs. another or largely fish vs. largely cephalopod, etc.) or it might simply mean the feeding upon different stocks of the same species. Seals differed in fatty acid signatures, and hence likely feeding habits, even within small areas, such as Port Fidalgo and Port Gravina within NE-PWS (Fig. 7), or in various bays and islands around Montague Island (Fig. 8). Misclassifications in the CART trees could represent those seals which were simply more wide-ranging in their foraging patterns or highly individual feeding habits. This suggests that seals from a given haulout location may be expected to feed nearby or at least on the same general prey sources. This conclusion is supported by previous data on satellite-tagged harbor seals. Frost et al. (1995) found that of six seals tagged from fall 1993 to spring 1994, none moved out of PWS and five remained virtually at the specific location at which they were tagged and routinely hauled out there throughout the study period. Indeed, using fatty acids signature analysis, harbor seals in PWS appear to depend on a very localized prey base.

Fatty acid signatures also indicated that seals from other areas in the Gulf of Alaska, especially SE Alaska, fed upon different diets than did animals in PWS. The SE animals, in particular, were easily distinguished from PWS and Kodiak animals, which is consistent with their far removed location in Stephens Passage. Kodiak animals shared more characteristics with Montague area animals, and the difficulty in separating them may simply be a function of a more common diet.

As noted previously, one of the interesting observations in all seals in the Gulf of Alaska was the occurrence of high levels of 20:1n-11, particularly in relation to its n-9 isomer. In phocid seals on the Atlantic coast (harbor seals, grey seals, harp seals, and hooded seals), 20:1n-9 is always the major isomer and 20:1n-11 is minor and often unmeasurable (Iverson et al. 1995; Kirsch et al. 1995; unpublished data). This is directly a result of the composition of most of the Atlantic prey species, including sandlance, herring, capelin, pollock and cod. Hence, the finding of high levels of 20:1n-11 and its ratio in PWS seals indicated that this must reflect the prey base, and that PWS prey differs markedly in fatty acid composition from comparable species in the Atlantic.

Indeed, the fatty acid composition of prey in PWS clearly explained the occurrence of reversed ratios of the 20:1 isomers in Alaska seals (Table 3, Fig. 9), and provide encouraging validation for fatty acids reflecting diet. Additionally, the component 22:1n-11 and its ratio to n-9, which are useful indicators on the Atlantic coast due to various copepods, were also useful indicators in Alaska prey species. These fatty acids were often chosen by CART to begin separation of prey by species (Figs. 10, 14). Indeed, our findings indicate that given a fatty acid profile from an unknown prey item, we could drop it through the initial prey tree (Fig. 10) and identify its species with a relatively low expected error rate. This will be extremely important to the use of fatty acid signature analysis of harbor seal diets.

The finding that the fatty acid composition of herring and pollock was directly related to body size (Figs. 12 and 13) clearly indicate that the diets of these fish change with size and age. Fish such as pollock are known to begin life feeding on small zooplankton, followed by larger zooplankton, and finally becoming piscivores as adults (Lalli & Parsons 1993). Herring are thought to occupy lower trophic levels feeding mainly on zooplankton, but again may change diets with growth. These dietary changes would be reflected in the fatty acid composition of the fish. Fatty acid signatures in herring and pollock also suggested localized habitat and feeding differences within areas of PWS (Figs. 11, 15, 16), although size classes from all locations will need to be represented for further conclusions. Given the likely complexity of PWS habitats, differences in composition by location within a species would not be unexpected. The major significance to the above findings, is that given a fatty acid composition of an unknown herring or pollock, one could drop these data through the various prey trees and essentially determine its size-class and location with reasonable certainty (Figs. 15 and 16). The potential value of this for signature analysis of harbor seals diets, is that eventually, we may be able to estimate, not only species composition of diets, but also size-class and location of species fed upon.

Although we are currently restricted by limited data on the prey base, as well as further devolpment of methodology, we can in the meantime compare some important components in both harbor seals and their potential prey. In this case, since ratios are not dependent upon absolute levels of individual components, but rather their relationship to one another, ratios of meaningfully associated isomers are particularly useful in such a comparison. By comparison alone (Fig. 17), it seems likely that a large portion of the diet of Montague area seals are comprised of herring and pollock and perhaps yellow fin sole (although sample size for sole is small), while seals in NC, NE, and NW PWS appear to feed less on these (especially herring) and perhaps more on octopus, squid/shrimp, and cod.

Like Montague seals, those from Kodiak appear to be feeding on pollock and herring, while seals from SE Alaska appear to have a diet more like (but also more extreme than) the NW/NE PWS seals. The fatty acid composition of the prey base in SE Alaska may differ considerably from PWS, so conclusions about diets of SE seals are limited.

Since box plots form the basis of CART splits, it is easy to visualize how a CART-type analysis would initially choose ratios of 20:1 and 22:1 to begin classifying a seal to a given prey item (e.g., Fig. 17). Indeed, sending a seal from the Montague area in PWS and from Kodiak through the second CART prey tree (Fig 14), would send them both down the right node with ratios of 20:1 > 2.17 (see Fig. 17). Thus, large herring would be predicted to dominate the diet of these seals followed by large pollock. Beyond this stage, absolute levels of 20:0 (at the next node, Fig. 14) will not be meaningful for further separation. In contrast, almost all NC, NE and NW-PWS seals would be sent down the left node of the tree with ratios of 20:1 < 2.17 (Figs. 14 and 17), and predictions would include diets predominated by small herring, sandlance, and cod. Again, no octopus, squid or shrimp could be included in the trees at this stage due to small sample sizes.

The determination of seal diets from fatty acid signatures will require completion of an extensive prey library (including perhaps a more extensive review of fish stocks and productivity patterns in PWS) and a numerical approach somewhat different than used here with CART as it currently stands. This will require the development of a very comprehensive and sophisticated pattern-matching program. As stated previously, CART essentially operates by looking at absolute levels of components to differentiate observations. Absolute levels of components in seals will never exactly match that in prey, given mixtures of diets and some biological modifications over time., A pattern-matching program, combined with a maximum-likelihood estimation, must be performed comparing all complete signatures (i.e. all 70 fatty acids at once) and possible combinations of signatures to create the closest possible match to the predator signature, while also weighting significance of indicator (only dietary) fatty acids. We conclude that this continued work and development will likely result in an important contribution to understanding the foraging ecology and marine food webs in PWS, which will also likely be aplicable to understanding other estuarine and marine envoironments.

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Table 1. Fatty acid Composition of Harbour Seal Blubbers in Prince William Sound and the Gulf of Alaska, 1994-1995

Sample	West Montague Island			
Year	Channel Island	Port Chalmers	Stockdale Hbr	Northwest PWS
Location	n=20	n=15	n = 10	n = 7
12:0	0.14 ± 0.008	0.16 ± 0.011	0.13 ± 0.009	0.15 ± 0.011
13:0	0.01 ± 0.002	0.00 ± 0.002	0.01 ± 0.003	0.01 ± 0.002
Iso14	0.02 ± 0.003	0.01 ± 0.002	0.01 ± 0.004	0.01 ± 0.004
14:0	5.29 ± 0.202	4.11 ± 0.215	4.33 ± 0.297	3.79 ± 0.163
14:1w9	0.11 ± 0.006	0.06 ± 0.011	0.09 ± 0.008	0.09 ± 0.014
14:1w7	0.09 ± 0.005	0.07 ± 0.007	0.08 ± 0.006	0.12 ± 0.008
14:1w5	1.99 ± 0.126	1.36 ± 0.152	1.73 ± 0.175	2.61 ± 0.203
Iso15	0.12 ± 0.004	0.12 ± 0.006	0.12 ± 0.004	0.10 ± 0.005
Anti15	0.07 ± 0.004	0.07 ± 0.006	0.06 ± 0.005	0.04 ± 0.004
15:0	0.25 ± 0.007	0.28 ± 0.007	0.26 ± 0.012	0.21 ± 0.008
15:1w8	0.01 ± 0.003	0.00 ± 0.001	0.01 ± 0.002	0.01 ± 0.002
15:1w6	0.09 ± 0.006	0.08 ± 0.004	0.09 ± 0.008	0.10 ± 0.007
Iso16	0.07 ± 0.003	0.08 ± 0.007	0.07 ± 0.003	0.07 ± 0.003
16:0	8.86 ± 0.277	9.35 ± 0.428	7.38 ± 0.490	7.43 ± 0.330
16:1w11	0.56 ± 0.040	0.60 ± 0.046	0.74 ± 0.065	0.54 ± 0.044
16:1w9	0.45 ± 0.018	0.43 ± 0.014	0.45 ± 0.026	0.57 ± 0.025
16:1w7	18.57 ± 0.965	16.83 ± 0.748	16.74 ± 1.184	23.40 ± 1.221
7Me16:0	0.27 ± 0.006	0.26 ± 0.007	0.25 ± 0.007	0.26 ± 0.012
16:1w5	0.03 ± 0.008	0.01 ± 0.006	0.03 ± 0.009	0.04 ± 0.012
16:2w6	0.17 ± 0.011	0.26 ± 0.025	0.20 ± 0.018	0.15 ± 0.015
Iso17	0.06 ± 0.006	0.11 ± 0.021	0.08 ± 0.021	0.04 ± 0.010
16:2w4	0.14 ± 0.017	0.22 ± 0.028	0.19 ± 0.035	0.12 ± 0.031
16:3w6	0.50 ± 0.037	0.33 ± 0.047	0.43 ± 0.063	0.41 ± 0.036
17:0	0.14 ± 0.014	0.18 ± 0.013	0.15 ± 0.012	0.10 ± 0.007
16:3w4	0.24 ± 0.017	0.17 ± 0.021	0.21 ± 0.019	0.17 ± 0.025
17:1	0.42 ± 0.012	0.52 ± 0.022	0.50 ± 0.038	0.43 ± 0.019
16:3w1	0.11 ± 0.012	0.12 ± 0.012	0.11 ± 0.020	0.07 ± 0.016
16:4w1	0.13 ± 0.041	0.14 ± 0.052	0.25 ± 0.041	0.17 ± 0.041
18:0	0.91 ± 0.047	1.11 ± 0.060	0.83 ± 0.071	0.74 ± 0.041
18:1w13	0.29 ± 0.017	0.34 ± 0.016	0.39 ± 0.023	0.14 ± 0.031
18:1w11	2.53 ± 0.195	2.54 ± 0.249	3.35 ± 0.424	1.18 ± 0.150
18:1w9	23.17 ± 1.145	19.70 ± 0.454	22.05 ± 0.713	25.33 ± 1.898
18:1w7	3.85 ± 0.174	3.77 ± 0.123	3.59 ± 0.106	4.50 ± 0.240
18:1w5	0.45 ± 0.010	0.48 ± 0.008	0.47 ± 0.007	0.44 ± 0.015
18:2d5,7	0.10 ± 0.014	0.05 ± 0.012	0.08 ± 0.017	0.12 ± 0.012
18:2w7	0.14 ± 0.007	0.14 ± 0.015	0.10 ± 0.012	0.16 ± 0.008
18:2w6	1.02 ± 0.030	1.09 ± 0.031	1.19 ± 0.044	1.02 ± 0.053
18:2w4	0.12 ± 0.008	0.12 ± 0.008	0.11 ± 0.011	0.13 ± 0.014
18:3w6	0.06 ± 0.005	0.06 ± 0.008	0.07 ± 0.006	0.07 ± 0.005
18:3w4	0.15 ± 0.007	0.15 ± 0.012	0.14 ± 0.013	0.11 ± 0.013

Table 1. continued

Sample Year	West Montague Island: Channel Island	Port Chalmers	Stockdale Hbr	Northwest PWS
18:3w3	0.67 ± 0.033	0.74 ± 0.023	0.75 ± 0.039	0.53 ± 0.041
18:3w1	0.05 ± 0.005	0.05 ± 0.011	0.06 ± 0.004	0.04 ± 0.007
18:4w3	1.12 ± 0.073	1.02 ± 0.047	1.00 ± 0.082	0.73 ± 0.045
18:4w1	0.21 ± 0.011	0.19 ± 0.011	0.20 ± 0.012	0.18 ± 0.013
20:0	0.08 ± 0.006	0.07 ± 0.003	0.07 ± 0.009	0.03 ± 0.006
20:1w11	6.14 ± 0.491	4.96 ± 0.410	6.43 ± 0.608	2.41 ± 0.295
20:1w9	1.62 ± 0.084	1.59 ± 0.058	1.83 ± 0.101	1.30 ± 0.076
ratio20:1	3.72 ± 0.158	3.10 ± 0.201	3.49 ± 0.196	1.90 ± 0.269
20:1w7	0.21 ± 0.019	0.32 ± 0.034	0.26 ± 0.044	0.17 ± 0.015
20:1w5	0.10 ± 0.014	0.11 ± 0.016	0.07 ± 0.014	0.05 ± 0.016
20:2w6	0.20 ± 0.018	0.24 ± 0.017	0.20 ± 0.020	0.15 ± 0.026
20:3w6	0.08 ± 0.011	0.10 ± 0.007	0.09 ± 0.008	0.08 ± 0.002
20:4w6	0.57 ± 0.068	0.74 ± 0.060	0.69 ± 0.091	0.64 ± 0.062
20:3w3	0.14 ± 0.025	0.17 ± 0.041	0.09 ± 0.008	0.10 ± 0.025
20:4w3	0.50 ± 0.034	0.80 ± 0.048	0.63 ± 0.043	0.52 ± 0.048
20:5w3	4.22 ± 0.290	5.61 ± 0.234	4.65 ± 0.246	4.59 ± 0.454
22:1w11	1.93 ± 0.303	1.10 ± 0.064	1.45 ± 0.331	0.30 ± 0.064
22:1w9	0.14 ± 0.013	0.14 ± 0.009	0.14 ± 0.016	0.09 ± 0.015
ratio22:1	12.70 ± 1.188	8.46 ± 0.615	9.97 ± 1.376	4.00 ± 1.209
22:1w7	0.03 ± 0.005	0.03 ± 0.007	0.02 ± 0.005	0.00 ± 0.004
22:2w6	0.06 ± 0.030	0.07 ± 0.020	0.04 ± 0.009	0.01 ± 0.003
21:5w3	0.31 ± 0.019	0.32 ± 0.009	0.30 ± 0.014	0.24 ± 0.038
22:4w6	0.13 ± 0.025	0.18 ± 0.022	0.16 ± 0.029	0.10 ± 0.013
22:5w6	0.13 ± 0.028	0.14 ± 0.008	0.12 ± 0.010	0.10 ± 0.010
22:4w3	0.07 ± 0.006	0.08 ± 0.005	0.08 ± 0.009	0.06 ± 0.005
22:5w3	2.75 ± 0.274	4.86 ± 0.335	4.55 ± 0.343	3.21 ± 0.370
22:6w3	6.60 ± 0.476	10.69 ± 0.647	8.89 ± 0.592	9.08 ± 1.237
24:1w11	0.01 ± 0.005	0.01 ± 0.003	0.02 ± 0.007	0.03 ± 0.007
24:1w9	0.14 ± 0.020	0.12 ± 0.020	0.07 ± 0.013	0.02 ± 0.005

Table 1. continued

Sample Year Location	Northcentral/ Northeast PWS n = 10	Southeast Gulf of Alaska n = 14	Kodiak Island n = 8
12:0	0.18 ± 0.016	0.08 ± 0.009	0.11 ± 0.012
13:0	0.00 ± 0.002	0.02 ± 0.001	0.01 ± 0.001
Iso14	0.00 ± 0.003	0.02 ± 0.002	0.02 ± 0.002
14:0	4.34 ± 0.233	3.09 ± 0.166	4.13 ± 0.181
14:1w9	0.07 ± 0.020	0.12 ± 0.011	0.11 ± 0.009
14:1w7	0.08 ± 0.012	0.08 ± 0.006	0.09 ± 0.010
14:1w5	1.81 ± 0.119	1.69 ± 0.165	2.12 ± 0.312
Iso15	0.12 ± 0.012	0.09 ± 0.005	0.11 ± 0.006
Anti15	0.05 ± 0.010	0.05 ± 0.005	0.05 ± 0.004
15:0	0.28 ± 0.016	0.21 ± 0.012	0.22 ± 0.009
15:1w8	0.00 ± 0.002	0.01 ± 0.002	0.01 ± 0.002
15:1w6	0.09 ± 0.006	0.09 ± 0.005	0.08 ± 0.005
Iso16	0.07 ± 0.006	0.06 ± 0.004	0.07 ± 0.005
16:0	9.51 ± 0.396	6.71 ± 0.449	7.66 ± 0.398
16:1w11	0.55 ± 0.082	0.50 ± 0.043	0.67 ± 0.035
16:1w9	0.53 ± 0.028	0.50 ± 0.019	0.45 ± 0.026
16:1w7	19.78 ± 1.043	18.97 ± 1.247	19.52 ± 1.589
7Me16:0	0.25 ± 0.007	0.22 ± 0.007	0.24 ± 0.010
16:1w5	0.01 ± 0.009	0.04 ± 0.003	0.06 ± 0.003
16:2w6	0.28 ± 0.031	0.15 ± 0.019	0.16 ± 0.022
Iso17	0.08 ± 0.010	0.03 ± 0.002	0.03 ± 0.003
16:2w4	0.22 ± 0.042	0.09 ± 0.007	0.09 ± 0.009
16:3w6	0.35 ± 0.057	0.61 ± 0.043	0.60 ± 0.029
17:0	0.19 ± 0.024	0.09 ± 0.009	0.10 ± 0.013
16:3w4	0.14 ± 0.016	0.49 ± 0.049	0.31 ± 0.033
17:1	0.52 ± 0.024	0.50 ± 0.042	0.42 ± 0.022
16:3w1	0.15 ± 0.032	0.03 ± 0.003	0.05 ± 0.004
16:4w1	0.05 ± 0.031	0.29 ± 0.029	0.33 ± 0.038
18:0	1.12 ± 0.074	0.80 ± 0.039	0.83 ± 0.067
18:1w13	0.18 ± 0.033	0.02 ± 0.010	0.20 ± 0.046
18:1w11	1.68 ± 0.164	1.34 ± 0.131	1.37 ± 0.153
18:1w9	25.16 ± 1.967	28.83 ± 1.451	25.03 ± 1.634
18:1w7	4.42 ± 0.222	4.97 ± 0.200	4.42 ± 0.360
18:1w5	0.43 ± 0.020	0.34 ± 0.018	0.43 ± 0.019
18:2d5,7	0.10 ± 0.023	0.06 ± 0.004	0.08 ± 0.013
18:2w7	0.19 ± 0.020	0.12 ± 0.007	0.12 ± 0.016
18:2w6	1.04 ± 0.054	1.05 ± 0.083	1.00 ± 0.070
18:2w4	0.14 ± 0.015	0.14 ± 0.007	0.13 ± 0.017
18:3w6	0.07 ± 0.012	0.05 ± 0.002	0.05 ± 0.004
18:3w4	0.15 ± 0.014	0.13 ± 0.009	0.11 ± 0.008

Table 1. continued

Sample Year	Northcentral/ Northeast PWS	Southeast Gulf of Alaska	Kodiak Island
18:3w3	0.61 ± 0.049	0.54 ± 0.053	0.62 ± 0.059
18:3w1	0.04 ± 0.010	0.05 ± 0.005	0.04 ± 0.006
18:4w3	0.77 ± 0.051	0.68 ± 0.041	0.87 ± 0.083
18:4w1	0.16 ± 0.010	0.19 ± 0.013	0.20 ± 0.022
20:0	0.05 ± 0.007	0.05 ± 0.002	0.06 ± 0.005
20:1w11	2.35 ± 0.178	2.50 ± 0.338	4.45 ± 0.600
20:1w9	1.29 ± 0.077	1.97 ± 0.200	1.45 ± 0.152
ratio20:1	1.85 ± 0.143	1.23 ± 0.125	3.04 ± 0.182
20:1w7	0.31 ± 0.050	0.25 ± 0.022	0.24 ± 0.044
20:1w5	0.11 ± 0.023	0.02 ± 0.002	0.03 ± 0.003
20:2w6	0.25 ± 0.031	0.15 ± 0.016	0.14 ± 0.021
20:3w6	0.08 ± 0.009	0.09 ± 0.006	0.08 ± 0.006
20:4w6	0.77 ± 0.118	0.49 ± 0.031	0.59 ± 0.081
20:3w3	0.22 ± 0.084	0.07 ± 0.009	0.06 ± 0.006
20:4w3	0.53 ± 0.058	0.56 ± 0.069	0.49 ± 0.063
20:5w3	4.46 ± 0.289	5.77 ± 0.319	5.38 ± 0.559
22:1w11	0.52 ± 0.090	0.32 ± 0.047	0.90 ± 0.193
22:1w9	0.16 ± 0.040	0.12 ± 0.024	0.12 ± 0.033
ratio22:1	4.42 ± 0.883	2.90 ± 0.285	8.86 ± 1.213
22:1w7	0.09 ± 0.044	0.01 ± 0.009	0.01 ± 0.003
22:2w6	0.02 ± 0.007	0.03 ± 0.006	0.02 ± 0.005
21:5w3	0.25 ± 0.009	0.36 ± 0.012	0.30 ± 0.041
22:4w6	0.17 ± 0.037	0.08 ± 0.008	0.12 ± 0.026
22:5w6	0.16 ± 0.022	0.10 ± 0.009	0.13 ± 0.018
22:4w3	0.06 ± 0.007	0.06 ± 0.005	0.06 ± 0.006
22:5w3	3.49 ± 0.413	4.52 ± 0.327	3.89 ± 0.480
22:6w3	8.46 ± 0.826	8.26 ± 0.715	8.07 ± 0.915
24:1w11	0.01 ± 0.003	0.01 ± 0.003	0.03 ± 0.008
24:1w9	0.11 ± 0.032	0.04 ± 0.005	0.05 ± 0.009

Values are mean weight percent of total fatty acids ± SE.

Table 2. Length, Mass, and Fat Content of Prey Species Collected in Prince William Sound, 1994-1995 (n = 163)

				LENGTH (cm)		MASS (g)		FAT CONTENT (%)	
Species	Location	Date	n	mean ± SEM	Range	mean ± SEM	Range	mean ± SEM	Range
	Montague Isl. NE	Apr-94	10	21.0 ± 0.52	17.7-23.9	76.6 ± 5.41	43.9-101.4	2.7 ± 0.32	1.7-4.5
	Montague Isl. NE	NA	10	16.2 ± 1.40	11.8-22.3	51.4 ± 13.61	12.5-120.7	5.4 ± 1.35	0.6-14.0
Herring	Montague Isl. NE	Nov-94	10	23.3 ± 0.58	19.8-26.7	154.6 ± 9.19	101.6-208.0	10.2 ± 0.76	6.3-13.9
	Montague W - Needles	Nov-94	7	18.9 ± 0.36	18.0-20.9	83.2 ± 5.30	70.5-111.9	13.3 ± 1.33	9.7-19.1
	Pt. Gravina	Nov-94	20	12.0 ± 0.97	8.4-18.9	24.6 ± 6.79	3.9-76.8	5.9 ± 0.96	0.9-15.2
	Pt. Gravina-St. Mat.	Jul-95	20	20.7 ± 0.42	18.4-24.5	88.4 ± 7.25	8.5-150.0	4.4 ± 0.42	1.1-9.1
	Trawl 168	Jul-94	3	NA		NA		3.5 ± 0.53	2.7-4.5
	Icy Bay	Nov-94	10	10.5 ± 0.29	9.8-12.9	7.1 ± 0.81	5.5-14.1	1.1 ± 0.14	0.6-2.1
Pollock	Pt. Gravina-St. Mat.	Nov-94	5	10.8 ± 0.18	10.3-11.3	7.4 ± 0.46	6.2-9.0	1.1 ± 0.12	0.8-1.4
	Esther Isl. Hatchery	Aug-95	14	17.4 ± 0.34	15.9-19.6	37.2 ± 1.62	29.4-49.3	1.3 ± 0.11	0.8-2.0
	Esther Isl.	Sep-95	12	15.6 ± 0.28	14.1-17.6	30.7 ± 1.68	22.6-42.6	2.4 ± 0.23	1.2-4.0
RockFish	Galena Bay	Sep-95	1	20.2		173.9		1.7	
Sandlance	Pt. Gravina-Beartrap	Apr-94	9	10.9 ± 0.18	9.9-11.6	9.1 ± 0.45	6.6-11.4	1.2 ± 0.15	0.8-1.8
PacificCod	Cordova Hbr	Jul-94	10	19.3 ± 0.34	17.3-20.6	57.5 ± 6.32	42.2-109.2	2.3 ± 0.26	0.9-3.6
Tomcod	Pt. Fidalgo-Irish Cove	Sep-95	5	20.0 ± 2.34	16.2-29.1	77.9 ± 34.43	33.9-214.8	1.1 ± 0.13	0.7-1.4
Smelt	Cruise911, Haul72	NA	4	20.5 ± 0.55	19.6-21.5	73.4 ± 12.30	52.1-108.4	2.5 ± 0.54	1.8-4.1
Yel.Fin Sole	Mntg. W-Pt. Chalmers	Sep-94	8	28.6 ± 0.89	25.6-33.1	291.6 ± 32.03	188.1-436.8	3.2 ± 0.55	1.5-5.3
Octopus	Galena Bay	Jul-94	2	36.5	33.0-40.0	303.2	196.4-409.9	1.3	1.1-1.5
Squid/Shr.	Pt. Gravina	Nov-94	3	NA		31.1 ± 6.58	18.0-39.0	1.6 ± 0.74	0.8-3.1

Table 3. Fatty Acid Composition of Prey Species Collected in Prince William Sound, 1994-1995

Species Location Coll. Date	Herring Montague Isl. NE Apr. 94 n = 10	Herring Montague Isl. NE unk. n = 10	Herring Montague Isl. NE Nov. 94 n = 10	Herring MontagueW-Needles Nov. 94 n = 7	Herring Pt. Gravina Nov. 94 n = 20
% Fat	2.7 ± 0.32	5.4 ± 1.35	10.2 ± 0.76	13.3 ± 1.33	5.9 ± 0.96
12:0	0.05 ± 0.003	0.08 ± 0.010	0.06 ± 0.005	0.07 ± 0.005	0.07 ± 0.006
13:0	0.02 ± 0.001	0.02 ± 0.002	0.02 ± 0.001	0.02 ± 0.001	0.04 ± 0.003
Iso14	0.02 ± 0.001	0.03 ± 0.002	0.02 ± 0.000	0.02 ± 0.001	0.03 ± 0.003
14:0	6.71 ± 0.410	6.29 ± 0.669	8.28 ± 0.309	6.97 ± 0.499	5.50 ± 0.358
14:1w9	0.19 ± 0.014	0.22 ± 0.038	0.22 ± 0.008	0.27 ± 0.019	0.30 ± 0.021
14:1w7	0.02 ± 0.002	0.02 ± 0.003	0.02 ± 0.002	0.02 ± 0.000	0.04 ± 0.004
14:1w5	0.08 ± 0.005	0.07 ± 0.015	0.13 ± 0.004	0.10 ± 0.009	0.08 ± 0.006
Iso15	0.12 ± 0.006	0.17 ± 0.022	0.17 ± 0.009	0.18 ± 0.010	0.21 ± 0.013
Anti15	0.04 ± 0.002	0.05 ± 0.008	0.05 ± 0.002	0.06 ± 0.004	0.08 ± 0.006
15:0	0.25 ± 0.009	0.26 ± 0.045	0.30 ± 0.011	0.33 ± 0.012	0.54 ± 0.036
15:1w8	0.01 ± 0.001	0.01 ± 0.003	0.01 ± 0.001	0.01 ± 0.004	0.01 ± 0.001
15:1w6	0.00 ± 0.000	0.01 ± 0.009	0.00 ± 0.000	0.00 ± 0.002	0.00 ± 0.001
Iso16	0.10 ± 0.012	0.13 ± 0.050	0.04 ± 0.003	0.06 ± 0.006	0.11 ± 0.017
16:0	15.10 ± 0.711	17.81 ± 1.073	13.22 ± 0.792	16.38 ± 0.796	19.18 ± 0.526
16:1w11	0.30 ± 0.014	0.38 ± 0.012	0.44 ± 0.025	0.38 ± 0.017	0.45 ± 0.017
16:1w9	0.15 ± 0.011	0.17 ± 0.022	0.14 ± 0.007	0.15 ± 0.010	0.26 ± 0.020
16:1w7	3.99 ± 0.252	5.42 ± 0.452	5.15 ± 0.473	5.99 ± 0.308	6.17 ± 0.307
7Me16	0.18 ± 0.008	0.19 ± 0.011	0.07 ± 0.043	0.23 ± 0.017	0.15 ± 0.023
16:1w5	0.06 ± 0.013	0.15 ± 0.027	0.05 ± 0.004	0.12 ± 0.028	0.14 ± 0.019
16:2w6	0.11 ± 0.009	0.11 ± 0.016	0.13 ± 0.004	0.10 ± 0.013	0.14 ± 0.014
Iso17	0.05 ± 0.005	0.06 ± 0.011	0.06 ± 0.005	0.06 ± 0.011	0.07 ± 0.005
16:2w4	0.25 ± 0.012	0.33 ± 0.052	0.24 ± 0.019	0.31 ± 0.037	0.44 ± 0.026
16:3w6	0.29 ± 0.022	0.38 ± 0.078	0.56 ± 0.047	0.44 ± 0.086	0.38 ± 0.066
17:0	0.12 ± 0.012	0.18 ± 0.036	0.13 ± 0.009	0.15 ± 0.018	0.26 ± 0.025
unk3	0.29 ± 0.062	0.07 ± 0.025	0.14 ± 0.045	0.09 ± 0.032	0.11 ± 0.021
16:3w4	0.17 ± 0.019	0.33 ± 0.071	0.40 ± 0.049	0.35 ± 0.065	0.34 ± 0.047
17:1	0.21 ± 0.014	0.19 ± 0.018	0.21 ± 0.011	0.23 ± 0.017	0.34 ± 0.038
16:3w1	0.13 ± 0.010	0.13 ± 0.027	0.10 ± 0.006	0.04 ± 0.008	0.13 ± 0.015
16:4w1	0.28 ± 0.024	0.64 ± 0.163	0.75 ± 0.089	0.67 ± 0.123	0.52 ± 0.055
unk1	0.17 ± 0.024	0.12 ± 0.041	0.02 ± 0.002	0.01 ± 0.003	0.14 ± 0.034
unk2	0.12 ± 0.014	0.09 ± 0.027	0.02 ± 0.003	0.02 ± 0.004	0.12 ± 0.026
18:0	2.11 ± 0.130	2.12 ± 0.274	1.24 ± 0.055	1.64 ± 0.188	2.55 ± 0.180
18:1w13	0.06 ± 0.007	0.02 ± 0.008	0.08 ± 0.011	0.03 ± 0.012	0.07 ± 0.010
18:1w11	0.58 ± 0.053	0.28 ± 0.030	0.64 ± 0.033	0.30 ± 0.029	0.19 ± 0.024
18:1w9	15.61 ± 1.125	12.09 ± 1.290	9.34 ± 1.059	14.39 ± 2.076	12.51 ± 0.549
18:1w7	2.66 ± 0.200	2.56 ± 0.193	1.98 ± 0.332	2.52 ± 0.320	3.12 ± 0.158
18:1w5	0.48 ± 0.013	0.54 ± 0.034	0.61 ± 0.023	0.58 ± 0.043	0.46 ± 0.024

Table 3. continued

Species	Herring	Herring	Herring	Herring	Herring
Location	Montague Isl. NE	Montague Isl. NE	Montague Isl. NE	MontagueW-Needles	Pt. Gravina
Coll. Date	Apr. 94	unk.	Nov. 94	Nov. 94	Nov. 94
18:2d5,7	0.02 ± 0.002	0.04 ± 0.004	0.03 ± 0.003	0.04 ± 0.006	0.05 ± 0.003
18:2w7	0.03 ± 0.002	0.03 ± 0.005	0.03 ± 0.003	0.03 ± 0.003	0.03 ± 0.004
18:2w6	0.77 ± 0.033	0.91 ± 0.072	0.90 ± 0.077	0.91 ± 0.058	1.04 ± 0.046
18:2w4	0.09 ± 0.005	0.17 ± 0.018	0.13 ± 0.011	0.16 ± 0.011	0.17 ± 0.009
18:3w6	0.04 ± 0.003	0.07 ± 0.007	0.07 ± 0.002	0.07 ± 0.010	0.08 ± 0.005
18:3w4	0.06 ± 0.003	0.08 ± 0.006	0.06 ± 0.006	0.08 ± 0.006	0.10 ± 0.007
18:3w3	0.37 ± 0.032	0.91 ± 0.096	0.89 ± 0.111	0.93 ± 0.105	0.91 ± 0.070
18:3w1	0.06 ± 0.002	0.09 ± 0.011	0.04 ± 0.004	0.07 ± 0.009	0.09 ± 0.010
18:4w3	0.80 ± 0.057	1.83 ± 0.208	2.22 ± 0.246	2.09 ± 0.277	1.80 ± 0.145
18:4w1	0.09 ± 0.003	0.17 ± 0.034	0.20 ± 0.014	0.19 ± 0.024	0.15 ± 0.015
20:0	0.24 ± 0.020	0.13 ± 0.026	0.23 ± 0.012	0.16 ± 0.015	0.13 ± 0.006
20:1w11	10.24 ± 1.336	4.02 ± 1.283	12.20 ± 1.134	5.56 ± 1.433	1.86 ± 0.418
20:1w9	2.30 ± 0.185	2.69 ± 0.516	3.01 ± 0.156	3.68 ± 0.523	2.28 ± 0.382
ratio20:1	4.36 ± 0.400	1.29 ± 0.377	4.16 ± 0.438	1.64 ± 0.436	0.86 ± 0.165
20:1w7	0.21 ± 0.012	0.31 ± 0.041	0.20 ± 0.012	0.23 ± 0.032	0.31 ± 0.021
20:1w5	0.08 ± 0.004	0.07 ± 0.014	0.12 ± 0.006	0.09 ± 0.007	0.11 ± 0.009
20:2w6	0.14 ± 0.005	0.21 ± 0.019	0.16 ± 0.010	0.19 ± 0.018	0.18 ± 0.007
20:3w6	0.03 ± 0.003	0.04 ± 0.010	0.03 ± 0.004	0.03 ± 0.005	0.05 ± 0.004
20:4w6	0.61 ± 0.060	0.56 ± 0.129	0.31 ± 0.018	0.40 ± 0.038	0.66 ± 0.058
20:3w3	0.04 ± 0.004	0.08 ± 0.007	0.06 ± 0.005	0.08 ± 0.009	0.09 ± 0.004
20:4w3	0.30 ± 0.016	0.53 ± 0.026	0.53 ± 0.036	0.58 ± 0.052	0.56 ± 0.034
20:5w3	6.38 ± 0.590	10.09 ± 0.184	7.32 ± 0.609	9.74 ± 0.452	11.22 ± 0.365
22:1w11	11.42 ± 1.590	6.13 ± 1.757	15.88 ± 1.581	8.74 ± 1.577	3.36 ± 0.778
22:1w9	0.49 ± 0.035	0.37 ± 0.049	0.58 ± 0.052	0.47 ± 0.041	0.43 ± 0.032
ratio22:1	22.98 ± 2.802	13.49 ± 2.901	27.76 ± 2.330	18.28 ± 2.807	6.93 ± 1.367
22:1w7	0.17 ± 0.005	0.16 ± 0.011	0.18 ± 0.009	0.16 ± 0.009	0.18 ± 0.009
22:2w6	0.01 ± 0.002	0.02 ± 0.002	0.02 ± 0.003	0.02 ± 0.002	0.01 ± 0.002
21:5w3	0.14 ± 0.006	0.32 ± 0.017	0.29 ± 0.015	0.33 ± 0.010	0.29 ± 0.017
22:4w6	0.06 ± 0.006	0.05 ± 0.008	0.05 ± 0.011	0.05 ± 0.004	0.08 ± 0.007
22:5w6	0.12 ± 0.011	0.16 ± 0.022	0.08 ± 0.005	0.13 ± 0.010	0.20 ± 0.013
22:4w3	0.03 ± 0.002	0.04 ± 0.003	0.05 ± 0.003	0.04 ± 0.003	0.05 ± 0.003
22:5w3	0.77 ± 0.049	0.92 ± 0.159	0.89 ± 0.085	0.78 ± 0.041	0.92 ± 0.063
22:6w3	11.97 ± 1.457	16.30 ± 2.939	7.28 ± 0.282	9.94 ± 0.570	16.33 ± 1.469
24:1w11	0.21 ± 0.029	0.11 ± 0.031	0.26 ± 0.037	0.14 ± 0.041	0.09 ± 0.015
24:1w9	0.84 ± 0.031	0.86 ± 0.084	0.67 ± 0.038	0.77 ± 0.048	0.99 ± 0.059

Table 3. continued

Species Location Coll. Date	Herring Pt. Gravina-St. Mat. Jul. 95 n = 20	Pollock Trawl 168 Jul. 94 n = 3	Pollock Icy Bay Nov. 94 n = 10	Pollock Pt. Gravina-St. Mat. Nov. 94 n = 5	Pollock Esther I. Hatchery Aug. 95 n = 14
% Fat	4.4 ± 0.42	3.5 ± 0.53	1.1 ± 0.14	1.1 ± 0.12	1.3 ± 0.11
12:0	0.06 ± 0.003	0.03 ± 0.000	0.02 ± 0.004	0.02 ± 0.002	0.02 ± 0.001
13:0	0.02 ± 0.001	0.01 ± 0.000	0.03 ± 0.011	0.01 ± 0.000	0.01 ± 0.001
Iso14	0.02 ± 0.001	0.01 ± 0.000	0.05 ± 0.006	0.02 ± 0.002	0.01 ± 0.001
14:0	7.22 ± 0.310	4.76 ± 0.044	2.50 ± 0.263	2.87 ± 0.230	3.22 ± 0.367
14:1w9	0.22 ± 0.010	0.27 ± 0.003	0.13 ± 0.015	0.13 ± 0.017	0.17 ± 0.010
14:1w7	0.01 ± 0.002	0.02 ± 0.000	0.01 ± 0.005	0.01 ± 0.004	0.02 ± 0.002
14:1w5	0.10 ± 0.005	0.05 ± 0.000	0.07 ± 0.019	0.05 ± 0.007	0.06 ± 0.006
Iso15	0.14 ± 0.004	0.13 ± 0.003	0.10 ± 0.006	0.08 ± 0.007	0.13 ± 0.009
Anti15	0.04 ± 0.002	0.03 ± 0.000	0.02 ± 0.002	0.02 ± 0.002	0.03 ± 0.003
15:0	0.27 ± 0.009	0.30 ± 0.003	0.31 ± 0.015	0.31 ± 0.013	0.24 ± 0.008
15:1w8	0.01 ± 0.001	0.02 ± 0.000	0.01 ± 0.002	0.00 ± 0.002	0.01 ± 0.001
15:1w6	0.00 ± 0.000	0.00 ± 0.000	0.00 ± 0.000	0.00 ± 0.000	0.01 ± 0.000
Iso16	0.05 ± 0.006	0.09 ± 0.000	0.34 ± 0.033	0.30 ± 0.022	0.05 ± 0.002
16:0	14.47 ± 0.391	17.45 ± 0.186	17.40 ± 0.260	17.26 ± 0.240	12.58 ± 0.639
16:1w11	0.34 ± 0.012	0.32 ± 0.007	0.38 ± 0.013	0.35 ± 0.009	0.36 ± 0.013
16:1w9	0.12 ± 0.005	0.18 ± 0.009	0.26 ± 0.023	0.19 ± 0.006	0.15 ± 0.006
16:1w7	4.82 ± 0.268	6.36 ± 0.072	3.51 ± 0.390	3.99 ± 0.308	4.53 ± 0.578
7Me16	0.20 ± 0.009	0.00 ± 0.000	0.00 ± 0.000	0.00 ± 0.000	0.36 ± 0.015
16:1w5	0.04 ± 0.004	0.06 ± 0.012	0.10 ± 0.011	0.10 ± 0.015	0.11 ± 0.008
16:2w6	0.11 ± 0.010	0.13 ± 0.003	0.15 ± 0.008	0.15 ± 0.002	0.13 ± 0.015
Iso17	0.04 ± 0.002	0.07 ± 0.000	0.06 ± 0.005	0.06 ± 0.004	0.04 ± 0.004
16:2w4	0.16 ± 0.023	0.18 ± 0.012	0.43 ± 0.046	0.30 ± 0.011	0.07 ± 0.004
16:3w6	0.58 ± 0.037	0.41 ± 0.003	0.34 ± 0.061	0.53 ± 0.043	0.70 ± 0.044
17:0	0.13 ± 0.010	0.17 ± 0.003	0.20 ± 0.017	0.20 ± 0.005	0.18 ± 0.015
unk3	0.34 ± 0.044	0.01 ± 0.003	0.08 ± 0.054	0.00 ± 0.000	0.66 ± 0.043
16:3w4	0.20 ± 0.051	0.18 ± 0.007	0.60 ± 0.104	1.17 ± 0.055	0.08 ± 0.016
17:1	0.20 ± 0.013	0.12 ± 0.003	0.20 ± 0.007	0.47 ± 0.036	0.11 ± 0.013
16:3w1	0.05 ± 0.006	0.10 ± 0.003	0.11 ± 0.006	0.10 ± 0.002	0.04 ± 0.003
16:4w1	0.45 ± 0.061	0.46 ± 0.003	0.31 ± 0.013	0.41 ± 0.041	0.37 ± 0.087
unk1	0.11 ± 0.011	0.09 ± 0.006	0.44 ± 0.043	0.36 ± 0.034	0.30 ± 0.040
unk2	0.09 ± 0.008	0.05 ± 0.000	0.26 ± 0.025	0.22 ± 0.019	0.23 ± 0.031
18:0	1.79 ± 0.082	2.77 ± 0.064	4.32 ± 0.152	4.20 ± 0.110	2.77 ± 0.248
18:1w13	0.04 ± 0.009	0.00 ± 0.000	0.02 ± 0.010	0.01 ± 0.010	0.08 ± 0.005
18:1w11	0.63 ± 0.047	1.12 ± 0.012	0.52 ± 0.053	0.42 ± 0.043	1.59 ± 0.219
18:1w9	11.43 ± 0.863	9.49 ± 0.170	10.95 ± 0.431	10.43 ± 0.153	5.93 ± 0.532
18:1w7	2.39 ± 0.159	2.46 ± 0.037	4.71 ± 0.361	4.33 ± 0.184	2.40 ± 0.186
18:1w5	0.52 ± 0.014	0.61 ± 0.012	0.26 ± 0.015	0.27 ± 0.014	0.56 ± 0.050

Table 3. continued

Species	Herring	Pollock	Pollock	Pollock	Pollock
Location	Pt. Gravina-St. Mat.	Trawl 168	Icy Bay	Pt. Gravina-St. Mat.	Esther I. Hatchery
Coll. Date	Jul. 95	Jul. 94	Nov. 94	Nov. 94	Aug. 95
18:2d5,7	0.02 ± 0.002	0.05 ± 0.006	0.05 ± 0.003	0.03 ± 0.004	0.05 ± 0.006
18:2w7	0.02 ± 0.002	0.02 ± 0.000	0.05 ± 0.007	0.06 ± 0.002	0.04 ± 0.006
18:2w6	0.76 ± 0.032	0.87 ± 0.009	0.72 ± 0.033	0.66 ± 0.046	0.69 ± 0.033
18:2w4	0.12 ± 0.006	0.20 ± 0.006	0.11 ± 0.007	0.18 ± 0.014	0.12 ± 0.008
18:3w6	0.05 ± 0.003	0.14 ± 0.003	0.07 ± 0.008	0.09 ± 0.008	0.06 ± 0.006
18:3w4	0.04 ± 0.002	0.07 ± 0.003	0.07 ± 0.006	0.18 ± 0.016	0.04 ± 0.004
18:3w3	0.45 ± 0.037	0.57 ± 0.015	0.53 ± 0.038	0.42 ± 0.039	0.60 ± 0.065
18:3w1	0.05 ± 0.004	0.05 ± 0.009	0.09 ± 0.009	0.08 ± 0.009	0.10 ± 0.006
18:4w3	0.94 ± 0.066	1.62 ± 0.015	1.41 ± 0.151	1.33 ± 0.158	1.48 ± 0.208
18:4w1	0.15 ± 0.007	0.18 ± 0.000	0.09 ± 0.007	0.22 ± 0.028	0.15 ± 0.023
20:0	0.23 ± 0.009	0.04 ± 0.000	0.06 ± 0.002	0.06 ± 0.002	0.10 ± 0.006
20:1w11	10.39 ± 1.012	0.53 ± 0.013	0.63 ± 0.186	0.66 ± 0.075	8.06 ± 1.213
20:1w9	3.24 ± 0.273	7.96 ± 0.270	1.12 ± 0.109	1.64 ± 0.164	2.45 ± 0.166
ratio20:1	3.72 ± 0.444	0.07 ± 0.002	0.50 ± 0.105	0.40 ± 0.023	3.06 ± 0.394
20:1w7	0.24 ± 0.015	0.17 ± 0.003	0.19 ± 0.009	0.22 ± 0.006	0.17 ± 0.006
20:1w5	0.08 ± 0.006	0.06 ± 0.003	0.08 ± 0.007	0.07 ± 0.006	0.10 ± 0.004
20:2w6	0.12 ± 0.006	0.17 ± 0.003	0.19 ± 0.004	0.20 ± 0.006	0.17 ± 0.011
20:3w6	0.04 ± 0.003	0.07 ± 0.000	0.05 ± 0.002	0.06 ± 0.002	0.07 ± 0.008
20:4w6	0.48 ± 0.041	0.53 ± 0.003	1.11 ± 0.075	1.14 ± 0.072	0.68 ± 0.096
20:3w3	0.04 ± 0.002	0.08 ± 0.000	0.08 ± 0.005	0.08 ± 0.004	0.16 ± 0.083
20:4w3	0.36 ± 0.013	0.55 ± 0.024	0.50 ± 0.019	0.56 ± 0.037	0.53 ± 0.040
20:5w3	7.11 ± 0.301	14.05 ± 0.078	14.16 ± 0.367	15.60 ± 0.296	9.80 ± 0.441
22:1w11	12.66 ± 0.942	4.12 ± 0.172	0.62 ± 0.202	0.89 ± 0.167	9.12 ± 1.521
22:1w9	0.53 ± 0.026	0.42 ± 0.013	0.33 ± 0.030	0.60 ± 0.041	0.57 ± 0.066
ratio22:1	24.18 ± 1.873	9.89 ± 0.099	1.63 ± 0.357	1.46 ± 0.210	13.42 ± 1.848
22:1w7	0.18 ± 0.006	0.09 ± 0.000	0.10 ± 0.006	0.11 ± 0.002	0.20 ± 0.019
22:2w6	0.01 ± 0.003	0.02 ± 0.000	0.04 ± 0.002	0.04 ± 0.002	0.02 ± 0.003
21:5w3	0.20 ± 0.007	0.42 ± 0.010	0.31 ± 0.020	0.50 ± 0.027	0.24 ± 0.010
22:4w6	0.04 ± 0.005	0.02 ± 0.003	0.06 ± 0.011	0.09 ± 0.009	0.17 ± 0.025
22:5w6	0.12 ± 0.007	0.16 ± 0.003	0.24 ± 0.016	0.23 ± 0.010	0.34 ± 0.041
22:4w3	0.04 ± 0.001	0.04 ± 0.003	0.03 ± 0.002	0.04 ± 0.004	0.04 ± 0.004
22:5w3	0.92 ± 0.026	0.88 ± 0.052	1.09 ± 0.056	1.18 ± 0.047	1.23 ± 0.043
22:6w3	12.19 ± 0.791	16.50 ± 0.122	25.11 ± 1.735	21.92 ± 1.053	22.82 ± 2.145
24:1w11	0.20 ± 0.027	0.04 ± 0.006	0.06 ± 0.021	0.08 ± 0.034	0.41 ± 0.067
24:1w9	0.57 ± 0.050	0.61 ± 0.012	1.29 ± 0.115	1.21 ± 0.098	1.02 ± 0.100

Table 3. continued

Species Location Coll. Date	Pollock Esther Island Sep. 95 n = 12	RockFish Galena Bay Sep. 95 n = 1	Sandlance Pt. Gravina-Beartrap Apr. 94 n = 9	Pacific Cod Cordova Hbr Jul. 94 n = 10	Tomcod Fidalgo-Irish Cove Sep. 95 n = 5
% Fat	2.4 ± 0.23	1.7	1.2 ± 0.15	2.3 ± 0.26	1.1 ± 0.13
12:0	0.02 ± 0.001	0.10	0.04 ± 0.005	0.02 ± 0.002	0.02 ± 0.002
13:0	0.01 ± 0.000	0.01	0.02 ± 0.003	0.01 ± 0.001	0.01 ± 0.002
Iso14	0.01 ± 0.001	0.01	0.03 ± 0.002	0.01 ± 0.002	0.01 ± 0.002
14:0	4.67 ± 0.143	3.44	3.23 ± 0.376	2.17 ± 0.249	1.23 ± 0.185
14:1w9	0.15 ± 0.007	0.20	0.34 ± 0.060	0.11 ± 0.022	0.11 ± 0.024
14:1w7	0.02 ± 0.001	0.03	0.03 ± 0.007	0.02 ± 0.002	0.02 ± 0.006
14:1w5	0.06 ± 0.002	0.08	0.04 ± 0.006	0.04 ± 0.005	0.02 ± 0.003
Iso15	0.11 ± 0.003	0.12	0.15 ± 0.024	0.07 ± 0.005	0.12 ± 0.005
Anti15	0.03 ± 0.002	0.04	0.06 ± 0.011	0.02 ± 0.002	0.03 ± 0.004
15:0	0.23 ± 0.004	0.31	0.47 ± 0.033	0.27 ± 0.013	0.61 ± 0.093
15:1w8	0.01 ± 0.002	0.01	0.00 ± 0.002	0.00 ± 0.002	0.01 ± 0.004
15:1w6	0.01 ± 0.000	0.00	0.00 ± 0.000	0.01 ± 0.003	0.00 ± 0.004
Iso16	0.04 ± 0.001	0.19	0.22 ± 0.032	0.21 ± 0.017	0.21 ± 0.040
16:0	12.62 ± 0.195	17.22	19.15 ± 0.284	14.50 ± 0.461	14.82 ± 0.377
16:1w11	0.31 ± 0.009	0.45	0.42 ± 0.010	0.44 ± 0.018	0.71 ± 0.068
16:1w9	0.15 ± 0.004	0.25	0.30 ± 0.014	0.38 ± 0.036	0.43 ± 0.015
16:1w7	6.44 ± 0.217	6.28	4.09 ± 0.537	3.84 ± 0.220	3.05 ± 0.198
7Me16	0.25 ± 0.005	0.26	0.00 ± 0.000	0.17 ± 0.021	0.26 ± 0.022
16:1w5	0.06 ± 0.003	0.14	0.16 ± 0.013	0.14 ± 0.013	0.18 ± 0.027
16:2w6	0.12 ± 0.002	0.23	0.15 ± 0.006	0.17 ± 0.013	0.41 ± 0.057
Iso17	0.04 ± 0.003	0.12	0.08 ± 0.004	0.03 ± 0.008	0.29 ± 0.042
16:2w4	0.05 ± 0.001	0.41	0.46 ± 0.025	0.47 ± 0.042	0.61 ± 0.062
16:3w6	0.80 ± 0.012	0.24	0.17 ± 0.037	0.19 ± 0.032	0.00 ± 0.000
17:0	0.13 ± 0.005	0.31	0.26 ± 0.033	0.22 ± 0.021	0.60 ± 0.075
unk3	0.86 ± 0.023	0.15	0.17 ± 0.035	0.16 ± 0.031	0.23 ± 0.065
16:3w4	0.03 ± 0.002	0.21	0.12 ± 0.031	0.11 ± 0.043	0.03 ± 0.011
17:1	0.08 ± 0.011	0.38	0.33 ± 0.019	0.31 ± 0.034	0.64 ± 0.113
16:3w1	0.04 ± 0.002	0.13	0.14 ± 0.008	0.16 ± 0.030	0.06 ± 0.015
16:4w1	0.91 ± 0.042	0.35	0.34 ± 0.041	0.16 ± 0.058	0.36 ± 0.068
unk1	0.17 ± 0.010	0.22	0.34 ± 0.049	0.31 ± 0.022	0.44 ± 0.058
unk2	0.12 ± 0.008	0.18	0.24 ± 0.033	0.23 ± 0.025	0.42 ± 0.070
18:0	2.42 ± 0.129	4.15	3.29 ± 0.176	3.85 ± 0.160	4.98 ± 0.408
18:1w13	0.11 ± 0.005	0.22	0.00 ± 0.000	0.31 ± 0.043	0.59 ± 0.200
18:1w11	1.70 ± 0.123	0.43	0.40 ± 0.036	1.09 ± 0.143	0.09 ± 0.019
18:1w9	5.40 ± 0.410	14.21	15.80 ± 1.410	15.51 ± 0.711	8.78 ± 0.411
18:1w7	2.10 ± 0.071	3.85	2.83 ± 0.090	4.03 ± 0.174	4.27 ± 0.368
18:1w5	0.48 ± 0.011	0.62	0.39 ± 0.031	0.43 ± 0.021	0.43 ± 0.062

Table 3. continued

Species	Pollock	RockFish	Sandlance	Pacific Cod	Tomcod
Location	Esther Island	Galena Bay	Pt. Gravina-Beartrap	Cordova Hbr	Fidalgo-Irish Cove
Coll. Date	Sep. 95	Sep. 95	Apr. 94	Jul. 94	Sep. 95
18:2d5,7	0.03 ± 0.002	0.06	0.04 ± 0.002	0.04 ± 0.005	0.05 ± 0.010
18:2w7	0.03 ± 0.005	0.02	0.02 ± 0.004	0.02 ± 0.004	0.02 ± 0.007
18:2w6	0.64 ± 0.016	0.98	1.18 ± 0.075	0.70 ± 0.049	0.80 ± 0.115
18:2w4	0.21 ± 0.004	0.14	0.08 ± 0.008	0.15 ± 0.017	0.11 ± 0.013
18:3w6	0.08 ± 0.003	0.07	0.05 ± 0.007	0.05 ± 0.005	0.07 ± 0.008
18:3w4	0.09 ± 0.006	0.06	0.07 ± 0.010	0.10 ± 0.004	0.06 ± 0.017
18:3w3	0.49 ± 0.011	0.69	0.67 ± 0.107	0.44 ± 0.053	0.78 ± 0.095
18:3w1	0.06 ± 0.003	0.14	0.14 ± 0.010	0.15 ± 0.010	0.24 ± 0.022
18:4w3	2.64 ± 0.100	1.49	0.81 ± 0.173	0.56 ± 0.099	0.98 ± 0.273
18:4w1	0.33 ± 0.007	0.11	0.05 ± 0.009	0.09 ± 0.028	0.06 ± 0.006
20:0	0.12 ± 0.004	0.11	0.13 ± 0.004	0.07 ± 0.008	0.09 ± 0.018
20:1w11	8.47 ± 0.465	2.07	0.51 ± 0.051	2.53 ± 0.316	0.86 ± 0.287
20:1w9	2.29 ± 0.060	1.11	2.68 ± 0.385	2.10 ± 0.210	0.78 ± 0.058
ratio20:1	3.68 ± 0.156	1.87	0.20 ± 0.017	1.22 ± 0.123	1.15 ± 0.444
20:1w7	0.22 ± 0.008	0.37	0.23 ± 0.006	0.52 ± 0.087	1.10 ± 0.321
20:1w5	0.09 ± 0.003	0.10	0.12 ± 0.017	0.06 ± 0.008	0.07 ± 0.010
20:2w6	0.15 ± 0.003	0.26	0.17 ± 0.014	0.31 ± 0.022	0.44 ± 0.057
20:3w6	0.07 ± 0.004	0.06	0.05 ± 0.003	0.08 ± 0.006	0.11 ± 0.017
20:4w6	0.56 ± 0.032	1.80	1.02 ± 0.077	2.14 ± 0.174	3.06 ± 0.488
20:3w3	0.06 ± 0.002	0.10	0.06 ± 0.006	0.12 ± 0.012	0.22 ± 0.037
20:4w3	0.69 ± 0.016	0.49	0.46 ± 0.033	0.61 ± 0.049	0.54 ± 0.073
20:5w3	13.67 ± 0.240	9.38	9.54 ± 0.363	11.84 ± 0.689	13.63 ± 0.501
22:1w11	7.88 ± 0.418	1.50	2.37 ± 0.387	1.38 ± 0.212	0.13 ± 0.016
22:1w9	0.65 ± 0.088	0.24	0.38 ± 0.028	0.30 ± 0.023	0.15 ± 0.014
ratio22:1	14.30 ± 1.575	6.23	6.05 ± 0.734	4.69 ± 0.651	0.96 ± 0.179
22:1w7	0.16 ± 0.005	0.12	0.19 ± 0.005	0.09 ± 0.013	0.17 ± 0.037
22:2w6	0.02 ± 0.001	0.04	0.02 ± 0.003	0.04 ± 0.013	0.03 ± 0.007
21:5w3	0.49 ± 0.012	0.22	0.15 ± 0.014	0.26 ± 0.035	0.24 ± 0.022
22:4w6	0.06 ± 0.006	0.20	0.09 ± 0.023	0.19 ± 0.029	0.73 ± 0.137
22:5w6	0.19 ± 0.006	0.32	0.27 ± 0.012	0.23 ± 0.013	0.49 ± 0.055
22:4w3	0.06 ± 0.002	0.07	0.04 ± 0.006	0.04 ± 0.004	0.04 ± 0.008
22:5w3	1.46 ± 0.047	1.33	1.08 ± 0.024	2.69 ± 0.208	3.80 ± 0.661
22:6w3	16.43 ± 0.556	20.01	21.58 ± 2.157	21.16 ± 0.654	24.50 ± 1.819
24:1w11	0.29 ± 0.012	0.10	0.05 ± 0.020	0.06 ± 0.010	0.04 ± 0.021
24:1w9	0.63 ± 0.023	0.78	1.48 ± 0.094	0.82 ± 0.044	0.60 ± 0.147

Table 3. continued

Species	Rainbow Smelt	Yellow Fin Sole	Octopus	Squid/Shrimp
Location	911 Haul72	Montg.W-Pt.Chalmers	Galena Bay	Port Gravina
Coll. Date	unk.	Sep. 94	Jul. 94	Nov. 94
	n = 4	n = 8	n = 2	n = 3
% Fat	2.5 ± 0.54	3.2 ± 0.55	1.3	1.6 ± 0.74
12:0	0.07 ± 0.009	0.04 ± 0.003	0.06	0.10 ± 0.028
13:0	0.01 ± 0.003	0.03 ± 0.001	0.00	0.03 ± 0.009
Iso14	0.01 ± 0.003	0.03 ± 0.003	0.06	0.09 ± 0.006
14:0	2.59 ± 0.349	4.49 ± 0.246	1.94	3.33 ± 0.435
14:1w9	0.06 ± 0.013	0.29 ± 0.022	0.07	0.05 ± 0.006
14:1w7	0.02 ± 0.000	0.04 ± 0.004	0.02	0.01 ± 0.003
14:1w5	0.19 ± 0.046	0.13 ± 0.013	0.09	0.10 ± 0.027
Iso15	0.07 ± 0.010	0.26 ± 0.020	0.09	0.17 ± 0.032
Anti15	0.02 ± 0.003	0.11 ± 0.013	0.04	0.05 ± 0.007
15:0	0.27 ± 0.028	0.53 ± 0.015	0.28	0.60 ± 0.139
15:1w8	0.01 ± 0.000	0.01 ± 0.001	0.00	0.00 ± 0.003
15:1w6	0.00 ± 0.003	0.02 ± 0.004	0.00	0.03 ± 0.015
Iso16	0.10 ± 0.034	0.17 ± 0.027	0.68	0.58 ± 0.091
16:0	18.12 ± 0.387	12.84 ± 0.424	14.87	17.21 ± 1.961
16:1w11	0.22 ± 0.024	0.94 ± 0.043	0.45	0.64 ± 0.165
16:1w9	0.34 ± 0.036	0.37 ± 0.016	0.26	0.19 ± 0.015
16:1w7	10.47 ± 1.651	6.43 ± 0.438	2.51	4.96 ± 0.210
7Me16	0.00 ± 0.000	0.23 ± 0.034	0.00	0.00 ± 0.000
16:1w5	0.15 ± 0.010	0.15 ± 0.008	0.05	0.04 ± 0.009
16:2w6	0.15 ± 0.038	0.31 ± 0.023	0.31	0.37 ± 0.093
Iso17	0.02 ± 0.003	0.06 ± 0.009	0.12	0.21 ± 0.071
16:2w4	0.28 ± 0.105	0.77 ± 0.036	0.06	0.09 ± 0.009
16:3w6	0.23 ± 0.141	0.30 ± 0.020	0.08	0.50 ± 0.160
17:0	0.23 ± 0.038	0.31 ± 0.022	0.58	0.39 ± 0.115
unk3	0.10 ± 0.056	0.16 ± 0.023	0.10	0.35 ± 0.192
16:3w4	0.04 ± 0.007	0.18 ± 0.018	0.05	0.36 ± 0.231
17:1	0.30 ± 0.043	0.43 ± 0.025	0.15	0.85 ± 0.196
16:3w1	0.08 ± 0.009	0.11 ± 0.003	0.14	0.17 ± 0.015
16:4w1	0.13 ± 0.031	0.20 ± 0.027	0.97	0.56 ± 0.067
unk1	0.20 ± 0.058	0.18 ± 0.025	0.07	0.05 ± 0.006
unk2	0.09 ± 0.025	0.12 ± 0.017	0.23	0.17 ± 0.045
18:0	3.80 ± 0.211	2.75 ± 0.199	3.37	2.50 ± 0.214
18:1w13	0.10 ± 0.009	0.16 ± 0.014	0.25	0.09 ± 0.020
18:1w11	0.10 ± 0.021	0.62 ± 0.050	0.28	0.18 ± 0.035
18:1w9	18.42 ± 2.628	11.25 ± 0.603	6.00	10.80 ± 0.102
18:1w7	4.76 ± 0.114	3.63 ± 0.158	3.95	5.61 ± 0.057
18:1w5	0.46 ± 0.042	0.56 ± 0.040	0.52	0.42 ± 0.088

Table 3. continued

Species	Rainbow Smelt	Yellow Fin Sole	Octopus	Squid/Shrimp
Location	911 Haul72	Montg.W-Pt.Chalmers	Galena Bay	Port Gravina
Coll. Date	unk.	Sep. 94	Jul. 94	Nov. 94
18:2d5,7	0.23 ± 0.109	0.08 ± 0.024	0.01	0.03 ± 0.003
18:2w7	0.02 ± 0.003	0.04 ± 0.004	0.03	0.05 ± 0.015
18:2w6	0.54 ± 0.181	0.94 ± 0.028	0.60	0.78 ± 0.009
18:2w4	0.10 ± 0.013	0.22 ± 0.015	0.12	0.14 ± 0.003
18:3w6	0.06 ± 0.015	0.08 ± 0.007	0.02	0.05 ± 0.015
18:3w4	0.05 ± 0.006	0.15 ± 0.009	0.04	0.07 ± 0.025
18:3w3	0.30 ± 0.134	0.59 ± 0.035	0.38	0.62 ± 0.021
18:3w1	0.16 ± 0.027	0.23 ± 0.010	0.10	0.03 ± 0.015
18:4w3	0.25 ± 0.049	0.94 ± 0.066	0.33	0.76 ± 0.294
18:4w1	0.02 ± 0.003	0.11 ± 0.005	0.07	0.07 ± 0.003
20:0	0.10 ± 0.007	0.14 ± 0.008	0.17	0.16 ± 0.039
20:1w11	0.40 ± 0.078	7.17 ± 0.761	3.46	1.62 ± 0.371
20:1w9	0.62 ± 0.139	1.94 ± 0.103	4.02	1.38 ± 0.073
ratio20:1	0.84 ± 0.330	3.64 ± 0.252	0.86	1.21 ± 0.327
20:1w7	0.25 ± 0.148	1.47 ± 0.098	0.68	0.93 ± 0.292
20:1w5	0.07 ± 0.006	0.16 ± 0.007	0.03	0.07 ± 0.023
20:2w6	0.16 ± 0.017	0.39 ± 0.012	0.58	0.41 ± 0.012
20:3w6	0.05 ± 0.014	0.14 ± 0.043	0.04	0.04 ± 0.003
20:4w6	1.74 ± 0.467	2.15 ± 0.196	4.24	1.92 ± 0.549
20:3w3	0.03 ± 0.008	0.15 ± 0.009	0.61	0.26 ± 0.091
20:4w3	0.20 ± 0.011	0.46 ± 0.023	0.24	0.30 ± 0.024
20:5w3	8.80 ± 0.535	9.21 ± 0.398	16.37	17.74 ± 0.493
22:1w11	0.15 ± 0.012	4.05 ± 0.532	2.97	1.62 ± 0.372
22:1w9	0.14 ± 0.028	0.43 ± 0.029	1.06	0.55 ± 0.110
ratio22:1	1.19 ± 0.182	9.28 ± 0.863	2.80	2.88 ± 0.271
22:1w7	0.00 ± 0.000	0.15 ± 0.026	0.20	0.25 ± 0.048
22:2w6	0.02 ± 0.000	0.06 ± 0.006	0.10	0.04 ± 0.012
21:5w3	0.16 ± 0.017	0.26 ± 0.050	0.27	0.39 ± 0.108
22:4w6	0.13 ± 0.029	0.45 ± 0.040	0.35	0.32 ± 0.114
22:5w6	0.26 ± 0.064	0.34 ± 0.024	0.28	0.22 ± 0.020
22:4w3	0.05 ± 0.011	0.11 ± 0.008	0.03	0.02 ± 0.003
22:5w3	1.47 ± 0.208	3.03 ± 0.164	1.57	1.09 ± 0.290
22:6w3	20.22 ± 2.652	14.78 ± 0.815	21.91	15.40 ± 0.160
24:1w11	0.04 ± 0.012	0.13 ± 0.013	0.15	0.14 ± 0.035
24:1w9	0.86 ± 0.105	0.64 ± 0.033	0.34	0.50 ± 0.100

Values are mean weight percent of total fatty acids ± SE.

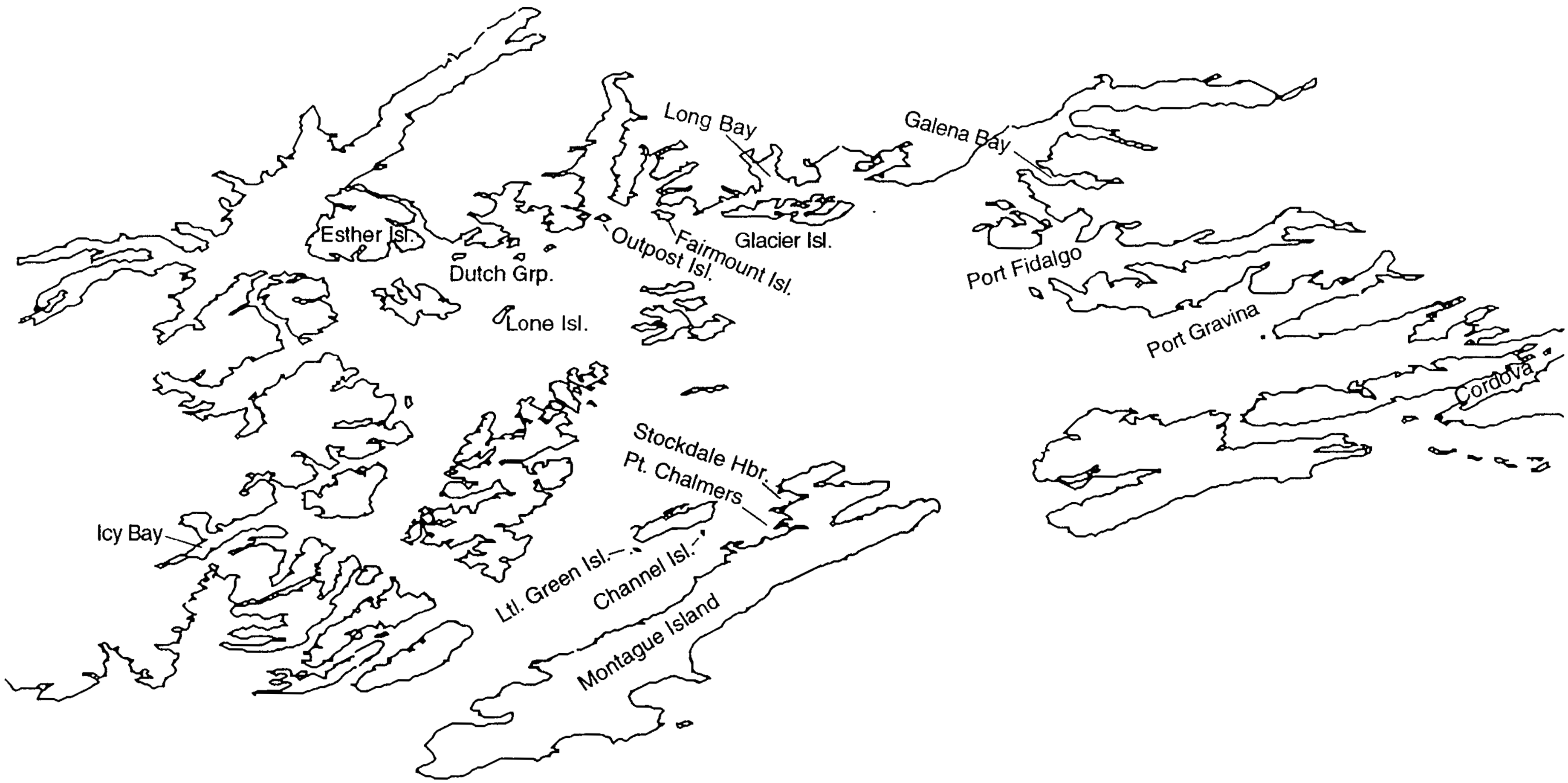

Figure 1. Map of Prince William Sound showing the locations of harbor seals and prey species sampled for fatty acid analysis.

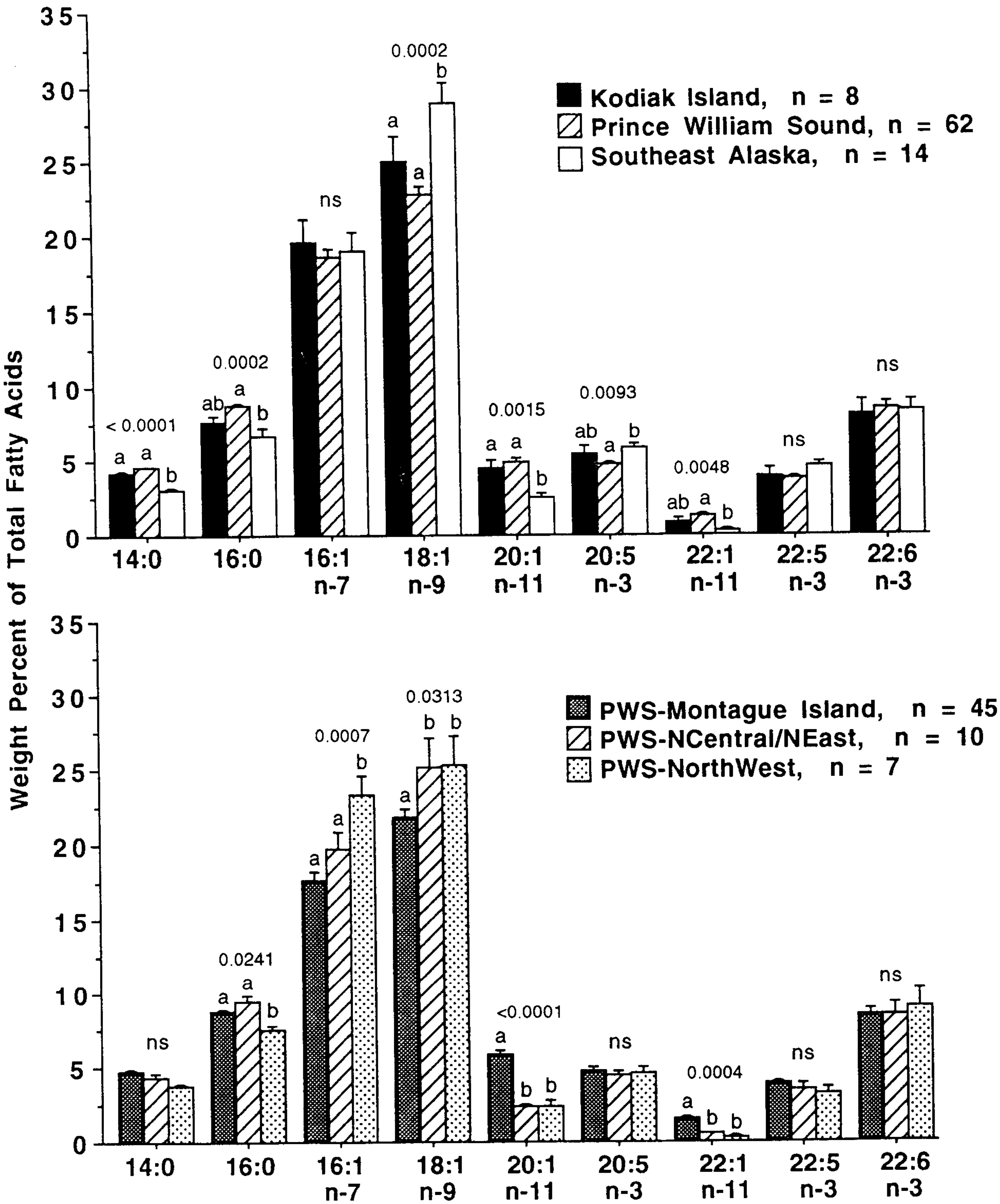

Figure 2. Composition (weight %) of prominant fatty acids in blubber collected from harbor seals (n = 84) in major areas of the Gulf of Alaska, 1994/1995 (a), and in general regions within Prince William Sound, 1994/1995 (b). Means with different letters were significantly different and numbers represent p values (ANOVA).

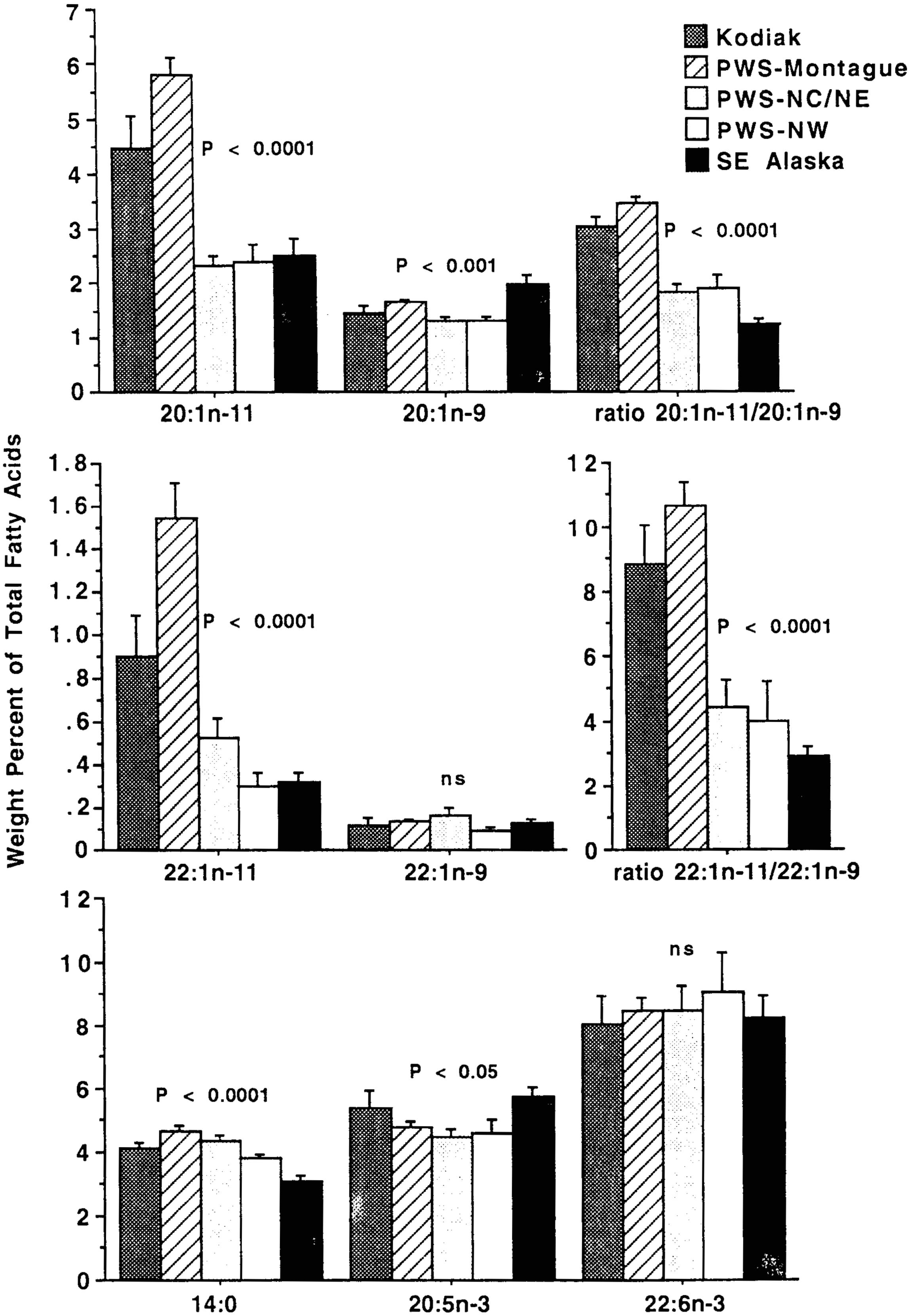

Figure 3. Selected dietary fatty acids and important isomer ratios (mean ± SEM) in harbor seal blubber which can be used to distinguish groups by major geographical region in the Gulf of Alaska as well as within areas of Prince William Sound. See Table 1and Fig. 1 for sample sizes.

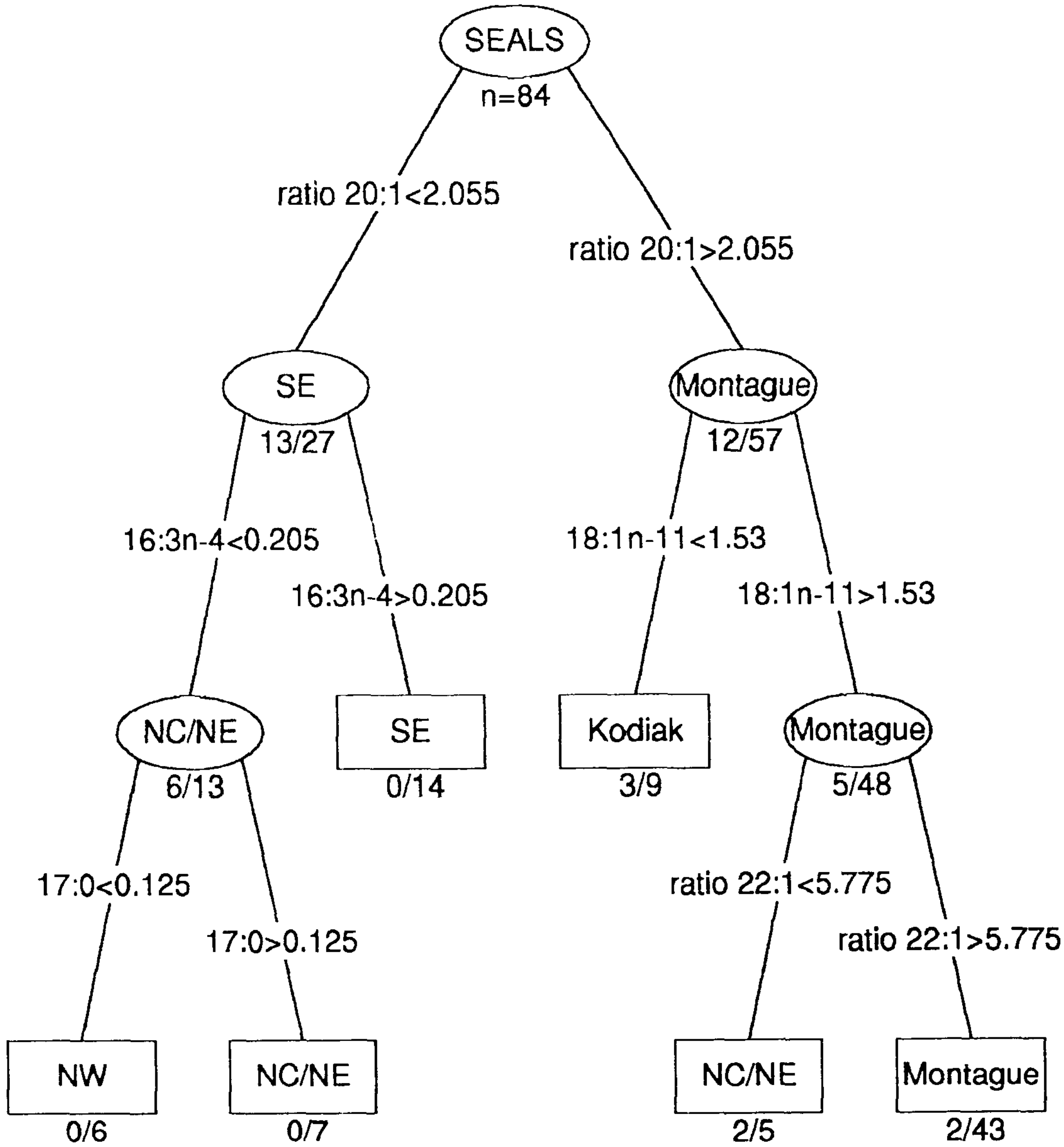

Figure 4. Classification tree of all harbor seals sampled in PWS and the Gulf of Alaska. Circles represent intermediate nodes and square boxes represent terminal nodes; labels within a circle or square indicate the classification at that node as represented by the largest number of observations with that label in that node. The fatty acid listed at each split is the variable chosen by the algorithm to create the split, with < and > values indicating the optimal splitting level (weight %) of that fatty acid (see also Fig. 6). Fractions under each intermediate and terminal node indicate the number of misclassifications over total number of observations in that node. Total misclassification rate was 7 out of 84.

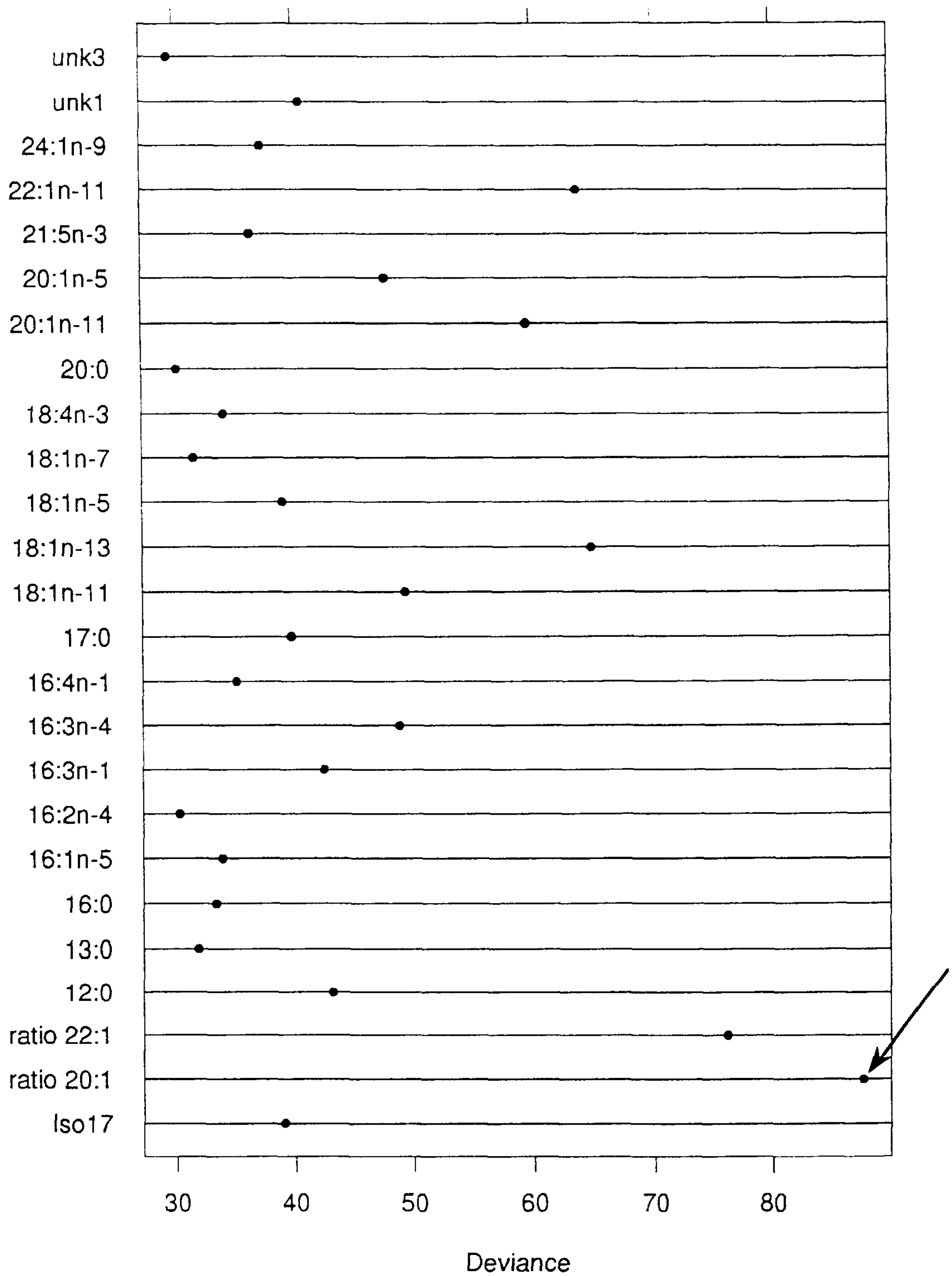

Figure 5. Dot chart of the change in deviance for the optimal cutpoint for the top 25 fatty acids considered for the first node. The ratio of 20:1n-11/n-9 had the largest change in deviance at > 85.0 and thus was algorithmically chosen for the first node split (Fig. 4).

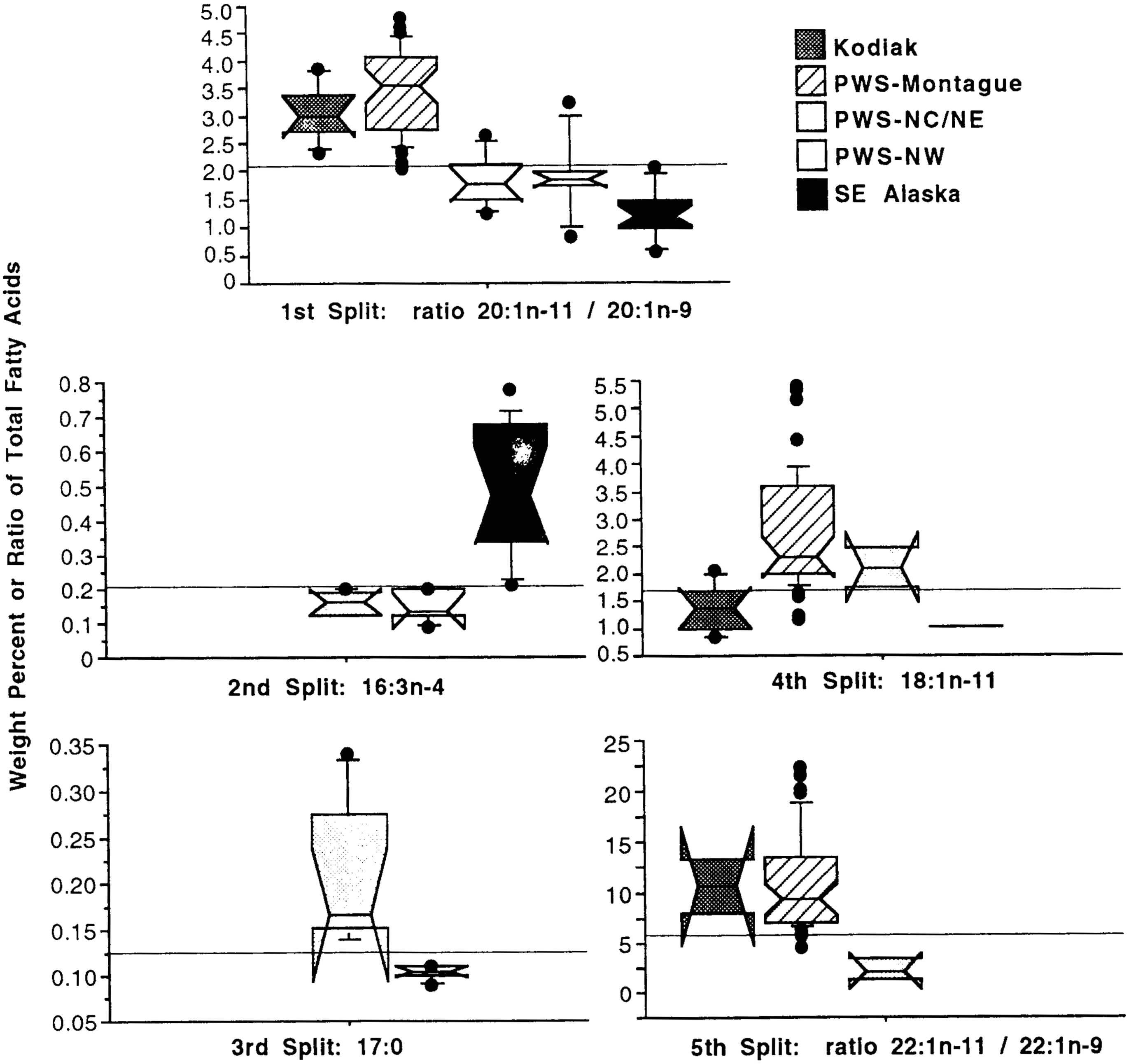

Figure 6. Box plots of the algorithmically selected variables showing the distribution of the data at the five nodes (see Fig. 4). The boxplot for the root node variable contains data from all observations. The boxplots for subsequent variables have removed the effects (observations) of the nodes higher up in the tree, i.e., once an observation has been classified, it is removed from any of the plots which follow, since it may mask the effects trying to be observed. The notched area of each box represents the 95% confidence interval on the mean; dots indicate outliers. The horizontal line represents the splitting value used by the CART algorithm.

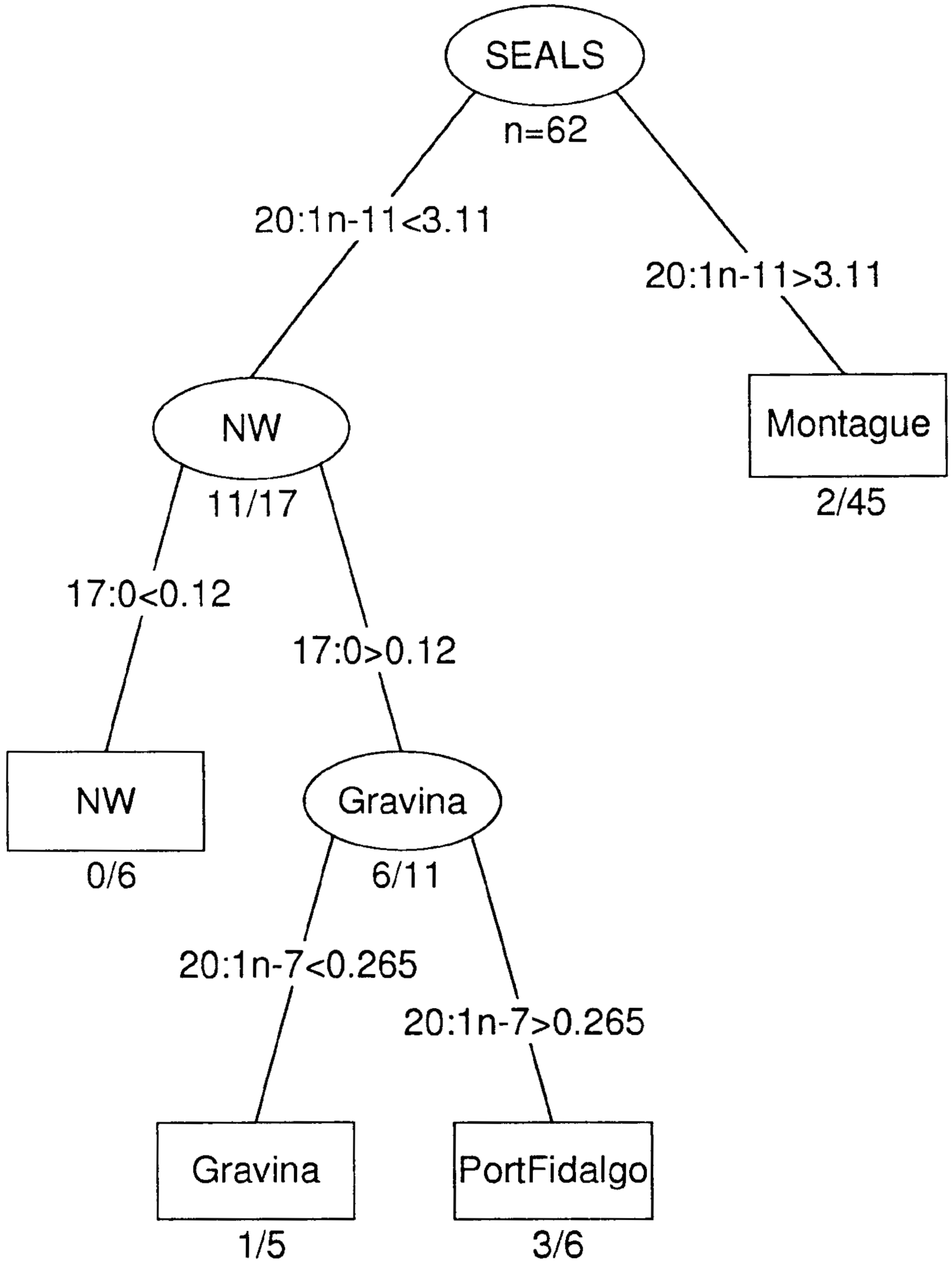

Figure 7. Classification tree of harbor seals sampled only in PWS. See Fig. 4 legend for explanation of tree. Number of seals sampled from Port Fidalgo was n = 3 and from Gravina was n = 5. Total misclassification rate was 6 out of 62.

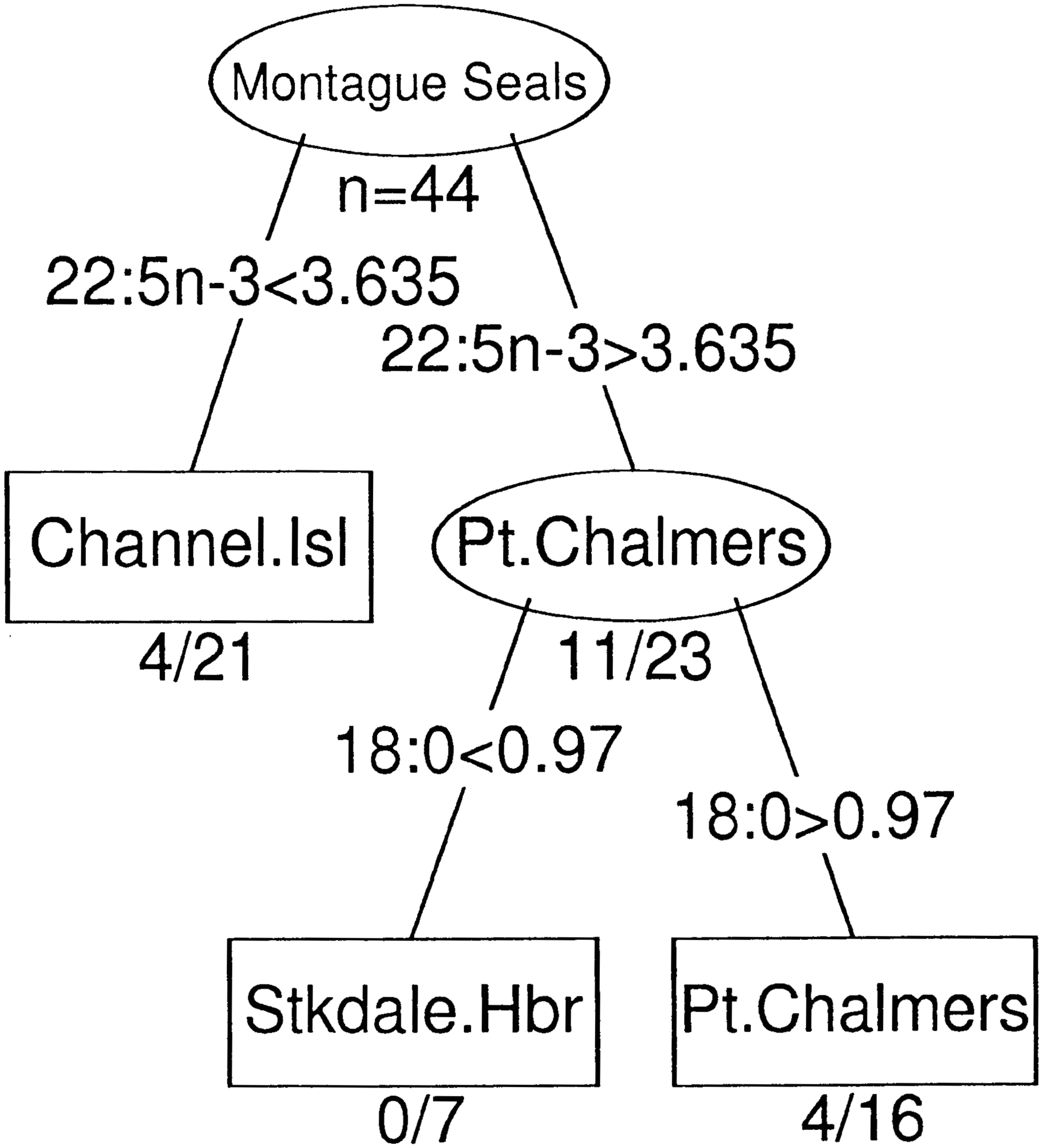

Figure 8. Classification of harbor seals sampled only near Montague Island in PWS (excluding 1 from Little Green Island). See Fig. 4 legend for explaination of tree. Total misclassification rate was 8 out of 44.

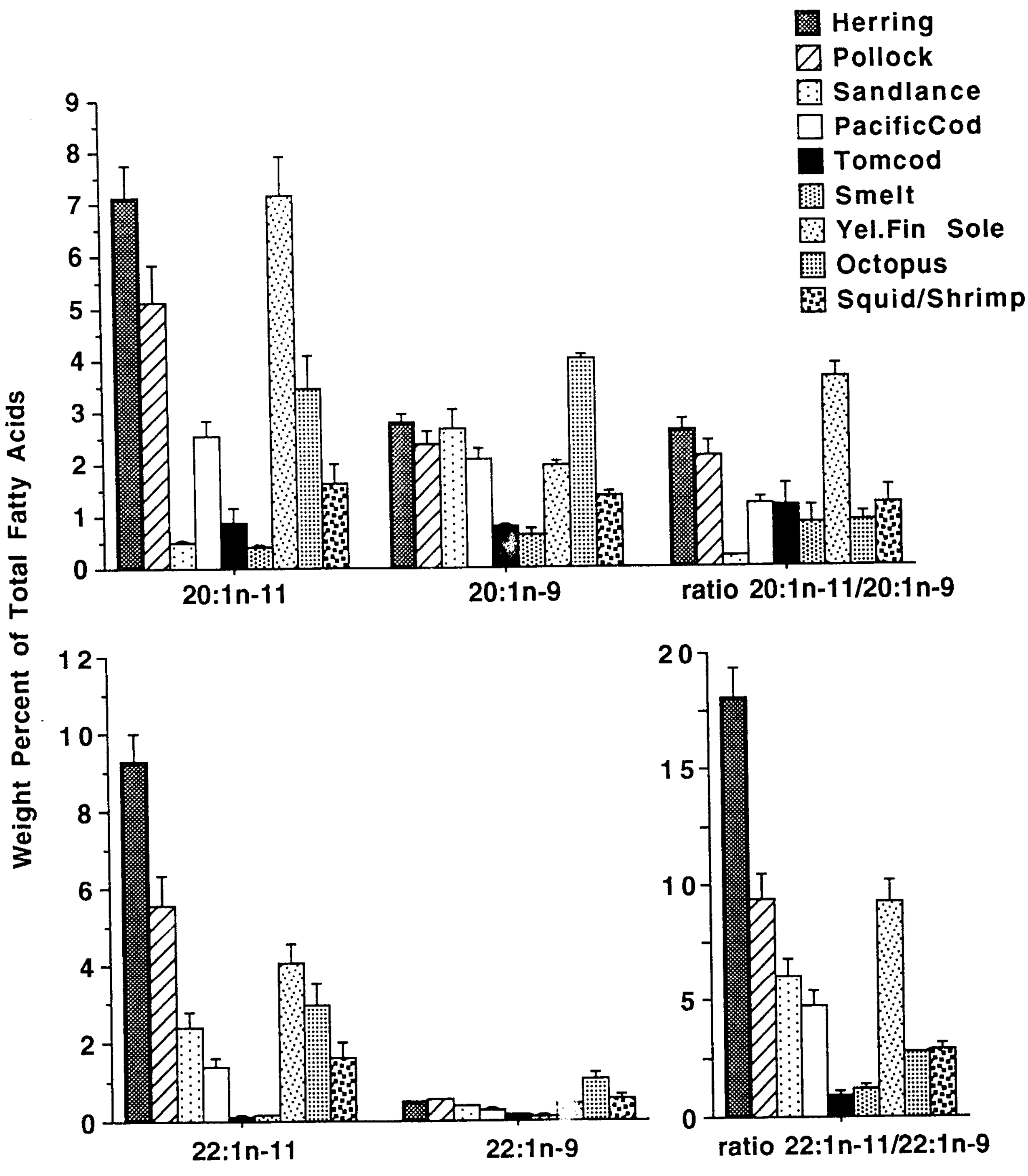

Figure 9. Variation in selected fatty acids and important isomer ratios (mean ± SEM) in prey species collected in Prince William Sound. See Table 2 for sample sizes.

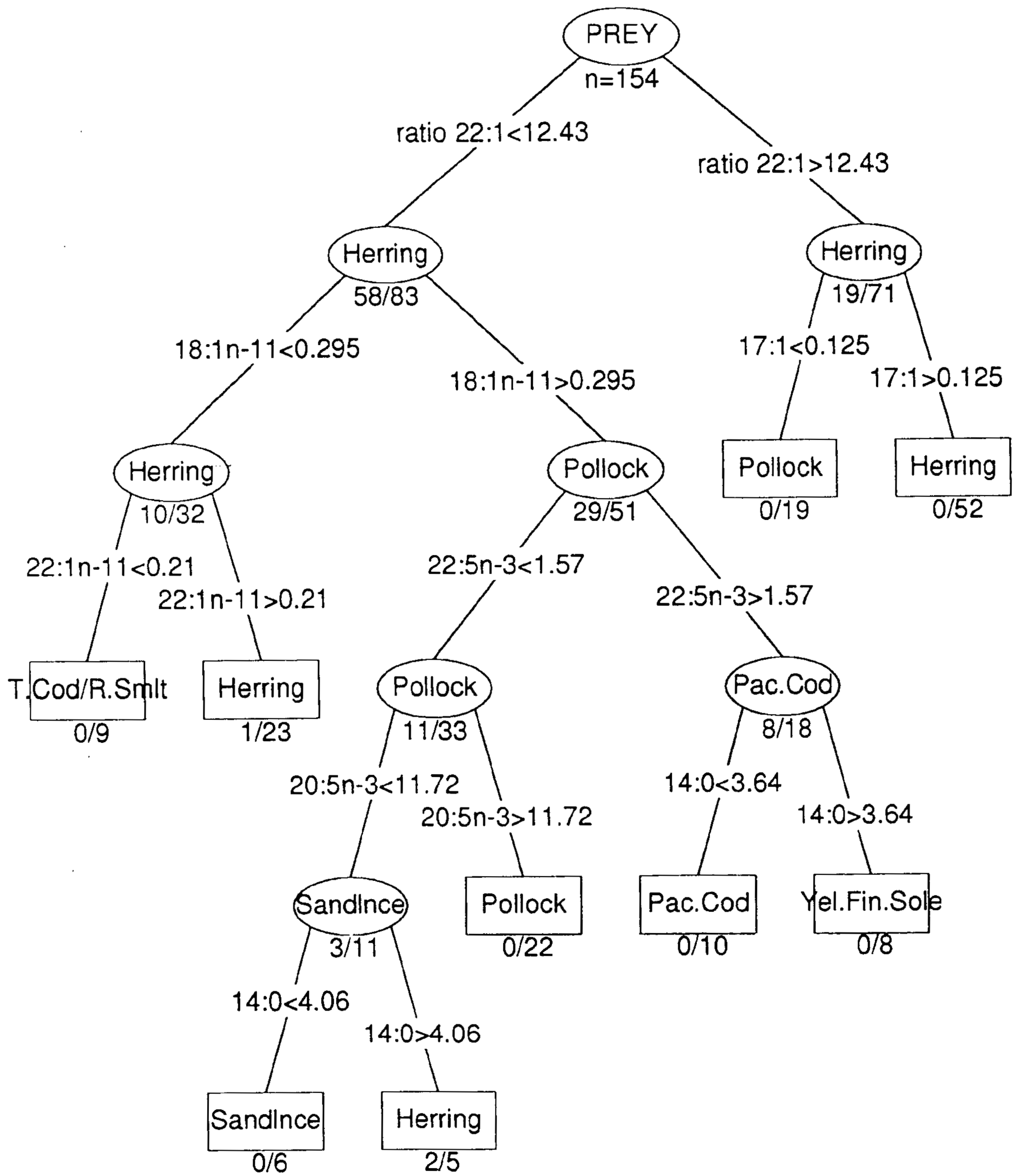

Figure 10. Classification tree of prey collected in PWS across species as a whole. See Fig. 4 legend for explanation of tree. Species with sample sizes < 4 were excluded from CART analysis. Total misclassification rate for identifying species was 3 out of 154.

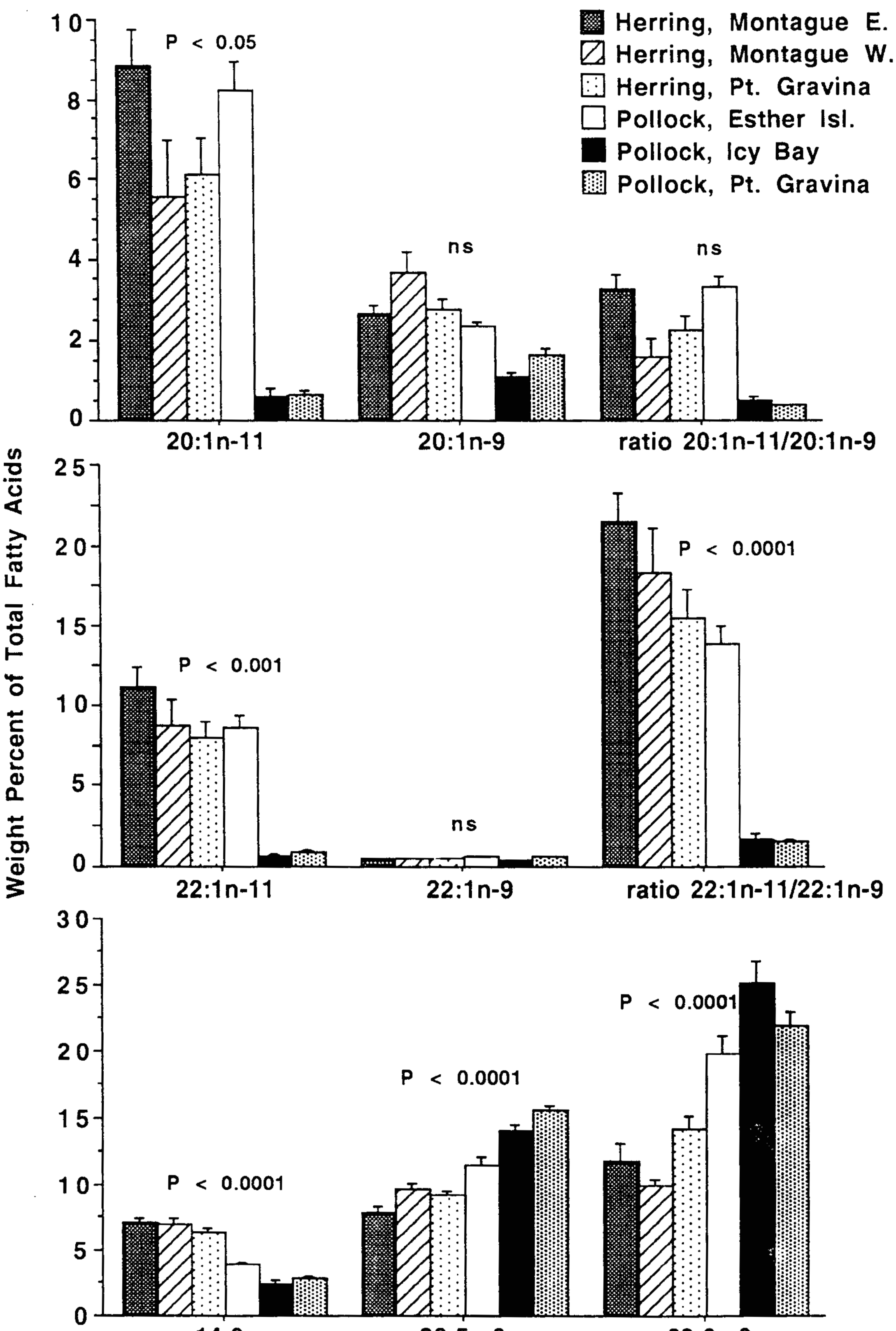

Figure 11. Variation in selected fatty acids and important isomer ratios (mean ± SEM) in herring and pollock as a function of area collected within Prince William Sound. P values represent significant differences found between herring and pollock, with locations combined.

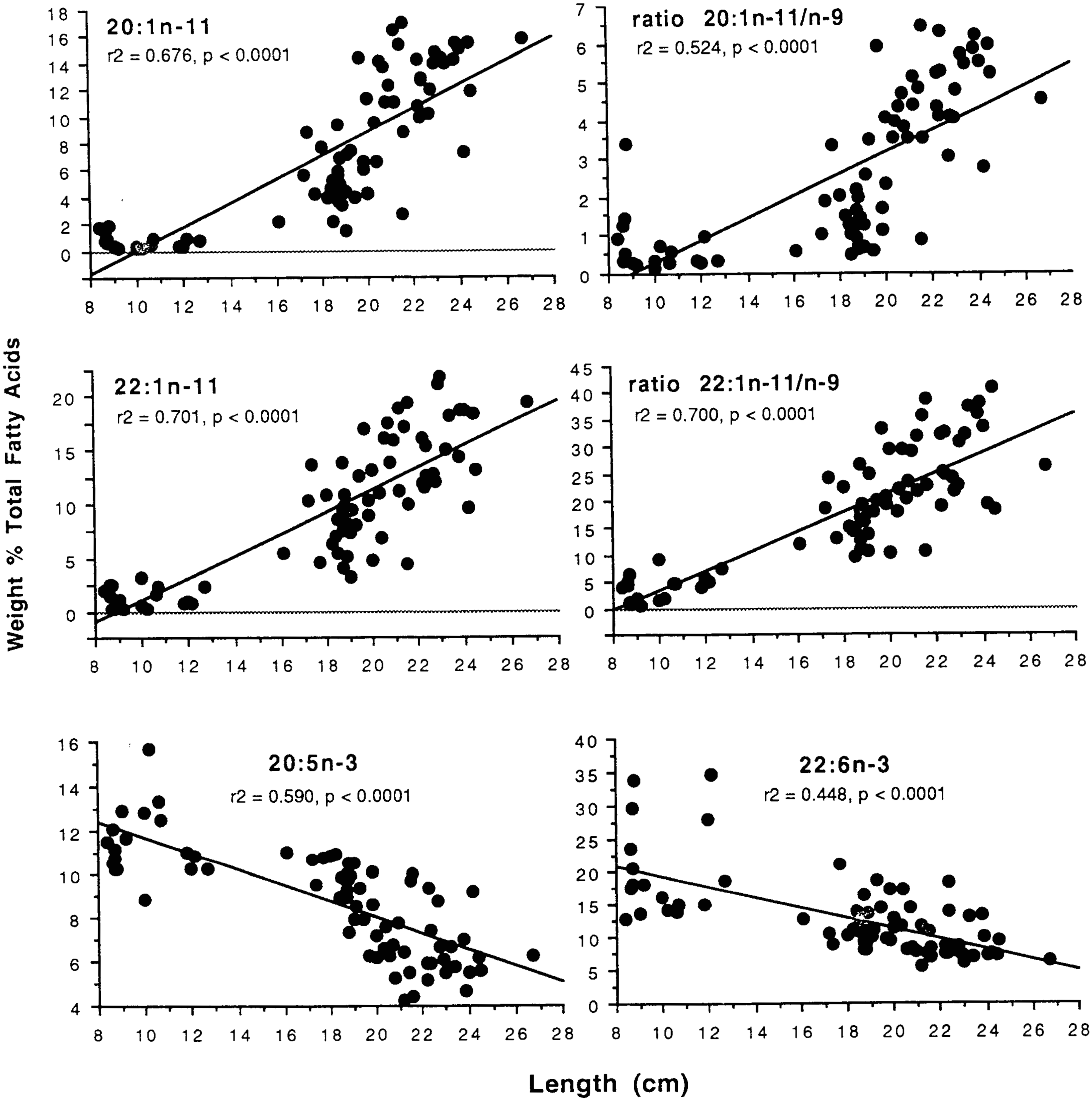

Figure 12. Variation of selected fatty acids and important isomers in herring from Prince William Sound as a function of body length.

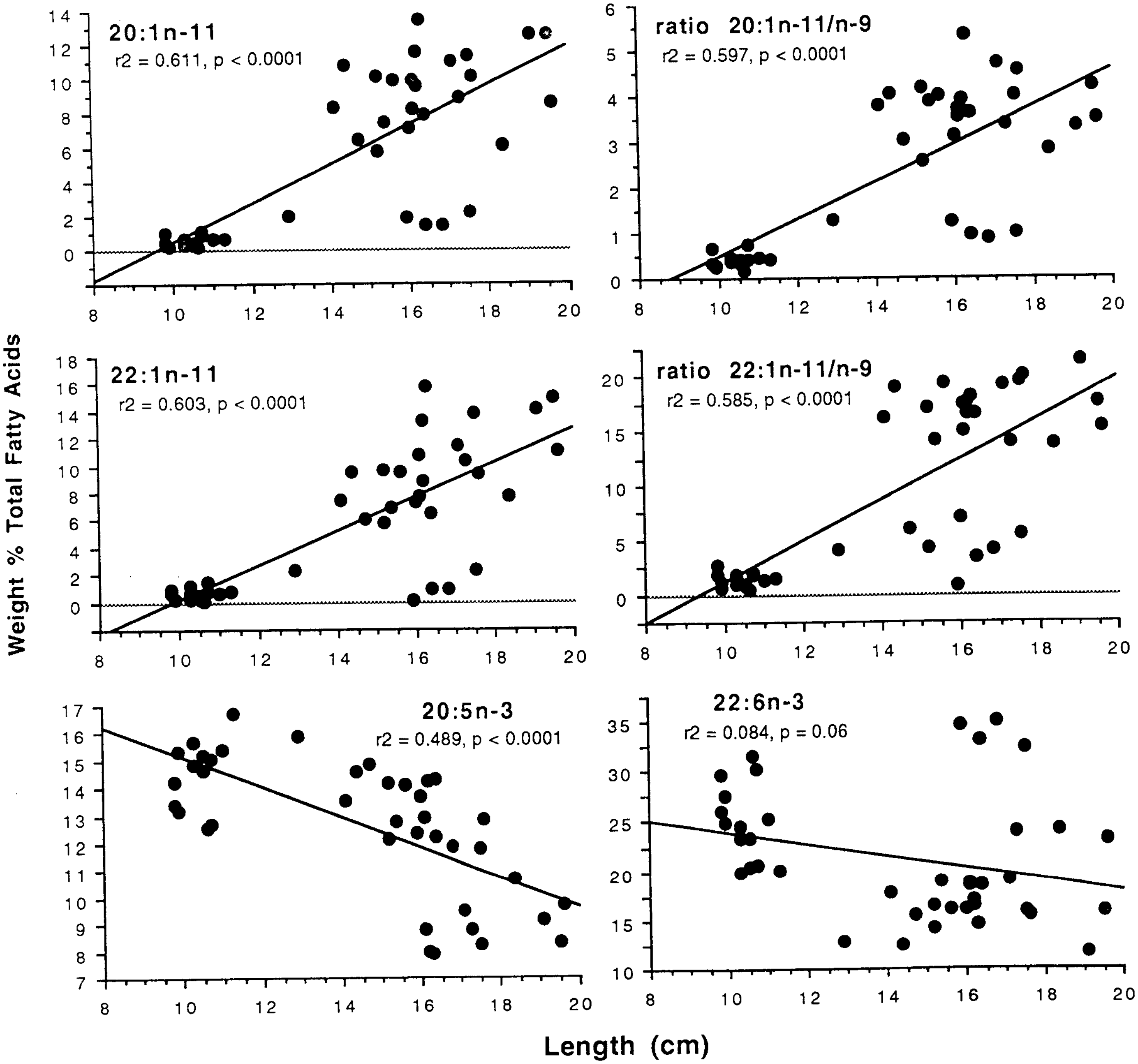

Figure 13. Variation of selected fatty acids and important isomers in pollock from Prince William Sound as a function of body length.

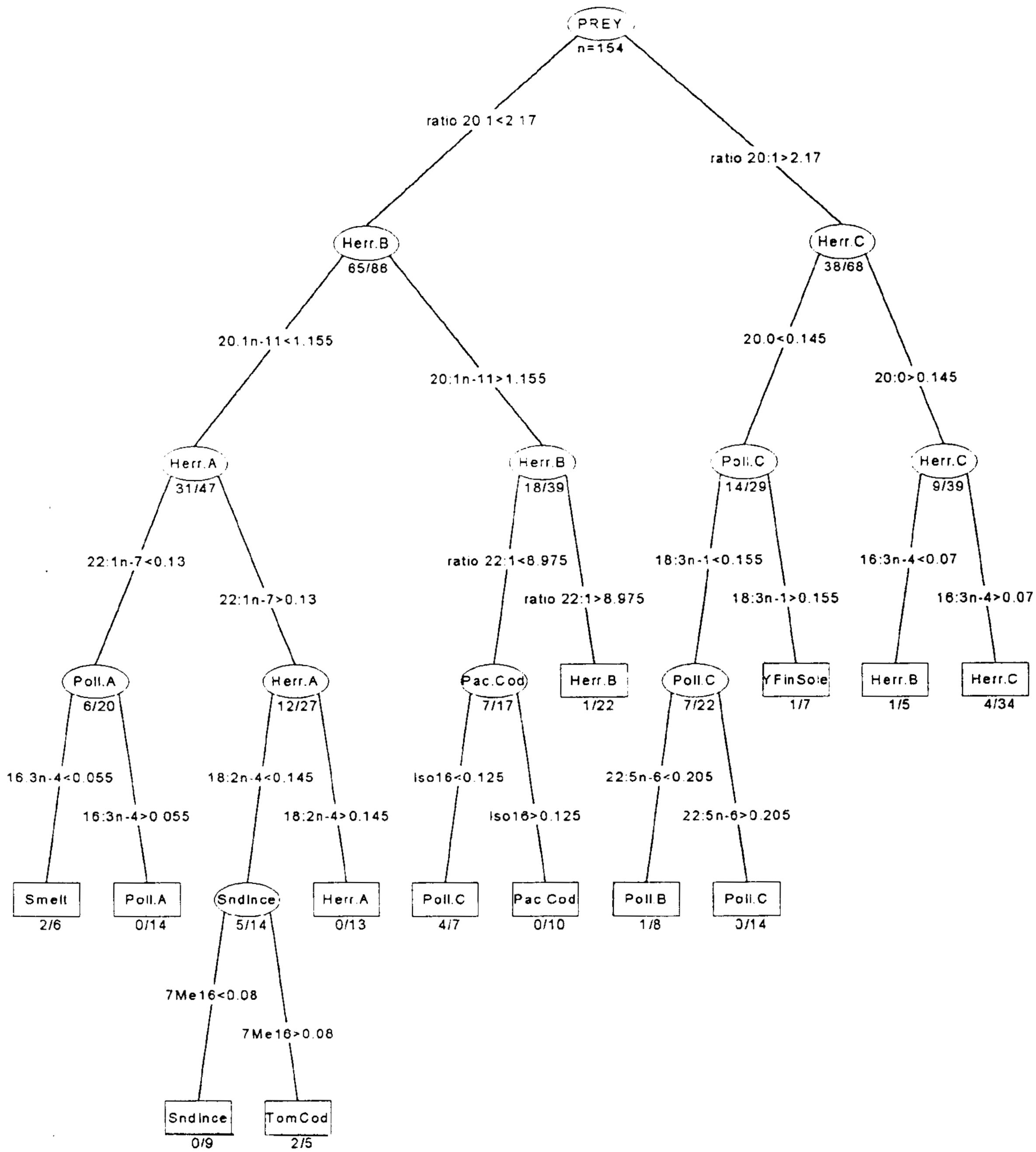

Figure 14. Classification tree of prey collected in PWS across species, but including divisions of 3 size classes within each herring (A, 8-14cm, B, 14-20cm, C, 20-28cm and pollock (A, 8-12cm, B, 12-16cm, C, 16-20cm). See Fig. 4 legend for explanation of tree. Species with sample sizes < 4 were excluded from CART analysis. Total misclassification rate was 15 out of 154.

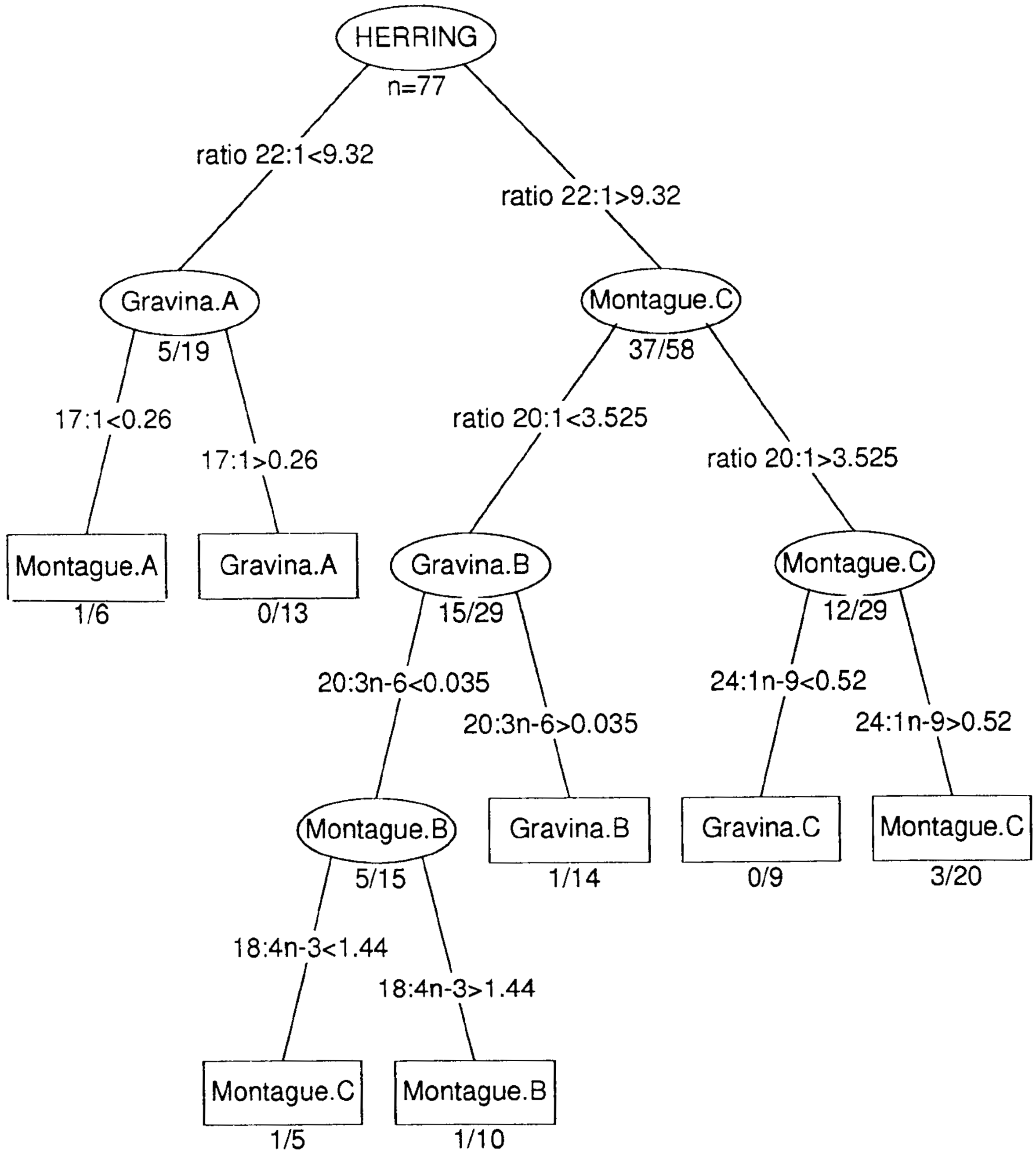

Figure 15. Classification tree of herring collected in PWS across divisions of 3 size classes (A, 8-14cm, B, 14-20cm, C, 20-28cm) and by location. See Fig. 4 legend for explanation of tree. Total misclassification rate was 7 out of 77.

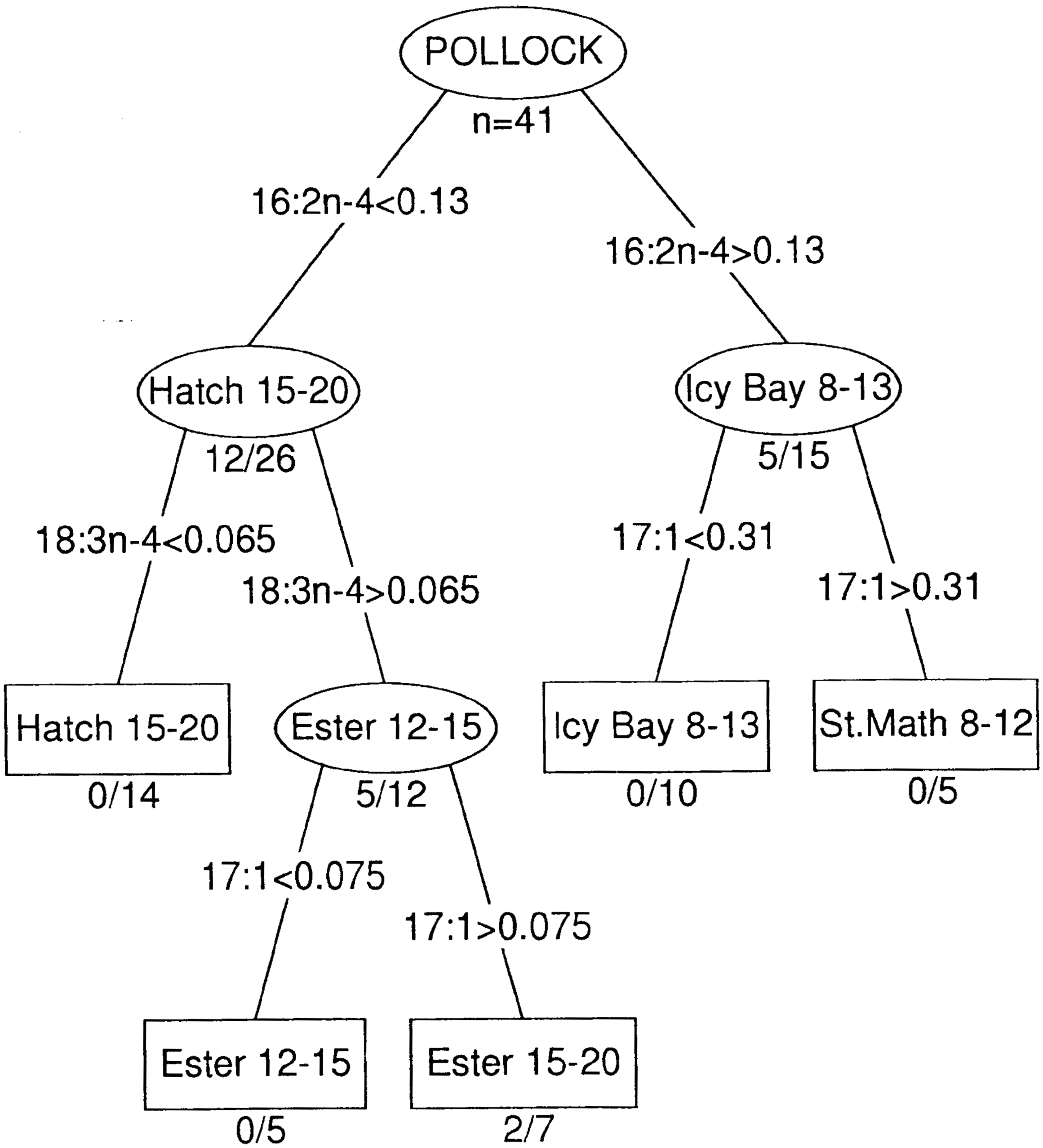

Figure 16. Classification tree of pollock collected in PWS across divisions of 3 size pollock (A, 8-12cm, B, 12-16cm, C, 16-20cm) and by location. See Fig. 4 legend for explanation of tree. Total misclassification rate was 2 out of 41.

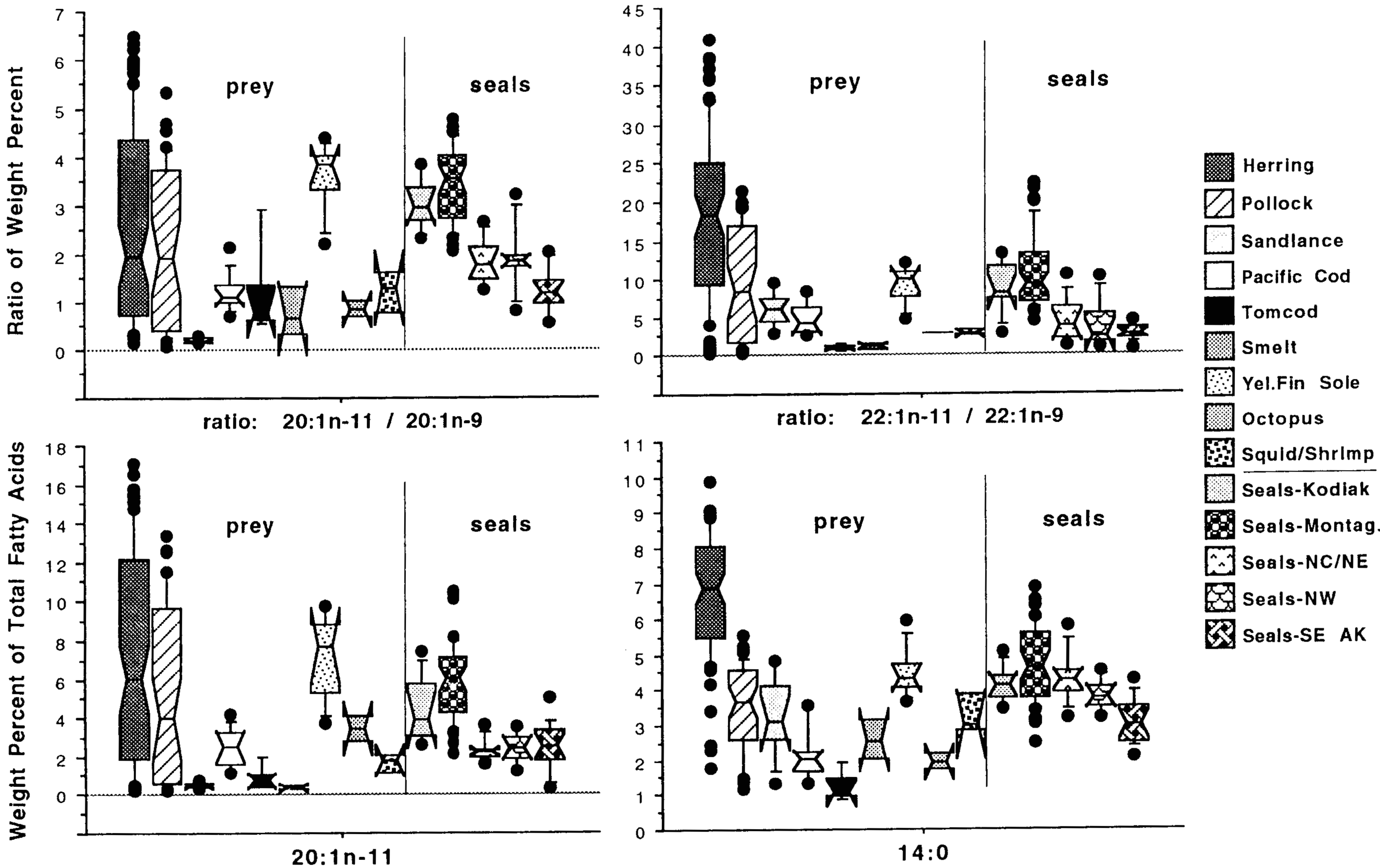

Figure 17. Box plots of selected fatty acids and important isomer ratios in prey collected in PWS in comparison to that found in blubber of harbor seals from areas in PWS and the Gulf of Alaska (Kodiak Island and Southeast Alaska). The notched ares of each box is the 95% confidence interval on the mean. See Tables 1 and 2 for sample sizes.