Exxon Valdez Oil Spill
Restoration Project Annual Report

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

Restoration Project 97064
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.

Kathryn J. Frost, Lloyd F. Lowry, and Jay M. Ver Hoef
Alaska Department of Fish and Game
Division of Wildlife Conservation
1300 College Road
Fairbanks, Alaska, USA 99701

Sara J. Iverson
Department of Biology
Dalhousie University
Halifax, Nova Scotia, Canada B3H 4J1

Tracey Gotthardt
Environment and Natural Resources Institute
University of Alaska Anchorage
707 A Street
Anchorage, Alaska, USA 99501

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Restoration Study Number 97064
Annual Report

Study History: Restoration Project 97064 continues the study effort conducted 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. 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: 1994 Annual Report, 1995 Annual Report, 1996 Annual Report , and 1997 Annual Report . Fatty acid studies funded under Restoration Project 94320-F (Trophic Interactions of Harbor Seals in Prince William Sound) were included in the 1994 annual report for 94064. Fatty acid studies were continued under 95064, 96064, and 97064.

Abstract: Harbor seal counts were 28% lower in 1997 than in 1990. To investigate whether food might be causing the decline, we sampled 50 seals in 1997 and attached satellite-tags to 12 pups. Movements of pups were similar to non-pups, with most relocations near the tagging site. Two adult females tagged in fall 1996 moved very little. Six juveniles made trips to Cook Inlet, Middleton Island, and the Copper River delta. Before 1995, only 2 of 30 tagged seals traveled to the Copper River delta. During 1995-1997, 8 of 19 spent time there. This is consistent with fatty acid analysis indicating that seal diets changed in 1995. Fatty acid analysis indicated that adult diets differed from subadults, especially for seals less than one year. During 1997, young PWS seals were in very good condition. Body fat was 43% in pups and 23% in yearlings. Annual, geographic, and size differences were also apparent in prey fatty acid composition. Seals from southcentral PWS made relatively shallow dives (<150 m) of short duration (<4 min). Adult females displayed strong site fidelity, seldom traveled, and made relatively short and shallow dives. Subadults traveled greater distances within and outside PWS, made deeper and longer dives, and utilized a greater variety of depths when diving.

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

Project Data: The following types of data have been collected by this project: aerial survey count data for 1989-1997, morphometric measurements of all seals that have been caught and handled, location and dive data for 63 seals that have been satellite tagged since 1992, results of disease assays conducted on harbor seal blood serum, and results of fatty acid signature analysis. All data exist as computer databases, either as FoxPro, Excel, or text files. All aerial survey, morphometric, location, dive behavior, and disease data are maintained by the principal investigator, Kathryn J. Frost, at the Alaska Department of Fish and Game, Division of Wildlife, 1300 College Road, Fairbanks, AK 99701-6009. E-mail: kfrost@fishgame.state.ak.us. Phone

(907) 459-7214. Fax (907) 452-6410. Fatty acids data are maintained by Dr. Sara Iverson at Dalhousie University, Department of Biology, Halifax, Nova Scotia B3H4J1. E-mail: siverson@is.dal.ca. Phone (902) 494-2566. Fax (902) 494-3736. Aerial survey data are available in annual reports of this project. Interested parties should contact the principal investigator about the availability of other data.

Citation:

Frost, K.J., L.F. Lowry, J.M. Ver Hoef , S.J. Iverson, and T. Gotthardt. 1998. Monitoring, habitat use, and trophic interactions of harbor seals in Prince William Sound, Alaska, *Exxon Valdez* Oil Spill Restoration Project Annual Report (Restoration Project 97064), Alaska Department of Fish and Game, Division of Wildlife Conservation, Fairbanks, Alaska.

TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

LIST OF TABLES

Page

CHAPTER 1

CHAPTER 2

CHAPTER 3

CHAPTER 4

LIST OF TABLES--Continued

LIST OF FIGURES

Page

CHAPTER 1

CHAPTER 2

CHAPTER 3

LIST OF FIGURES—Continued

LIST OF FIGURES--Continued

LIST OF FIGURES--Continued

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 were of particular concern since the counts of harbor seals along a trend count route in PWS had declined by over 40% from 1984 to 1988, and similar declines were occurring 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. 97064 from October 1996 through September 1997, and some preliminary results from October 1997 through March 1998 under 98064. The report has been prepared as four chapters presenting: a) analysis of trend count surveys during 1990-1997, b) movements of satellite tagged seals, c) foraging ecology as indicated by fatty acid analysis, and d) diving behavior of adult female and subadult seals.

The objectives for 97064 were modified somewhat from the objectives originally presented in the 3-year proposal submitted to the EVOS Trustee Council in 1995. It became clear from sensitivity analyses and simulations developed as part of the harbor seal population model that survival of age classes 0-4 has a large impact on the dynamics of the harbor seal population. The population would be far more sensitive to changes in survival of these age classes than to changes in adult survival. We also thought it likely that younger seals would be more sensitive to changes in food availability.

Initially, it was not possible to instrument small, subadult seals with satellite-linked depth recorders (SDRs) because the tags were too large. However, developments in satellite tag design meant that reliable 0.25-watt tags, small enough to be carried by pups, were available by summer 1997. With the newly acquired capability to monitor the movements and diving behavior of small seals, we changed the focus of Study 97064 to emphasize pups and juveniles. In lieu of instrumenting more adults during 1997, we attached small satellite tags to 12 newly-weaned pups. We also caught and sampled more yearlings and other subadults than in previous years.

These proposed modifications will provide us with a more well-rounded picture of what harbor seals in PWS are doing. It is clear from the tagging studies conducted to date that movement patterns of subadults and adults are different, and that subadults are more likely to range over a wider area. Since pups are thought to be an especially vulnerable age class, and also less flexible in the range of prey they can consume, it will be extremely valuable to obtain information on their movements and diving behavior.

In 1997, aerial surveys were flown during the molting period at 25 trend count haulout sites that have been monitored since 1984. The unadjusted mean count (751) was the second lowest since 1990. 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. When Poisson regression was used to adjust counts to a standardized set of survey conditions, results showed a highly significant decline of 4.6% per year. Adjusted molting period counts for 1997 were 28% lower than counts in 1990 ($p=0.001$). Overall, molt period counts have

declined by 63% since the first trend count surveys were conducted in the early 1980s. These results show that the long-term decline has not ended.

Time of day was the most significant factor affecting the counts of seals during aerial surveys, followed by date, and time of count relative to low tide. Tide height was not significant. The model predicted that counts would have been highest in the period 2-4 hrs before midday, 1.5 hr before to 1.5 hr after low tide, and on the earliest survey dates in mid-August.

It is essential to continue to monitor the trend in abundance of PWS harbor seals, and to continue to develop better statistical methods for analyzing the trend count data. While the existing approach to adjusting counts has greatly improved our ability to detect trend, some problems still exist with the calculation of sample variance and therefore our ability to statistically evaluate trend results. In the future, we plan to conduct a reanalysis of trend count data using hierarchical Bayes models that relate observed seal count to covariates.

In this report we summarize behavior and movements of eight seals tagged with SDRs in fall 1996, and present preliminary results of seal captures and pup tagging done in summer 1997. Seven of the eight SDRs deployed in September transmitted data for 133-274 days. The prototype 0.25-watt unit transmitted for 89 days. SDRs attached to two adult female seals were not duty cycled, and provided locations on 71%-88% of the days seals were tracked with 3.0-3.6 locations per day. One adult female stayed near Port Chalmers where it was tagged for the entire 257 day tracking period. The other left PWS immediately and spent October through mid May near the Copper River delta, moved back into PWS, was in the Icy Bay (PWS) area until mid-June, then returned to Port Chalmers, near where it had been tagged. Duty-cycled SDRs attached to five juvenile seals provided locations on 39%-52% of the days seals were tracked with 0.8-1.3 locations per day. All five of the tagged juvenile seals moved considerably during the tracking period. One moved to Cook Inlet in November and stayed there all winter, three others spent time in the Copper river delta, and one traveled between PWS and Middleton Island. Only two of the five tagged juvenile seals were in PWS at the end of the tracking period. The tagged pup moved extensively, traveling to the GOA west of Middleton, the Copper River delta, east as far as Cape Suckling, and eventually to Johnstone Bay on the Kenai Peninsula.

Over the four years of this study there appears to have been a change in the feeding locations of seals during winter-spring. Prior to fall 1995, only 2 of 30 tagged seals had gone to the Copper River delta. Since then, 8 of 14 adult female and juvenile seals tagged in fall 1995 and 1996 spent a considerable amount of time at the Copper River delta, especially during March-June. It is clear from our tagging studies that some harbor seals in PWS move considerable distances to feed during winter months. The distance from southcentral PWS, where most seals were tagged, to the GOA (either near Middleton Island or the Copper River delta) is more than 100 km. This is greater movement than has been reported for harbor seals in most other studies.

Fifty seals were captured, sampled, and tagged in 1997, including 19 pups, 7 yearlings and 24 older than yearlings. Twelve newly-weaned pups were instrumented with small 0.25-watt SDRs. Four of these were still transmitting in March 1998. The duration of tracking of these individuals will be in excess of 250 days. Locations have been received on 24%-62% of the days transmitters were operational, with an average of 0.3-1.2 locations received per day. Two pups tagged prior to 1997 made numerous relatively long trips. In contrast, the 12 pups tagged in 1997 did not show any extraordinary movements. Most relocations were near the locations where seals were captured, with some movements to College Fiord, Danger Island, eastern PWS, and the Gulf of Alaska east of Middleton Island.

Fat content has been determined for 792 individual prey in 12 taxa. The fat content of most species averaged 3% or less. Herring had the highest fat content of any species analyzed (7.3%), but this ranged widely (0.5 - 19.1%). Flatfish species (other than yellowfin sole) and pink salmon smolt had the lowest fat contents at generally less than 1%. Within species, fat content appeared to vary mostly with season, but possibly also size. Herring was highest in fat in the fall and lower in fat in both spring and summer. In contrast, pollock appeared slightly higher in fat in spring than in summer or fall. Many prey from northwestern PWS were consistently high in fat content regardless of season or size class.

Fatty acid signatures were determined for 792 individual prey from PWS, representing 17 taxa (capelin, chum salmon, flathead sole, rex sole, yellowfin sole, unidentified flatfish, herring, octopus, Pacific cod, pink salmon, pollock, rainbow smelt, rockfish, sandlance, shrimp, squid, and tomcod). Species were clearly distinguishable by their fatty acid signatures with an average of 95% accuracy. Groups of species, such as flatfish and salmon, were also predictable. Fatty acid signatures of prey such as pollock, capelin and herring also differed by size class and location, with season having little effect.

Blubber from 296 Alaska harbor seals has now been analyzed for fatty acids. Greater than 99% of all PWS animals were correctly separated from other GOA seals. When the major areas of the GOA and PWS were divided into specific finer-scale locations within these areas, individuals continued to be classified with greater than 90% accuracy. Across the major locations of GOA and PWS, adults generally differed from older subadults in only minor and mostly non-significant ways, while highly significant differences were found with location for every component tested. Adults differed most from the youngest, smallest animals, namely the half-year-olds, yearlings and < 40 kg subadults. In a similar analysis comparing males versus females, most differences were attributable to major location with fewer differences between sexes, although in specific regions differences between males and females were apparent within the major age classes.

Fatty acid signatures in blubber of seals sampled since 1994 indicate that diets have changed over the four years of the study. Evidence suggested that diets in the years 1996 and 1997 differed most from 1994 and 1995. The pronounced difference in diet among years is consistent with results from satellite tagged seals, which indicated that more seals fed outside of PWS, particularly in the Copper River delta, in 1996 and 1997 than in the previous two years.

During 1997, preliminary modeling began to use fatty acids for estimating diet composition. This requires the development of a statistical model which uses prey species signatures to compute the most-likely mixture of signatures which would "match" the signature of the seal. In our initial modeling we performed analyses on all fatty acids, and based only on dietary fatty acids. Both analyses indicated that herring were the major prey in southcentral PWS. Depending on the type of model analysis, either Pacific cod or squid was the next most important prey. In our ongoing research we will be looking at techniques and modifications to assess and improve the fits of the signatures to estimated diets.

Body composition was determined for 25 seals captured in June 1997. Newly weaned pups averaged 32 kg body mass and were 43% body fat. When compared to harbor seal pups at Sable Island, Nova Scotia, fat content was similar but body mass averaged almost 7 kg greater. PWS yearlings averaged 38 kg, and 23% body fat. This was almost double the fat content of Sable Island yearlings.

University of Alaska graduate student Tracey Gotthardt is using data collected by this project, as well as by the EVOS-funded APEX project, as the basis for her Master of Science thesis entitled "Harbor Seal Foraging Ecology in Prince William Sound." A draft of her thesis chapter analyzing the diving behavior of 14 seals from southcentral PWS is included as part of this annual report. Results indicate that the movements and diving behavior of individual seals varied widely, but, overall, seals from the southcentral region of PWS made relatively shallow dives (less than 150 m) of short duration (less than 4 min). Adult female seals displayed strong fidelity to their haulout sites, seldom traveled, and their diving behavior was characterized by relatively short and shallow dives (20-40 m). Five of the seven adult females not only stayed within the boundaries of PWS, but they seldom traveled further than 25 km from the area where they were tagged. Subadults tended to travel greater distances both within and outside of PWS, made deeper and longer dives, and overall, utilized a greater variety of depths when diving. Only one subadult remained in PWS for the full duration of its tagging period.

Adult seals that never left the Port Chalmers area consistently had maximum dives of 28-40 m, which reflects the bottom depth for that area. Adult females that traveled had considerably more variation in their daily maximum dives, and their deepest dives were made outside of PWS. Subadult seals had more variability in their maximum dive depths, and made deeper dives, ranging from 124-360 m. Six subadults had maximum dive depths of 232 m or deeper. Unlike the two adult female seals which dove the deepest outside of PWS, 5 of 7 subadults made their deepest dives while foraging at various geographic locations within PWS. Overall, it appears that harbor seals are diving the deepest and making the most dives during the winter. At the same time, they are also making the longest dives. This is probably in relation to a reduced prey base as fish move out of PWS to overwinter in the Gulf of Alaska, or because seals are feeding on deep overwintering schools of herring.

CHAPTER ONE

MONITORING THE TREND OF HARBOR SEALS IN PRINCE WILLIAM SOUND, ALASKA, AFTER THE *EXXON VALDEZ* OIL SPILL

OBJECTIVE 1

Monitor the abundance and trends of harbor seals at trend count sites in oiled and unoiled areas of PWS to determine whether the PWS harbor seal population has declined, stabilized, or increased since the EVOS.

OBJECTIVE 2

Recommend a schedule for continued aerial survey monitoring based on observed trend and statistical characteristics of survey data.

OBJECTIVE 9

Provide information to subsistence hunters so they can make informed decisions about the appropriate level of harvest for harbor seals.

This report to be cited as:

Frost, K. F., L. F. Lowry, and J. M. Ver Hoef. 1998. Monitoring the trend of harbor seals in Prince William Sound, Alaska, after the Exxon Valdez oil spill. Pages 1-19 *in* Monitoring, habitat use, and trophic interactions if harbor seals in Prince William Sound, Alaska. Annual Report to the *Exxon Valdez* Oil Spill Trustee Council. Restoration Study 97064. Alaska Department of Fish and Game, Division of Wildlife Conservation, Fairbanks, AK.

MONITORING THE TREND OF HARBOR SEALS IN PRINCE WILLIAM SOUND, ALASKA, AFTER THE *EXXON VALDEZ* OIL SPILL

Kathryn J. Frost, Lloyd F. Lowry, Jay M. Ver Hoef
Alaska Department of Fish and Game
1300 College Road
Fairbanks, Alaska 99701 U.S.A.

ABSTRACT

We used aerial counts to monitor the trend in numbers of harbor seals, *Phoca vitulina richardsi*, in Prince William Sound, Alaska, following the 1989 *Exxon Valdez* oil spill. Repetitive counts were made at 25 haulout sites during the annual molt period each year from 1990 through 1997. A generalized linear model indicated that time of day, date, and time relative to low tide significantly affected seal counts. When Poisson regression was used to adjust counts to a standardized set of survey conditions, results showed a highly significant decline of 4.6% per year. Unadjusted counts indicated a slight, but not statistically significant, decline in the number of seals. The number of harbor seals on the trend count route in eastern and central PWS has been declining since at least 1984 with an overall population reduction of 63% through 1997. We conclude that harbor seals in PWS have not yet recovered from the oil spill.

Programs to monitor long-term changes in animal population sizes should account for factors that can cause short-term variations in indices of abundance. The inclusion of such factors as covariates in models can improve the accuracy of monitoring programs.

Key words: aerial surveys, *Exxon Valdez* oil spill, generalized linear model, harbor seal, *Phoca vitulina richardsi*, Poisson regression, population monitoring, Prince William Sound, trend analysis

NOTE: This chapter has been submitted as a manuscript to the journal Marine Mammal Science, and has been provisionally accepted.

INTRODUCTION

Monitoring programs to track long-term changes in population size are increasingly important in applied ecological studies. While indices of abundance have long been used in classical wildlife management, they have assumed additional importance in recent years as a means of measuring anthropogenic impacts on the natural world, and the recovery, or lack thereof, from such impacts. Along with the realization of the importance of monitoring and environmental assessment programs has come increased attention to the design of such programs (Eberhardt and Thomas 1991, Taylor and Gerrodette 1993, Link et al. 1994) and their analysis (Mapstone 1995, Thomas and Martin 1996, Craig *et al.* 1997).

Harbor seals are one of the most common marine mammal species in Prince William Sound (PWS), Alaska, and adjacent parts of the Gulf of Alaska. PWS has over 4,800 km of coastline, consisting of many fiords, bays, islands, and offshore rocks. The exact number of harbor seals inhabiting the region is unknown, but is at least several thousand (T. R. Loughlin, unpublished report, National Marine Mammal Laboratory, NMFS, Seattle, WA.). Between 1984 and 1988 the number of seals counted at haulout sites in eastern and central PWS declined by about 40% (Frost et al. 1994a).

On 24 March 1989, the *T/V Exxon Valdez* ran aground on Bligh Reef in northeastern PWS, spilling approximately 40 million liters of crude oil (Morris and Loughlin 1994). Studies conducted as part of a "Natural Resources Damage Assessment" program documented a substantial impact of the spill on harbor seals (Frost *et al.* 1994a & b, Lowry *et al.* 1994, Spraker *et al.* 1994). Approximately 300 seals were estimated to have died due to the spill, and pup production in 1989 was about 26% lower than normal (Frost *et al.* 1994a). Subsequent to the oil spill as part of damage assessment and restoration science studies programs, monitoring of the harbor seal population was continued by flying aerial surveys during 1990-1997.

Many studies have demonstrated effects of time of day, date, and tide on the hauling out behavior of harbor seals (Schneider and Payne 1983, Stewart 1984, Harvey 1987, Pauli and Terhune 1987, Yochem *et al.* 1987, Thompson and Harwood 1990, Moss 1992). The data to describe those behavioral patterns has usually come from continuous or repetitive visual observations of seal haulouts, or from telemetry studies. Information derived from those studies has been used in the design of harbor seal surveys, to the extent that survey programs are generally designed to occur on dates and at times when the greatest number of seals are expected to be out of the water and available for counting (Pitcher 1990, Harvey *et al.* 1990, Olesiuk *et al.* 1990, Huber 1995). However, once a "survey window" has been established counts have usually been treated as replicates during analyses, and the possible effects of other factors on annual abundance estimates have been ignored.

This paper presents an analysis of aerial survey counts of harbor seals in PWS. The objectives are to: 1) describe how covariates affected counts of harbor seals during surveys; 2) use the covariates to adjust haulout counts; and 3) determine whether or not significant population trends have occurred.

METHODS

Aerial Surveys

We conducted aerial surveys along a trend count route that covered 25 harbor seal haulout sites in eastern and central PWS (Figure 1). The route included 7 sites that were substantially affected by the *Exxon Valdez* oil spill and 18 unoiled sites that were outside of the primary affected area (Frost *et al.* 1994a). Surveys were flown during the molting period (August-September) in 1984 and 1988-1997.

Visual counts of seals were conducted from a single-engine fixed-wing aircraft (Cessna 185) at altitudes of 200-300 m, usually with the aid of 7-power binoculars. Counts were usually conducted from two hours before low tide to two hours after low tide. A survey normally included counts at all 25 sites, but occasionally some sites could not be counted because of poor weather or a rapidly rising tide. For each survey the date, time and height of low tide, and time of sunrise and sunset were recorded. Each site was circled until the observer was confident that an accurate count had been made, and the time of the count was recorded. For larger groups of seals (generally those of 40 or more) color photographs were taken using a hand-held 35-mm camera, and seals were counted from images projected on a white surface. Each year several survey flights, usually 7-10, were made. The total number of counts for all sites and all years was 2,014.

Factors Affecting when Seals are Hauled Out

We used a generalized linear model (McCullagh and Nelder 1989) with a log link function and a Poisson distribution to analyze the factors that may affect the number of seals hauled out and available to be counted during surveys. The model may be written as: $\Pr(Z_{tij} = z) = \exp(-\lambda_{tij})\lambda_{tij}^{z} / z!$ with $ln(\lambda_{tij}) = \beta'\mathbf{x}_{tij}$ where β is a parameter vector and $\mathbf{x}_{tij}$ is a vector containing information on the state of covariates: year, site, time of tide, height of tide, time of day, date for the j^{th} flight at site i in year t.

To estimate the average count at each site in any given year, we first used a model that contained site, year, and the interaction of site by year. These factors were used in all models. Then, effects for time of day, time of low tide, date, and tide height were entered into the model one at a time. If a factor with m parameters increased 2*log-likelihood by more than a χ^2-distribution with m degrees of freedom at α=0.05, we considered the factor to affect significantly the number of seals counted at haulouts. The factor with the largest 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 not significant. Time of day and time relative to low tide were analyzed as categorical data. Time increments before and after midday were placed in six separate categories and increments before and after low tide in eight categories. We combined some categories within a factor when preliminary analysis indicated that it could be done without changing the fit (again, if combining two categories decreased 2*log-likelihood by more than a χ^2-distribution with one degree of freedom, we considered that the fit was essentially unchanged). Date was a continuous variable entered into the model as a polynomial up to a quadratic power. Dates were numbered beginning 15 August and scaled so that each day was equal to 0.1 to keep parameter estimates from becoming too small (causing problems with significant digits in software packages). To construct the initial model, we used data from all surveys conducted during 1984-1997.

After obtaining a parsimonious model and fitting the parameters as described above, the count data were adjusted to a standardized set of covariates. The adjustment amounts to estimating counts at each site for each year as the expected count under optimal conditions.

Trend Analysis

A linear regression model was fitted to the adjusted yearly count estimates for 1990-1997. This model assumes constant amount of change per year. We also considered a model on the log-scale, where the rate of change is constant. Again, we used a generalized linear model (McCullagh and Nelder 1989) with a log link function and a Poisson distribution to model trend through time. This is also called Poisson regression. Linear and Poisson regressions were also fitted to the unadjusted counts.

This analysis was complicated because we first adjusted yearly counts for each site to a standardized date, time of day, and time relative to low tide, then summed over sites to get a yearly index, and then used the index in a trend regression analysis. Under these circumstances, it is difficult to pass the uncertainty associated with adjusting the counts to the trend analysis. Therefore, we used bootstrap methods (Efron and Tibshirani 1993, Manly 1997) for the whole procedure. We resampled with replacement from the daily flights for each year, with the number of resamples equal to the actual number of flights for that year. After obtaining the bootstrap sample, we used the generalized linear model to re-estimate parameters, adjusted the counts based on the bootstrap parameter estimates, and then did both linear and Poisson regression trend estimation on the bootstrap samples. The trend parameters from the bootstrap appeared symmetrically distributed and centered on the original parameter estimate. Bootstrapping the whole procedure was quite computer intensive and only 200 resampled estimates were obtained, so we used the standard bootstrap method by taking,

estimate $\pm z_{\alpha/2}$(Bootstrap Standard Deviation)

(Manly 1997) and if 0 was contained in the interval, there was little evidence of trend for the stated α-level.

Bootstrapping was used to estimate variance of the unadjusted counts by resampling from the actual count values for each site in each year.

RESULTS

Factors Affecting when Seals are Hauled Out

Three primary factors significantly affected the counts of seals during aerial surveys (Table 1). Time of day was the most significant factor, followed by date, and time of count relative to low tide ($P < 0.001$ for all three). Tide height was not significant.

The model predicted that counts would have been highest in the period 2-4 hrs before midday with 25% more seals expected than 2-4 hrs after midday (Figure 2a). (These calculations are obtained from Table 1 by taking the exponent of the parameter estimates; e.g., exp (-0.2842)=0.753, or 24.7% lower counts in the period 2-4 hours after midday). Relative to low tide, the model predicted the highest counts from 1.5 hr before to 1.5 hr after low tide, with substantially lower counts (about 29% lower) more than 1.5 hrs after low tide (Figure 2b).

With regard to date, the model predicted that the highest counts would have occurred on the earliest survey dates, and that there would be an approximately linear decrease in counts throughout the survey period (Figure 3). Relative to 15 August, counts would have been 22% lower on 31 August and 45% lower on 16 September.

Trends in Seal Counts

Annual changes in unadjusted counts were substantial, ranging from 18% below to 17% above the previous year's counts, and regression analysis indicated no significant trend (Table 2; Figure 4).

Parameter estimates from the generalized linear model (Table 1) were used to correct all unadjusted counts to "optimum" conditions, i.e., 15 August, 4-2 hrs before midday, and 1.0 to 0.5 h before, 0 to 0.5 h after, or 1.0 to 1.5 h after low tide. Annual adjusted counts were 16%-40% higher than unadjusted counts (Table 2). The adjusted counts showed a significant decline in the number of seals in the trend area with linear ($P = 0.008$) and loglinear ($P < 0.001$) regression analysis (Figure 4).

DISCUSSION

Factors Affecting Harbor Seal Counts

We were concerned about the effects that date, time of day, and tide might have had on our aerial survey counts. There are several ways to deal with covariate effects in study design. The best approach that results in the least variability is to design the study so that the potential covariates are constant. For example, for harbor seals we would like to sample on consecutive days from 15-21 August, at 10:00 am, and at slack low tide. However, the fact that weather conditions and the time and height of low tide on a particular date vary from year to year precludes such an approach. Another approach is to randomize sampling relative to the covariate. For example, if survey dates are chosen randomly from within the general molt period the effect of that covariate across years would "cancel out." This would result in more variability than keeping the covariates constant, but it is still design-unbiased, so simple linear or nonlinear trend models could be used to examine trend. However, it would only be possible to use this approach for one covariate such as date, and that would be logistically impractical. The third approach, the one we adopted, is to sample over a one to two week period as weather allows, and then use a model to adjust the counts to a standard set of conditions.

Aerial surveys are commonly used for assessing abundance of harbor seals. Most survey programs try to use a relatively narrow and standard "survey window" (i.e., they attempt to hold covariates constant). Some investigators have used correction factors to adjust counts to account for certain measurable covariate effects. Olesiuk et al. (1990) used a correction factor to adjust for differences in dates of surveys relative to the pupping season. Thompson and Harwood (1990) used time-lapse photography to measure changes in the number of seals hauled out relative to time of day, then used that relationship to standardize aerial counts. Frequently, however, the assumption has been made that some or all potential covariate effects are unimportant and that ignoring them will have little effect on interpretation of results.

Our analysis showed that time of day, date, and time relative to low tide all significantly influenced harbor seal counts in PWS, and an assumption that covariate effects were negligible would have been erroneous. The model predicted counts to be highest before midday, and within 1.5 hours of low tide. The model also predicted that peak counts would occur earlier in August than our surveys historically have begun, and that counts would decrease from the earliest survey date throughout the survey period. Our purpose in developing this model was to understand the factors affecting our counts, not to describe the behavior of harbor seals. Nonetheless, the results are consistent with those of investigators who have conducted behavioral studies of harbor seals in that the proportion of seals hauled out is related to date, time of day, and tide.

Many studies have shown that there are site-specific variations in harbor seal behavior patterns depending on habitat type, effects of disturbance, and other factors (*e.g.*, Harvey 1987, Olesiuk et al. 1990, Moss 1992, Thompson *et al.* 1997), and therefore parameter values for covariate effects could vary greatly in different situations. If annual counts are to be used to monitor harbor seal trend in an area, studies should be done to assess factors that could influence seal behavior at that locale (Thompson *et al.* 1997). Results from those studies can be used for designing an initial survey protocol, as well as to select variables that should be recorded during surveys and used in subsequent data analyses.

Trend in Harbor Seal Numbers in PWS

Our analysis of PWS harbor seal counts showed that adjusting counts to consider variation in survey conditions greatly improved our ability to detect a trend. If we ignored the possible effects of covariates and looked only at unadjusted counts we would have concluded that, although there was a negative slope to the regression line, the trend in seal numbers during 1990-1997 was not significant. When we considered covariates and counts from each year were "normalized" to standard conditions, the decline in seal numbers became highly significant. The adjusted count of seals on the trend route in 1997 was 28% lower than in 1990, and loglinear regression indicated that the population has been declining at an average rate of 4.6% per year. Because the model corrects each individual count for three covariates it is difficult to determine which aspects of survey design biased the interpretation of results from unadjusted counts. A partial explanation can be seen in the effect of date. During 1990-1994, the median dates for our surveys ranged from 27 August to 4 September, while the median dates during 1995-1997 were 21-23 August. Because a lower proportion of seals would be hauled out on later survey dates, counts made in earlier years were biased low therefore masking the declining trend in abundance.

The number of harbor seals on the trend count route in eastern and central PWS has been declining since at least 1984 (Frost *et al.* 1994a). Using the parameter estimates derived in this study to correct the 1984 count data we estimate an adjusted trend route count of 2,523 seals for that year. This indicates an overall population reduction of 63% during the period 1984-1997.

One objective of studies done in PWS subsequent to the *Exxon Valdez* oil spill has been to monitor recovery of injured species. In the case of harbor seals, the *Exxon Valdez* oil spill Trustee Council has determined that recovery will have occurred when the population trend is stable or increasing. Based on this study, we conclude that as of 1997 harbor seals in PWS have not yet recovered from the oil spill.

Significance to Monitoring Studies

Measurement of the trend in abundance of a population is an important tool for wildlife conservation. For example, as noted above, the decision of whether or not harbor seals in PWS have "recovered" from the *Exxon Valdez* oil spill depends entirely on whether or not the population is still declining.

In some cases it may be possible to use survey data to assess population trends without concern for covariate effects, for example where changes are relatively large, data are collected over long periods of time, and study design holds covariates relatively constant. The conclusion that harbor seal numbers on Tugidak Island in the Gulf of Alaska underwent a major decline appears reliable, as counts were made under strict conditions, the decline was large (about 85%), and data were collected over a 12 year period (Pitcher 1990). Confidence in the Tugidak situation is increased by the fact that similar trends were seen in both pupping and molting period counts. Conclusions that harbor seal numbers have increased in southern California (Stewart *et al.* 1988), Oregon (Harvey *et al.* 1990), and Washington (Huber 1995) also are likely to be correct, although in those studies counts were made in a relatively wide range of conditions and consideration of covariates in data analyses would likely improve the assessment of trends.

Where covariates have strong effects that cannot be avoided in study design they must be accounted for in the analysis. For example, Beaufort state and cloud cover have strong effects on counts of harbor porpoise (*Phocoena phocoena*), and therefore Forney *et al.* (1991) used those factors as covariates in their trend analysis. In an analysis of Florida manatee (*Trichechus manatus latirostris*) aerial survey data, Garrott et al. (1995) modeled the effects of survey conditions and air and water temperature on counts. About 50% of the variation in counts was explained by those variables, and when counts were adjusted for covariate effects a significant increase was seen in the number of manatees counted on the east coast of Florida during 1982-1991.

In many situations, analyses of the kind we performed are not possible because 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 allow the evaluation of population trends, and can also provide a way to measure the impacts of human activities or accidents such as the *Exxon Valdez* oil spill.

ACKNOWLEDGMENTS

This study was conducted as part of the *Exxon Valdez* Oil Spill Restoration Program, funded by the *Exxon Valdez* Oil Spill Trustee Council. Funding for harbor seal surveys in PWS in 1992 was provided by the National Marine Fisheries Service, National Marine Mammal Laboratory. Ken Pitcher conceived the idea of harbor seal trend counts in PWS, and Dennis McAllister and Jon Lewis flew some of the earlier surveys. We thank Steve Ranney, the pilot for all of the aerial surveys, for his careful and conscientious support. Rob DeLong assisted with data analyses and presentation. Dean Hughes, Joe Sullivan, Sheila Westfall, Melanie Bosch, Melissa Johnson, and Diana Ground provided administrative support for this project. Grey Pendleton, Tim Gerrodette, Jeff Laake, and an anonymous reviewer provided helpful comments on drafts of the manuscript.

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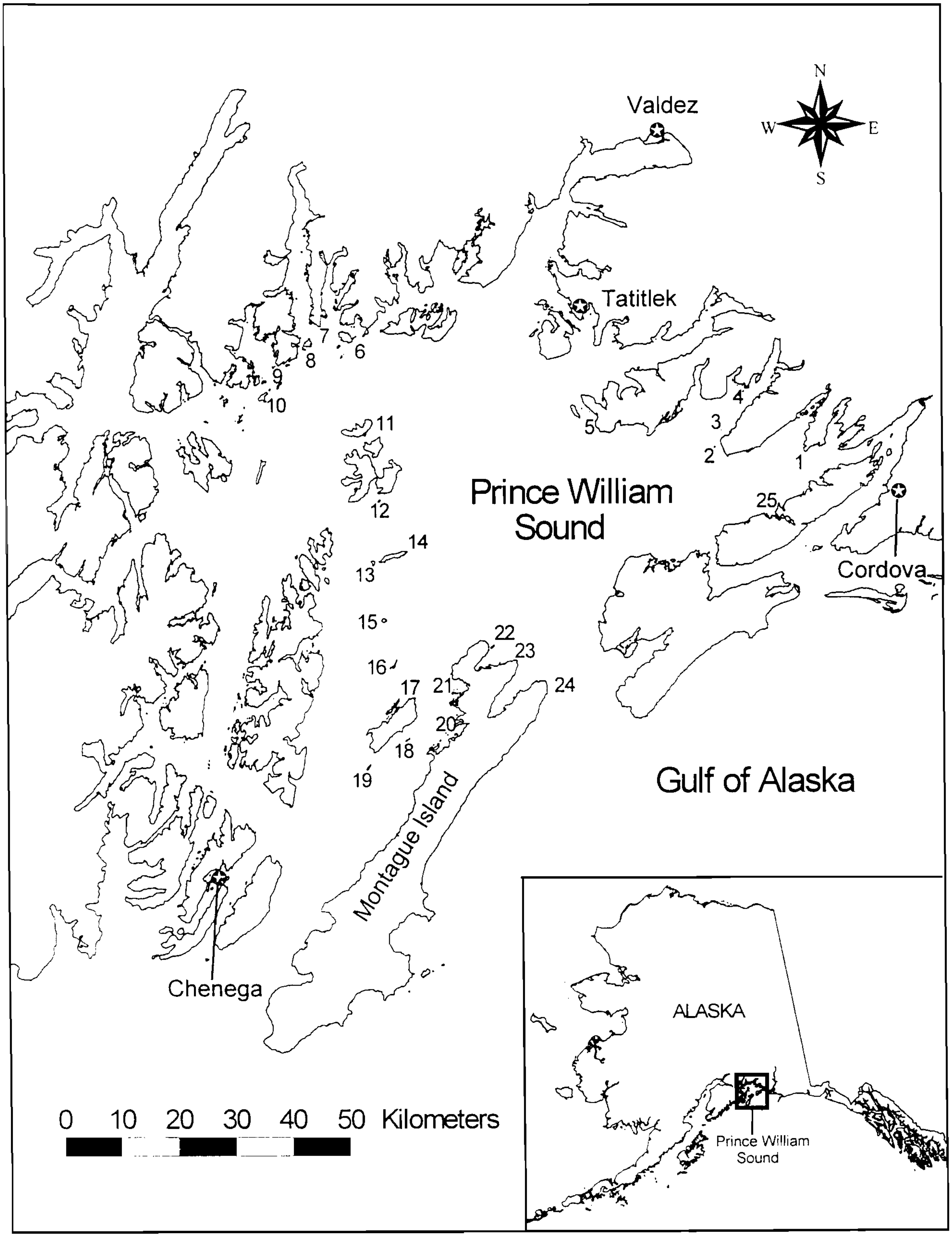
Table 1. Parameter estimates for factors affecting counts of hauled out harbor seals in Prince William Sound.

Factor	Category	Parameter estimate
Time of day	before (midday - 4 hr)	-0.0461
	(midday - 4 hr) to (midday - 2 hr)	-0.0000
	(midday - 2 hr) to (midday)	-0.1984
	(midday) to (midday + 2 hr)	-0.1594
	(midday + 2 hr) to (midday + 4 hr)	-0.2842
	after (midday + 4 hr)	-0.1594
Date	day/10 since August 15	-0.1239
	$(\text{day}/10 \text{ since August } 15)^2$	-0.0192
Time relative to low tide	before (lowtide - 1.5 hours)	-0.1602
	(lowtide - 1.5 hrs) to (lowtide - 1 hr)	-0.0531
	(lowtide - 1 hr) to (lowtide - 0.5 hr)	0.0000
	(lowtide - 0.5 hr) to (lowtide)	-0.0550
	(lowtide) to (lowtide + 0.5 hr)	0.0000
	(lowtide + 0.5 hr) to (lowtide + 1 hr)	-0.0550
	(lowtide + 1 hr) to (lowtide + 1.5 hrs)	0.0000
	after (lowtide + 1.5 hrs)	-0.3417

Table 2. Unadjusted and adjusted mean counts, and regression analyses, for harbor seals trend counts in Prince William Sound, 1990-1997. Adjusted counts were derived using parameter estimates in Table 1. Standard deviations of slope estimates were calculated by bootstrapping.

Year	Unadjusted Count	Adjusted Count
1990	779	1299
1991	920	1215
1992	769	1150
1993	774	1140
1994	740	996
1995	869	1131
1996	808	966
1997	751	935
linear regression		
slope estimate	-5.885	-47.530
standard deviation	4.260	17.939
Pr (H_0: slope=0)	0.167	0.008
loglinear regression		
slope estimate	-0.007	-0.043
standard deviation	0.005	0.011
Pr (H_0: slope=0)	0.170	<0.001

List of Figure Captions



Valdez
N
W
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Tatitlek
Prince William Sound
Cordova
Gulf of Alaska
Montague Island
Chenega
0 10 20 30 40 50 Kilometers
ALASKA
Prince William Sound
1
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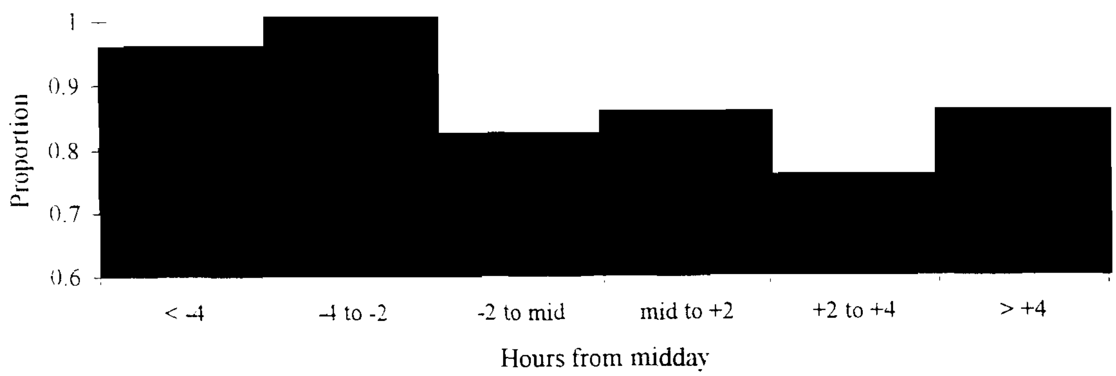
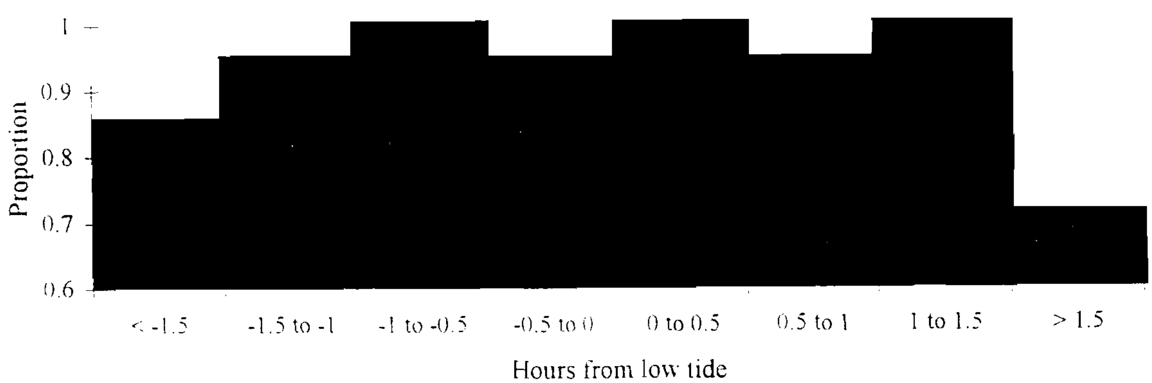
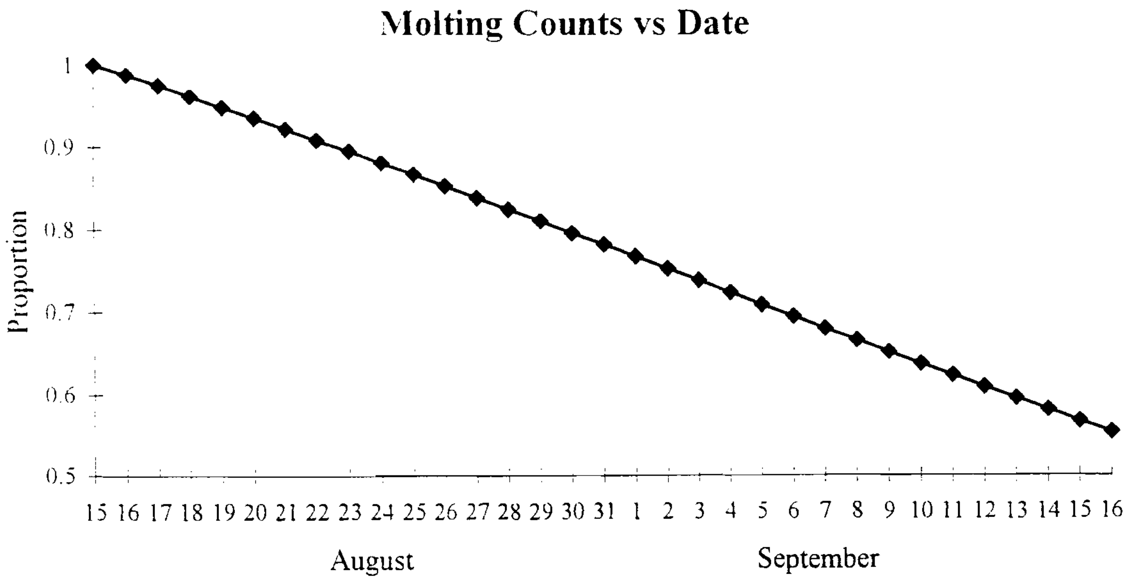
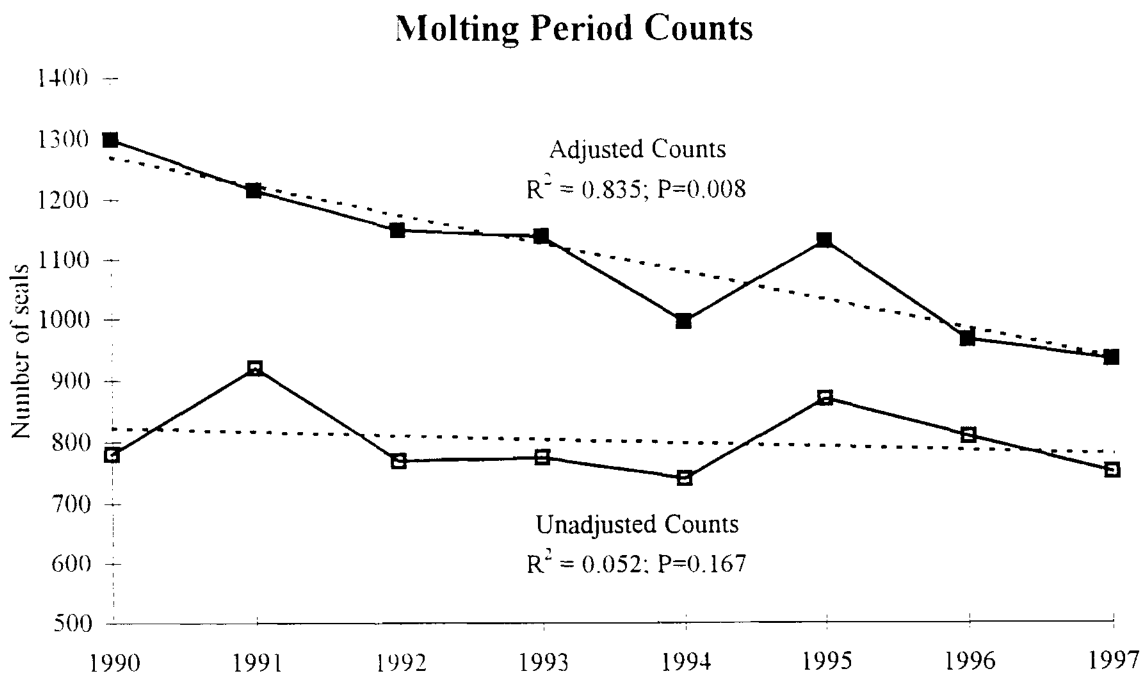
Molting Counts vs Time of Day **A**



Molting Counts vs Time of Low Tide **B**




Molting Counts vs Date
Proportion
1
0.9
0.8
0.7
0.6
0.5
15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
August
September


Molting Period Counts
Adjusted Counts
R² = 0.835; P=0.008
Unadjusted Counts
R² = 0.052; P=0.167
Number of seals
1400
1300
1200
1100
1000
900
800
700
600
500
1990
1991
1992
1993
1994
1995
1996
1997

CHAPTER TWO

TAGGING OF HARBOR SEALS IN PRINCE WILLIAM SOUND WITH SATELLITE-LINKED DEPTH RECORDERS, 1996-1997

Lloyd F. Lowry and Kathryn J. Frost
Alaska Department of Fish and Game
1300 College Road
Fairbanks, AK 99701

OBJECTIVE 8

Determine foraging range and diving behavior of harbor seal pups and juveniles and compare to similar information for other age groups.

This report to be cited as:

Lowry, L. F. and K. J. Frost. 1998. Tagging of harbor seals in Prince William Sound with satellite-linked depth recorders, 1996-1997. Pages 20-37 *in* Monitoring, habitat use, and trophic interactions if harbor seals in Prince William Sound, Alaska. Annual Report to the *Exxon Valdez* Oil Spill Trustee Council. Restoration Study 97064. Alaska Department of Fish and Game, Division of Wildlife Conservation, Fairbanks, AK.

TAGGING OF HARBOR SEALS IN PRINCE WILLIAM SOUND WITH SATELLITE-LINKED DEPTH RECORDERS, 1996-1997

Lloyd F. Lowry and Kathryn J. Frost
Alaska Department of Fish and Game
1300 College Road
Fairbanks, AK 99701

INTRODUCTION

A major component of the EVOS harbor seal Restoration Science Study has been the use of satellite-linked depth recorders (SDRs) to investigate seal movements and behavior. Pilot studies done in 1991 were not very successful (Frost and Lowry 1994), but beginning in 1992 seals were regularly captured and tagged at several locations in Prince William Sound (PWS) (Frost et al. 1995, 1996, 1997). The geographic emphasis of the tagging work has been southcentral PWS, at haulouts in the region between Seal Island and Port Chalmers.

Initially the SDRs available were relatively large, and they were applied to larger, generally adult, seals. As smaller tags became available, emphasis shifted to tagging juveniles. During the period from May 1992 through September 1996, successful tag deployments were made on 51 seals (15 adult females, 12 adult males, 11 juvenile females, 11 juvenile males, 2 pups).

An even smaller SDR became available in 1996, and we attached one to a pup in September. In 1997, the small SDRs were attached to 12 pups.

In this report we summarize behavior and movements of seals tagged with SDRs in fall 1996, and present preliminary results of seal captures and pup tagging done in summer 1997. The former analysis, in combination with previous reports (Frost et al. 1995, 1996, 1997) provides a complete description of results from all tags we have attached to adults and juveniles, by tagging period. We are currently combining all these data for a final analysis in which the sample of tagged seals will be separated by age/sex class. Results of that analysis will be presented in the next annual report and in a manuscript for publication in the peer reviewed literature..

METHODS

Capture and Tagging of Seals

Field work was conducted at locations in southcentral PWS during June-July 1997. Personnel were transported from Whittier to the study sites aboard the vessel *Pacific Star*.

Detailed descriptions of methods used to capture and tag seals have been given in previous reports (Frost et al. 1995, 1996, 1997). The following is an abbreviated description, and readers should consult earlier reports for full details.

Seals were caught by entanglement in nets deployed near their haulouts. Most animals older than pups were sedated with a mixture of ketamine and diazepam administered intramuscularly at standard doses (Geraci et al. 1981). Pups were manually restrained. 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 170), flipper-punch skin samples for genetic analysis (G. O'Corry-Crowe and R. Westlake, Southwest Fisheries Science Center, La Jolla, CA), and blubber biopsies for analyses of fatty acids (S. Iverson, Dalhousie University) and energy content (M. Castellini, University of Alaska Fairbanks, Project 001). Deuterium oxide was administered orally to 30 seals.

SDRs were glued to the mid-dorsal surface of seals using Devcon quick-setting epoxy (Fedak et al. 1984, Stewart et al. 1989). The SDRs were manufactured by Wildlife Computers (Redmond, WA). All units attached in 1997 were type ST-10 (0.25-watt) transmitters measuring 10 cm x 5 cm x 3 cm and weighing 170 g. They were powered by 2 lithium 2/3 A cells and were rated for about 15,000 transmissions.

SDRs stored dive depths, dive durations, and the amount of time spent at depth in six hour blocks (0300-0900 hrs, 0900-1500 hrs, 1500-2100 hrs, and 2100-0300 hrs local time) that were transmitted to the satellite once the six hour period was complete. Dive data for pups tagged in 1997 were accumulated in 10 bins as follows: depths of 4-10m, 11-20m, 21-35m, 36-50m, 51-75m, 76-100m, 101-150m, 151-200 m, 201-250m, and over 250 m; and durations of 0-1 minutes, >1-2 minutes, >2-3 minutes, >3-4 minutes, >4-5 minutes, >5-6 minutes, >6-8 minutes, >8-10 minutes, >10-12 minutes, and greater than 12 minutes. In addition the tags included timeline software (version 3.14), which recorded for each 20 minute segment of the day whether the conductivity switch had been mostly wet or mostly dry.

To conserve battery power, all tags were programmed to transmit only during hours of good satellite coverage (0400-1900 hours local time). Tags were set for a transmission cycle of one day on and one day off. In addition, the number of transmissions sent per day was limited to 100. With such a programming protocol, the tags should have operated over a period of about 300 days if the batteries provided 15,000 transmissions.

Satellite Tag Data Analysis

Detailed descriptions of methods used to compile and analyze satellite tag data have been given in previous reports (Frost et al. 1995, 1996). The following is an abbreviated description, and readers should consult earlier reports for full details.

Data from satellite tagged seals were obtained from Service Argos. Data included a location for the SDR if sufficient signals were received during a satellite pass, or sensor data if only one uplink occurred. 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.

A system was developed for identifying and eliminating erroneous location records based on an error index value (Keating 1994) and the time, distance, and speed between sequential pairs of locations. Location records that did not fit screening parameters were removed from the database. Numbers of location records referred to in this report include only those records that remained after the complete screening process.

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 daily position for each seal based on all records obtained for a 24 hour period, local time. An additional database was created from the all-location database that included only on-land records with location quality greater than zero, and all at-sea records. Average positions were calculated from that database for each haulout bout (i.e., one or more consecutive on-land locations).

RESULTS

Capture and Tagging of Seals

In 1997 we captured and processed 50 seals (Table 1). Of the 50 seals, 19 were pups, 7 were yearlings, and 24 were older than yearlings. We attached 12 SDRs, all to pups, on animals captured at Little Green Island (3), Applegate Rocks (4), Seal Island (2), and Port Chalmers (3).

Satellite-linked Depth Recorder Performance—Fall 1996

The experimental 0.25-watt SDR attached to a pup in fall 1996 transmitted until 23 December (Table 2). It provided locations on 66% of the days it was tracked, with an average of 3.1 locations received per day. It made over 11,000 transmissions.

The other seven tags operated for 164-274 days (mean for those tags 211 days; Table 2). The two large SDRs that were attached to adult female seals were not duty cycled, and provided locations on 71%-88% of the days seals were tracked with 3.0-3.6 locations per day. Duty-cycled SDRs attached to five juvenile seals provided locations on 39%-52% of the days seals were tracked with 0.8-1.3 locations per day.

Performance of Tags Attached to Pups—Summer 1997

Data received through December 1997 from 12 harbor seal pups tagged with SDRs in PWS during summer 1997 have been preliminarily analyzed (Table 3). As of the end of December eight of the tags were no longer transmitting. Those SDRs operated for 28-172 days (average=95 days). The four SDRs that were still operating at the end of December have continued to provide data at least into March 1998. The duration of tracking of those individuals will be in excess of 250 days. Locations have been received on 24%-62% of the days transmitters were operational, with an average of 0.3-1.2 locations received per day.

Movements of Seals Tagged in Fall 1996

The movements of seals tagged in September 1996 are shown in Figure 1 and are summarized in Table 4. One adult female (96-9) stayed near Port Chalmers where it was tagged for the entire 257 day tracking period. The other adult female (96-13) left PWS immediately after it was tagged and spent the period from October through mid May in the vicinity of the Copper River delta. It then moved back into PWS and was in the Icy Bay (PWS) area until mid-June when it returned to Port Chalmers, near where it had been tagged.

All five of the tagged juvenile seals moved considerably during the tracking period. Seal 96-7 left PWS in November and moved around the Kenai Peninsula and into Cook Inlet where it remained until the signals from the tag stopped in early March. Seal 96-10 stayed in PWS until early May when it moved to the Copper River Delta and then to Icy Bay (in the Gulf of Alaska). Seal 96-11 spent most of its time in PWS, but was in the Copper River delta in late February and early March. Seal 96-12 left PWS in mid-November and moved to Patton Bay on the outer coast of Montague Island and then to the Copper River delta. Seal 96-14 was in PWS most of the time, but made a trip to Middleton Island in March. Only two of the five tagged juvenile seals were in PWS at the end of the tracking period.

Although it was tracked for only 89 days, the tagged pup (96-8) moved extensively (Table 2, Figure 2). Two days after it was tagged at Port Chalmers it was located in the Gulf of Alaska west of Middleton Island. It then moved to the Copper River Delta, eastward to Cape Suckling, then back to the Copper River delta. Between October 11 and December 1 it made four trips to sea, each time moving southwestard from the Copper River delta to minimum distances of 60-230 km. It then left the Copper River delta and moved to Johnstone Bay on the Kenai Peninsula where it remained until the last signals were received.

DISCUSSION

Capture and Tagging of Seals

Seal capture operation in PWS during June-July 1997 went very well. Our primary objective was to catch and tag weaned pups. Sizes of pups we handled ranged from 21.2-39.2 kg. Based on the data in Pitcher and Calkins (1979) we expected weaned pups to weigh 20-25 kg, therefore we are confident that the great majority of our sample of pups had been weaned or were ready to be weaned.

Satellite-linked Depth Recorder Performance

We continued to have very good performance from the 0.5 watt SDRs with version 3.10 software that we attached to seals in September 1996. One tag transmitted until February, two until March, one until April, and three until June. The average duration of operation for fall 1996 tags (211 days) was somewhat less than that for tags attached in fall 1995 (231 days; Frost et al. 1997), and longer than for tags attached in fall 1993-1994 (185 days; Frost et al. 1996).

In fall 1995 we attached a prototype 0.25 watt SDR to a subadult seal. That tag performed erratically and was considered a failure (Frost et al. 1997). The 0.25 watt SDR attached in fall 1996 worked much better, giving regular locations over a period of 89 days. In addition that SDR had timeline software, which on preliminary inspection appears to have given accurate records of when the seal was hauled out.

Based on the success of the 0.25 watt tag tested in fall 1996 we decided to use those units on pups tagged in summer 1997. We assumed that the 1996 tag had failed due to low battery power so we made several modifications to the programming to ensure that the batteries would last at least 300 days (see methods). A preliminary analysis shows that this approach was successful, as we obtained a location for each tagged seal about every other day and four of the SDRs were still providing data in March.

Movements and Behavior of Adult and Juvenile Seals

The adult and juvenile seals tagged in fall 1996 showed considerable movements. Only one adult female stayed in PWS during the entire tracking period. Four seals (one adult female and three juvenile males) spent time at the Copper River delta. One of those continued moving eastward to Icy Bay, approximately 320 km from the tagging location. One juvenile female made a trip to Middleton Island. Another juvenile female moved to Chinitna Bay in Cook Inlet, which was the first extensive westward movement (approximately 330 km straight line distance from the tagging location) made by any seal tagged during this study.

Movements of seals tagged in September 1995 and 1996 were different from previous years. Six seals tagged in central PWS in fall 1993 all stayed within the Sound, and only 2 of 8 tagged in southern PWS in fall 1994 spent considerable time offshore the GOA (Frost et al. 1996). In contrast, 5 of 7 seals tagged in fall 1995 and 6 of 7 in fall 1997 (not including the pup) moved out of PWS, going to either Middleton Island (3 animal), the Copper River delta (8 animals), or Cook Inlet (1 animal).

Over the four years of this study there appears to have been a change in the feeding locations of seals during winter-spring. Prior to fall 1995, only 2 of 30 tagged seals had gone to the Copper River delta: a juvenile male tagged in May 1992 was at the delta from May 25-June 5 and June 12-July 18, and a juvenile female tagged in September 1994 was briefly at the delta in October while en route to Yakutat Bay (Frost et al. 1995, 1996). Since then, 8 of 14 adult female and juvenile seals tagged in fall 1995 and 1996 spent a considerable amount of time at the Copper River delta, especially during March-June.

It is clear from these tagging studies that some harbor seals in PWS move considerable distances to feed during winter months. The distance from south-central PWS, where most seals were tagged, to the GOA (either near Middleton Island or the Copper River delta) is more than 100 km. This is greater movement than has been reported for harbor seals in most other studies. Suryan (1995) used VHF radio telemetry to study the use of three haulouts in the northern San Juan Islands, Washington. The greatest recorded movement was 28 km. 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. Working in the Channel Islands off southern California, Stewart and Yochem (1994) found that some subadults moved to other islands or the mainland, while satellite tagged adults mostly stayed near the island where they were tagged.

As indicated previously, we have begun an analysis of all the SDR data from all seals tagged during 1992-1996. We anticipate that a detailed description of the movements and behavior of adult and juvenile seals will be presented in the next annual report of this project and in a manuscript for publication.

Movements of Harbor Seal Pups

The pup tagged in fall 1996 (96-8) showed very different behavior from adult and juvenile seals in that it made numerous trips from the Copper River delta southwestward into the Gulf of Alaska (Figure 2). Prior to 1996 we had tagged one other pup, an animal (95-8) captured at Gravina Island in September 1995 and outfitted with a small 0.5 watt SDR. A detailed examination of location data for this seal (Figure 3) indicates that it too made numerous relatively long trips, in this case four trips from the area where it was captured in eastern PWS to College Fiord in northwestern PWS.

A preliminary analysis of location data for the 12 pups equipped with SDRs in summer 1997 (Figure 4) does not show extraordinary movements. Most relocations were near the locations where seals were captured, with some movements to College Fiord, Danger Island, eastern PWS, and the Gulf of Alaska east of Middleton Island. It should be noted that the dataset from these seals differs from those for 95-8 and 96-8 in several ways: 1) data for 95-8 and 96-8 begin in September when the seals were about four months old while 1997 data begin at the time of weaning in late June-early July; 2) the place of birth is not known for 95-8 and 96-8, but is known for seals tagged in 1997 (i.e., they were almost certainly born very near where they were captured); and 3) because of restrictions put on transmission schedules the location data will be more sparse for the seals tagged in 1997.

ACKNOWLEDGEMENTS

This study was conducted as part of the *Exxon Valdez* Oil Spill Restoration Program, funded by the *Exxon Valdez* oil spill Trustee Council. Many people assisted in the capture, sampling, and tagging of seals. We especially thank Rob DeLong, Jay Ver Hoef, Sara Iverson, Robin Brown, Gay Sheffield, Brian Fadely. Randy Zarnke, Tracey Gotthardt, Jennifer Burns, and Maggie Castellini. The Captain, Glen Hodge, and the crew of the research vessel *Pacific Star* provided excellent logistic support. Dean Hughes, Joe Sullivan, Bill Hauser, Melanie Bosch, Celia Rozen and Diana Ground provided administrative support for this project.

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Table 1. Harbor seals captured, sampled, and tagged during field operations in Prince William Sound, June-July 1997.

Specimen	Location	Date	PTTID	Age	Sex	Wt	SL	AxG	DNA	Vib	Fat	Ultra	Blood	D_20
PWS-1-97	Seal Island	1997-06-27	11038	Pup	F	30.0	99.0	84.0	Y	Y1		Y	Y	Y
PWS-2-97	Seal Island	1997-06-27	11039	Pup	F	34.6	97.0	87.0	Y	Y1	Y	Y	Y	Y
PWS-3-97	Applegate Rcks	1997-06-27	11041	Pup	M	32.0	94.0	87.0	Y	Y1	Y	Y	Y	Y
PWS-4-97	Applegate Rcks	1997-06-27	11040	Pup	F	30.7	94.0	85.0	Y	Y1	Y	Y	Y	Y
PWS-5-97	Applegate Rcks	1997-06-27		Sub	F	65.2	133.0	97.0	Y	Y1	Y	Y	Y	Y
PWS-6-97	Applegate Rcks	1997-06-27		Yrl	M	36.7	108.0	90.0	Y	Y1	Y	Y	Y	Y
PWS-7-97	Applegate Rcks	1997-06-27		Pup	M	28.5	99.0	80.0	Y	Y1	Y	Y	Y	N
PWS-8-97	Applegate Rcks	1997-06-27		Pup	F	26.3	88.0	80.0	Y	Y1	Y	Y	Y	N
PWS-9-97	Little Green Is	1997-06-28		Sub	M	46.1	117.0	95.0	Y	Y1	Y	Y	Y	Y
PWS-10-97	Little Green Is	1997-06-28	11042	Pup	M	35.0	102.0	95.0	Y	Y1	Y	Y	Y	Y
PWS-11-97	Little Green Is	1997-06-28	11043	Pup	F	28.8	95.0	80.0	Y	Y1	Y	Y	Y	Y
PWS-12-97	Little Green Is	1997-06-28		Yrl	M	38.6	114.0	87.0	Y	Y1	Y	Y	Y	Y
PWS-13-97	Little Green Is	1997-06-28	11044	Pup	F	28.3	89.0	86.0	Y	Y1	Y	Y	Y	Y
PWS-14-97	Little Green Is	1997-06-28		Yrl	F	38.9	110.0	87.0	Y	Y1	Y	Y	Y	Y
PWS-15-97	Channel Island	1997-06-28		Sub	M	74.3	136.0	97.0	Y	Y1	Y	Y	Y	Y
PWS-16-97	Channel Island	1997-06-28		Sub	F	59.6	125.0	92.0	Y	Y1	Y	Y	Y	Y
PWS-17-97	Port Chalmers	1997-06-28	2093	Pup	F	31.0	95.0	87.0	Y	Y1	Y	Y	Y	Y
PWS-18-97	Port Chalmers	1997-06-28		Sub	M	51.8	126.0	97.0	Y	Y1	Y	Y	Y	Y
PWS-19-97	Port Chalmers	1997-06-28	2094	Pup	M	39.2	103.0	87.0	Y	Y1	Y	Y	Y	Y
PWS-20-97	Port Chalmers	1997-06-29		Ad	M	70.1	147.0	104.0	Y	Y1	Y	Y	Y	N
PWS-21-97	Port Chalmers	1997-06-29		Ad	M	74.2	140.0	108.0	Y	Y1	Y	Y	Y	N
PWS-22-97	Port Chalmers	1997-06-29		Ad	M	93.5	151.0	117.0	Y	Y1	Y	Y	Y	N
PWS-23-97	Port Chalmers	1997-06-29	2095	Pup	M	32.2	100.0	83.0	Y	Y1	Y	Y	Y	Y
PWS-24-97	Port Chalmers	1997-06-29		Yrl	F	32.9	110.0	81.0	Y	Y1	Y	Y	Y	Y
PWS-25-97	Port Chalmers	1997-06-29		Ad	F	61.1	140.0	95.0	Y	Y1	Y	Y	Y	N
PWS-26-97	Port Chalmers	1997-06-29		Pup	M	28.7	88.0	83.0	Y	Y1	Y	Y	Y	N

Table 1. Continued.

Specimen	Location	Date	PTTID	Age	Sex	Wt	SL	AxG	DNA	Vib	Fat	Ultra	Blood	D_20
PWS-27-97	Port Chalmers	1997-06-29		Sub	F	40.6	120.0	84.0	Y	Y1	Y	Y	Y	Y
PWS-28-97	Olsen Bay	1997-06-30		Yrl	M	37.4	107.0	92.0	Y	Y1	Y	Y	Y	Y
PWS-29-97	Olsen Bay	1997-06-30		4?	F	52.5	136.0	90.0	Y	Y1	Y	Y	Y	Y
PWS-30-97	Olsen Bay	1997-06-30		Yrl	M	40.1	112.0	89.0	Y	Y1	Y	Y	Y	Y
PWS-31-97	Olsen Bay	1997-06-30		Pup	M	25.5	89.0	77.0	Y	Y1	Y	Y	Y	N
PWS-32-97	Olsen Bay	1997-06-30		Pup	F	23.5	87.0	74.0	Y	Y1	N	Y	Y	N
PWS-33-97	Olsen Bay	1997-06-30		Ad	F	46.9	130.0	90.0	Y	Y1	Y	Y	Y	N
PWS-34-97	Olsen Bay	1997-06-30		Sub	F	47.2	125.0	89.0	Y	Y1	Y	Y	Y	N
PWS-35-97	Applegate Rcks	1997-07-01		Sub	M	37.8	117.0	90.0	Y	Y1	Y	Y	Y	Y
PWS-36-97	Applegate Rcks	1997-07-01		Yrl	M	33.9	116.0	84.0	Y	Y1	Y	Y	Y	Y
PWS-37-97	Applegate Rcks	1997-07-01		Sub	F	42.5	116.0	103.0	Y	Y1	Y	Y	Y	N
PWS-38-97	Applegate Rcks	1997-07-01		Pup	M	24.3	97.0	81.0	Y	Y1	Y	Y	Y	N
PWS-39-97	Applegate Rcks	1997-07-01		Sub	F	42.4	120.0	88.0	Y	Y1	Y	Y	Y	Y
PWS-40-97	Applegate Rcks	1997-07-01		Ad	F	67.4	138.0	97.0	Y	Y1	Y	Y	Y	N
PWS-41-97	Applegate Rcks	1997-07-01		Pup	F	21.2	83.0	74.0	N	N	N	N	N	N
PWS-42-97	Applegate Rcks	1997-07-01		Sub	F	41.4	105.0	93.0	Y	Y1	Y	Y	Y	Y
PWS-43-97	Applegate Rcks	1997-07-01		Sub	M	46.6	123.0	92.0	Y	Y1	Y	N	Y	Y
PWS-44-97	Applegate Rcks	1997-07-01		Sub	M	38.3	118.0	87.0	Y	Y1	Y	Y	Y	N
PWS-45-97	Applegate Rcks	1997-07-01		Sub	M	40.9	124.0	92.0	Y	Y1	Y	N	Y	N
PWS-46-97	Applegate Rcks	1997-07-01		Sub	F	39.4	109.0	91.0	Y	Y1	Y	Y	Y	Y
PWS-47-97	Applegate Rcks	1997-07-01	2096	Pup	F	26.9	87.0	78.0	Y	Y1	Y	Y	Y	Y
PWS-48-97	Applegate Rcks	1997-07-01	2097	Pup	F	32.4	92.0	84.0	Y	Y1	Y	Y	Y	Y
PWS-49-97	Applegate Rcks	1997-07-01		Ad	F	67.5	143.0	100.0	Y	Y1	Y	N	Y	N
PWS-50-97	Applegate Rcks	1997-07-01		Ad	M	46.5	118.0	93.0	Y	Y1	Y	N	Y	N

Table 2. Performance of satellite-linked depth recorders attached to harbor seals in Prince William Sound, September 1996.

SDR	ID Number	Age\ Sex[a]	Date Attached	Date of Last Transmission	Total Days Operational	No. Days w/ Locations	Total No. Locations
2280[b]	96-7	JF	9/26/96	3/8/97	164	64	158
2287[b]	96-8	PF	9/26/96	12/23/96	89	59	272
2098	96-9	AF	9/27/96	6/10/97	257	226	768
2283[b]	96-10	JM	9/27/96	6/27/97	274	109	228
2284[b]	96-11	JM	9/27/96	3/17/97	172	90	230
2285[b]	96-12	JM	9/27/96	2/6/97	133	67	172
2286	96-13	AF	9/27/96	6/21/97	268	190	973
2281[b]	96-14	JF	9/28/96	4/23/97	208	92	262

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

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

Table 3. Performance of satellite-linked depth recorders attached to harbor seal pups in Prince William Sound, June-July 1997.

SDR	ID Number	Sex	Date Attached	Date of Last Transmission	Total Days Operational	No. Days w/ Locations	Total No. Locations
2281	97-1	F	6/27/97	12/30/97[a]	187+	84	149
11038	97-2	F	6/27/97	10/22/97	118	28	38
11039	97-3	F	6/27/97	8/25/97	60	26	31
11041	97-4	M	6/27/97	8/15/97	50	22	42
11042	97-5	M	6/28/97	12/30/97[a]	186+	102	199
11043	97-6	F	6/28/97	12/16/97	172	106	198
11044	97-7	F	6/28/97	10/4/97	99	46	74
2093	97-8	F	6/28/97	9/21/97	86	50	90
2094	97-9	M	6/28/97	12/31/97[a]	187+	109	209
2095	97-10	M	6/29/97	11/20/97	145	57	78
2096	97-11	F	7/1/97	12/30/97[a]	183+	97	166
2097	97-12	F	7/1/97	7/28/97	28	16	21

[a] These SDRs operated at least into March 1998, but the data have not yet been completely processed.

Table 4. Summary of movements of harbor seals satellite tagged in Prince William Sound, September 1996.

ID	Start Date	Tag Location		Last Location	Stop date
96-7	9/26/96	Channel I.	Applegate Rks. 9/30-11/16 Augustine I. 12/16-17 Chinitna Bay 12/18-3/8	Chinitna Bay	3/8/97
96-8	9/26/96	Port Chalmers	Gulf W. of Middleton I. 9/29-30; 10/14-18; 10/29-11/4; 11/10-20 Copper River Delta 10/2-3; 10/8-12; 10/20-27; 11/7-8;11/22-12/2 Cape Suckling 10/5-6 S. end Montague I. 12/4 Johnstone Bay 12/5-23	Johnstone Bay	12/23/96
96-9	9/27/96	Port Chalmers	Stockdale Hbr. 12/29-5/24 Channel I. 10/11-6/9	Port Chalmers	6/10/97
96-10	9/27/96	Stockdale Hbr.	Columbia Bay 10/12-11/22 Copper River Delta 5/3-6/2 Icy Bay (Gulf of AK) 6/9-6/27	Icy Bay	6/27/97
96-11	9/27/96	Channel I.	Applegate Rks. 10/8-1/16; 1/30-2/8 Green I. 1/18-28 N. end Montague I. 2/11-23; 3/11-14 Copper River Delta 2/27-3/7	Zaikof Bay	3/17/97
96-12	9/27/96	Channel I.	Port Chalmers/Montague I. 9/29-11/11 Patton Bay 11/29-12/14 Copper River Delta and East 1/15-2/6	S.E. of Copper River Delta	2/6/97
96-13	9/27/96	Channel I.	Copper River Delta (E. and S.) 9/29-5/18 Icy Bay (PWS) 5/24-6/17	Port Chalmers	6/18/97
96-14	9/28/96	Applegate Rks.	Channel I. 11/9-2/4 Middleton I. 3/8-4/1 Port Chalmers 4/7-23	Port Chalmers	4/23/97

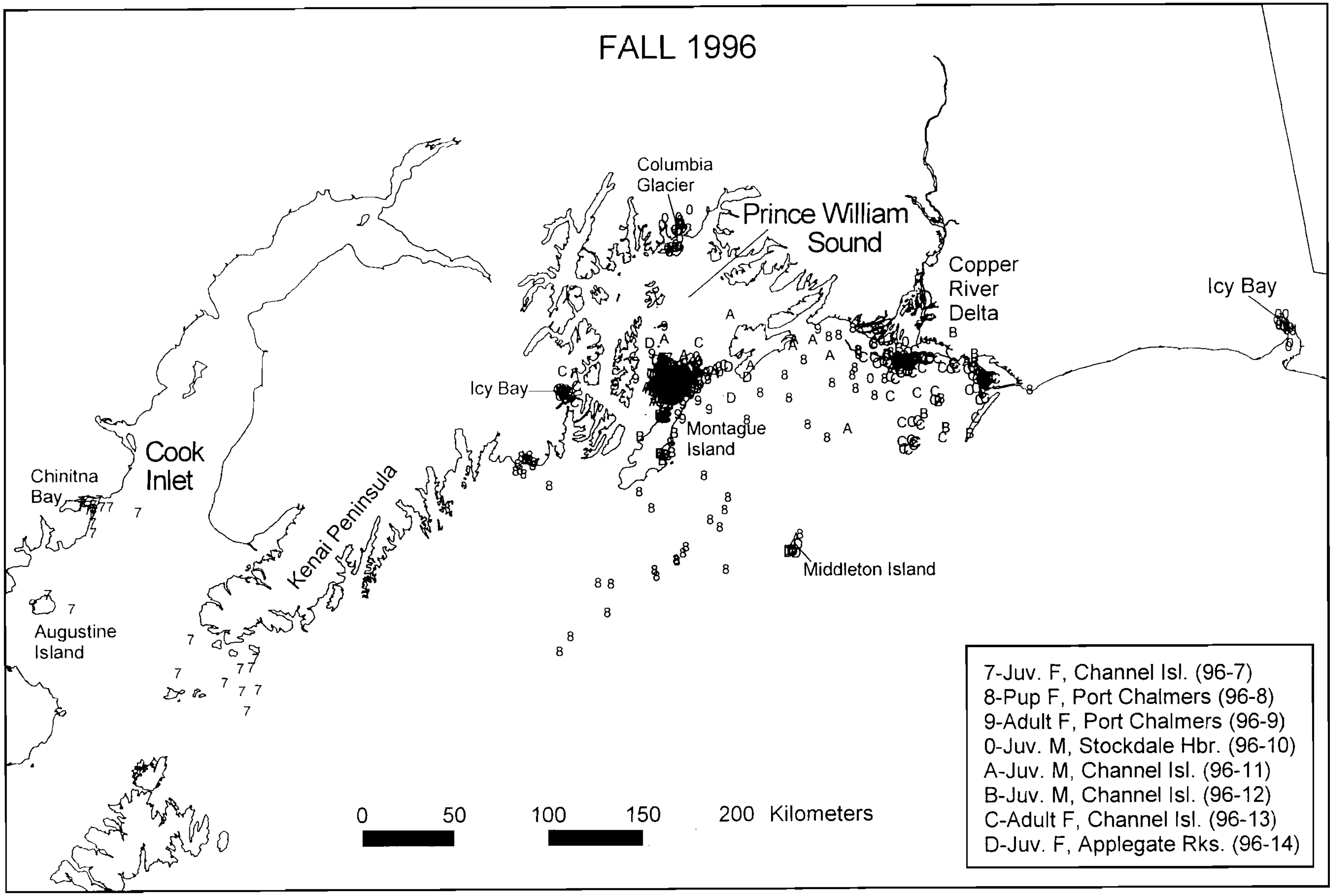


Figure 1. Average daily locations of 8 satellite tagged harbor seals in Prince William Sound and the Gulf of Alaska, September 1996-June 1997.

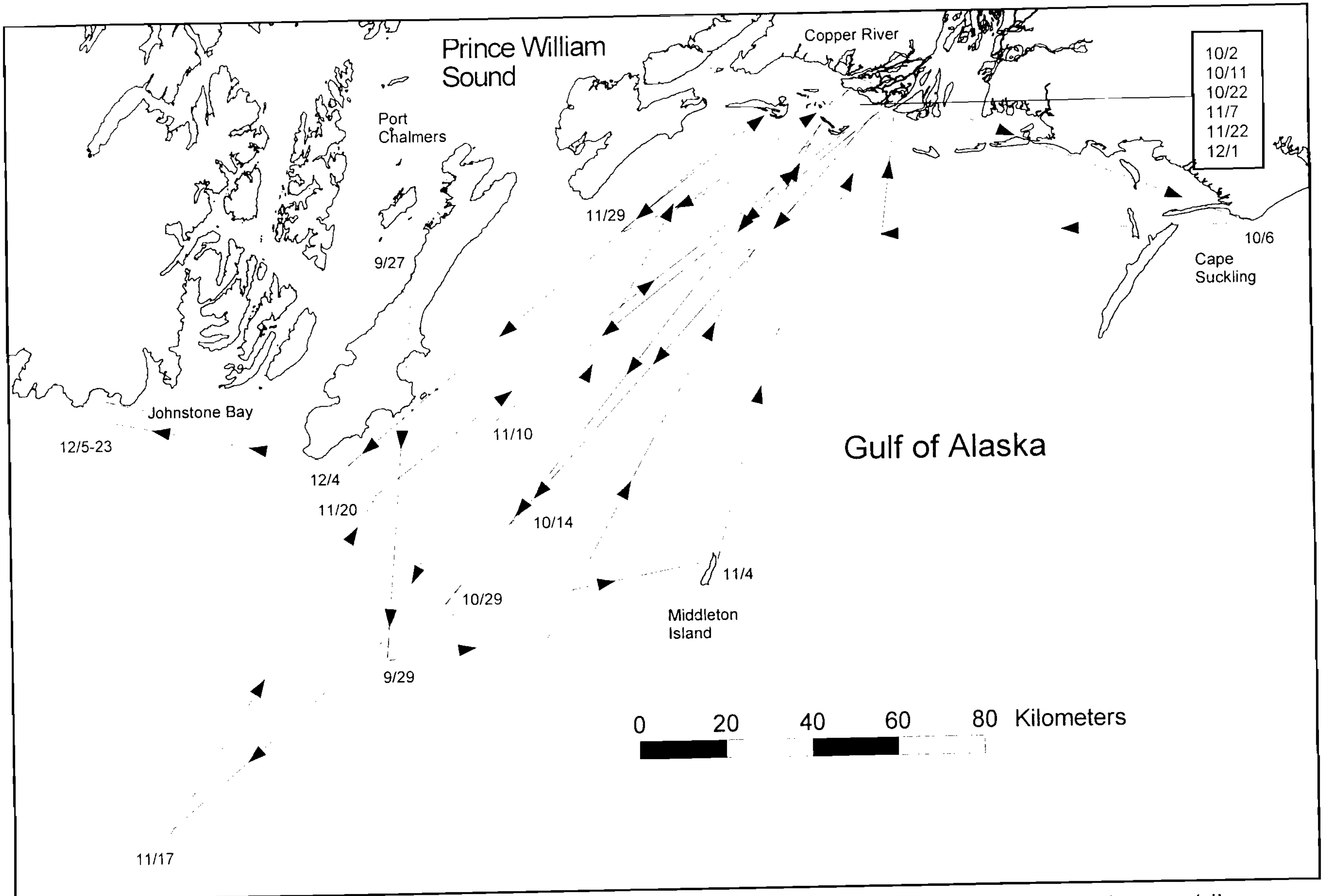
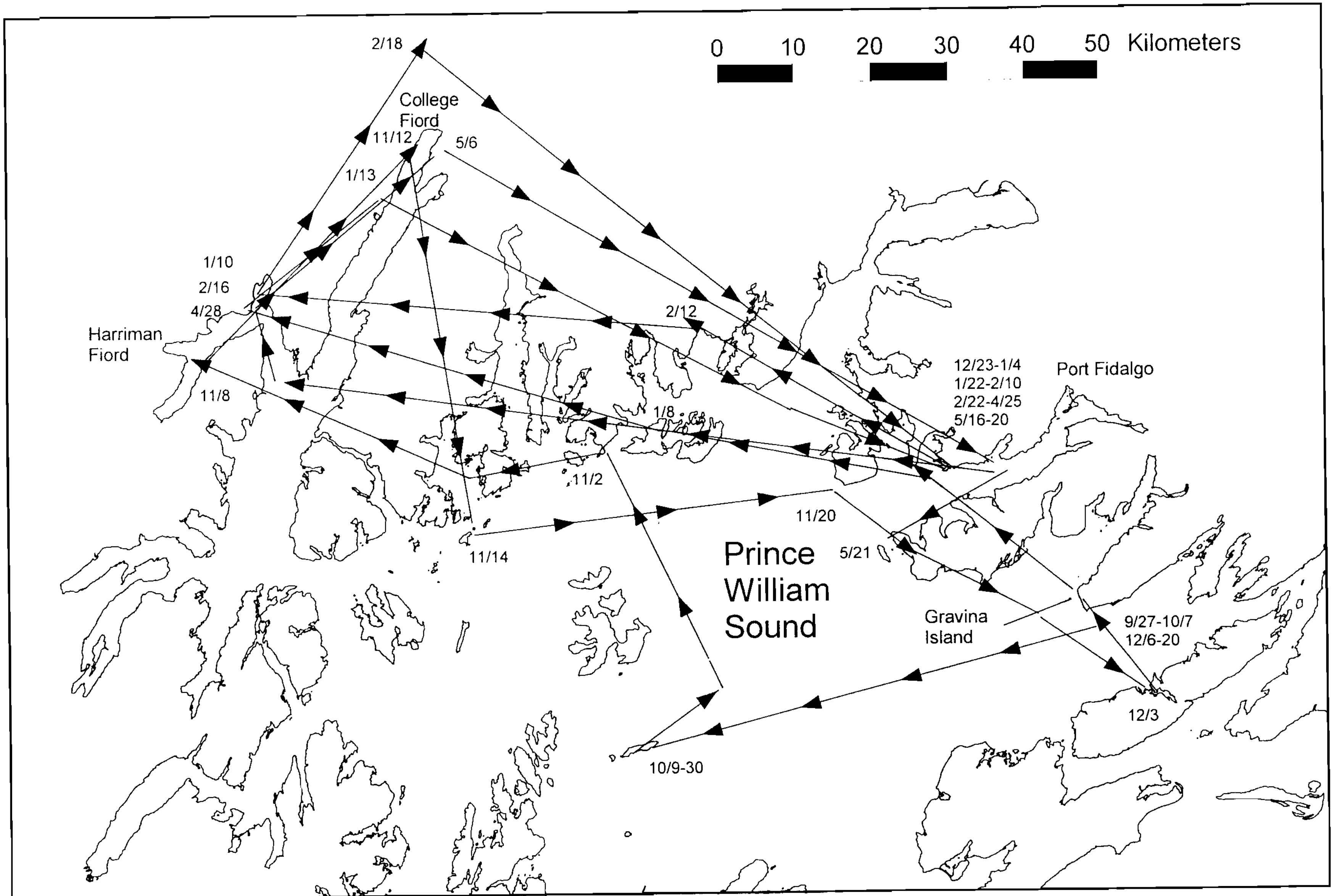


Figure 2. Movements of satellite-tagged female pup harbor seal 96-8, 27 September-23 December 1996. Gray dots show actual average daily locations for the seal, and numbers indicate the month and day(s) when the seal was at a particular location.



Figrue 3. Movements of satellite-tagged female pup harbor seal 95-8, 25 September 1995-21 May 1996. Gray dots show actual average daily locations for the seal, and numbers indicate the month and day(s) when the seal was at a particular location.

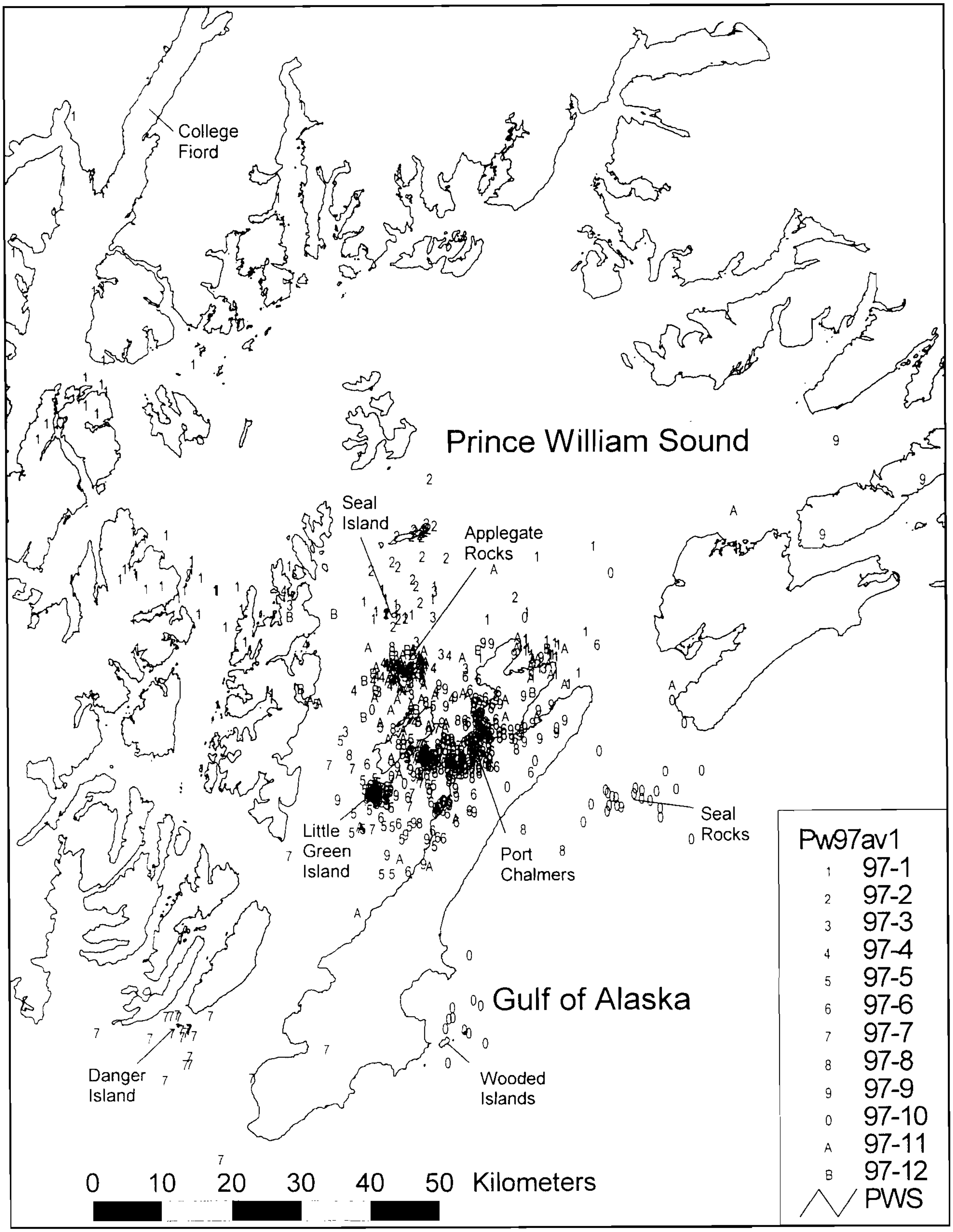


Figure 4. Average daily locations of 12 satellite tagged harbor seal pups in Prince William Sound, June-December 1997.

CHAPTER THREE

THE USE OF FATTY ACID SIGNATURES TO INVESTIGATE FORAGING ECOLOGY AND FOOD WEBS IN PRINCE WILLIAM SOUND, ALASKA: HARBOR SEALS AND THEIR PREY

OBJECTIVE 3

Identify important prey species in the diets of harbor seals in PWS, with a particular emphasis on pups and yearlings, and determine whether there are dietary differences among different components of the population.

OBJECTIVE 4

In conjunction with research efforts being done on the Scotian Shelf, develop mathematical models and associated software programs to quantitatively estimate species composition of individual harbor seal diets.

OBJECTIVE 5

Determine whether there are differences in diets and important prey species among populations of harbor seals in areas of the Gulf of Alaska where they are continuing to decline (e.g., PWS and northern GOA) and areas where the population is stable or increasing (SEAK).

OBJECTIVE 6

Determine whether changes in harbor seal diets and important prey species have occurred over the past two decades.

OBJECTIVE 7

Compare estimates of abundance and importance of harbor seal prey to trawl survey data and data obtained from seabird diet studies being conducted concurrently under the APEX program.

This report to be cited as:

Iverson, S. J., K. J. Frost, S. Lang, C. Field, and W Blanchard. 1998. The use of fatty acid signatures to investigate foraging ecology and food webs in Prince William Sound, Alaska: harbor seals and their prey. Pages 38-117 *in* Monitoring, habitat use, and trophic interactions of harbor seals in Prince William Sound, Alaska. Annual Report to the *Exxon Valdez* Oil Spill Trustee Council. Restoration Study 97064. Alaska Department of Fish and Game, Division of Wildlife Conservation, Fairbanks, AK.

THE USE OF FATTY ACID SIGNATURES TO INVESTIGATE FORAGING ECOLOGY AND FOOD WEBS IN PRINCE WILLIAM SOUND, ALASKA: HARBOR SEALS AND THEIR PREY

Sara J. Iverson[1], Kathryn J. Frost[2], Shelley Lang[1], Chris Field[3] and Wade Blanchard[3]

[1]Department of Biology
Dalhousie University
Halifax, Nova Scotia B3H 4J1 Canada

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

[3]Department of Mathematics and Statistics
Dalhousie University
Halifax, Nova Scotia B3H 4J1 Canada

INTRODUCTION

Marine mammals and seabirds are apex predators in ecosystems in which fishes and cephalopods are important prey. As such, a strong relationship would be expected between predator populations and fish stock abundances, a relationship that is likely influenced by factors such as commercial fisheries and ecosystem changes (e.g., Beddington, Beverton & Lavigne 1985; Springer 1993). In many parts of the world pinniped populations have increased as predicted after protection from over-exploitation (e.g., Olesiuk, Bigg & Ellis 1990; Shelton et al. 1995). However, large declines in populations of harbor seals (*Phoca vitulina richardsi*) and Steller sea lions (*Eumetopias jubatus*) have been documented in the Bering Sea and the Gulf of Alaska, especially Prince William Sound (PWS) (Pitcher 1990; Loughlin, Perlov & Vladimirov 1992). Likewise, since the 1970's numerous species of seabirds have also declined in PWS. These unanticipated declines have prompted monitoring and assessment of marine mammal, seabird, and fish population trends, and perhaps most importantly, have furthered the idea of using predators as samplers of forage fish abundances (Duffy 1996; Roseneau & Byrd 1996). The latter aspect may provide the most useful information towards addressing the question of "Is it food?", since the mean abundance of prey at large spatial scales, as determined from fisheries surveys, may not be relevant to the scale at which seals and seabirds forage (e.g., Duffy 1996; NRC 1996).

In PWS, harbor seals are one of the most abundant and widely distributed marine mammals, hauling out and/or breeding at more than 50 sites. Since 1984 harbor seal numbers in PWS have declined by about 60%, with only part of this decline attributable to the 1989 *Exxon Valdez* oil spill (Frost & Lowry 1994). The decline in harbor seals has not been limited to PWS, but has also occurred in adjacent parts of the Gulf of Alaska (Pitcher 1990). A change in the trophic structure of the ecosystem, and hence the availability of prey, is among the hypothesized causes for this observed decline, as well as that of other apex predators. Thus, understanding the diet of harbor seals, particularly over time and in areas of stable versus decreasing populations, and how they may depend on seasonal or area-specific concentrations of prey, is not only needed in the management of harbor seals as a resource, but also as important indicators of other marine resources, namely forage fishes and other prey.

Unfortunately, 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 truly makes its living by. Past studies of harbor seal diets in PWS and the Gulf of Alaska (GOA) have been conducted using these types of methods (Pitcher 1980a and 1980b), however, this is not possible in PWS, particularly in a declining population.

Thus the use of fatty acid signature analysis (Iverson 1993) has been advanced to study marine food webs and pinniped diets (Iverson 1995). Fatty acids are the largest constituent of lipids and those of carbon chain length 14 or greater are often deposited in animal tissue with minimal modification from diet. Lipids in the marine food web are exceptionally complex and diverse. Owing to various restrictions and specificities in the biosynthesis and modification of fatty acids among different taxonomic groups (e.g., Paradis & Ackman 1976; Ackman 1980; Cook 1985; Fraser et al. 1989), many components appear which can be traced to a general or even specific ecological origin. 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 on a high fat diet (Iverson et al. 1995), or may reflect an integration of diet over a period of time when not rapidly fattening (Kirsch, Iverson & Bowen 1995). By sampling a core of blubber from a free-ranging seal, one may relatively non-invasively obtain information about diet that is not dependent on prey with hard parts, nor limited to nearshore influences. Similarly, these patterns extend to fish as predators, in that body lipids strongly reflect the influences of their dietary lipids (Kirsch et al., in press).

To date, the methods of fatty acid signature analysis have been used both to identify general trophic level of diets and to detect major and minor shifts in diet within populations (Iverson, Arnould & Boyd 1997; Smith, Iverson & Bowen 1997). Of the two most comprehensive ecosystem studies which have ever been conducted in this area (Iverson, Frost & Lowry 1997; Iverson, Bowen & Ackman, unpublished data), work in the Gulf of Alaska and funded by the Trustee Council has come the farthest in advancing the development of this method. In the first 2.5 years of study in PWS [Frost et al. 1997: (Iverson & Frost Appendix)], fatty acid signatures indicated that fine-scale structure of foraging distribution of harbor seals could be discerned, and that this was likely due not only to localized feeding patterns in seals, but also to specific differences in prey species with size and location or habitat within PWS (Iverson, Frost & Lowry 1997).

In the present study, we report on part of our longer term research project which investigates both harbor seals and their prey in PWS and the GOA using fatty acid signature analysis, and which also focuses on the further development of fatty acid signature analysis. These analyses of harbor seals and prey species in PWS and the GOA are continuing and therefore some of the results presented in this report are incomplete; this report includes all data analyzed from our previous 1997 report (1994-1997: prey, n = 528; seals, n = 218) as well as that analyzed since. The primary goals of our present analyses were: 1) to continue to build a library of prey species fatty acid signatures and with a stronger assessment of the influence of factors such as size-class, geographical location, season, and eventually year, on species signatures; 2) to continue to build our sample of the harbor seal population both within areas of PWS as well as elsewhere in the GOA; 3) to assess whether harbor seals differ in diet according to age-class or sex; and 4) to begin to assess whether there have been differences in the diets of harbor seals over a 3-4 year period. Our ultimate goal is to link the prey species to observed differences in seal fatty acids and to determine percentage species composition of seal diets. This has been a large focus of our efforts in the past 6 months. These modeling efforts are still in a relatively young stage of development, but preliminary work and results are summarized. A new component of our study, begun in 1997, has also been aimed at examining the condition of PWS seals at young ages post-weaning by measuring total body composition. These data are also reported.

METHODS

Sample Collection

Figure 1 depicts a map of PWS showing major locations of harbor seals and prey species sampled for this study, which should be referred to throughout this report. For the purpose of analyses, PWS locations were divided into regions as follows: central (C), northeast (NE), northwest (NW), southcentral (SC), southeast (SE), and southwest (SW) PWS (see Fig. 1). Prey species were collected from fishing trawls and as opportunity provided in PWS at various locations and seasons during 1994, 1995, and 1996 and stored frozen until analysis. A total of 792 individual prey representing 18 taxa [capelin, chum, flathead sole, rex sole, unidentified flatfish sp., yellowfin sole, greenling, Pacific herring, octopus, Pacific cod, pink salmon (adults and smolts), walleye pollock, rainbow smelt, copper rockfish, sandlance, shrimp, squid, and tomcod] 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, still remains for herring (n = 236) and pollock (n = 159), however reasonably large samples sizes are becoming available for other species such as capelin (n = 79), flatfish (n = 88), pink salmon (n = 40 smolts), sandlance (n = 40), squid (n = 82) and tomcod (n = 24). Most species were not sampled from all areas, or across all seasons and years, precluding some direct comparisons.

Blubber from a total of 296 harbor seals was sampled in 1994, 1995, 1996 and 1997, and analyzed for fatty acid composition. Most of the seals were caught by entanglement in nets deployed near haulout sites. Blubber core samples were collected from the pelvic region of each seal using sterile 6 mm biopsy punches and immediately placed in chloroform containing BHT (butylated hydroxytoluene) as an antioxidant and stored frozen (-20°C) until analysis. Blubber cores (5-7 cm) were consistently taken through the full depth of the blubber layer, excluding that directly nearest (0.3 cm) to the skin; these deeper areas comprise all the metabolically active sites where deposition of fatty acids occur during periods of fattening (Koopman, Iverson & Gaskin 1996; Iverson unpublished data). Some blubber samples were also obtained from Alaska Native subsistence hunters in PWS as part of a biosampling program designed to make specimen material from harvested seals available to researchers. Blubber samples obtained in this manner were frozen in airtight plastic bags until they could be shipped to a laboratory where they were placed in chloroform/BHT and frozen. Seals were sampled in PWS (n = 210) which was further divided into the same general locations as prey collections (see above and Fig. 1), and from other areas of the GOA: near Kodiak Island (N., n = 18 from Uganik Passage; S. n = 10 at Tugidak Island), in Southeast Alaska (SEA, n = 47) from areas of Stephen's Passage, Sitka, Peril Straight, and Ketchikan, and from Yakutat (SCA, n = 11). Not all areas were sampled in all years, seasons or among age classes, precluding some direct comparisons.

In 1997, the focus of our study changed slightly to concentrate on assessing aspects of foraging and body composition in young seals (primarily within the first year post-weaning). Thus in June of 1997, a total of 30 animals were given deuterium oxide (D_2O), a heavy non-radioactive isotope of water, which allows accurate measurement of total body water and other body constituents (Oftedal & Iverson 1987; Iverson et al. 1993; Bowen & Iverson 1998). Animals were captured and weighed to the nearest 0.5 kg. Pups were checked for the presence of milk by gastric intubation, and all milk was removed if present to avoid delay in equilibration of isotope. Stomach contents of older animals were not checked or evaluated, however. An exact pre-weighed amount of D_2O (99.8% purity, Sigma) was delivered by gastric intubation using a 12-French stomach tube. Syringe and stomach tube were then rinsed with two 5-cc quantities of fresh water; air was then blown through the tube as it was withdrawn to insure complete quantitative isotope delivery. Animals were held in nets for 2-4 hours and two serial blood samples were taken 20 min. apart at the end of this holding period to determine whether (and at what concentration) equilibration of isotope had occurred. Serum was collected from centrifuged blood samples and stored frozen until analysis at Dalhousie University.

Lipid and Fatty Acid Analysis

After recording length and mass of each whole prey, each 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 or more individuals were combined for total fat content and fatty acid measurements; in these cases all group analyses were considered to be equal to a sample size of one (n = 1). 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. 1997).

Fatty acid methyl esters were prepared directly from 100 mg of the pure extracted lipid (filtered and dried over anhydrous sodium sulfate), using 1.5 ml 8% boron trifluoride in methanol (w/w) and 1.5 ml hexane, capped under nitrogen, and heated at 100°C for 1 hour. Fatty acid methyl esters were extracted into hexane, concentrated, and brought up to volume (50 mg/ml) with high purity hexane. This method of transesterification, as employed in our lab with fresh reagents, was routinely tested and found to produce identical results to that using Hilditch reagent (0.5 N H_2SO_4 in methanol).

Duplicate analyses of fatty acid methyl esters were performed on samples using temperature-programmed gas liquid chromatography according to Iverson (1988) and Iverson, Sampugna & Oftedal (1992), on a Perkin Elmer Autosystem II Capillary FID gas chromatograph fitted with a 30m x 0.25 mm id. column coated with 50% cyanopropyl polysiloxane (0.25μ film thickness; J&W DB-23; Folsom, CA) and linked to a computerized integration system (Turbochrom 4 software, PE Nelson). Identifications of fatty acids and isomers were determined from the following sources: known standard mixtures (Nu Check Prep., Elysian, MN), silver-nitrate (argentation) chromatography (Iverson 1988), and several secondary external reference standard mixtures composed of natural mixtures of fatty acids from several fish and seal oils which had been identified by chemical degradative and spectroscopic procedures including hydrogenation and GC-mass spectrometry performed in the laboratory of R. G. Ackman (Iverson et al. 1997).

Individual fatty acids are expressed as weight percent of total fatty acids after employing mass response factors relative to 18:0. Theoretical relative response factors were used for this purpose, with minor adjustments made after tests with accurate quantitative standard mixtures (Nu Check Prep., Elysian, MN). GC columns were kept in good condition throughout the study by changing septa daily, cleaning the injector liner regularly, by use of a guard column, and by frequent replacement. All sample chromatograms and identifications were individually checked daily and freshly made quantitative standard mixtures were rerun several times weekly to determine any column deterioration, replacement, or re-programming of GC necessary. Fatty acids are expressed as weight percent of total fatty acids and are designated by shorthand IUPAC nomenclature of carbon chain length:number of double bonds and location (n-x) of the double bond nearest the terminal methyl group.

Body Composition Analysis

For the study on body composition, total free-water was collected from blood sera by heat distillation according to the method of Oftedal & Iverson (1987) and D_2O concentration was determined by quantitative infrared spectrophotometry on a Perkin Elmer Fourier Transform IR Spectrophotometer (Oftedal & Iverson 1987). All samples were read in triplicate.

Equilibration was considered to have occurred when the isotope levels measured in the two serial blood samples taken during the equilibration period were within 3% D_2O concentration of each other. For five of the 30 animals, equilibration had not occurred and thus data was not available for these individuals. These individuals were non-pups and the delay in equilibration may have been due to the presence of food in the stomach. The other 25 animals had all equilibrated by the end of the holding period.

Isotope dilution space was converted to total body water (TBW) using the equation:

$$\text{TBW (kg)} = 0.003 + [0.968 \times (\text{dilution space})]$$

as derived by Bowen & Iverson (1998). TBW was then used to calculate total body fat (TBF) and total body protein (TBP) content using the equations:

$$\%TBF = 105.1 - (1.47 \times \%TBW)$$
and
$$\%TBP = (0.42 \times \%TBW) - 4.75$$

as derived by Reilly and Fedak (1990) for grey seals.

Data Analysis and Interpretation

Fat content and fatty acid data were analyzed using regression and analysis of variance (ANOVA) on a limited subset of variables, and also using methods of classification and regression trees (CART) in S-plus according to methods described in Iverson et al. (1997) and Smith, et al. (1997). There are no restrictions in CART on the number of variables (fatty acids) that can be used in the analysis, thus the complete data sets of fatty acids were used. 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. A restriction on CART analyses is that group sizes less than 4 cannot be classified, thus groups with sample sizes of 3 or less were excluded from any of the CART analyses.

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 and compared these to the original tree. Because of the extent and complexity of the present data set, only a subset of all final classification trees are presented and discussed in this report. Application of the SPLUS software is described in Clark & Pregibon (1992) and Venables & Ripley (1994).

The methods and discussion of the recent diet modeling work is presented separately in the results section. All data are presented as mean ± SEM, unless otherwise indicated.

RESULTS

Prey Species - Fat Content

Collection, morphometric measurement, and fat content data for prey species collected and analyzed in PWS are summarized in Table 1. Because several species analyzed occurred over a large size range and differences with size were expected (Iverson et al. 1997), several within-species size classes were created: the length distributions available for herring and pollock were divided into three: for herring, small, medium, and large corresponded to lengths of 8.0-14.0 cm, 14.1-20.1 cm, and 20.2-27.0 cm, respectively; for pollock, small, medium, and large corresponded to lengths of 5.0-11.9 cm, 12.0-18.9 cm, and 19.0-25.9 cm, respectively. Tomcod were also divided into two size classes of small and large (Table 1). Although squid collected represented a wide range of sizes, there was little evidence from fatty acid data that splitting by size was appropriate.

Herring had the highest fat content of any species analyzed (7.3%), but this ranged widely (0.5 - 19.1%). The fat content of most other species averaged 3% or less. Flatfish species (other than yellowfin sole and pink salmon smolt) had the lowest fat contents at generally less than 1%. Within species, fat content appeared to vary mostly with season, but possibly also size. Confounding of collection distributions (i.e. all one size class from one season) precluded strict analysis of this in most species. Across years, herring was highest in fat in the fall ($7.4 \pm 0.51\%$, $n = 65$, $P < 0.0001$) and lower in fat in both spring ($3.4 \pm 0.17\%$, $n = 51$) and summer ($4.4 \pm 0.25\%$, $n = 121$). In contrast, pollock analyzed appeared to be slightly higher in fat in the spring ($2.6 \pm 0.28\%$, $n = 26$, $P < 0.0001$) than in the summer ($1.5 \pm 0.12\%$, $n = 40$) and fall ($1.6 \pm 0.08\%$, $n = 95$). However, many of the pollock in spring were collected from the NW, where many species exhibit a higher fat content than in other areas. For instance, in both herring and pollock, individuals from the NW were consistently high in fat content regardless of season or size class. This was clearly seen in pollock, where all individuals sampled in spring were from the NW and averaged 4.2% fat (see Frost et al. 1997). Similar findings were true for species such as capelin and squid.

Prey Species - Fatty Acids

Approximately 70 fatty acids and isomers were routinely identified in all prey species (Table 2). Two additional components were formed from the ratio of two sets of important isomers as suggested by Iverson et al. (1997): ratio of 20:1n-11 to 20:1n-9 (R20:1) and ratio of 22:1n-11 to 22:1n-9 (R22:1). In previous reports (see Frost et al. 1997) differences between and within prey species in fatty acid composition have been well-illustrated. Given the size of the current data set, only subsets of these aspects will be illustrated.

Despite variations within prey species, and often a confounding of sample collection (differences in size-classes, seasons, locations and years), prey continue to be readily and accurately distinguished from one another based upon their fatty acid signature. This can be illustrated using CART analysis, which compares all 70 fatty acids simultaneously across all species of prey (excluding prey with sample sizes less than 4) (Fig. 2). Using the algorithmically chosen variable 22:5n-3, the resulting classification tree correctly identified 94.7% of all prey species in PWS by their fatty acid signatures alone (Fig. 2). This was based on a sample size of 792 prey and this was the same variable selected in a previous analysis containing 525 prey (see Frost el al. 1997). Groupings of species were also predictable. For instance, despite apparent differences among the flatfish species (see below), all flatfish (including yellowfin sole) were classified together down the far right node of the tree with few misclassifications (Fig. 2). Adult and smolt pink salmon and chum, though different in some respects (Table 2), initially traveled together down the middle of the tree and later were correctly separated with 100, 95 and 100%

accuracy, respectively (Fig. 2). Squid were also readily separated with only 2 out of 82 misclassifications. In general, capelin, herring, pollock, sandlance and tomcod required more splits and fatty acids in order to be correctly classified and appeared at several points in the tree, however much of this pattern could be explained by the predictable variation observed with size class and location of collection.

An illustration of species and individual differences can be demonstrated among the flatfish species analyzed (Fig. 3). Differences in major fatty acids were apparent between species and within species among locations (i.e., flathead sole and yellowfin sole). Particularly striking was the difference between yellowfin sole collected in SC vs. SE PWS (Fig. 3). Unfortunately, the locations of collection were often confounded with differing season and year of collection, thus it was not possible to attribute one factor alone to the variation observed within species. However, despite these individual variations, flatfish species were able to be distinguished from one another by CART to their correct species with 92% accuracy, including yellowfin sole (Fig.4). When locations (and seasons) of collection were included in the analysis, again groups were classified with good accuracy (Fig. 5).

The most extensive collection data exists for herring, providing a better opportunity to assess factors contributing to individual variability in fatty acid signatures. As stated previously, differences were expected among size or age classes of species which change their diet over life stages. When size classes were factored into the CART analysis of herring alone, small, medium and large individuals could be accurately (94%) distinguished by their fatty acid signatures (Fig. 6). The majority of large and medium herring were classified in different areas in the tree from small, although there was some overlap (Fig. 6). However, when collection locations were included in the analysis, some of this overlap was explained (Fig. 7). Nevertheless, collection locations were still confounded somewhat by sampling year and season. Thus, individual data points can be considered using various separation factors. As an illustration of this, four abundant indicator fatty acids can be compared in herring across body size (length), using three sets of separation factors (Figs. 8 and 9). The three sets of factors considered were location within PWS, season, and year. All three could not be illustrated on the same plot due to complexity of symbols, however when examined together several trends were apparent. In general, the most important of these factors in determining individual variability appeared to be size class. In the major fatty acids 20:1n-11 and 22:1n-11, 67.5% and 72%, repectively, of the variability was explained by length alone (Fig. 8), while for 20:5n-3 and 22:6n-3, 55.9% and 29.6%, respectively, of the variability was explained by length (Fig. 9). Aside from a couple of isolated groups which appeared to differ from the overall pattern, within most locations, seasons and years, herring fatty acids varied in a predicted similar manner according to size (Figs. 8 and 9). However, again, despite this variation (primarily by size) in selected fatty acids, herring as a whole were still distinguished correctly from all other species with 98.7% accuracy (Fig. 2).

Evidence also suggested differences in capelin with body size. In capelin, mass was a better predictor of body size variation than was length and body mass explained about 50% of the variation occurring in several abundant indicator fatty acids (Fig. 10). Location may also play a role in variability (CART tree, 98.7% correct classification, Fig. 11), but this was somewhat confounded with size as the largest capelin were all from one area and season (C, summer). Similar correct classifications were found for pollock by location and season (Fig. 12). But again, the classification of species overall was high with 93.7% of capelin and 97.5% of pollock being correctly identified by their overall fatty acid signatures (Fig. 2).

In summary, although within species differences were apparent and usually predictable with both size class and collection location (Figs. 5-12), species could still be readily differentiated from one another across species as a whole using fatty acid signatures, with an average of 95% accuracy (Fig. 2).

Harbor Seal Fatty Acids

Table 3 summarizes the collection data for blubber samples from harbor seals in areas of PWS as well as the GOA. Additionally, data on age-class and sex were available for most animals sampled. In some cases where age-class was not noted but measurements were available, an equation using body length and mass was used to estimate age-class. In cases where animals from 1994-1996 were initially listed as "pups", but captured in either the fall (i.e., Sept., Oct.) or early spring (i.e., March, April) , these were deemed to actually be half-year-olds and yearlings, respectively. "Pups" as contained herein refers only to actual suckling or newly weaned pups (within first few weeks) captured in June. A summary of these demographic groups is also presented in Table 3. Where possible, differences between locations, years, and age groups were tested, although again not all age groups were available from all locations and all locations were not available from all years. In trying to understand foraging patterns in various locations, suckling pups were removed from most general analyses, as the fatty acid signatures would reflect only milk consumed (and some fetal biosynthesis) and therefore would complicate the analysis. For this same reason, in cases where ages were not known at all, individuals were not included in statistical analyses.

The same approximately 70 fatty acids and isomers found in PWS prey were routinely identified in harbor seal blubber samples across all locations (Table 4). Where sample size was large enough to do so, fatty acid data also were divided into demographic groups within location for illustration. Variations between some groups of seals by location alone were apparent, as well as among demographic groups, especially in indicator fatty acids (generally those starting with 20:1n-11, Table 4).

Differences among locations can be tested using CART which compares all 70 fatty acids. When all adults and subadults were combined (half-year-olds and suckling pups excluded), the results of CART analyses continued to confirm the earlier observations (Frost et al. 1997) of differences between major locations of the GOA (i.e., PWS and elsewhere in the GOA , Fig. 13). The ratio of 20:1n-11/n-9 was algorithmically selected by CART for the initial separation and seals were classified to the major area of collection with 94.8% accuracy, based upon fatty acid signature. Greater than 99% of all PWS animals were correctly separated from other GOA seals (Fig. 13). When the major areas of the GOA and PWS were divided into specific finer-scale locations within these areas, individuals continued to be classified with 90% accuracy using the same initial variable, the ratio of 20:1n-11/n-9 (Fig. 14); however, when GOA areas were left as major areas and only PWS was divided into fine-scale locations, the classifications were more accurate at 94%. Nevertheless, the results of these analyses did suggest differences between seals within SEA among areas of Stephens Passage, Sitka, and Peril Straight, although these may have reflected year influences as well (Peril Straight animals were all collected in 1996, while the others were collected in 1995). Animals from Ketchikan could not be included in this analysis as ages were not available.

The above analyses considered only location as the classifying variable. Differences in diet, and thus blubber fatty acid signature, are likely to occur with age and size in seals, hence demographic groups need to be considered in evaluations of dietary differences with location. Other potential factors could be sex of the animal, season and year of study. Unfortunately many of these factors for most groups could not be directly tested due to sample size and confounding of collections (see Table 3). However, where possible, some of these variables can be illustrated.

For instance, across the major locations of GOA and PWS, adults could be compared to subadults (excluding yearlings and younger animals) using 9 abundant indicator fatty acids (Fig. 15). Indeed, in this analysis, adults generally differed from subadults in only minor and mostly non-significant ways, while highly significant differences were found with location for every component tested (Fig. 15). In a similar analysis, and thus combining all adults and subadults but comparing males versus females, again, most differences were attributable to major location with fewer differences between sexes (Fig. 16).

Given the apparent differences within finer-scale areas of the GOA (Fig. 14), these can also be examined using a few selected dietary fatty acids with age groups (Fig. 17). In this case, given the complexity of the data set, PWS is excluded and only other areas within the GOA are considered; additionally, it is perhaps likely that the most important dietary differences would occur in the youngest subadults, thus animals in their first year of life are illustrated as this time period may be most important in assessing age effects. Again, sample sizes are often small for these groups, however, a few selected dietary fatty acids can be used to illustrate potential patterns. Using four important indicator fatty acids, some differences were still apparent among fine-scale regions of SEA, but also age classes became more important factors, even though only adults and subadults could be included in the 2-way ANOVA due to sample size. Although yearlings and half year olds could not be tested in this analysis, they appeared to differ the most from adults (Fig. 17).

More detailed analyses of factors influencing diets, and thus fatty acid signatures, can be completed for PWS animals. In particular, seals in SC and SE PWS were sampled in several age classes, in several seasons, and across 4 years and differences could potentially occur in diets among these factors. First, combining data across all years and seasons, patterns for seals in SC PWS and SE PWS can be illustrated using the same 4 important indicator fatty acids (Fig. 18). In this case, since "subadults" is a somewhat large category, these were divided into two groups: those > 40 kg and those < 40 kg to examine all size classes in as much detail as possible. While some differences may have been present between SC and SE, the most pronounced differences were found among age classes. In particular, the adults differed most from the youngest, smallest animals, namely the half-year-olds, yearlings and < 40 kg subadults (Fig. 18), which was also suggested for animals in other areas of GOA (Fig. 17).

Since the harbor seals collected in southern PWS represent the only group to date with a sampling extensive enough to begin to evaluate differences in individuals across age classes, seasons and years, SC and SE seals were combined for further analysis. Thus, variation among individuals using factors other than location can be illustrated using the same 4 important indicator fatty acids (Fig. 19). Necessarily having to omit animals collected in summer of 1997 from the 2-way analyses, there was limited evidence that differences occurred across years or seasons, and much stronger evidence that differences occurred between adults and other age-classes (Fig. 19). Seasonal differences appear to be more important in subadult classes than in adults, but again, it was not possible to test all factors at once, so interpretations were limited.

CART analysis of southern seals, combined across seasons and years, also separated adults from subadults from yearlings with 88.8% accuracy (Fig. 20). However, in contrast to ANOVA, using all adults, subadults and yearlings combined, CART separated animals by year alone with 96.9% accuracy, suggesting that some year differences may have been present (Fig. 21). Finally, eliminating any concern over location differences and examining SC PWS animals only (n = 119) and combining years and seasons, not only were age class differences apparent but also differences between males and females were apparent within the major age classes (Fig. 22). CART analysis confirmed this (data not presented).

Since adults appeared to differ mostly from animals within the first year of life, adults and subadults were combined to be able to look at patterns in individuals across all locations within PWS (excluding yearlings and younger). CART correctly classified seals to location within PWS and year of collection with 92.1% accuracy (Fig. 23). Evidence suggested that not only did seal diets differ with location within PWS but also that the years 1996 and 1997 differed most from 1994 and 1995. The findings of location and year differences in fatty acid signatures between individuals (i.e., diet differences by location), suggest that individual harbor seals tend to forage and feed fairly site-specifically (Fig. 23). This can to some extent be tested using data from satellite-tagged seals (Frost et al. 1996 and 1997). A number of harbor seals were satellite-tagged in PWS at the time of blubber sampling. Unfortunately, due to logistic constraints, these animals are tagged and followed after they are sampled for fatty acids, but if we assume that in general seals may behave similarly after tagging as they did before tagging, we can look at distribution of these animals during the year following tagging and compare to information from their fatty acid signatures. The animals that were satellite-tagged in these years were all (n = 31) correctly identified to their location and year of deployment in this tree (Fig. 24). Unfortunately, four animals tagged in the SE in 1994 and 1995 (94-4, 95-2, 95-7 and 95-8) could not be included in this particular analysis because the sample size for their location groups was too small (< 4, Table 3) to be able to be used in CART. Data records from these animals indicate with few exceptions that animals tagged at a given location not only remained in the general region of initial capture in PWS, but most remained close to the specific haul-out site at which they were tagged throughout the study period (Frost et al. 1996 and 1997). These results suggest that differences in fatty acid signatures of seals from different locations, reflect specific foraging in each location.

Harbor Seal Body Composition 1997

The body composition of 25 harbor seals captured in June 1997 from SC and SE PWS is reported in Table 5. Pups (n = 12) averaged 32 kg body mass and were comprised of 43% fat and 13% protein. These animals were either about to be weaned or had recently been weaned. Yearlings averaged only 6 kg heavier, but were leaner at 23% body fat and 19% protein. Older subadults averaged 18-20% body fat (Table 5).

Modeling and Estimation of Harbor Seal Diets using Fatty Acid Signatures

The use of fatty acids to elucidate trophic relationships or differences among groups of animals had been demonstrated. The next stage is to use fatty acids to estimate diet composition. This requires the development of a statistical model which takes all possible prey species signatures and computes the most-likely mixture of signatures (species and levels) to create the closest signature (a maximum-likelihood estimate) to that of the predator and which includes an error component in the estimation. Such a statistical program must eventually incorporate information on a wide range of potential prey signatures and the variability in these signatures with size-class and geographical location, as well as season if applicable. The mathematical model must also incorporate a relative weighting of prey signatures that reflects the proximate fat content of each prey and size-class, and finally, a weighting on individual fatty acids as a function of their ability to be biosynthesized by the predator. The efforts to try to develop such a model are underway and the following summarizes the initial work in this area.

The issue is to try to estimate the composition of a seal's diet based on the relationship of its fatty acid signature to that of the typical prey that it might eat. Our initial approach has been to take a weighted mixture of the fatty acid profiles of the prey types and to choose the weighting which minimizes the distance from the seal or seals under consideration. The data we have used to develop the model is based on PWS harbor seals and prey signatures from the same area. Future work will incorporate information from captive studies conducted at Dalhousie University as well as collaboration with a similar type of ecosystem study as that in PWS being conducted on the Scotian Shelf. In the next paragraph, we outline the initial approach in more detail.

Let y_i be the fatty acid signature for the *i*th seal. This will be a vector where the *j*th entry is the percent of the *j*th fatty acid (e.g. 12:0, 13:0, Iso14). Note that the entries in the vector will sum to 100%. We denote x_{tk} to be the fatty acid acid signature for the *k*th prey of prey type *t* (e.g. herring {S,M,L}, pollock, etc.). Since seals eat a variety of prey of a given prey type, we used the "average" prey, where $\bar{x}_t$ is the mean composition vector for prey type *t*. We now want to find the weighted combination of the mean prey vectors which most closely resembles the given seal in terms of fatty acid profile. If we let $\boldsymbol{p}$ be a vector of the same length as the number of prey types, where the elements of $\boldsymbol{p}$ are positive and sum to 1, then we can think of a composite diet as being made up $100\,p_t$% of prey type *t*. In other words we have a composite prey $\hat{x} = \sum_t p_t \bar{x}_t$ which is a mixture of the individual prey types. Expressed mathematically, we want to find the probability vector p, such that the distance between the seal fatty acid profile, say y, and the composite prey $\hat{x}$ is minimized. The next step is to define a distance between the seal and the composite prey. Since both are vectors that sum to 1, we can think of both as discrete probability distributions. We have chosen to use the forward Kullback-Liebler distance to measure the distance. The distance between the compositional vectors y and $\hat{x}$ is given by

$$D(\hat{x},y) = \sum_j y_j \log(y_j / \hat{x}_j).$$

We then use a nonlinear optimization to find the minimizing vector, $\boldsymbol{p}$. The problem is then to find $\boldsymbol{p}$ to minimize

$$\sum_j y_j \log(y_j / (\sum_t p_t \bar{x}_t)\text{analysis}$$

As part of the development of the model we will try other distance measures including least squares and a robust measure.

We have currently implemented the algorithm to use two sets of fatty acids: all the fatty acids in common between prey and seals or to use only the fatty acids known to be of dietary origin (i.e. could not be biosynthesized by the seals). The algorithm can then be run to find the estimated composite diet either for an individual seal or for a group of seals.

To illustrate the procedures, we have completed several runs on PWS seals using the prey from that area. We view these results as preliminary and have included them to indicate the current state of the model building. Additionally, because of the time required for model building, only the subset of prey completed for an earlier report (n = 528) were used in the present analyses. To begin with a simpler set of data, we used 16 adult seals from SC PWS collected in 1996 and tried to find the composite prey using the common prey types. By "common prey types", we excluded from our initial modeling trials those prey species for which we had only a few individual analyses, since these might not be representative of the species. Again, our initial attempts were designed to simplify data sets in order to work on problems in the modeling program itself. We performed two sets of analyses: 1) based on all fatty acids, and 2) based on the dietary fatty acids only (generally those greater than 18:2n-6). In both cases we determined composite diets which best fit: a) each individual seal (i.e. a different composition for each seal), and b) which best fit the group of seals (i.e. one composite diet for all 16 seals).

1) If we use all fatty acids, the composite prey was a mixture of medium and large herring and Pacific cod. All the other 11 prey types had a weight of 0. This was true both a) when fitting each individual seal and b) when fitting all 16 seals as a group.

a) For the individual seals, the estimated percentages of the herrings and Pacific cod varied from seal to seal, ranging from 1-83% medium-sized herring (average 32.7 ± 6.47%), 0-75% large herring (30.8 ± 6.51%), and 11-62% Pacific cod (36.5 ± 4.27%). An example of the fit of a diet estimate to one of the seals is illustrated in both an absolute and a logit transformed plot (Figs. 25 and 26, respectively).

b) When all seals were fitted as a group, the estimate was 30.9% medium herring, 31.2% large herring and 37.8% Pacific cod. The fits of these diet estimates to the average seal are illustrated in both absolute and logit transformed plots (Figs. 27 and 28, respectively).

2) Turning to the analysis performed using only the dietary fatty acids:

a) When we determined results on an individual basis (considering each seal separately), individual variability was even more apparent and a larger suite of prey species was estimated to make up the diet: small herring (4.2 ± 1.83%), medium herring (6.0 ± 2.75%), large herring (65.9 ± 8.19%), squid (17.1 ± 4.33%), pink salmon smolts (2.5 ± 1.35%), tomcod (2.0 ± 1.00%), Pacific cod (1.0 ± 0.59%), octopus (0.7 ± 0.38%), and flatfish (0.4 ± 0.26%).

b) When all 16 seals were fit as a group, using only dietary fatty acids, the composite prey was made up of only medium and large herring (12.4% and 64.9%, respectively) plus squid (19.8%). Again, fits of these diet estimates to individual or groups of seals are illustrated in Figs. 29-32. As can be seen, the fits are reasonable for many of the fatty acids but show some discrepancy for others (Figs. 25-32). In our ongoing research we will be looking at techniques and modifications to assess the fits. We must also expand the models to fit methods for assessing the variability in our estimates of the composite prey; that is, given the known variability within prey species, it will likely not be appropriate to use a composite average for each species.

DISCUSSION

Prince William Sound is a large, complex estuarine system that also has characteristics of a small inland sea (Niebauer, Royer & Weingartner 1994). Localized habitats have differing depths (up to 700 m), temperatures, and salinities, and levels and patterns of glacial, fresh and saltwater input (Walters, Josberger & Driedger 1988; Niebauer et al. 1994) which are likely to result in different food web structures (e.g., Lalli & Parsons 1993). Since fatty acid signatures are significantly affected by spatial or temporal heterogeneity in habitats and food webs (Sargent et al. 1988; Iverson 1993; St. John & Lund 1996), analyses of fatty acids in harbor seals and their prey provide an opportunity to study the spatial scales of foraging and habitat use. Our findings support the notion of differences in habitat use and foraging on small spatial scales in both harbor seals and their prey in PWS, and at larger spatial scales elsewhere in the Gulf of Alaska.

Prey species in PWS differed notably in fatty acid composition and continue to be readily separated from one another using CART (Table 2, Fig. 2). Additionally, not only could species such as herring and pollock be differentiated from one another using fatty acid signatures, but they could also be distinguished by size-class and potentially location within PWS (Figs. 6-9; and Frost etal. 1997). Other prey species such as capelin and flatfish could also be identified by location or size class (Figs. 3-5 and 10-11). The finding that the fatty acid composition of species changes with body size indicates that the diets of these fish change with size and age. Indeed, fish such as pollock begin life feeding on small zooplankton, copepods eggs and nauplii, followed by larger zooplankton, and finally becoming piscivores as adults (Pereyra 1976; Frost & Lowry 1981; Lalli & Parsons 1993). Herring are thought to occupy lower trophic levels feeding mainly on zooplankton, but including small fishes as they get older (NRC 1996). Differences in fatty acid signatures in species such as herring within size classes continue to suggest localized habitat and feeding differences within areas of PWS, conclusions which were originally supported by the results of extensive stomach content analysis (Sturdevant 1996) of these species in PWS (as described in Frost et al. 1997). The fact that within-species differences in fish fatty acid composition are apparent and directly related to diet has been demonstrated in captive or controlled feeding studies (Kirsch et al. 1998). However despite this, prey are still able to be distinguished by species as a whole (this study; Kirsch et al. 1998).

Although our data among seasons for most prey species are limited, data for herring suggests that size-class is the most important factor influencing differences in fatty acid composition, followed by location (Figs. 6-9). The effects of season and year, while possibly evident, remain difficult to fully evaluate given the limitations of our data set. Fat content is likely to be affected by season (i.e. feeding level), with most species being highest in fat in the summer and fall and lowest in fat immediately after the wintering period, but this may also depend upon the area of collection. These patterns in fat content are most likely due to the fact that prey reduce or cease feeding during the winter months (e.g., Sturdevant 1996), resulting in a reduction of fat content. The apparent relative stability in fatty acid patterns among seasons and years (compared to size and location) remain in support of the notion that, even during poor feeding conditions, the original food web signature is retained in the existing lipid stores of the prey (Martin, Wright & Means 1984; St. John & Lund 1996).

Overall, results suggest that given a fatty acid composition of an unknown herring or pollock or other species, one could essentially determine its size-class and location within the study area with reasonable certainty if adequate sampling and analysis has been performed (e.g., Figs. 8-9). This could provide an important tool for studying foraging ecology and stock structure of fish species. Also, these prey characteristics should enhance the power of using fatty acids for examining foraging and feeding behavior in predators such as harbor seals within PWS, since they likely explain the different blubber fatty acid patterns of seals feeding in one area versus another.

Our data from harbor seal blubber fatty acid signatures, as well as from satellite telemetry data (Frost et al. 1997), suggests strongly that our initial conclusions were correct: that animals not only haul out site-specifically, but also forage and feed site-specifically. Within PWS over a spatial scale of about 80 km, differences observed in fatty acid patterns between harbor seals sampled in the SC, NE, NW, vs. SE areas indicate that these groups had different diets. Seals differed in fatty acid signatures, and hence likely feeding habits, even within small areas, such as Port Fidalgo and Port Gravina (see Fig. 1) separated by about 25 km in eastern PWS, or over a finer scale of 9-15 km in various bays and islands around Montague Island. Our results suggest that seals sampled at a particular haulout location had foraged and fed nearby or at least on the same general prey sources. Misclassifications in the CART trees could represent those seals which were simply more wide-ranging in their foraging patterns or that had highly individual feeding habits. These conclusions are supported by data on movements of satellite-tagged seals (Fig. 24). Of a large number of harbor seals tagged in PWS between 1992 and 1996, very few left PWS for any time, and most remained close to the specific location at which they were tagged throughout the study period (Frost et al. 1997). Overall, findings from fatty acid signature analysis and satellite telemetry suggest that harbor seals in PWS may depend on a very localized prey base.

Data on harbor seals have become increasingly available from other parts of Alaska, and fatty acid signature analysis also indicated differences in feeding on a broader geographical scale of 400-800 km in the GOA. Seals from other areas of the GOA (SEA, Yakutat and Kodiak) were distinguished from one another and from PWS animals (Fig. 13), and within smaller areas of SEA (Fig. 14).

In addition to general differences among locations, there was an indication that diets of seals changed over the 3-4 years of study (Figs. 19, 21, 23, 24). The most data is available for PWS seals and these data suggest that diets in 1996 may have shifted from those in 1994 and 1995, which may have coincided with a resurgence in capelin in 1996 (E. Brown, pers. comm.). Lastly, evidence indicates that the diets of demographic groups of seals differ. Although not all age-classes are available from all areas, it is clear that the diets of adults tend to differ from that of subadults and especially from that of subadults within the first year post-weaning. In the future, it will be important to document diet differences among age-groups in the declining PWS harbor seal population, as well as differences which occur in the same age-groups but in areas where the population is stable. It will also be important to compare this information with data available from time peri ods of lesser declines (1970's and 1980's) since we can clearly detect year differences. Recently, we have attempted the analysis of several archived blubber samples collected in the early 1970's and have found encouraging results (Table 6). That is, the samples were relatively clean and free of oxidation, which provides the opportunity to assess changes over a longer term period.

Juveniles in particular are thought to be significantly affected by reduced prey availability at relevant scales to the nutrition of individuals (NRC 1996). Thus, there could be several indications about stresses on juveniles through understanding diets. Small forage fish species such as capelin and sandlance have long been an important part of pinniped diets and a decline in these prey species may have affected the seal populations which depend upon them. If a reduction in these prey were apparent in the diets of adult seals in areas of decline, this would suggest a lower abundance of these prey in general. If indeed juveniles were found to be dependent on and limited to smaller size prey, this would coincide with the above finding. If juveniles were feeding on smaller but different prey than the small prey in adult diets, this might indicate competition with large animals for available food and further indication of low abundance of important forage fish species. Lastly, we now know from captive experiments, that if juveniles are forced to consume a low quality, low fat prey, they are simply unable to fatten, which could have severe consequences for newly weaned animals. Interestingly, the young animals that were studied in PWS in June of 1997, appeared to be in good condition (Table 5). In particular, newly weaned (or near-weaning) pups averaged about 7 kg more than the same age-group pups on Sable Island, NS (Muelbert, Bowen & Iverson, pers. comm.). Although body composition was similar in the two groups, because PWS pups were bigger, they had absolutely greater fat stores. The six PWS yearlings measured were about twice the fat content of yearlings measured on Sable Island. These results suggest that the animals we captured in 1997 were doing better than expected. Whether this is a trend representative of the population, or simply a function of the animals we were able to sample, requires further investigation.

The above discussion has addressed solely the differences observed in the fatty acid composition of the blubber of seals from various age-classes, locations, seasons and years. Through differences in fatty acid composition we have inferred differences in diet composition. Using fatty acids to determine the diet of seals is facilitated by the fact that seals go through bi-annual periods of extensive blubber fat depletion followed by intensive fattening and that 2-4 prey species often account for most of the diet of individuals. The aim of fatty acid signature analysis will now be to link specific prey species, in a quantitative manner, to observed differences in seals.

After several years' work, the prey library established in PWS has been expanded to an extent that we can begin to do this, especially for seals living in PWS, providing the development of a modeling program. The work on the development of mathematical models is now well-underway and is described in the Results section (Figs. 25-32). As described previously, future work will incorporate ground-truthing information from captive studies conducted at Dalhousie University as well as work with a similar type and size of ecosystem study (as that in PWS) being conducted on the Scotian Shelf. Several questions will be incorporated into future work including, how predictable is a compositie prey and how can the actual prey variability be incorporated? How can the best fit of diet be assessed? And finally, biosynthesis of some fatty acids will take place, thus altering their representation in the predator's signature; hence a weighting on specific fatty acids will be necessary to incorporate into the model. Again, aspects from studies being conducted in collaboration with the present study will be used to address these factors.

In conclusion, since harbor seals are likely to adjust their foraging patterns to changes in abundance of local prey (Olesiuk 1993; Tollit & Thompson 1996), this suggests that determining diets or changes in diets of harbor seals over time using fatty acid signatures may provide clues not only to changes in foraging patterns, but also to differences in local prey availability, predominant species size classes, and species abundance at the spatial and temporal scales that are essential to the nutrition of individual animals. The ability of fatty acid signatures to detect relationships between and within predators and prey on small spatial scales has previously demonstrated its use in understanding aspects of foraging ecology. The future possibility of quantitatively estimating diets will allow us to begin to specifically address hypotheses concerning the diets of both individuals and populations.

ACKNOWLEDGMENTS

We thank C. Beck, A. Bowen, J. Lassner, J. Marcus, J. Smith and L. Smith for laboratory assistance. This study was conducted as part of the *Exxon Valdez* Oil Spill Restoration Program, funded by the *Exxon Valdez* oil spill Trustee Council. This study was also supported in part by Natural Sciences and Engineering Research Council (NSERC) operating and equipment grants to S.J.I.

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Table 1: Collection data and Fat Content of PWS Prey Species Analyzed (n = 792).

Species		n	Locations	Years	Seasons	Length (cm) Mean ± SEM	range	Mass (g) Mean ± SEM	range	Fat Content (%) Mean ± SEM	range
Capelin		79	C,NE,NW,SC	1995,1996	all	12.8 ± 0.11	8.6 - 14.4	14.6 ± 0.54	2.2 - 25.8	1.5 ± 0.10	0.5 - 4.2
Chum		7	SE	1996	Sum	10.2 ± 0.68	8.3 - 14.0	10.6 ± 2.85	5.3 - 27.5	1.2 ± 0.07	1.0 - 1.5
Flatfish	Flathead Sole	33	NW,SC,SE	1995,1996	Sum, Fall	17.0 ± 0.69	8.7 - 26.2	45.2 ± 5.73	5.0 - 168.8	1.3 ± 0.10	0.6 - 3.0
Flatfish	Rex Sole	15	SE	1995,1996	Sum, Fall	18.1 ± 0.62	14.5 - 23.0	31.4 ± 3.92	3.0 - 64.4	1.0 ± 0.07	0.6 - 1.6
Flatfish	Unknown Sp.	24	NE	1995	Fall	19.7 ± 0.57	15.6 - 26.2	61.8 ± 6.78	23.1 - 168.3	0.9 ± 0.08	0.4 - 1.6
Flatfish	Yellowfin Sole	16	SC,NE	1994,1996	Sum, Fall	25.4 ± 0.97	19.7 - 33.1	207.9 ± 26.84	94.0 - 436.8	2.2 ± 0.36	1.0 - 5.3
Greenling		2	SC	1996	Fall	36.5 ± 0.80	35.7 - 37.3	573.4 ± 8.11	565.3 - 581.5	1.1 ± 0.08	1.0 - 1.2
Herring	Large	60	SC,SE	1995,1996	all	22.3 ± 0.20	20.2 - 26.7	115.2 ± 4.37	62.7 - 208.0	5.4 ± 0.41	1.1 - 13.2
Herring	Medium	62	SC,SE,SW	1994 - 1996	all	17.7 ± 0.22	14.5 - 20.1	58.0 ± 2.51	8.5 - 101.6	7.3 ± 0.52	1.7 - 19.1
Herring	Small	114	all	1994 - 1996	all	11.4 ± 0.13	8.4 - 14.0	14.0 ± 0.59	3.9 - 27.4	3.6 ± 0.18	0.5 - 10.7
Octopus		7	NE,SC	1994 - 1996	Sum, Fall	44.0 ± 6.53	23.0 - 71.6	722.0 ± 290.50	159.1 - 1858.0	1.0 ± 0.09	0.8 - 1.5
Pacific Cod		16	SE,SW	1994,1995	Sum, Fall	38.4 ± 17.6	17.3 - 302	84.9 ± 11.60	42.2 - 205.3	1.7 ± 0.25	0.5 - 3.6
Pink Salmon	Adult	5	NE	1996	Sum	47.8 ± 0.48	46.7 - 49.4	1438.9 ± 90.42	1238.7 - 1776.2	2.4 ± 0.35	1.7 - 3.4
Pink Salmon	Smolt	40	C,NE	1996	Sum	8.6 ± 0.24	6.7 - 12.3	6.2 ± 0.53	2.5 - 16.3	0.8 ± 0.03	0.5 - 1.6
Pollock	Large	54	all	1994 - 1996	all	21.3 ± 0.38	19.0 - 29.6	73.7 ± 4.52	40.9 - 180.1	1.7 ± 0.10	0.7 - 4.5
Pollock	Medium	73	all	1994 - 1996	all	16.5 ± 0.21	12.6 - 18.9	33.7 ± 1.03	14.1 - 52.8	2.0 ± 0.13	0.6 - 4.8
Pollock	Small	32	all	1994,1995	all	8.3 ± 0.39	5.2 - 11.3	4.5 ± 0.53	0.8 - 12.1	1.3 ± 0.11	0.6 - 3.9
Rainbow Smelt		4	n/a	1994	n/a	20.5 ± 0.55	19.6 - 21.5	73.4 ± 14.21	52.1 - 108.4	2.5 ± 0.60	1.8 - 4.1
Rockfish		1	C,NE,SE	1995	Fall	20.2		173.90		1.7	
Sandlance		40	C,NE,SE	1994 - 1996	all	12.0 ± 0.21	8.7 - 15.4	8.0 ± 0.34	1.8 - 13.6	2.6 ± 0.16	0.8 - 4.7
Shrimp		2*	SE	1994	Fall	n/a		n/a		1.6 ± 0.92	0.8 - 3.1
Squid		82	NW,SC,SE	1994 - 1996	all	26.1 ± 1.19	13.5 - 72.8	45.0 ± 5.50	5.2 - 345.4	1.6 ± 0.07	0.8 - 3.3
Tomcod	Large	14	NE	1995,1996	Sum, Fall	20.2 ± 0.90	16.2 - 29.1	70.2 ± 13.16	33.9 - 214.8	1.1 ± 0.09	0.7 - 1.8
Tomcod	Small	10	n/a	1996	Sum	8.8 ± 0.31	7.3 - 10.6	5.3 ± 0.74	2.3 - 10.8	0.6 ± 0.06	0.4 - 1.0

All values were derived from whole prey that were ground and analyzed individually. In cases where prey were to small to be analyzed seperately, several individuals were combined for analysis and considered to be an n of 1. See Fig. 1 for definition of locations (C, NE, NW, SC, SE, SW). Seasons included spring (Sp), summer (Sum) and Fall.

* Each sample consisted of 23 individual shrimp ground together.

Table 2: Fatty Acid Composition of PWS Prey Species (n = 792). Values are mean mass % of total fatty acids ± SEM. All values are derived from whole prey that were ground and analyzed individually. See Table 1 for collection and proximate data.

	Capelin	**Chum**	**Flatfish**		
			Flatfish Unk Sp.	**Flathead Sole**	**Rex Sole**
n	79	7	24	33	15
12:0	0.36 ± 0.044	0.02 ± 0.002	0.01 ± 0.002	0.03 ± 0.004	0.03 ± 0.005
13:0	0.01 ± 0.001	0.00 ± 0.001	0.02 ± 0.002	0.02 ± 0.001	0.06 ± 0.009
Iso14	0.02 ± 0.001	0.02 ± 0.003	0.03 ± 0.003	0.02 ± 0.003	0.02 ± 0.005
14:0	5.05 ± 0.308	1.35 ± 0.211	2.17 ± 0.124	2.45 ± 0.133	2.59 ± 0.206
14:1n-9	0.14 ± 0.010	0.05 ± 0.007	0.24 ± 0.033	0.22 ± 0.023	0.10 ± 0.011
14:1n-7	0.00 ± 0.001	0.01 ± 0.002	0.03 ± 0.004	0.05 ± 0.004	0.08 ± 0.007
14:1n-5	0.05 ± 0.005	0.01 ± 0.003	0.03 ± 0.004	0.05 ± 0.004	0.05 ± 0.007
Iso15	0.08 ± 0.006	0.06 ± 0.008	0.11 ± 0.007	0.14 ± 0.005	0.14 ± 0.015
Anti15	0.02 ± 0.003	0.02 ± 0.005	0.04 ± 0.004	0.06 ± 0.005	0.07 ± 0.011
15:0	0.23 ± 0.009	0.23 ± 0.005	0.40 ± 0.019	0.41 ± 0.012	0.77 ± 0.041
15:1n-8	0.00 ± 0.000	0.00 ± 0.000	0.02 ± 0.006	0.01 ± 0.002	0.02 ± 0.004
15:1n-6	0.00 ± 0.001	0.00 ± 0.000	0.03 ± 0.005	0.02 ± 0.003	0.03 ± 0.004
Iso16	0.19 ± 0.010	0.38 ± 0.022	0.79 ± 0.039	0.60 ± 0.021	0.69 ± 0.037
16:0	15.56 ± 0.217	21.36 ± 0.317	14.98 ± 0.183	15.43 ± 0.110	14.50 ± 0.219
16:1n-11	0.37 ± 0.013	0.29 ± 0.013	0.44 ± 0.008	0.54 ± 0.025	0.71 ± 0.032
16:1n-9	0.16 ± 0.024	0.65 ± 0.053	0.37 ± 0.015	0.35 ± 0.007	0.39 ± 0.013
16:1n-7	2.74 ± 0.168	2.09 ± 0.135	5.11 ± 0.461	7.84 ± 0.559	8.62 ± 0.771
7Me16:0	0.23 ± 0.008	0.19 ± 0.011	0.30 ± 0.009	0.48 ± 0.027	0.33 ± 0.026
16:1n-5	0.10 ± 0.005	0.08 ± 0.006	0.23 ± 0.010	0.35 ± 0.016	0.46 ± 0.022
16:2n-6	0.04 ± 0.005	0.04 ± 0.003	0.03 ± 0.006	0.05 ± 0.006	0.06 ± 0.007
Iso17	0.15 ± 0.021	0.07 ± 0.013	0.15 ± 0.013	0.20 ± 0.010	0.22 ± 0.015
16:2n-4	0.20 ± 0.011	0.40 ± 0.037	0.23 ± 0.029	0.35 ± 0.033	0.46 ± 0.052
16:3n-6	0.25 ± 0.026	0.06 ± 0.007	0.40 ± 0.025	0.44 ± 0.019	0.43 ± 0.062
17:0	0.15 ± 0.012	0.33 ± 0.013	0.28 ± 0.023	0.56 ± 0.069	0.93 ± 0.139
16:3n-4	0.24 ± 0.021	0.07 ± 0.005	0.21 ± 0.036	0.34 ± 0.023	0.21 ± 0.028
17:1	0.03 ± 0.005	0.16 ± 0.004	0.31 ± 0.037	0.26 ± 0.029	0.48 ± 0.027
16:3n-1	0.10 ± 0.006	0.25 ± 0.011	0.11 ± 0.005	0.25 ± 0.019	0.33 ± 0.040
16:4n-1	0.51 ± 0.055	0.29 ± 0.008	0.72 ± 0.042	0.73 ± 0.039	0.45 ± 0.032
18:0	2.48 ± 0.088	5.23 ± 0.158	4.94 ± 0.155	4.07 ± 0.101	4.64 ± 0.171
18:1n-13	0.04 ± 0.005	0.01 ± 0.004	0.10 ± 0.018	0.18 ± 0.026	0.59 ± 0.035
18:1n-11	0.59 ± 0.023	0.07 ± 0.011	0.16 ± 0.012	0.15 ± 0.018	0.13 ± 0.011
18:1n-9	6.38 ± 0.267	9.16 ± 0.226	8.68 ± 0.287	8.82 ± 0.344	4.65 ± 0.306
18:1n-7	2.17 ± 0.081	2.78 ± 0.103	4.57 ± 0.173	5.47 ± 0.158	5.84 ± 0.329
18:1n-5	0.53 ± 0.010	0.42 ± 0.027	0.34 ± 0.016	0.64 ± 0.032	0.39 ± 0.052
18:2d57	0.01 ± 0.001	0.13 ± 0.012	0.02 ± 0.003	0.03 ± 0.003	0.04 ± 0.004
18:2n-7	0.00 ± 0.001	0.05 ± 0.003	0.00 ± 0.003	0.03 ± 0.003	0.01 ± 0.005

Table 2: Fatty Acid Composition of PWS Prey Species (n = 792). Values are mean mass % of total fatty acids ± SEM. All values are derived from whole prey that were ground and analyzed individually. See Table 1 for collection and proximate data.

	Capelin	Chum	Flatfish		
			Flatfish Unk Sp.	Flathead Sole	Rex Sole
18:2n-6	0.75 ± 0.025	1.35 ± 0.172	0.77 ± 0.025	0.75 ± 0.015	0.69 ± 0.027
18:2n-4	0.16 ± 0.005	0.11 ± 0.007	0.14 ± 0.015	0.17 ± 0.009	0.18 ± 0.023
18:3n-6	0.03 ± 0.003	0.12 ± 0.010	0.13 ± 0.006	0.10 ± 0.008	0.16 ± 0.012
18:3n-4	0.05 ± 0.002	0.06 ± 0.006	0.10 ± 0.011	0.07 ± 0.006	0.08 ± 0.016
18:3n-3	0.52 ± 0.037	0.68 ± 0.073	0.26 ± 0.026	0.32 ± 0.025	0.19 ± 0.017
18:3n-1	0.10 ± 0.003	0.09 ± 0.006	0.23 ± 0.016	0.12 ± 0.009	0.11 ± 0.023
18:4n-3	1.11 ± 0.098	0.61 ± 0.072	0.78 ± 0.111	0.90 ± 0.070	0.64 ± 0.086
18:4n-1	0.19 ± 0.011	0.05 ± 0.003	0.04 ± 0.006	0.07 ± 0.007	0.07 ± 0.009
20:0	0.13 ± 0.005	0.07 ± 0.005	0.08 ± 0.003	0.08 ± 0.005	0.10 ± 0.013
20:1n-11	6.79 ± 0.447	0.21 ± 0.064	1.30 ± 0.112	1.08 ± 0.076	1.18 ± 0.066
20:1n-9	1.75 ± 0.091	0.46 ± 0.042	1.08 ± 0.045	1.01 ± 0.042	0.80 ± 0.082
R20:1	3.73 ± 0.123	0.43 ± 0.111	1.27 ± 0.139	1.10 ± 0.069	1.66 ± 0.212
20:1n-7	0.19 ± 0.010	0.15 ± 0.015	1.07 ± 0.134	1.14 ± 0.089	2.14 ± 0.065
20:1n-5	0.05 ± 0.004	0.01 ± 0.012	0.06 ± 0.004	0.04 ± 0.010	0.05 ± 0.008
20:2n-6	0.16 ± 0.007	0.24 ± 0.015	0.20 ± 0.007	0.26 ± 0.018	0.50 ± 0.028
20:3n-6	0.03 ± 0.002	0.17 ± 0.014	0.08 ± 0.002	0.07 ± 0.002	0.10 ± 0.004
20:4n-6	0.63 ± 0.050	2.04 ± 0.253	5.05 ± 0.312	3.10 ± 0.189	4.89 ± 0.328
20:3n-3	0.05 ± 0.004	0.14 ± 0.011	0.08 ± 0.009	0.10 ± 0.009	0.18 ± 0.019
20:4n-3	0.44 ± 0.016	0.63 ± 0.040	0.32 ± 0.026	0.39 ± 0.017	0.38 ± 0.025
20:5n-3	12.98 ± 0.320	10.19 ± 0.505	12.14 ± 0.325	14.99 ± 0.416	15.59 ± 0.425
22:1n-11	6.29 ± 0.505	0.12 ± 0.017	0.62 ± 0.074	0.49 ± 0.080	0.45 ± 0.030
22:1n-9	0.34 ± 0.021	0.08 ± 0.017	0.15 ± 0.013	0.17 ± 0.015	0.13 ± 0.012
R22:1	17.21 ± 0.774	1.65 ± 0.164	4.53 ± 0.492	2.65 ± 0.250	4.04 ± 0.430
22:1n-7	0.07 ± 0.005	0.08 ± 0.011	0.17 ± 0.011	0.23 ± 0.013	0.39 ± 0.014
22:2n-6	0.00 ± 0.001	0.00 ± 0.000	0.09 ± 0.012	0.02 ± 0.004	0.02 ± 0.010
21:5n-3	0.35 ± 0.007	0.19 ± 0.013	0.22 ± 0.016	0.34 ± 0.019	0.32 ± 0.019
22:4n-6	0.07 ± 0.007	0.11 ± 0.015	0.47 ± 0.031	0.37 ± 0.025	0.84 ± 0.057
22:5n-6	0.16 ± 0.007	0.45 ± 0.033	0.57 ± 0.022	0.46 ± 0.025	0.72 ± 0.054
22:4n-3	0.02 ± 0.002	0.04 ± 0.002	0.09 ± 0.012	0.02 ± 0.005	0.05 ± 0.007
22:5n-3	1.50 ± 0.042	2.53 ± 0.049	2.48 ± 0.059	2.69 ± 0.071	3.66 ± 0.110
22:6n-3	24.34 ± 0.948	31.81 ± 1.165	22.68 ± 0.889	17.84 ± 0.841	15.27 ± 0.635
24:1	1.19 ± 0.037	0.86 ± 0.026	1.19 ± 0.068	0.72 ± 0.041	0.41 ± 0.040

Table 2: Fatty Acid Composition of PWS Prey Species (n = 792). Values are mean mass % of total fatty acids ± SEM. All values are derived from whole prey that were ground and analyzed individually. See Table 1 for collection and proximate data.

	Flatfish	Herring			Octopus
	Yellowfin Sole	Large	Medium	Small	
n	16	60	62	114	7
12:0	0.04 ± 0.004	0.10 ± 0.014	0.07 ± 0.005	0.05 ± 0.002	0.04 ± 0.008
13:0	0.03 ± 0.003	0.02 ± 0.001	0.03 ± 0.001	0.03 ± 0.002	0.01 ± 0.003
Iso14	0.03 ± 0.002	0.02 ± 0.001	0.02 ± 0.001	0.02 ± 0.001	0.04 ± 0.008
14:0	3.92 ± 0.234	7.63 ± 0.145	6.74 ± 0.130	6.34 ± 0.219	1.47 ± 0.146
14:1n-9	0.36 ± 0.047	0.22 ± 0.006	0.31 ± 0.013	0.36 ± 0.012	0.11 ± 0.036
14:1n-7	0.07 ± 0.008	0.01 ± 0.001	0.02 ± 0.003	0.03 ± 0.002	0.02 ± 0.009
14:1n-5	0.10 ± 0.011	0.10 ± 0.003	0.09 ± 0.002	0.08 ± 0.004	0.07 ± 0.015
Iso15	0.23 ± 0.016	0.15 ± 0.004	0.20 ± 0.007	0.20 ± 0.008	0.08 ± 0.012
Anti15	0.12 ± 0.009	0.04 ± 0.002	0.07 ± 0.003	0.07 ± 0.003	0.04 ± 0.011
15:0	0.56 ± 0.018	0.28 ± 0.007	0.37 ± 0.010	0.43 ± 0.018	0.32 ± 0.041
15:1n-8	0.01 ± 0.003	0.01 ± 0.001	0.01 ± 0.001	0.01 ± 0.001	0.01 ± 0.004
15:1n-6	0.03 ± 0.004	0.00 ± 0.002	0.02 ± 0.004	0.00 ± 0.001	0.04 ± 0.020
Iso16	0.36 ± 0.053	0.05 ± 0.004	0.06 ± 0.003	0.13 ± 0.007	0.81 ± 0.123
16:0	12.92 ± 0.220	14.08 ± 0.246	17.46 ± 0.282	19.92 ± 0.183	15.13 ± 0.594
16:1n-11	0.86 ± 0.041	0.42 ± 0.017	0.49 ± 0.022	0.48 ± 0.012	0.40 ± 0.040
16:1n-9	0.39 ± 0.012	0.14 ± 0.005	0.17 ± 0.006	0.20 ± 0.008	0.16 ± 0.028
16:1n-7	10.05 ± 0.986	4.73 ± 0.173	5.85 ± 0.135	5.85 ± 0.175	2.29 ± 0.587
7Me16:0	0.28 ± 0.022	0.22 ± 0.013	0.27 ± 0.012	0.24 ± 0.008	0.22 ± 0.060
16:1n-5	0.35 ± 0.055	0.08 ± 0.008	0.10 ± 0.010	0.17 ± 0.007	0.33 ± 0.079
16:2n-6	0.20 ± 0.031	0.09 ± 0.006	0.11 ± 0.008	0.09 ± 0.005	0.10 ± 0.055
Iso17	0.19 ± 0.034	0.07 ± 0.009	0.22 ± 0.034	0.18 ± 0.023	0.12 ± 0.022
16:2n-4	0.66 ± 0.041	0.36 ± 0.026	0.27 ± 0.029	0.38 ± 0.016	0.09 ± 0.046
16:3n-6	0.42 ± 0.032	0.30 ± 0.026	0.28 ± 0.036	0.34 ± 0.022	0.06 ± 0.025
17:0	0.47 ± 0.047	0.13 ± 0.011	0.16 ± 0.009	0.21 ± 0.012	0.84 ± 0.102
16:3n-4	0.31 ± 0.037	0.29 ± 0.018	0.26 ± 0.019	0.31 ± 0.020	0.09 ± 0.036
17:1	0.39 ± 0.021	0.16 ± 0.011	0.18 ± 0.012	0.21 ± 0.011	0.08 ± 0.019
16:3n-1	0.20 ± 0.024	0.09 ± 0.005	0.09 ± 0.006	0.17 ± 0.010	0.15 ± 0.102
16:4n-1	0.48 ± 0.077	0.44 ± 0.048	0.55 ± 0.040	0.71 ± 0.062	0.39 ± 0.153
18:0	3.21 ± 0.161	1.57 ± 0.045	1.77 ± 0.042	2.28 ± 0.072	4.44 ± 0.410
18:1n-13	0.32 ± 0.054	0.06 ± 0.006	0.02 ± 0.003	0.04 ± 0.004	0.44 ± 0.062
18:1n-11	0.39 ± 0.067	0.61 ± 0.027	0.29 ± 0.020	0.10 ± 0.011	0.17 ± 0.034
18:1n-9	7.69 ± 0.978	10.76 ± 0.441	14.07 ± 0.434	12.21 ± 0.241	3.28 ± 0.800
18:1n-7	4.33 ± 0.208	2.20 ± 0.089	2.46 ± 0.069	2.66 ± 0.067	4.10 ± 0.370
18:1n-5	0.42 ± 0.041	0.56 ± 0.009	0.65 ± 0.023	0.59 ± 0.016	0.46 ± 0.025
18:2d57	0.05 ± 0.014	0.02 ± 0.002	0.04 ± 0.004	0.05 ± 0.003	0.02 ± 0.006
18:2n-7	0.02 ± 0.005	0.01 ± 0.002	0.03 ± 0.003	0.01 ± 0.002	0.07 ± 0.019

Table 2: Fatty Acid Composition of PWS Prey Species (n = 792). Values are mean mass % of total fatty acids ± SEM. All values are derived from whole prey that were ground and analyzed individually. See Table 1 for collection and proximate data.

	Flatfish	Herring			Octopus
	Yellowfin Sole	Large	Medium	Small	
18:2n-6	0.80 ± 0.041	0.81 ± 0.024	0.99 ± 0.025	1.13 ± 0.044	0.58 ± 0.065
18:2n-4	0.23 ± 0.011	0.11 ± 0.004	0.14 ± 0.004	0.18 ± 0.006	0.13 ± 0.028
18:3n-6	0.12 ± 0.013	0.05 ± 0.003	0.06 ± 0.003	0.08 ± 0.002	0.09 ± 0.025
18:3n-4	0.13 ± 0.010	0.05 ± 0.003	0.06 ± 0.003	0.06 ± 0.003	0.08 ± 0.022
18:3n-3	0.40 ± 0.052	0.62 ± 0.038	0.99 ± 0.061	0.94 ± 0.054	0.21 ± 0.049
18:3n-1	0.18 ± 0.017	0.05 ± 0.003	0.07 ± 0.003	0.10 ± 0.004	0.07 ± 0.023
18:4n-3	1.10 ± 0.070	1.45 ± 0.097	2.27 ± 0.156	2.22 ± 0.102	0.28 ± 0.084
18:4n-1	0.13 ± 0.007	0.14 ± 0.009	0.16 ± 0.007	0.16 ± 0.011	0.09 ± 0.017
20:0	0.10 ± 0.010	0.23 ± 0.005	0.14 ± 0.007	0.11 ± 0.004	0.19 ± 0.045
20:1n-11	4.24 ± 0.842	11.55 ± 0.410	4.31 ± 0.381	2.04 ± 0.247	1.50 ± 0.546
20:1n-9	1.43 ± 0.167	2.84 ± 0.078	2.98 ± 0.200	1.00 ± 0.056	3.81 ± 0.320
R20:1	2.64 ± 0.300	4.25 ± 0.180	1.60 ± 0.153	1.76 ± 0.152	0.41 ± 0.137
20:1n-7	1.99 ± 0.162	0.22 ± 0.007	0.24 ± 0.010	0.20 ± 0.009	1.01 ± 0.242
20:1n-5	0.13 ± 0.011	0.08 ± 0.005	0.07 ± 0.004	0.03 ± 0.005	0.11 ± 0.049
20:2n-6	0.39 ± 0.022	0.14 ± 0.005	0.18 ± 0.006	0.20 ± 0.008	0.57 ± 0.045
20:3n-6	0.12 ± 0.021	0.03 ± 0.002	0.03 ± 0.003	0.04 ± 0.001	0.06 ± 0.011
20:4n-6	2.61 ± 0.204	0.38 ± 0.019	0.43 ± 0.019	0.58 ± 0.024	5.60 ± 0.503
20:3n-3	0.14 ± 0.011	0.06 ± 0.011	0.08 ± 0.004	0.09 ± 0.006	0.73 ± 0.201
20:4n-3	0.48 ± 0.018	0.43 ± 0.017	0.64 ± 0.033	0.58 ± 0.020	0.27 ± 0.037
20:5n-3	14.18 ± 1.316	6.75 ± 0.191	9.56 ± 0.189	11.77 ± 0.210	18.27 ± 0.656
22:1n-11	2.24 ± 0.534	14.01 ± 0.504	6.64 ± 0.482	2.39 ± 0.264	1.16 ± 0.508
22:1n-9	0.27 ± 0.043	0.60 ± 0.020	0.45 ± 0.020	0.24 ± 0.014	0.76 ± 0.098
R22:1	6.39 ± 0.879	24.15 ± 0.932	14.25 ± 0.760	9.38 ± 0.935	1.26 ± 0.451
22:1n-7	0.23 ± 0.026	0.17 ± 0.004	0.14 ± 0.005	0.14 ± 0.004	0.24 ± 0.035
22:2n-6	0.03 ± 0.008	0.03 ± 0.018	0.01 ± 0.003	0.00 ± 0.001	0.13 ± 0.075
21:5n-3	0.37 ± 0.038	0.21 ± 0.012	0.29 ± 0.010	0.31 ± 0.008	0.47 ± 0.073
22:4n-6	0.52 ± 0.044	0.08 ± 0.018	0.04 ± 0.003	0.04 ± 0.003	0.56 ± 0.073
22:5n-6	0.42 ± 0.027	0.10 ± 0.004	0.14 ± 0.005	0.18 ± 0.006	0.46 ± 0.058
22:4n-3	0.06 ± 0.013	0.07 ± 0.022	0.05 ± 0.005	0.03 ± 0.003	0.03 ± 0.008
22:5n-3	3.14 ± 0.117	0.83 ± 0.021	0.75 ± 0.020	0.86 ± 0.025	2.45 ± 0.315
22:6n-3	12.76 ± 0.719	10.66 ± 0.420	13.02 ± 0.359	17.90 ± 0.657	21.57 ± 0.991
24:1	0.52 ± 0.066	0.87 ± 0.038	0.92 ± 0.020	0.97 ± 0.076	0.23 ± 0.068

Table 2: Fatty Acid Composition of PWS Prey Species (n = 792). Values are mean mass % of total fatty acids ± SEM. All values are derived from whole prey that were ground and analyzed individually. See Table 1 for collection and proximate data.

	Pacific Cod	**Pink salmon**		**Pollock**	
		Adult	**Smolts**	**Large**	**Medium**
n	16	5	40	54	73
12:0	0.02 ± 0.002	0.04 ± 0.006	0.02 ± 0.005	0.20 ± 0.129	0.14 ± 0.037
13:0	0.01 ± 0.001	0.03 ± 0.004	0.02 ± 0.002	0.10 ± 0.093	0.01 ± 0.001
Iso14	0.00 ± 0.001	0.02 ± 0.002	0.01 ± 0.002	0.19 ± 0.130	0.01 ± 0.001
14:0	1.57 ± 0.251	2.96 ± 0.155	1.99 ± 0.104	3.91 ± 0.161	4.15 ± 0.197
14:1n-9	0.08 ± 0.016	0.05 ± 0.006	0.05 ± 0.003	0.21 ± 0.009	0.15 ± 0.005
14:1n-7	0.01 ± 0.002	0.02 ± 0.001	0.02 ± 0.002	0.10 ± 0.092	0.01 ± 0.002
14:1n-5	0.03 ± 0.006	0.07 ± 0.005	0.00 ± 0.001	0.06 ± 0.003	0.06 ± 0.003
Iso15	0.07 ± 0.005	0.15 ± 0.007	0.13 ± 0.007	0.12 ± 0.005	0.11 ± 0.004
Anti15	0.02 ± 0.002	0.06 ± 0.002	0.06 ± 0.005	0.02 ± 0.002	0.02 ± 0.001
15:0	0.27 ± 0.010	0.42 ± 0.039	0.58 ± 0.022	0.26 ± 0.008	0.25 ± 0.007
15:1n-8	0.00 ± 0.001	0.00 ± 0.001	0.00 ± 0.001	0.38 ± 0.180	0.01 ± 0.001
15:1n-6	0.00 ± 0.002	0.00 ± 0.000	0.00 ± 0.001	0.10 ± 0.092	0.01 ± 0.003
Iso16	0.26 ± 0.021	0.15 ± 0.005	0.54 ± 0.016	0.16 ± 0.011	0.10 ± 0.010
16:0	14.75 ± 0.300	12.65 ± 0.530	18.41 ± 0.123	15.28 ± 0.309	14.27 ± 0.327
16:1n-11	0.41 ± 0.015	0.39 ± 0.028	0.57 ± 0.033	0.34 ± 0.007	0.36 ± 0.010
16:1n-9	0.38 ± 0.024	0.27 ± 0.014	0.40 ± 0.018	0.16 ± 0.006	0.15 ± 0.006
16:1n-7	2.91 ± 0.338	3.79 ± 0.172	2.32 ± 0.167	5.56 ± 0.267	5.38 ± 0.209
7Me16:0	0.18 ± 0.014	0.32 ± 0.034	0.27 ± 0.008	0.28 ± 0.007	0.31 ± 0.010
16:1n-5	0.14 ± 0.009	0.23 ± 0.023	0.22 ± 0.016	0.12 ± 0.008	0.11 ± 0.007
16:2n-6	0.11 ± 0.021	0.03 ± 0.003	0.03 ± 0.004	0.17 ± 0.091	0.12 ± 0.006
Iso17	0.07 ± 0.014	0.13 ± 0.012	0.12 ± 0.004	0.08 ± 0.005	0.07 ± 0.005
16:2n-4	0.56 ± 0.043	0.34 ± 0.016	0.63 ± 0.038	0.31 ± 0.027	0.43 ± 0.043
16:3n-6	0.12 ± 0.030	0.17 ± 0.013	0.06 ± 0.009	0.34 ± 0.037	0.32 ± 0.038
17:0	0.27 ± 0.025	0.26 ± 0.091	0.47 ± 0.013	0.43 ± 0.051	0.30 ± 0.036
16:3n-4	0.08 ± 0.028	0.41 ± 0.043	0.13 ± 0.013	0.28 ± 0.026	0.33 ± 0.050
17:1	0.28 ± 0.023	0.01 ± 0.004	0.09 ± 0.014	0.14 ± 0.012	0.09 ± 0.008
16:3n-1	0.23 ± 0.030	0.09 ± 0.039	0.23 ± 0.023	0.08 ± 0.007	0.07 ± 0.006
16:4n-1	0.28 ± 0.052	0.11 ± 0.022	0.23 ± 0.009	0.32 ± 0.025	0.68 ± 0.088
18:0	4.47 ± 0.231	3.91 ± 0.187	4.79 ± 0.107	2.99 ± 0.120	2.92 ± 0.122
18:1n-13	0.26 ± 0.034	0.14 ± 0.014	0.06 ± 0.008	0.08 ± 0.009	0.07 ± 0.006
18:1n-11	0.74 ± 0.145	1.09 ± 0.157	0.13 ± 0.018	1.02 ± 0.084	1.16 ± 0.080
18:1n-9	13.55 ± 0.795	12.30 ± 0.889	6.61 ± 0.180	9.51 ± 0.383	7.85 ± 0.412
18:1n-7	3.90 ± 0.137	2.82 ± 0.215	2.30 ± 0.068	3.45 ± 0.139	3.18 ± 0.181
18:1n-5	0.40 ± 0.019	0.63 ± 0.075	0.40 ± 0.022	0.41 ± 0.012	0.52 ± 0.017
18:2d57	0.05 ± 0.006	0.04 ± 0.003	0.11 ± 0.009	0.11 ± 0.092	0.03 ± 0.003
18:2n-7	0.02 ± 0.003	0.06 ± 0.011	0.12 ± 0.023	0.02 ± 0.003	0.03 ± 0.003

Table 2: Fatty Acid Composition of PWS Prey Species (n = 792). Values are mean mass % of total fatty acids ± SEM. All values are derived from whole prey that were ground and analyzed individually. See Table 1 for collection and proximate data.

	Pacific Cod	**Pink salmon**		**Pollock**	
		Adult	**Smolts**	**Large**	**Medium**
18:2n-6	0.60 ± 0.045	1.39 ± 0.083	1.32 ± 0.088	0.69 ± 0.025	0.68 ± 0.024
18:2n-4	0.12 ± 0.016	0.11 ± 0.009	0.10 ± 0.011	0.14 ± 0.005	0.15 ± 0.006
18:3n-6	0.06 ± 0.007	0.10 ± 0.007	0.12 ± 0.008	0.08 ± 0.002	0.08 ± 0.003
18:3n-4	0.08 ± 0.007	0.09 ± 0.007	0.05 ± 0.009	0.09 ± 0.005	0.08 ± 0.004
18:3n-3	0.34 ± 0.047	0.98 ± 0.108	1.13 ± 0.066	0.53 ± 0.038	0.51 ± 0.027
18:3n-1	0.16 ± 0.009	0.08 ± 0.008	0.15 ± 0.012	0.09 ± 0.006	0.09 ± 0.004
18:4n-3	0.41 ± 0.079	1.58 ± 0.141	0.89 ± 0.056	1.37 ± 0.081	1.79 ± 0.099
18:4n-1	0.06 ± 0.020	0.15 ± 0.016	0.04 ± 0.006	0.19 ± 0.015	0.23 ± 0.020
20:0	0.08 ± 0.005	0.07 ± 0.005	0.08 ± 0.003	0.08 ± 0.003	0.10 ± 0.005
20:1n-11	1.72 ± 0.332	2.53 ± 0.244	0.35 ± 0.084	5.65 ± 0.444	6.65 ± 0.489
20:1n-9	1.67 ± 0.192	1.69 ± 0.137	0.52 ± 0.055	2.15 ± 0.115	2.19 ± 0.072
R20:1	0.91 ± 0.129	1.49 ± 0.034	0.60 ± 0.086	2.52 ± 0.129	2.81 ± 0.160
20:1n-7	0.41 ± 0.066	0.25 ± 0.060	0.22 ± 0.013	0.20 ± 0.005	0.21 ± 0.005
20:1n-5	0.04 ± 0.008	0.08 ± 0.010	0.20 ± 0.036	0.07 ± 0.007	0.09 ± 0.004
20:2n-6	0.31 ± 0.015	0.31 ± 0.033	0.29 ± 0.010	0.20 ± 0.008	0.18 ± 0.006
20:3n-6	0.08 ± 0.005	0.11 ± 0.007	0.11 ± 0.008	0.05 ± 0.002	0.05 ± 0.002
20:4n-6	2.66 ± 0.220	0.98 ± 0.026	1.48 ± 0.043	0.80 ± 0.049	0.74 ± 0.052
20:3n-3	0.12 ± 0.008	0.15 ± 0.016	0.16 ± 0.007	0.17 ± 0.091	0.12 ± 0.028
20:4n-3	0.48 ± 0.054	1.91 ± 0.185	1.09 ± 0.044	0.60 ± 0.018	0.68 ± 0.033
20:5n-3	10.92 ± 0.527	12.87 ± 0.126	8.75 ± 0.257	11.48 ± 0.284	12.15 ± 0.237
22:1n-11	0.91 ± 0.204	3.60 ± 0.435	0.27 ± 0.056	5.95 ± 0.513	6.50 ± 0.484
22:1n-9	0.23 ± 0.027	0.43 ± 0.036	0.12 ± 0.019	0.80 ± 0.101	0.60 ± 0.031
R22:1	3.51 ± 0.602	8.38 ± 0.429	2.40 ± 0.337	8.20 ± 0.638	10.83 ± 0.768
22:1n-7	0.12 ± 0.014	0.08 ± 0.006	0.06 ± 0.008	0.17 ± 0.012	0.15 ± 0.006
22:2n-6	0.02 ± 0.009	0.02 ± 0.010	0.05 ± 0.010	0.02 ± 0.003	0.02 ± 0.002
21:5n-3	0.22 ± 0.026	0.33 ± 0.015	0.15 ± 0.008	0.33 ± 0.015	0.37 ± 0.014
22:4n-6	0.23 ± 0.029	0.05 ± 0.004	0.10 ± 0.006	0.07 ± 0.008	0.09 ± 0.007
22:5n-6	0.33 ± 0.037	0.14 ± 0.015	0.43 ± 0.037	0.18 ± 0.012	0.18 ± 0.015
22:4n-3	0.03 ± 0.004	0.06 ± 0.004	0.07 ± 0.003	0.06 ± 0.007	0.12 ± 0.015
22:5n-3	2.30 ± 0.187	4.40 ± 0.175	2.53 ± 0.030	1.19 ± 0.034	1.16 ± 0.031
22:6n-3	27.24 ± 2.114	20.40 ± 0.430	36.02 ± 0.602	19.13 ± 0.764	18.37 ± 0.805
24:1	1.13 ± 0.089	0.57 ± 0.062	0.72 ± 0.029	1.03 ± 0.054	1.09 ± 0.040

Table 2: Fatty Acid Composition of PWS Prey Species (n = 792). Values are mean mass % of total fatty acids ± SEM. All values are derived from whole prey that were ground and analyzed individually. See Table 1 for collection and proximate data.

	Pollock Small	Rainbow Smelt	Rockfish	Sandlance	Shrimp
n	32	4	1	40	2
12:0	0.05 ± 0.026	0.07 ± 0.009	0.10	0.08 ± 0.008	0.13 ± 0.005
13:0	0.01 ± 0.003	0.01 ± 0.003	0.01	0.03 ± 0.001	0.04 ± 0.010
Iso14	0.02 ± 0.004	0.01 ± 0.003	0.01	0.03 ± 0.001	0.09 ± 0.005
14:0	2.60 ± 0.212	2.59 ± 0.349	3.44	5.68 ± 0.268	2.90 ± 0.110
14:1n-9	0.19 ± 0.014	0.06 ± 0.013	0.20	0.31 ± 0.016	0.05 ± 0.005
14:1n-7	0.01 ± 0.002	0.02 ± 0.000	0.03	0.03 ± 0.002	0.01 ± 0.005
14:1n-5	0.04 ± 0.006	0.19 ± 0.046	0.08	0.07 ± 0.004	0.07 ± 0.010
Iso15	0.11 ± 0.009	0.07 ± 0.010	0.12	0.22 ± 0.010	0.20 ± 0.030
Anti15	0.04 ± 0.006	0.02 ± 0.003	0.04	0.10 ± 0.005	0.05 ± 0.010
15:0	0.31 ± 0.014	0.27 ± 0.028	0.31	0.41 ± 0.016	0.73 ± 0.105
15:1n-8	0.00 ± 0.001	0.01 ± 0.000	0.01	0.02 ± 0.002	0.00 ± 0.000
15:1n-6	0.00 ± 0.000	0.00 ± 0.003	0.00	0.00 ± 0.001	0.04 ± 0.010
Iso16	0.30 ± 0.014	0.10 ± 0.034	0.19	0.17 ± 0.009	0.67 ± 0.020
16:0	17.79 ± 0.323	18.12 ± 0.387	17.22	18.59 ± 0.389	15.39 ± 1.245
16:1n-11	0.45 ± 0.022	0.22 ± 0.024	0.45	0.51 ± 0.018	0.80 ± 0.070
16:1n-9	0.22 ± 0.010	0.34 ± 0.036	0.25	0.19 ± 0.013	0.20 ± 0.010
16:1n-7	3.06 ± 0.264	10.47 ± 1.651	6.28	5.93 ± 0.346	5.06 ± 0.320
7Me16:0	0.24 ± 0.042	0.00 ± 0.000	0.26	0.22 ± 0.022	0.00 ± 0.000
16:1n-5	0.15 ± 0.010	0.15 ± 0.010	0.14	0.18 ± 0.009	0.05 ± 0.005
16:2n-6	0.09 ± 0.011	0.15 ± 0.038	0.23	0.11 ± 0.005	0.47 ± 0.025
Iso17	0.09 ± 0.009	0.02 ± 0.003	0.12	0.14 ± 0.006	0.28 ± 0.035
16:2n-4	0.45 ± 0.028	0.28 ± 0.105	0.41	0.46 ± 0.020	0.10 ± 0.010
16:3n-6	0.22 ± 0.033	0.23 ± 0.141	0.24	0.36 ± 0.028	0.34 ± 0.060
17:0	0.13 ± 0.019	0.23 ± 0.038	0.31	0.25 ± 0.029	0.50 ± 0.060
16:3n-4	0.55 ± 0.067	0.04 ± 0.007	0.21	0.38 ± 0.031	0.14 ± 0.055
17:1	0.16 ± 0.027	0.30 ± 0.043	0.38	0.19 ± 0.013	0.98 ± 0.250
16:3n-1	0.12 ± 0.006	0.08 ± 0.009	0.13	0.21 ± 0.013	0.18 ± 0.010
16:4n-1	0.41 ± 0.070	0.13 ± 0.031	0.35	0.78 ± 0.063	0.49 ± 0.010
18:0	3.87 ± 0.130	3.80 ± 0.211	4.15	2.61 ± 0.103	2.71 ± 0.030
18:1n-13	0.07 ± 0.011	0.10 ± 0.009	0.22	0.13 ± 0.020	0.11 ± 0.000
18:1n-11	0.55 ± 0.064	0.10 ± 0.021	0.43	0.18 ± 0.030	0.20 ± 0.050
18:1n-9	9.52 ± 0.289	18.42 ± 2.628	14.21	10.80 ± 0.652	10.91 ± 0.005
18:1n-7	3.16 ± 0.228	4.76 ± 0.114	3.85	2.20 ± 0.088	5.63 ± 0.095
18:1n-5	0.60 ± 0.059	0.46 ± 0.042	0.62	0.58 ± 0.031	0.50 ± 0.050
18:2d57	0.05 ± 0.007	0.23 ± 0.109	0.06	0.07 ± 0.005	0.03 ± 0.000
18:2n-7	0.04 ± 0.005	0.02 ± 0.003	0.02	0.02 ± 0.004	0.04 ± 0.010

Table 2: Fatty Acid Composition of PWS Prey Species (n = 792). Values are mean mass % of total fatty acids ± SEM. All values are derived from whole prey that were ground and analyzed individually. See Table 1 for collection and proximate data.

	Pollock Small	**Rainbow Smelt**	**Rockfish**	**Sandlance**	**Shrimp**
18:2n-6	0.80 ± 0.059	0.54 ± 0.181	0.98	1.40 ± 0.089	0.78 ± 0.015
18:2n-4	0.12 ± 0.008	0.10 ± 0.013	0.14	0.17 ± 0.010	0.14 ± 0.000
18:3n-6	0.08 ± 0.004	0.06 ± 0.015	0.07	0.10 ± 0.005	0.04 ± 0.005
18:3n-4	0.08 ± 0.010	0.05 ± 0.006	0.06	0.06 ± 0.003	0.06 ± 0.035
18:3n-3	0.59 ± 0.050	0.30 ± 0.134	0.69	1.11 ± 0.069	0.64 ± 0.025
18:3n-1	0.13 ± 0.008	0.16 ± 0.027	0.14	0.15 ± 0.007	0.04 ± 0.010
18:4n-3	1.49 ± 0.095	0.25 ± 0.049	1.49	2.78 ± 0.185	0.47 ± 0.065
18:4n-1	0.11 ± 0.022	0.02 ± 0.003	0.11	0.15 ± 0.013	0.07 ± 0.000
20:0	·0.07 ± 0.005	0.10 ± 0.007	0.11	0.11 ± 0.007	0.20 ± 0.015
20:1n-11	1.48 ± 0.443	0.40 ± 0.078	2.07	2.23 ± 0.478	1.98 ± 0.165
20:1n-9	1.52 ± 0.119	0.62 ± 0.139	1.11	1.47 ± 0.168	1.32 ± 0.080
R20:1	0.72 ± 0.156	0.84 ± 0.330	1.87	1.39 ± 0.218	1.51 ± 0.216
20:1n-7	0.15 ± 0.010	0.25 ± 0.148	0.37	0.37 ± 0.050	1.20 ± 0.225
20:1n-5	0.09 ± 0.005	0.07 ± 0.006	0.10	0.07 ± 0.011	0.10 ± 0.015
20:2n-6	0.23 ± 0.009	0.16 ± 0.017	0.26	0.29 ± 0.022	0.42 ± 0.015
20:3n-6	0.05 ± 0.002	0.05 ± 0.014	0.06	0.04 ± 0.002	0.05 ± 0.005
20:4n-6	0.92 ± 0.050	1.74 ± 0.467	1.80	0.57 ± 0.051	2.46 ± 0.140
20:3n-3	0.09 ± 0.004	0.03 ± 0.008	0.10	0.11 ± 0.006	0.17 ± 0.020
20:4n-3	0.64 ± 0.025	0.20 ± 0.011	0.49	0.65 ± 0.028	0.28 ± 0.010
20:5n-3	12.89 ± 0.338	8.80 ± 0.535	9.38	13.08 ± 0.366	17.26 ± 0.170
22:1n-11	1.58 ± 0.387	0.15 ± 0.012	1.50	2.84 ± 0.555	1.99 ± 0.095
22:1n-9	0.46 ± 0.047	0.14 ± 0.028	0.24	0.27 ± 0.018	0.65 ± 0.090
R22:1	3.05 ± 0.625	1.19 ± 0.182	6.23	8.41 ± 1.420	3.09 ± 0.282
22:1n-7	0.13 ± 0.012	0.00 ± 0.000	0.12	0.14 ± 0.008	0.30 ± 0.005
22:2n-6	0.07 ± 0.018	0.02 ± 0.000	0.04	0.01 ± 0.002	0.04 ± 0.020
21:5n-3	0.31 ± 0.021	0.16 ± 0.017	0.22	0.36 ± 0.020	0.28 ± 0.030
22:4n-6	0.12 ± 0.014	0.13 ± 0.029	0.20	0.04 ± 0.007	0.43 ± 0.070
22:5n-6	0.23 ± 0.008	0.26 ± 0.064	0.32	0.20 ± 0.009	0.24 ± 0.020
22:4n-3	0.05 ± 0.010	0.05 ± 0.011	0.07	0.05 ± 0.003	0.03 ± 0.005
22:5n-3	0.97 ± 0.037	1.47 ± 0.208	1.33	0.85 ± 0.024	1.37 ± 0.150
22:6n-3	27.07 ± 1.140	20.22 ± 2.652	20.01	16.82 ± 0.792	15.26 ± 0.105
24:1	1.24 ± 0.050	0.90 ± 0.107	0.88	1.06 ± 0.055	0.78 ± 0.005

Table 2: Fatty Acid Composition of PWS Prey Species (n = 792). Values are mean mass % of total fatty acids ± SEM. All values are derived from whole prey that were ground and analyzed individually. See Table 1 for collection and proximate data.

	Squid	**Tomcod**	
		Large	**Small**
n	82	14	10
12:0	0.16 ± 0.056	0.02 ± 0.002	0.01 ± 0.001
13:0	0.01 ± 0.002	0.00 ± 0.001	0.01 ± 0.000
Iso14	0.05 ± 0.006	0.01 ± 0.003	0.01 ± 0.001
14:0	2.36 ± 0.095	1.43 ± 0.115	1.33 ± 0.097
14:1n-9	0.11 ± 0.004	0.08 ± 0.012	0.14 ± 0.013
14:1n-7	0.05 ± 0.008	0.03 ± 0.005	0.02 ± 0.002
14:1n-5	0.09 ± 0.006	0.02 ± 0.003	0.00 ± 0.001
Iso15	0.05 ± 0.003	0.15 ± 0.016	0.13 ± 0.005
Anti15	0.02 ± 0.004	0.04 ± 0.008	0.05 ± 0.003
15:0	0.37 ± 0.033	0.52 ± 0.038	0.40 ± 0.016
15:1n-8	0.00 ± 0.001	0.01 ± 0.003	0.00 ± 0.001
15:1n-6	0.01 ± 0.001	0.01 ± 0.003	0.00 ± 0.000
Iso16	0.62 ± 0.024	0.32 ± 0.029	0.41 ± 0.018
16:0	19.12 ± 0.266	14.98 ± 0.174	16.54 ± 0.129
16:1n-11	0.28 ± 0.019	0.54 ± 0.043	0.57 ± 0.021
16:1n-9	0.11 ± 0.004	0.47 ± 0.015	0.40 ± 0.008
16:1n-7	3.13 ± 0.261	3.83 ± 0.280	1.78 ± 0.093
7Me16:0	0.21 ± 0.008	0.26 ± 0.016	0.25 ± 0.013
16:1n-5	0.17 ± 0.009	0.34 ± 0.042	0.28 ± 0.014
16:2n-6	0.01 ± 0.003	0.16 ± 0.055	0.03 ± 0.002
Iso17	0.06 ± 0.009	0.29 ± 0.029	0.16 ± 0.009
16:2n-4	0.20 ± 0.014	0.46 ± 0.046	0.88 ± 0.055
16:3n-6	0.21 ± 0.022	0.10 ± 0.022	0.06 ± 0.005
17:0	0.50 ± 0.066	0.67 ± 0.046	0.52 ± 0.029
16:3n-4	0.08 ± 0.013	0.32 ± 0.065	0.21 ± 0.012
17:1	0.08 ± 0.012	0.27 ± 0.085	0.01 ± 0.003
16:3n-1	0.19 ± 0.015	0.04 ± 0.010	0.07 ± 0.005
16:4n-1	0.14 ± 0.011	0.30 ± 0.029	0.34 ± 0.022
18:0	2.19 ± 0.031	5.05 ± 0.184	4.95 ± 0.117
18:1n-13	0.09 ± 0.003	1.05 ± 0.177	0.25 ± 0.066
18:1n-11	0.31 ± 0.029	0.52 ± 0.265	0.13 ± 0.011
18:1n-9	9.27 ± 0.422	8.21 ± 0.622	7.56 ± 0.227
18:1n-7	3.89 ± 0.183	5.35 ± 0.308	2.43 ± 0.104
18:1n-5	0.55 ± 0.017	0.38 ± 0.025	0.41 ± 0.020
18:2d57	0.02 ± 0.005	0.02 ± 0.007	0.04 ± 0.006
18:2n-7	0.05 ± 0.009	0.03 ± 0.007	0.08 ± 0.015

Table 2: Fatty Acid Composition of PWS Prey Species (n = 792). Values are mean mass % of total fatty acids ± SEM. All values are derived from whole prey that were ground and analyzed individually. See Table 1 for collection and proximate data.

	Squid	Tomcod	
		Large	Small
18:2n-6	0.74 ± 0.018	0.99 ± 0.196	1.14 ± 0.073
18:2n-4	0.13 ± 0.004	0.14 ± 0.009	0.13 ± 0.015
18:3n-6	0.05 ± 0.005	0.13 ± 0.017	0.15 ± 0.007
18:3n-4	0.03 ± 0.003	0.09 ± 0.014	0.05 ± 0.006
18:3n-3	0.31 ± 0.021	0.67 ± 0.118	0.72 ± 0.045
18:3n-1	0.07 ± 0.005	0.14 ± 0.023	0.24 ± 0.025
18:4n-3	0.57 ± 0.062	0.76 ± 0.116	1.02 ± 0.095
18:4n-1	0.05 ± 0.004	0.07 ± 0.009	0.02 ± 0.012
20:0	0.11 ± 0.011	0.08 ± 0.009	0.14 ± 0.010
20:1n-11	2.30 ± 0.208	0.80 ± 0.102	0.36 ± 0.086
20:1n-9	2.82 ± 0.091	0.91 ± 0.131	0.66 ± 0.043
R20:1	0.79 ± 0.054	1.02 ± 0.167	0.58 ± 0.151
20:1n-7	0.18 ± 0.009	1.16 ± 0.144	0.28 ± 0.057
20:1n-5	0.04 ± 0.011	0.06 ± 0.009	0.25 ± 0.033
20:2n-6	0.65 ± 0.024	0.65 ± 0.063	0.44 ± 0.019
20:3n-6	0.05 ± 0.007	0.17 ± 0.017	0.10 ± 0.012
20:4n-6	0.85 ± 0.031	3.21 ± 0.213	1.91 ± 0.229
20:3n-3	0.88 ± 0.041	0.29 ± 0.032	0.18 ± 0.007
20:4n-3	0.38 ± 0.015	0.53 ± 0.038	0.53 ± 0.016
20:5n-3	15.82 ± 0.189	15.27 ± 0.551	12.74 ± 0.413
22:1n-11	1.49 ± 0.146	0.20 ± 0.043	0.08 ± 0.012
22:1n-9	0.39 ± 0.017	0.10 ± 0.015	0.07 ± 0.005
R22:1	3.64 ± 0.286	2.50 ± 0.473	1.07 ± 0.122
22:1n-7	0.09 ± 0.004	0.11 ± 0.019	0.06 ± 0.005
22:2n-6	0.01 ± 0.001	0.10 ± 0.021	0.09 ± 0.010
21:5n-3	0.39 ± 0.008	0.28 ± 0.015	0.20 ± 0.011
22:4n-6	0.04 ± 0.010	0.90 ± 0.102	0.14 ± 0.020
22:5n-6	0.15 ± 0.004	0.42 ± 0.031	0.33 ± 0.005
22:4n-3	0.01 ± 0.008	0.04 ± 0.006	0.04 ± 0.004
22:5n-3	0.54 ± 0.014	4.57 ± 0.394	1.26 ± 0.159
22:6n-3	25.48 ± 0.919	19.52 ± 1.432	34.56 ± 0.920
24:1	0.44 ± 0.018	0.52 ± 0.062	0.95 ± 0.047

Table 3: Collection data for Harbor Seal Blubber Samples Analyzed (n = 296).

			Number of Individuals Sampled						
Year	Area	Location	Adults	Sub Adults > 40 kg	Sub Adults < 40 kg	Yearlings	Half Years	Pups	n/a
1994	PWS	NE	-	1	-	-	2	-	-
		NW	3	1	-	-	-	-	-
		SC	13	8	7	-	2	-	-
		SE	1	-	1	-	1	-	-
	GOA		-	-	-	-	-	-	-
1995	PWS	NW	-	2	3	-	-	-	-
		SC	14	10	7	1	1	-	-
		SE	-	1	2	-	1	-	-
	GOA	Kodiak N.	4	2	-	2	-	-	-
		SEA	15	2	1	1	1	-	3
1996	PWS	SC	25	9	5	3	4	-	4
		SE	17	1	5	1	4	-	-
		SW	-	1	-	-	1	-	-
	GOA	Kodiak N.	8	-	1	-	1	-	-
		SCA	6	2	3	-	-	-	-
		SEA	9	2	3	-	-	-	10
1997	PWS	SC	10	8	3	5	-	16	-
		SE	1	1	-	2	-	2	-
	GOA	Kodiak S.	-	-	-	-	-	10	-
		Total	126	51	41	15	18	28	17 $\boxed{296}$

Animals from 1994 - 1996 which were initially listed as "pups" but captured either in the fall (*ie.* Sept., Oct.) or early spring (*ie.* March, April) were deemed to actually be half-year-olds and yearlings, respectively. "Pups" as contained herein refers only to actual suckling or newly weaned pups (within the first few weeks) captured in June. Some animals captured in June 1997 were also known to be yearlings. Subadults (both > and < 40 kg) were combined for most analyses.

Table 4: Fatty Acid Composition of Harbor Seal Blubber (n = 279). Values are mean mass % of total fatty acids ± SEM. See Table 3 for summary of collection data.

	PRINCE WILLIAM SOUND				
	NE	**NW**	**SC**		
	All Groups	**All Groups**	**Adults**	**Sub Adults**	**Yearlings**
n	3	9	62	57	9
12:0	0.23 ± 0.009	0.16 ± 0.014	0.11 ± 0.004	0.12 ± 0.005	0.13 ± 0.010
13:0	0.00 ± 0.000	0.01 ± 0.002	0.01 ± 0.001	0.01 ± 0.001	0.02 ± 0.001
Iso14	0.00 ± 0.000	0.01 ± 0.004	0.02 ± 0.001	0.02 ± 0.001	0.02 ± 0.001
14:0	4.38 ± 0.131	3.96 ± 0.192	4.60 ± 0.137	5.55 ± 0.122	5.66 ± 0.337
14:1n-9	0.05 ± 0.029	0.09 ± 0.017	0.10 ± 0.005	0.12 ± 0.006	0.12 ± 0.012
14:1n-7	0.10 ± 0.012	0.10 ± 0.014	0.06 ± 0.002	0.08 ± 0.003	0.08 ± 0.007
14:1n-5	1.98 ± 0.171	2.33 ± 0.239	1.23 ± 0.058	1.77 ± 0.074	1.67 ± 0.224
Iso15	0.15 ± 0.032	0.10 ± 0.006	0.12 ± 0.002	0.12 ± 0.002	0.12 ± 0.006
Anti15	0.05 ± 0.024	0.04 ± 0.007	0.06 ± 0.002	0.05 ± 0.002	0.05 ± 0.004
15:0	0.34 ± 0.029	0.22 ± 0.008	0.26 ± 0.006	0.24 ± 0.004	0.26 ± 0.006
15:1n-8	0.00 ± 0.000	0.00 ± 0.002	0.01 ± 0.003	0.02 ± 0.004	0.01 ± 0.001
15:1n-6	0.10 ± 0.014	0.09 ± 0.007	0.06 ± 0.003	0.07 ± 0.004	0.06 ± 0.006
Iso16	0.08 ± 0.004	0.07 ± 0.005	0.07 ± 0.004	0.06 ± 0.003	0.07 ± 0.003
16:0	10.23 ± 0.564	7.78 ± 0.343	8.60 ± 0.215	9.08 ± 0.155	10.09 ± 0.329
16:1n-11	0.76 ± 0.151	0.54 ± 0.038	0.69 ± 0.036	0.61 ± 0.021	0.62 ± 0.053
16:1n-9	0.58 ± 0.076	0.56 ± 0.021	0.40 ± 0.008	0.42 ± 0.011	0.42 ± 0.022
16:1n-7	21.27 ± 1.988	21.87 ± 1.378	14.03 ± 0.343	16.97 ± 0.532	16.77 ± 1.349
7Me16:0	0.27 ± 0.007	0.26 ± 0.009	0.26 ± 0.004	0.27 ± 0.004	0.25 ± 0.008
16:1n-5	0.00 ± 0.000	0.03 ± 0.011	0.13 ± 0.012	0.09 ± 0.010	0.17 ± 0.017
16:2n-6	0.33 ± 0.064	0.17 ± 0.023	0.13 ± 0.012	0.12 ± 0.009	0.09 ± 0.011
Iso17	0.10 ± 0.004	0.05 ± 0.010	0.11 ± 0.007	0.08 ± 0.005	0.10 ± 0.012
16:2n-4	0.33 ± 0.038	0.15 ± 0.033	0.29 ± 0.017	0.24 ± 0.022	0.24 ± 0.025
16:3n-6	0.23 ± 0.008	0.41 ± 0.035	0.35 ± 0.021	0.44 ± 0.026	0.43 ± 0.038
17:0	0.21 ± 0.049	0.11 ± 0.009	0.19 ± 0.014	0.16 ± 0.013	0.22 ± 0.049
16:3n-4	0.12 ± 0.002	0.15 ± 0.024	0.27 ± 0.015	0.26 ± 0.010	0.27 ± 0.025
17:1	0.56 ± 0.028	0.44 ± 0.017	0.29 ± 0.029	0.26 ± 0.024	0.26 ± 0.049
16:3n-1	0.15 ± 0.004	0.08 ± 0.014	0.10 ± 0.006	0.08 ± 0.006	0.09 ± 0.008
16:4n-1	0.01 ± 0.010	0.13 ± 0.040	0.20 ± 0.019	0.26 ± 0.029	0.22 ± 0.058
18:0	1.23 ± 0.192	0.82 ± 0.063	1.09 ± 0.036	0.99 ± 0.030	1.19 ± 0.074
18:1n-13	0.26 ± 0.053	0.14 ± 0.034	0.36 ± 0.010	0.31 ± 0.009	0.29 ± 0.020
18:1n-11	1.88 ± 0.130	1.34 ± 0.194	2.96 ± 0.138	2.65 ± 0.137	2.73 ± 0.268
18:1n-9	22.68 ± 2.866	26.15 ± 1.887	23.20 ± 0.602	24.12 ± 0.731	23.87 ± 1.793
18:1n-7	4.26 ± 0.165	4.61 ± 0.234	3.91 ± 0.086	3.99 ± 0.101	4.18 ± 0.309
18:1n-5	0.50 ± 0.044	0.43 ± 0.015	0.48 ± 0.008	0.45 ± 0.006	0.46 ± 0.016
18:2d57	0.16 ± 0.036	0.11 ± 0.016	0.05 ± 0.004	0.08 ± 0.006	0.08 ± 0.009

Table 4: Fatty Acid Composition of Harbor Seal Blubber (n = 279). Values are mean mass % of total fatty acids ± SEM. See Table 3 for summary of collection data.

	PRINCE WILLIAM SOUND				
	NE	NW	SC		
	All Groups	All Groups	Adults	Sub Adults	Yearlings
18:2n-7	0.20 ± 0.029	0.16 ± 0.007	0.08 ± 0.005	0.10 ± 0.006	0.09 ± 0.008
18:2n-6	0.91 ± 0.097	1.03 ± 0.041	1.09 ± 0.018	0.99 ± 0.019	0.98 ± 0.029
18:2n-4	0.14 ± 0.027	0.14 ± 0.018	0.11 ± 0.004	0.11 ± 0.004	0.11 ± 0.008
18:3n-6	0.08 ± 0.019	0.06 ± 0.008	0.05 ± 0.003	0.06 ± 0.003	0.08 ± 0.006
18:3n-4	0.14 ± 0.005	0.12 ± 0.012	0.12 ± 0.006	0.12 ± 0.005	0.09 ± 0.011
18:3n-3	0.51 ± 0.117	0.56 ± 0.039	0.66 ± 0.019	0.60 ± 0.024	0.50 ± 0.039
18:3n-1	0.04 ± 0.023	0.04 ± 0.008	0.05 ± 0.004	0.04 ± 0.003	0.03 ± 0.007
18:4n-3	0.72 ± 0.129	0.74 ± 0.036	0.96 ± 0.030	1.04 ± 0.046	0.84 ± 0.070
18:4n-1	0.14 ± 0.014	0.17 ± 0.012	0.16 ± 0.008	0.18 ± 0.009	0.14 ± 0.019
20:0	0.05 ± 0.013	0.04 ± 0.005	0.08 ± 0.004	0.08 ± 0.004	0.09 ± 0.012
20:1n-11	2.31 ± 0.035	2.46 ± 0.281	6.78 ± 0.299	6.66 ± 0.286	6.13 ± 0.556
20:1n-9	1.31 ± 0.240	1.32 ± 0.061	2.08 ± 0.063	1.88 ± 0.056	1.89 ± 0.113
R20:1	1.91 ± 0.392	1.89 ± 0.228	3.22 ± 0.082	3.50 ± 0.084	3.24 ± 0.184
20:1n-7	0.41 ± 0.121	0.21 ± 0.034	0.31 ± 0.023	0.22 ± 0.010	0.25 ± 0.021
20:1n-5	0.12 ± 0.043	0.06 ± 0.014	0.07 ± 0.005	0.07 ± 0.006	0.05 ± 0.007
20:2n-6	0.33 ± 0.031	0.17 ± 0.027	0.21 ± 0.010	0.17 ± 0.008	0.18 ± 0.020
20:3n-6	0.09 ± 0.005	0.08 ± 0.003	0.07 ± 0.003	0.06 ± 0.005	0.05 ± 0.006
20:4n-6	1.00 ± 0.140	0.61 ± 0.052	0.58 ± 0.031	0.49 ± 0.034	0.55 ± 0.087
20:3n-3	0.10 ± 0.028	0.09 ± 0.020	0.13 ± 0.041	0.08 ± 0.011	0.05 ± 0.008
20:4n-3	0.49 ± 0.098	0.52 ± 0.052	0.67 ± 0.033	0.46 ± 0.019	0.41 ± 0.044
20:5n-3	4.40 ± 0.585	4.50 ± 0.373	4.62 ± 0.160	4.01 ± 0.160	3.51 ± 0.328
22:1n-11	0.40 ± 0.110	0.35 ± 0.060	2.04 ± 0.154	2.47 ± 0.211	2.37 ± 0.456
22:1n-9	0.19 ± 0.087	0.13 ± 0.037	0.25 ± 0.026	0.21 ± 0.013	0.24 ± 0.023
R22:1	2.52 ± 0.662	3.95 ± 1.022	9.01 ± 0.437	11.84 ± 0.635	9.19 ± 1.121
22:1n-7	0.17 ± 0.106	0.04 ± 0.035	0.03 ± 0.003	0.03 ± 0.003	0.02 ± 0.009
22:2n-6	0.02 ± 0.020	0.01 ± 0.003	0.03 ± 0.006	0.02 ± 0.011	0.00 ± 0.001
21:5n-3	0.25 ± 0.021	0.24 ± 0.029	0.29 ± 0.007	0.28 ± 0.010	0.25 ± 0.015
22:4n-6	0.23 ± 0.048	0.10 ± 0.011	0.14 ± 0.013	0.10 ± 0.012	0.11 ± 0.025
22:5n-6	0.20 ± 0.064	0.11 ± 0.009	0.12 ± 0.005	0.11 ± 0.011	0.14 ± 0.044
22:4n-3	0.07 ± 0.015	0.05 ± 0.005	0.08 ± 0.004	0.06 ± 0.003	0.08 ± 0.024
22:5n-3	3.23 ± 0.248	3.26 ± 0.389	4.36 ± 0.180	2.69 ± 0.136	2.86 ± 0.334
22:6n-3	8.11 ± 1.178	8.97 ± 1.018	8.66 ± 0.368	6.18 ± 0.259	6.39 ± 0.771
24:1	0.06 ± 0.030	0.05 ± 0.008	0.12 ± 0.008	0.11 ± 0.008	0.12 ± 0.014

Table 4: Fatty Acid Composition of Harbor Seal Blubber (n = 279). Values are mean mass % of total fatty acids ± SEM. See Table 3 for summary of collection data.

	PRINCE WILLIAM SOUND				
	SC		SE		
	Half Years	Pups	Adults	Sub Adults	Yearlings
n	7	16	19	11	3
12:0	0.14 ± 0.018	0.15 ± 0.004	0.10 ± 0.006	0.12 ± 0.009	0.11 ± 0.012
13:0	0.01 ± 0.003	0.02 ± 0.001	0.02 ± 0.002	0.02 ± 0.002	0.02 ± 0.000
Iso14	0.02 ± 0.003	0.02 ± 0.001	0.02 ± 0.001	0.02 ± 0.002	0.03 ± 0.003
14:0	5.65 ± 0.238	5.72 ± 0.199	4.26 ± 0.259	4.56 ± 0.222	5.62 ± 0.110
14:1n-9	0.11 ± 0.022	0.09 ± 0.003	0.14 ± 0.008	0.13 ± 0.012	0.14 ± 0.026
14:1n-7	0.09 ± 0.007	0.09 ± 0.003	0.07 ± 0.007	0.09 ± 0.005	0.07 ± 0.010
14:1n-5	1.96 ± 0.153	1.77 ± 0.072	1.30 ± 0.114	1.71 ± 0.142	1.31 ± 0.225
Iso15	0.13 ± 0.004	0.11 ± 0.002	0.13 ± 0.006	0.12 ± 0.005	0.13 ± 0.010
Anti15	0.05 ± 0.008	0.04 ± 0.002	0.05 ± 0.003	0.06 ± 0.004	0.06 ± 0.008
15:0	0.25 ± 0.008	0.25 ± 0.007	0.28 ± 0.020	0.26 ± 0.010	0.26 ± 0.011
15:1n-8	0.02 ± 0.009	0.01 ± 0.002	0.00 ± 0.002	0.01 ± 0.002	0.00 ± 0.003
15:1n-6	0.07 ± 0.008	0.06 ± 0.003	0.08 ± 0.007	0.08 ± 0.005	0.05 ± 0.004
Iso16	0.05 ± 0.008	0.07 ± 0.003	0.09 ± 0.007	0.08 ± 0.005	0.07 ± 0.009
16:0	10.01 ± 0.386	11.24 ± 0.166	7.96 ± 0.501	8.91 ± 0.289	10.63 ± 0.836
16:1n-11	0.58 ± 0.043	0.62 ± 0.020	0.69 ± 0.035	0.46 ± 0.050	0.55 ± 0.065
16:1n-9	0.42 ± 0.026	0.47 ± 0.025	0.47 ± 0.035	0.48 ± 0.031	0.42 ± 0.044
16:1n-7	19.52 ± 1.072	19.87 ± 0.457	15.08 ± 0.753	18.65 ± 0.773	14.48 ± 1.859
7Me16:0	0.29 ± 0.013	0.25 ± 0.004	0.25 ± 0.005	0.24 ± 0.008	0.23 ± 0.019
16:1n-5	0.08 ± 0.023	0.17 ± 0.009	0.21 ± 0.017	0.15 ± 0.027	0.23 ± 0.015
16:2n-6	0.11 ± 0.020	0.10 ± 0.003	0.07 ± 0.015	0.11 ± 0.027	0.07 ± 0.007
Iso17	0.06 ± 0.008	0.09 ± 0.007	0.14 ± 0.012	0.09 ± 0.016	0.11 ± 0.007
16:2n-4	0.25 ± 0.066	0.18 ± 0.010	0.30 ± 0.020	0.22 ± 0.032	0.34 ± 0.028
16:3n-6	0.41 ± 0.063	0.50 ± 0.038	0.36 ± 0.033	0.41 ± 0.031	0.32 ± 0.003
17:0	0.08 ± 0.016	0.12 ± 0.007	0.19 ± 0.016	0.16 ± 0.021	0.27 ± 0.144
16:3n-4	0.31 ± 0.024	0.30 ± 0.024	0.38 ± 0.047	0.29 ± 0.029	0.23 ± 0.066
17:1	0.14 ± 0.070	0.35 ± 0.029	0.23 ± 0.064	0.33 ± 0.069	0.22 ± 0.108
16:3n-1	0.07 ± 0.012	0.09 ± 0.005	0.09 ± 0.010	0.10 ± 0.032	0.10 ± 0.037
16:4n-1	0.25 ± 0.083	0.44 ± 0.051	0.21 ± 0.038	0.22 ± 0.036	0.13 ± 0.037
18:0	0.93 ± 0.043	1.00 ± 0.029	0.94 ± 0.078	1.00 ± 0.038	1.44 ± 0.190
18:1n-13	0.28 ± 0.014	0.36 ± 0.019	0.36 ± 0.018	0.21 ± 0.034	0.26 ± 0.042
18:1n-11	2.34 ± 0.254	3.55 ± 0.311	2.82 ± 0.221	1.69 ± 0.215	2.10 ± 0.464
18:1n-9	20.81 ± 1.863	20.13 ± 1.370	25.15 ± 1.123	25.61 ± 1.533	29.62 ± 0.610
18:1n-7	3.62 ± 0.162	4.03 ± 0.186	3.99 ± 0.184	4.40 ± 0.289	4.41 ± 0.147
18:1n-5	0.47 ± 0.016	0.46 ± 0.017	0.45 ± 0.012	0.45 ± 0.019	0.46 ± 0.023
18:2d57	0.11 ± 0.029	0.12 ± 0.013	0.03 ± 0.006	0.07 ± 0.015	0.09 ± 0.013

Table 4: Fatty Acid Composition of Harbor Seal Blubber (n = 279). Values are mean mass % of total fatty acids ± SEM. See Table 3 for summary of collection data.

	PRINCE WILLIAM SOUND				
	SC		SE		
	Half Years	**Pups**	**Adults**	**Sub Adults**	**Yearlings**
18:2n-7	0.10 ± 0.019	0.11 ± 0.004	0.06 ± 0.008	0.11 ± 0.020	0.08 ± 0.011
18:2n-6	0.94 ± 0.033	0.94 ± 0.035	1.19 ± 0.037	1.10 ± 0.043	0.91 ± 0.027
18:2n-4	0.13 ± 0.012	0.14 ± 0.009	0.12 ± 0.007	0.13 ± 0.008	0.11 ± 0.018
18:3n-6	0.07 ± 0.012	0.12 ± 0.002	0.06 ± 0.004	0.07 ± 0.007	0.08 ± 0.009
18:3n-4	0.16 ± 0.015	0.11 ± 0.011	0.14 ± 0.009	0.12 ± 0.015	0.10 ± 0.018
18:3n-3	0.59 ± 0.057	0.38 ± 0.016	0.66 ± 0.029	0.62 ± 0.045	0.40 ± 0.019
18:3n-1	0.03 ± 0.010	0.04 ± 0.002	0.04 ± 0.004	0.04 ± 0.007	0.04 ± 0.020
18:4n-3	1.14 ± 0.092	0.92 ± 0.063	0.91 ± 0.057	0.86 ± 0.058	0.55 ± 0.034
18:4n-1	0.21 ± 0.025	0.23 ± 0.024	0.15 ± 0.015	0.14 ± 0.010	0.08 ± 0.012
20:0	0.05 ± 0.007	0.05 ± 0.004	0.06 ± 0.006	0.06 ± 0.007	0.11 ± 0.019
20:1n-11	5.46 ± 0.418	5.74 ± 0.539	5.05 ± 0.407	3.29 ± 0.405	4.88 ± 1.359
20:1n-9	1.68 ± 0.087	1.48 ± 0.096	1.89 ± 0.108	1.59 ± 0.118	2.17 ± 0.228
R20:1	3.30 ± 0.316	3.77 ± 0.150	2.65 ± 0.137	2.07 ± 0.193	2.31 ± 0.674
20:1n-7	0.18 ± 0.010	0.16 ± 0.014	0.28 ± 0.045	0.25 ± 0.054	0.35 ± 0.076
20:1n-5	0.09 ± 0.023	0.04 ± 0.005	0.05 ± 0.009	0.05 ± 0.007	0.07 ± 0.010
20:2n-6	0.20 ± 0.017	0.18 ± 0.009	0.21 ± 0.015	0.19 ± 0.018	0.21 ± 0.035
20:3n-6	0.06 ± 0.007	0.06 ± 0.003	0.07 ± 0.003	0.06 ± 0.006	0.06 ± 0.010
20:4n-6	0.53 ± 0.071	0.60 ± 0.070	0.51 ± 0.039	0.57 ± 0.056	0.53 ± 0.117
20:3n-3	0.16 ± 0.071	0.04 ± 0.005	0.09 ± 0.015	0.14 ± 0.076	0.06 ± 0.017
20:4n-3	0.48 ± 0.057	0.41 ± 0.029	0.70 ± 0.055	0.51 ± 0.050	0.39 ± 0.066
20:5n-3	4.85 ± 0.488	4.11 ± 0.290	4.91 ± 0.270	4.69 ± 0.358	2.77 ± 0.274
22:1n-11	1.79 ± 0.219	1.18 ± 0.164	1.54 ± 0.244	0.97 ± 0.188	1.86 ± 1.051
22:1n-9	0.15 ± 0.016	0.10 ± 0.012	0.20 ± 0.026	0.15 ± 0.023	0.52 ± 0.221
R22:1	12.10 ± 1.278	11.54 ± 0.701	7.74 ± 0.651	6.62 ± 0.817	5.20 ± 3.366
22:1n-7	0.01 ± 0.007	0.00 ± 0.002	0.02 ± 0.006	0.02 ± 0.006	0.03 ± 0.018
22:2n-6	0.01 ± 0.005	0.00 ± 0.003	0.02 ± 0.006	0.00 ± 0.003	0.00 ± 0.000
21:5n-3	0.29 ± 0.021	0.31 ± 0.016	0.29 ± 0.008	0.26 ± 0.020	0.21 ± 0.034
22:4n-6	0.09 ± 0.015	0.09 ± 0.018	0.12 ± 0.018	0.12 ± 0.022	0.14 ± 0.045
22:5n-6	0.09 ± 0.009	0.09 ± 0.008	0.13 ± 0.008	0.13 ± 0.012	0.12 ± 0.014
22:4n-3	0.06 ± 0.007	0.05 ± 0.004	0.08 ± 0.007	0.07 ± 0.004	0.07 ± 0.015
22:5n-3	3.04 ± 0.403	3.01 ± 0.213	4.32 ± 0.353	3.50 ± 0.348	2.44 ± 0.329
22:6n-3	7.36 ± 0.858	6.38 ± 0.439	8.96 ± 0.588	8.50 ± 0.729	5.86 ± 0.358
24:1	0.11 ± 0.036	0.02 ± 0.004	0.10 ± 0.015	0.10 ± 0.021	0.16 ± 0.036

Table 4: Fatty Acid Composition of Harbor Seal Blubber (n = 279). Values are mean mass % of total fatty acids ± SEM. See Table 3 for summary of collection data.

	PRINCE WILLIAM SOUND			GULF OF ALASKA	
				Kodiak N.	
	SE		SW		
	Half Years	Pups	All Groups	Adults	Sub Adults
n	6	2	2	12	3
12:0	0.11 ± 0.028	0.14 ± 0.035	0.13 ± 0.055	0.08 ± 0.007	0.10 ± 0.005
13:0	0.01 ± 0.003	0.02 ± 0.000	0.01 ± 0.002	0.02 ± 0.002	0.01 ± 0.002
Iso14	0.02 ± 0.005	0.03 ± 0.003	0.03 ± 0.005	0.02 ± 0.003	0.02 ± 0.003
14:0	5.21 ± 0.426	3.56 ± 0.488	5.15 ± 0.558	4.22 ± 0.104	3.53 ± 0.229
14:1n-9	0.10 ± 0.015	0.09 ± 0.015	0.14 ± 0.015	0.14 ± 0.010	0.10 ± 0.025
14:1n-7	0.10 ± 0.014	0.10 ± 0.015	0.11 ± 0.015	0.08 ± 0.004	0.08 ± 0.010
14:1n-5	2.30 ± 0.513	1.86 ± 0.363	2.12 ± 0.445	1.39 ± 0.118	1.77 ± 0.406
Iso15	0.11 ± 0.008	0.11 ± 0.008	0.11 ± 0.010	0.14 ± 0.011	0.11 ± 0.006
Anti15	0.05 ± 0.008	0.06 ± 0.005	0.05 ± 0.005	0.06 ± 0.009	0.04 ± 0.007
15:0	0.24 ± 0.021	0.25 ± 0.020	0.21 ± 0.023	0.27 ± 0.022	0.23 ± 0.030
15:1n-8	0.01 ± 0.005	0.00 ± 0.003	0.00 ± 0.003	0.01 ± 0.002	0.01 ± 0.003
15:1n-6	0.06 ± 0.014	0.09 ± 0.000	0.06 ± 0.000	0.08 ± 0.006	0.08 ± 0.008
Iso16	0.07 ± 0.005	0.10 ± 0.018	0.07 ± 0.000	0.10 ± 0.016	0.06 ± 0.008
16:0	10.07 ± 0.534	8.32 ± 1.918	8.70 ± 2.393	8.23 ± 0.291	7.71 ± 0.397
16:1n-11	0.47 ± 0.035	0.49 ± 0.022	0.55 ± 0.125	0.71 ± 0.036	0.71 ± 0.032
16:1n-9	0.54 ± 0.044	0.57 ± 0.058	0.50 ± 0.060	0.44 ± 0.019	0.42 ± 0.016
16:1n-7	20.88 ± 2.432	19.59 ± 4.290	20.05 ± 4.988	15.68 ± 0.633	19.39 ± 2.591
7Me16:0	0.27 ± 0.013	0.24 ± 0.015	0.23 ± 0.008	0.28 ± 0.026	0.26 ± 0.028
16:1n-5	0.11 ± 0.033	0.27 ± 0.040	0.17 ± 0.005	0.17 ± 0.035	0.09 ± 0.032
16:2n-6	0.10 ± 0.030	0.09 ± 0.015	0.07 ± 0.020	0.09 ± 0.019	0.10 ± 0.041
Iso17	0.08 ± 0.014	0.16 ± 0.045	0.09 ± 0.010	0.12 ± 0.032	0.05 ± 0.012
16:2n-4	0.21 ± 0.039	0.29 ± 0.048	0.19 ± 0.002	0.23 ± 0.038	0.13 ± 0.040
16:3n-6	0.35 ± 0.064	0.24 ± 0.030	0.40 ± 0.055	0.52 ± 0.032	0.48 ± 0.118
17:0	0.14 ± 0.029	0.15 ± 0.010	0.26 ± 0.143	0.16 ± 0.025	0.11 ± 0.020
16:3n-4	0.27 ± 0.060	0.14 ± 0.002	0.18 ± 0.005	0.41 ± 0.037	0.37 ± 0.097
17:1	0.23 ± 0.099	0.58 ± 0.030	0.37 ± 0.030	0.16 ± 0.056	0.27 ± 0.122
16:3n-1	0.07 ± 0.034	0.16 ± 0.010	0.10 ± 0.010	0.05 ± 0.006	0.07 ± 0.020
16:4n-1	0.13 ± 0.032	0.12 ± 0.005	0.18 ± 0.028	0.30 ± 0.029	0.25 ± 0.083
18:0	1.05 ± 0.120	0.95 ± 0.023	0.70 ± 0.090	1.00 ± 0.057	0.88 ± 0.147
18:1n-13	0.21 ± 0.034	0.34 ± 0.055	0.30 ± 0.038	0.28 ± 0.036	0.25 ± 0.032
18:1n-11	1.29 ± 0.158	2.18 ± 0.140	2.08 ± 0.120	1.59 ± 0.119	1.43 ± 0.188
18:1n-9	27.04 ± 2.582	25.01 ± 4.265	31.10 ± 10.300	24.88 ± 1.335	22.85 ± 0.594
18:1n-7	4.58 ± 0.243	4.55 ± 0.583	4.82 ± 0.705	4.82 ± 0.297	4.11 ± 0.183
18:1n-5	0.44 ± 0.014	0.45 ± 0.018	0.40 ± 0.055	0.40 ± 0.017	0.41 ± 0.012
18:2d57	0.14 ± 0.025	0.11 ± 0.025	0.08 ± 0.010	0.05 ± 0.009	0.05 ± 0.026

Table 4: Fatty Acid Composition of Harbor Seal Blubber (n = 279). Values are mean mass % of total fatty acids ± SEM. See Table 3 for summary of collection data.

	PRINCE WILLIAM SOUND			GULF OF ALASKA	
				Kodiak N.	
	SE		SW		
	Half Years	Pups	All Groups	Adults	Sub Adults
18:2n-7	0.15 ± 0.034	0.10 ± 0.018	0.11 ± 0.025	0.07 ± 0.009	0.10 ± 0.035
18:2n-6	0.96 ± 0.043	1.20 ± 0.065	1.08 ± 0.032	1.04 ± 0.040	1.12 ± 0.103
18:2n-4	0.10 ± 0.007	0.11 ± 0.013	0.09 ± 0.015	0.13 ± 0.011	0.11 ± 0.020
18:3n-6	0.08 ± 0.009	0.10 ± 0.023	0.07 ± 0.020	0.05 ± 0.005	0.04 ± 0.010
18:3n-4	0.12 ± 0.017	0.08 ± 0.010	0.07 ± 0.007	0.13 ± 0.009	0.12 ± 0.015
18:3n-3	0.46 ± 0.060	0.51 ± 0.025	0.47 ± 0.032	0.61 ± 0.044	0.71 ± 0.086
18:3n-1	0.04 ± 0.007	0.06 ± 0.010	0.03 ± 0.002	0.05 ± 0.004	0.04 ± 0.000
18:4n-3	0.70 ± 0.092	0.63 ± 0.027	0.72 ± 0.080	0.88 ± 0.056	0.89 ± 0.052
18:4n-1	0.11 ± 0.013	0.09 ± 0.015	0.10 ± 0.028	0.18 ± 0.018	0.18 ± 0.034
20:0	0.05 ± 0.010	0.05 ± 0.018	0.04 ± 0.005	0.06 ± 0.005	0.04 ± 0.007
20:1n-11	3.06 ± 0.482	3.55 ± 0.957	4.00 ± 0.678	4.35 ± 0.488	3.31 ± 0.334
20:1n-9	1.35 ± 0.129	1.31 ± 0.330	1.39 ± 0.112	1.74 ± 0.120	1.47 ± 0.267
R20:1	2.27 ± 0.274	2.69 ± 0.052	2.85 ± 0.256	2.47 ± 0.207	2.45 ± 0.560
20:1n-7	0.20 ± 0.050	0.27 ± 0.095	0.10 ± 0.007	0.35 ± 0.066	0.21 ± 0.019
20:1n-5	0.08 ± 0.040	0.03 ± 0.010	0.00 ± 0.000	0.04 ± 0.005	0.03 ± 0.006
20:2n-6	0.24 ± 0.041	0.26 ± 0.002	0.19 ± 0.060	0.21 ± 0.020	0.15 ± 0.044
20:3n-6	0.06 ± 0.013	0.08 ± 0.008	0.04 ± 0.000	0.06 ± 0.004	0.08 ± 0.009
20:4n-6	0.63 ± 0.171	0.76 ± 0.045	0.38 ± 0.095	0.59 ± 0.069	0.61 ± 0.039
20:3n-3	0.09 ± 0.053	0.06 ± 0.000	0.05 ± 0.023	0.07 ± 0.007	0.07 ± 0.012
20:4n-3	0.36 ± 0.073	0.55 ± 0.010	0.30 ± 0.040	0.55 ± 0.052	0.69 ± 0.180
20:5n-3	3.42 ± 0.552	3.70 ± 0.013	2.92 ± 0.677	6.25 ± 0.415	6.56 ± 0.231
22:1n-11	0.97 ± 0.333	0.37 ± 0.175	0.70 ± 0.030	1.08 ± 0.145	0.62 ± 0.142
22:1n-9	0.18 ± 0.029	0.11 ± 0.045	0.08 ± 0.010	0.14 ± 0.014	0.12 ± 0.062
R22:1	5.37 ± 1.577	3.38 ± 0.217	8.84 ± 0.730	7.99 ± 0.927	6.63 ± 1.512
22:1n-7	0.02 ± 0.007	0.00 ± 0.000	0.00 ± 0.000	0.02 ± 0.003	0.00 ± 0.003
22:2n-6	0.01 ± 0.008	0.03 ± 0.015	0.00 ± 0.000	0.03 ± 0.005	0.03 ± 0.015
21:5n-3	0.22 ± 0.022	0.26 ± 0.010	0.23 ± 0.040	0.34 ± 0.015	0.32 ± 0.012
22:4n-6	0.13 ± 0.056	0.20 ± 0.058	0.05 ± 0.005	0.14 ± 0.026	0.10 ± 0.007
22:5n-6	0.10 ± 0.024	0.16 ± 0.025	0.06 ± 0.013	0.12 ± 0.009	0.16 ± 0.031
22:4n-3	0.04 ± 0.007	0.08 ± 0.005	0.04 ± 0.005	0.06 ± 0.005	0.07 ± 0.013
22:5n-3	2.52 ± 0.610	4.94 ± 0.650	2.03 ± 0.625	4.59 ± 0.329	4.80 ± 0.970
22:6n-3	6.21 ± 1.247	8.96 ± 0.258	4.96 ± 1.715	8.62 ± 0.557	10.59 ± 1.525
24:1	0.09 ± 0.036	0.05 ± 0.033	0.04 ± 0.010	0.08 ± 0.011	0.08 ± 0.006

Table 4: Fatty Acid Composition of Harbor Seal Blubber (n = 279). Values are mean mass % of total fatty acids ± SEM. See Table 3 for summary of collection data.

	GULF OF ALASKA			
	Kodiak N.		Kodiak S.	SCA
	Yearlings	Half Years	Pups	Yakutat All Groups
n	2	1	10	11
12:0	0.16 ± 0.000	0.02	0.21 ± 0.014	0.09 ± 0.009
13:0	0.01 ± 0.000	0.02	0.02 ± 0.002	0.02 ± 0.000
Iso14	0.02 ± 0.000	0.03	0.04 ± 0.003	0.02 ± 0.001
14:0	4.66 ± 0.410	4.49	3.68 ± 0.183	5.67 ± 0.308
14:1n-9	0.11 ± 0.025	0.09	0.05 ± 0.003	0.13 ± 0.005
14:1n-7	0.12 ± 0.020	0.15	0.16 ± 0.012	0.06 ± 0.002
14:1n-5	3.06 ± 0.957	3.62	3.25 ± 0.370	1.02 ± 0.077
Iso15	0.10 ± 0.007	0.14	0.09 ± 0.006	0.13 ± 0.005
Anti15	0.05 ± 0.002	0.04	0.04 ± 0.003	0.05 ± 0.003
15:0	0.24 ± 0.035	0.25	0.24 ± 0.015	0.24 ± 0.007
15:1n-8	0.01 ± 0.000	0.02	0.02 ± 0.004	0.00 ± 0.001
15:1n-6	0.10 ± 0.005	0.16	0.14 ± 0.012	0.04 ± 0.004
Iso16	0.07 ± 0.023	0.10	0.13 ± 0.004	0.05 ± 0.005
16:0	8.81 ± 1.010	10.43	10.22 ± 0.213	8.73 ± 0.219
16:1n-11	0.59 ± 0.075	0.43	0.35 ± 0.102	0.51 ± 0.032
16:1n-9	0.49 ± 0.088	0.52	0.71 ± 0.026	0.46 ± 0.023
16:1n-7	23.98 ± 2.793	32.05	32.33 ± 2.000	10.10 ± 0.499
7Me16:0	0.28 ± 0.025	0.25	0.22 ± 0.008	0.24 ± 0.013
16:1n-5	0.07 ± 0.005	0.14	0.27 ± 0.016	0.19 ± 0.009
16:2n-6	0.17 ± 0.050	0.11	0.13 ± 0.010	0.04 ± 0.004
Iso17	0.03 ± 0.007	0.09	0.14 ± 0.011	0.09 ± 0.007
16:2n-4	0.10 ± 0.043	0.17	0.25 ± 0.028	0.31 ± 0.011
16:3n-6	0.54 ± 0.090	0.25	0.16 ± 0.023	0.27 ± 0.017
17:0	0.12 ± 0.055	0.11	0.15 ± 0.012	0.15 ± 0.029
16:3n-4	0.25 ± 0.023	0.37	0.11 ± 0.012	0.44 ± 0.015
17:1	0.44 ± 0.075	0.02	0.52 ± 0.033	0.01 ± 0.004
16:3n-1	0.05 ± 0.010	0.05	0.13 ± 0.015	0.07 ± 0.010
16:4n-1	0.26 ± 0.113	0.17	0.11 ± 0.016	0.11 ± 0.028
18:0	0.92 ± 0.238	0.78	0.80 ± 0.042	1.27 ± 0.053
18:1n-13	0.15 ± 0.153	0.28	0.21 ± 0.017	0.30 ± 0.016
18:1n-11	1.08 ± 0.198	1.48	0.44 ± 0.076	1.80 ± 0.180
18:1n-9	24.10 ± 5.798	16.25	17.78 ± 0.991	35.29 ± 2.223
18:1n-7	5.17 ± 0.082	3.53	4.70 ± 0.223	3.81 ± 0.178
18:1n-5	0.47 ± 0.032	0.42	0.34 ± 0.014	0.44 ± 0.021
18:2d57	0.13 ± 0.045	0.13	0.17 ± 0.015	0.07 ± 0.017

Table 4: Fatty Acid Composition of Harbor Seal Blubber (n = 279). Values are mean mass % of total fatty acids ± SEM. See Table 3 for summary of collection data.

	GULF OF ALASKA			
	Kodiak N.		Kodiak S.	SCA
	Yearlings	Half Years	Pups	Yakutat All Groups
18:2n-7	0.18 ± 0.015	0.15	0.20 ± 0.013	0.04 ± 0.003
18:2n-6	0.83 ± 0.133	0.75	0.72 ± 0.069	1.08 ± 0.040
18:2n-4	0.16 ± 0.080	0.10	0.11 ± 0.010	0.07 ± 0.011
18:3n-6	0.06 ± 0.010	0.08	0.10 ± 0.009	0.03 ± 0.006
18:3n-4	0.10 ± 0.028	0.12	0.07 ± 0.006	0.12 ± 0.006
18:3n-3	0.48 ± 0.022	0.35	0.21 ± 0.023	0.54 ± 0.057
18:3n-1	0.05 ± 0.028	0.03	0.04 ± 0.005	0.04 ± 0.003
18:4n-3	0.68 ± 0.010	0.64	0.39 ± 0.062	0.69 ± 0.127
18:4n-1	0.16 ± 0.050	0.14	0.09 ± 0.012	0.07 ± 0.016
20:0	0.06 ± 0.015	0.03	0.02 ± 0.002	0.08 ± 0.008
20:1n-11	3.39 ± 0.690	1.96	0.58 ± 0.106	6.18 ± 0.632
20:1n-9	1.17 ± 0.280	0.75	0.61 ± 0.086	2.09 ± 0.094
R20:1	2.92 ± 0.109	2.61	0.94 ± 0.122	2.92 ± 0.218
20:1n-7	0.35 ± 0.190	0.11	0.25 ± 0.054	0.19 ± 0.015
20:1n-5	0.02 ± 0.013	0.01	0.02 ± 0.005	0.08 ± 0.006
20:2n-6	0.12 ± 0.050	0.25	0.34 ± 0.015	0.16 ± 0.014
20:3n-6	0.09 ± 0.015	0.06	0.05 ± 0.004	0.05 ± 0.005
20:4n-6	0.80 ± 0.328	0.70	1.20 ± 0.057	0.43 ± 0.067
20:3n-3	0.06 ± 0.023	0.05	0.07 ± 0.008	0.04 ± 0.008
20:4n-3	0.33 ± 0.063	0.40	0.27 ± 0.036	0.38 ± 0.071
20:5n-3	4.00 ± 1.968	4.64	4.45 ± 0.374	2.97 ± 0.610
22:1n-11	0.70 ± 0.238	0.24	0.02 ± 0.007	2.69 ± 0.279
22:1n-9	0.19 ± 0.143	0.04	0.02 ± 0.006	0.24 ± 0.015
R22:1	6.59 ± 3.742	6.86	0.44 ± 0.176	10.87 ± 0.776
22:1n-7	0.01 ± 0.010	0.00	0.00 ± 0.002	0.02 ± 0.004
22:2n-6	0.01 ± 0.008	0.03	0.03 ± 0.009	0.01 ± 0.008
21:5n-3	0.22 ± 0.190	0.28	0.33 ± 0.025	0.18 ± 0.028
22:4n-6	0.18 ± 0.113	0.08	0.21 ± 0.021	0.09 ± 0.016
22:5n-6	0.13 ± 0.063	0.10	0.15 ± 0.010	0.09 ± 0.010
22:4n-3	0.05 ± 0.020	0.04	0.04 ± 0.008	0.05 ± 0.007
22:5n-3	3.15 ± 1.870	3.12	3.69 ± 0.245	2.67 ± 0.474
22:6n-3	5.33 ± 1.775	7.51	7.35 ± 0.541	6.06 ± 0.833
24:1	0.06 ± 0.030	0.03	0.01 ± 0.003	0.18 ± 0.022

Table 4: Fatty Acid Composition of Harbor Seal Blubber (n = 279). Values are mean mass % of total fatty acids ± SEM. See Table 3 for summary of collection data.

	GULF OF ALASKA		
	South East Alaska		
	Peril St. All Groups	Sitka All Groups	Stephen's Passage All Groups
n	11	9	14
12:0	0.09 ± 0.009	0.12 ± 0.006	0.08 ± 0.009
13:0	0.02 ± 0.002	0.02 ± 0.002	0.02 ± 0.001
Iso14	0.02 ± 0.002	0.02 ± 0.001	0.02 ± 0.002
14:0	3.37 ± 0.190	3.91 ± 0.201	3.09 ± 0.166
14:1n-9	0.14 ± 0.010	0.10 ± 0.028	0.12 ± 0.011
14:1n-7	0.07 ± 0.004	0.06 ± 0.008	0.08 ± 0.006
14:1n-5	1.12 ± 0.074	0.96 ± 0.166	1.69 ± 0.165
Iso15	0.11 ± 0.006	0.14 ± 0.009	0.09 ± 0.005
Anti15	0.05 ± 0.004	0.05 ± 0.004	0.05 ± 0.005
15:0	0.24 ± 0.014	0.32 ± 0.022	0.21 ± 0.012
15:1n-8	0.00 ± 0.001	0.00 ± 0.000	0.01 ± 0.002
15:1n-6	0.07 ± 0.003	0.05 ± 0.002	0.09 ± 0.005
Iso16	0.07 ± 0.007	0.09 ± 0.010	0.06 ± 0.004
16:0	8.22 ± 0.311	9.84 ± 0.445	6.71 ± 0.449
16:1n-11	0.51 ± 0.032	0.65 ± 0.066	0.50 ± 0.043
16:1n-9	0.45 ± 0.010	0.45 ± 0.027	0.50 ± 0.019
16:1n-7	15.43 ± 0.662	13.67 ± 0.966	18.97 ± 1.247
7Me16:0	0.23 ± 0.006	0.29 ± 0.021	0.22 ± 0.007
16:1n-5	0.18 ± 0.012	0.23 ± 0.021	0.04 ± 0.003
16:2n-6	0.06 ± 0.004	0.06 ± 0.010	0.15 ± 0.019
Iso17	0.11 ± 0.009	0.13 ± 0.021	0.03 ± 0.002
16:2n-4	0.23 ± 0.014	0.24 ± 0.037	0.09 ± 0.007
16:3n-6	0.38 ± 0.033	0.42 ± 0.073	0.61 ± 0.043
17:0	0.20 ± 0.038	0.18 ± 0.026	0.09 ± 0.009
16:3n-4	0.47 ± 0.027	0.50 ± 0.036	0.49 ± 0.049
17:1	0.02 ± 0.004	0.03 ± 0.002	0.50 ± 0.042
16:3n-1	0.07 ± 0.010	0.10 ± 0.009	0.03 ± 0.003
16:4n-1	0.17 ± 0.040	0.27 ± 0.065	0.29 ± 0.029
18:0	1.17 ± 0.032	1.51 ± 0.130	0.80 ± 0.039
18:1n-13	0.21 ± 0.029	0.25 ± 0.050	0.02 ± 0.010
18:1n-11	1.55 ± 0.203	1.53 ± 0.237	1.34 ± 0.131
18:1n-9	25.57 ± 1.192	21.97 ± 1.649	28.83 ± 1.451
18:1n-7	5.30 ± 0.379	4.67 ± 0.280	4.97 ± 0.200
18:1n-5	0.37 ± 0.018	0.36 ± 0.030	0.34 ± 0.018
18:2d57	0.03 ± 0.005	0.03 ± 0.018	0.06 ± 0.004

Table 4: Fatty Acid Composition of Harbor Seal Blubber (n = 279). Values are mean mass % of total fatty acids ± SEM. See Table 3 for summary of collection data.

	GULF OF ALASKA		
	South East Alaska		
	Peril St. All Groups	Sitka All Groups	Stephen's Passage All Groups
18:2n-7	0.07 ± 0.005	0.06 ± 0.007	0.12 ± 0.007
18:2n-6	1.22 ± 0.053	1.28 ± 0.084	1.05 ± 0.083
18:2n-4	0.14 ± 0.009	0.14 ± 0.015	0.14 ± 0.007
18:3n-6	0.05 ± 0.004	0.05 ± 0.012	0.05 ± 0.002
18:3n-4	0.16 ± 0.007	0.16 ± 0.013	0.13 ± 0.009
18:3n-3	0.66 ± 0.047	0.84 ± 0.082	0.54 ± 0.053
18:3n-1	0.04 ± 0.004	0.03 ± 0.009	0.05 ± 0.005
18:4n-3	0.82 ± 0.065	1.42 ± 0.288	0.68 ± 0.041
18:4n-1	0.15 ± 0.016	0.15 ± 0.021	0.19 ± 0.013
20:0	0.04 ± 0.003	0.04 ± 0.005	0.05 ± 0.002
20:1n-11	2.88 ± 0.401	2.37 ± 0.411	2.50 ± 0.338
20:1n-9	2.09 ± 0.208	2.09 ± 0.328	1.97 ± 0.200
R20:1	1.40 ± 0.178	1.16 ± 0.157	1.23 ± 0.125
20:1n-7	0.31 ± 0.025	0.31 ± 0.043	0.25 ± 0.022
20:1n-5	0.04 ± 0.004	0.06 ± 0.005	0.02 ± 0.002
20:2n-6	0.24 ± 0.009	0.26 ± 0.023	0.15 ± 0.016
20:3n-6	0.08 ± 0.005	0.08 ± 0.005	0.09 ± 0.006
20:4n-6	0.66 ± 0.036	0.78 ± 0.067	0.49 ± 0.031
20:3n-3	0.09 ± 0.006	0.10 ± 0.012	0.07 ± 0.009
20:4n-3	0.65 ± 0.061	0.80 ± 0.099	0.56 ± 0.069
20:5n-3	6.21 ± 0.312	7.43 ± 0.822	5.77 ± 0.319
22:1n-11	0.81 ± 0.137	1.01 ± 0.193	0.32 ± 0.047
22:1n-9	0.20 ± 0.015	0.19 ± 0.036	0.12 ± 0.024
R22:1	4.19 ± 0.819	6.30 ± 1.078	2.90 ± 0.285
22:1n-7	0.04 ± 0.018	0.02 ± 0.007	0.01 ± 0.009
22:2n-6	0.04 ± 0.009	0.03 ± 0.011	0.03 ± 0.006
21:5n-3	0.37 ± 0.008	0.39 ± 0.037	0.36 ± 0.012
22:4n-6	0.12 ± 0.015	0.16 ± 0.029	0.08 ± 0.008
22:5n-6	0.13 ± 0.008	0.15 ± 0.022	0.10 ± 0.009
22:4n-3	0.08 ± 0.005	0.07 ± 0.007	0.06 ± 0.005
22:5n-3	5.64 ± 0.341	5.25 ± 0.637	4.52 ± 0.327
22:6n-3	9.41 ± 0.701	10.76 ± 1.046	8.26 ± 0.715
24:1	0.10 ± 0.006	0.08 ± 0.013	0.05 ± 0.005

Table 5. Body Composition of Harbor Seals Sampled in SC and SE Prince William Sound, June 1997, as determined by Isotope Dilution

Age Group	Mass (kg)	%Body Water	% Body Protein	%Body Fat
Pups (n = 12)	31.8 ± 0.97	42.7 ± 0.56	13.2 ± 0.24	42.6 ± 0.82
Yearlings (n = 6)	37.7 ± 1.04	56.0 ± 0.59	18.8 ± 0.25	23.1 ± 0.87
2-3 yr old (n = 2)	43.4 ± 2.75	57.8 ± 1.07	19.5 ± 0.45	20.5 ± 1.56
Subadult (n = 5)	41.5 ± 1.50	59.6 ± 1.76	20.3 ± 0.74	17.8 ± 2.58

Table 6. Fatty Acid Composition (Mass %) of Archived Harbor Seal Blubbers (1970's)

	KOD74-7	KPHS-1	MHHS-11
12:0	0.11	0.12	0.34
13:0	0.10	0.02	0.03
Iso14	0.02	0.01	0.06
14:0	5.75	6.24	6.21
14:1n-9	0.27	0.17	0.00
14:1n-7	0.06	0.09	0.15
14:1n-5	1.06	1.65	4.90
Iso15	0.13	0.11	0.15
Anti15	0.04	0.03	0.03
15:0	0.22	0.22	0.17
15:1n-8	0.00	0.00	0.01
15:1n-6	0.03	0.04	0.10
Iso16	0.08	0.04	0.08
16:0	12.26	10.95	14.13
16:1n-11	0.80	0.65	0.49
16:1n-9	0.33	0.45	0.83
16:1n-7	15.35	17.18	41.41
7Me16:0	0.29	0.28	0.37
16:1n-5	0.12	0.09	0.10
16:2n-6	0.05	0.08	0.11
Iso17	0.07	0.05	0.05
16:2n-4	0.15	0.18	0.08
16:3n-6	0.62	0.56	0.10
17:0	0.06	0.08	0.05
16:3n-4	0.21	0.28	0.23
17:1	0.00	0.00	0.00
16:3n-1	0.05	0.04	0.05
16:4n-3	0.33	0.21	0.08
16:4n-1	0.00	0.00	0.05
18:0	1.18	1.18	0.85
18:1n-13	0.06	0.26	0.17
18:1n-11	0.00	0.00	0.00
18:1n-9	28.79	26.68	12.36
18:1n-7	6.60	5.41	3.83
18:1n-5	0.30	0.41	0.40
18:2d5,7	0.04	0.06	0.20
18:2n-7	0.05	0.08	0.28
18:2n-6	0.86	0.71	0.30
18:2n-4	0.12	0.11	0.06
18:3n-6	0.04	0.05	0.03
18:3n-4	0.12	0.10	0.10
18:3n-3	0.33	0.45	0.12
18:3n-1	0.01	0.03	0.00
18:4n-3	0.56	0.80	0.17

continued:

	KOD74-7	KPHS-1	MHHS-11
18:4n-1	0.18	0.11	0.08
20:0	0.06	0.06	0.04
20:1n-11	2.99	6.06	0.54
20:1n-9	1.97	2.57	0.18
R20:1	1.52	2.36	3.06
20:1n-7	0.20	0.27	0.14
20:1n-5	0.05	0.04	0.10
20:2n-6	0.07	0.17	0.40
20:3n-6	0.02	0.02	0.03
20:4n-6	0.28	0.41	1.15
20:3n-3	0.00	0.04	0.01
20:4n-3	0.25	0.27	0.06
20:5n-3	5.84	3.33	1.56
22:1n-11	0.00	0.00	0.03
22:1n-9	0.63	2.33	0.00
R22:1	0.00	0.00	0.00
22:1n-7	0.06	0.28	0.00
22:2n-6	0.00	0.00	0.00
21:5n-3	0.42	0.24	0.08
22:4n-6	0.00	0.08	0.16
22:5n-6	0.04	0.07	0.11
22:4n-3	0.00	0.04	0.00
22:5n-3	3.83	2.55	1.39
22:6n-3	5.35	4.76	4.76
24:1n-11	0.00	0.00	0.00
24:1n-9	0.03	0.08	0.07

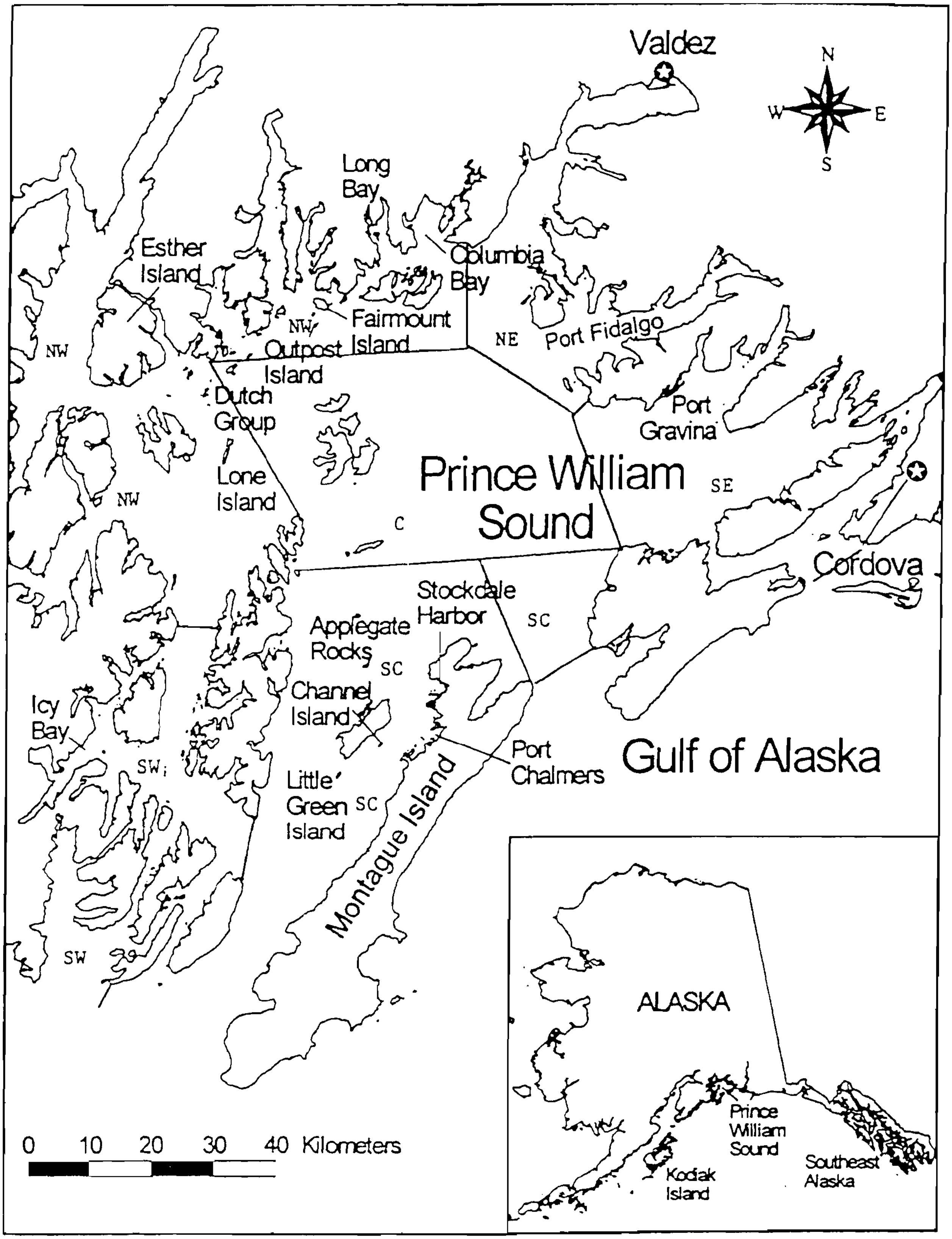
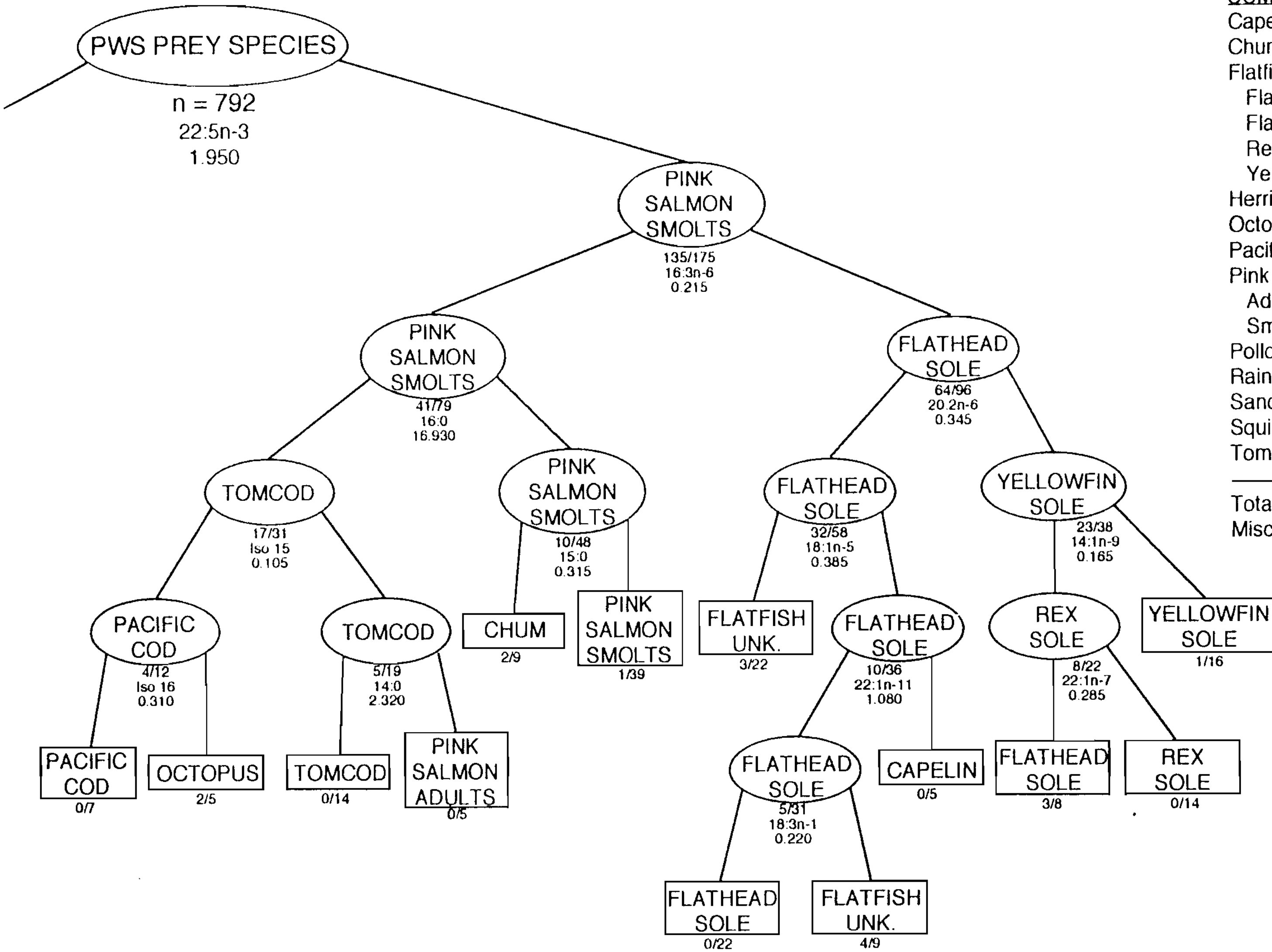
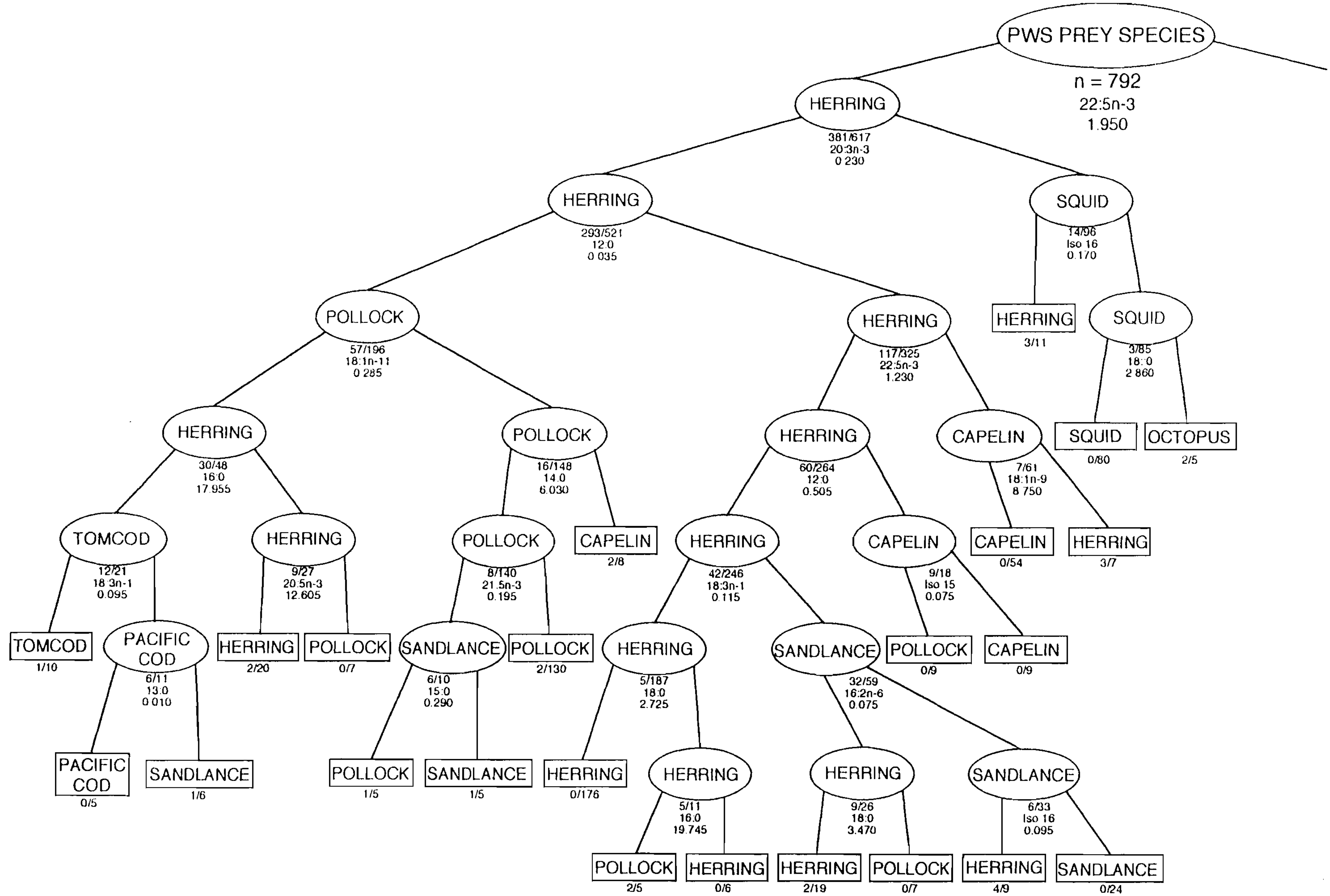


Figure 1. Prince William Sound (PWS), Alaska, showing major locations of harbor seals and prey sampled. General locations are indicated by boundary markers which coincide with fisheries zones.



SUMMARY:	correct/total	
Capelin	74/79	93.7%
Chum	7/7	100%
Flatfish		
Flathead Sole	27/33	81.8%
Flatfish Unk. sp.	24/24	100%
Rex Sole	14/15	93.3%
Yellowfin Sole	15/17	88.2%
Herring	234/237	98.7%
Octopus	6/7	85.7%
Pacific Cod	12/16	75.0%
Pink Salmon		
Adults	5/5	100%
Smolts	38/40	95%
Pollock	158/162	97.5%
Rainbow Smelt	0/4	-
Sandlance	33/40	82.5%
Squid	80/82	97.6%
Tomcod	23/24	95.8%
Total:	750/792	94.7%
Misclassified:		42

Figure 2: Classification tree of all prey sampled in PWS (sample size ≥ 4). Ellipses represent intermediate nodes and rectangle boxes represent terminal nodes; labels within an ellipse or rectangle indicate the classification at that node as represented by the largest number of observations that node. The fatty acid listed at each node is the variable chosen to split; the value listed is the optimal splitting value for that fatty acid (> down right node and < down left node). fractions under each node indicate the number of misclassifications over the total number of observations in that node. The summary table lists the totals correctly classified.


PWS PREY SPECIES
n = 792
22:5n-3
1.950
HERRING
381/617
20:3n-3
0 230
HERRING
293/521
12:0
0 035
SQUID
14/96
Iso 16
0.170
POLLOCK
57/196
18:1n-11
0 285
HERRING
117/325
22:5n-3
1.230
HERRING
3/11
SQUID
3/85
18:0
2 860
HERRING
30/48
16:0
17.955
POLLOCK
16/148
14.0
6.030
HERRING
60/264
12:0
0.505
CAPELIN
7/61
18:1n-9
8 750
SQUID
0/80
OCTOPUS
2/5
TOMCOD
12/21
18:3n-1
0.095
HERRING
9/27
20:5n-3
12.605
POLLOCK
8/140
21.5n-3
0.195
CAPELIN
2/8
HERRING
42/246
18:3n-1
0.115
CAPELIN
9/18
Iso 15
0.075
CAPELIN
0/54
HERRING
3/7
TOMCOD
1/10
PACIFIC COD
6/11
13:0
0 010
HERRING
2/20
POLLOCK
0/7
SANDLANCE
6/10
15:0
0.290
POLLOCK
2/130
HERRING
5/187
18:0
2.725
SANDLANCE
32/59
16:2n-6
0.075
POLLOCK
0/9
CAPELIN
0/9
PACIFIC COD
0/5
SANDLANCE
1/6
POLLOCK
1/5
SANDLANCE
1/5
HERRING
0/176
HERRING
5/11
16:0
19.745
HERRING
9/26
18:0
3.470
SANDLANCE
6/33
Iso 16
0.095
POLLOCK
2/5
HERRING
0/6
HERRING
2/19
POLLOCK
0/7
HERRING
4/9
SANDLANCE
0/24

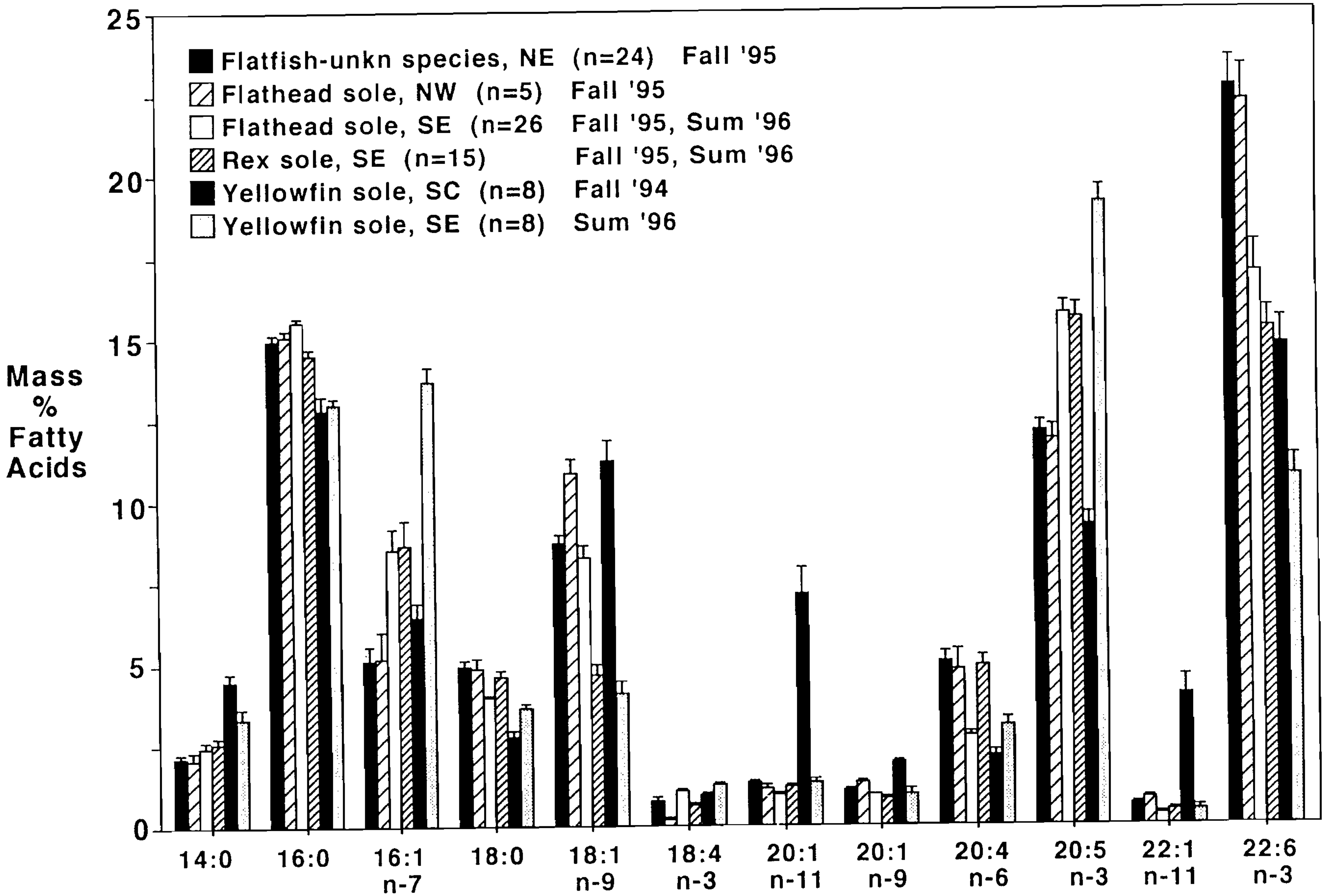
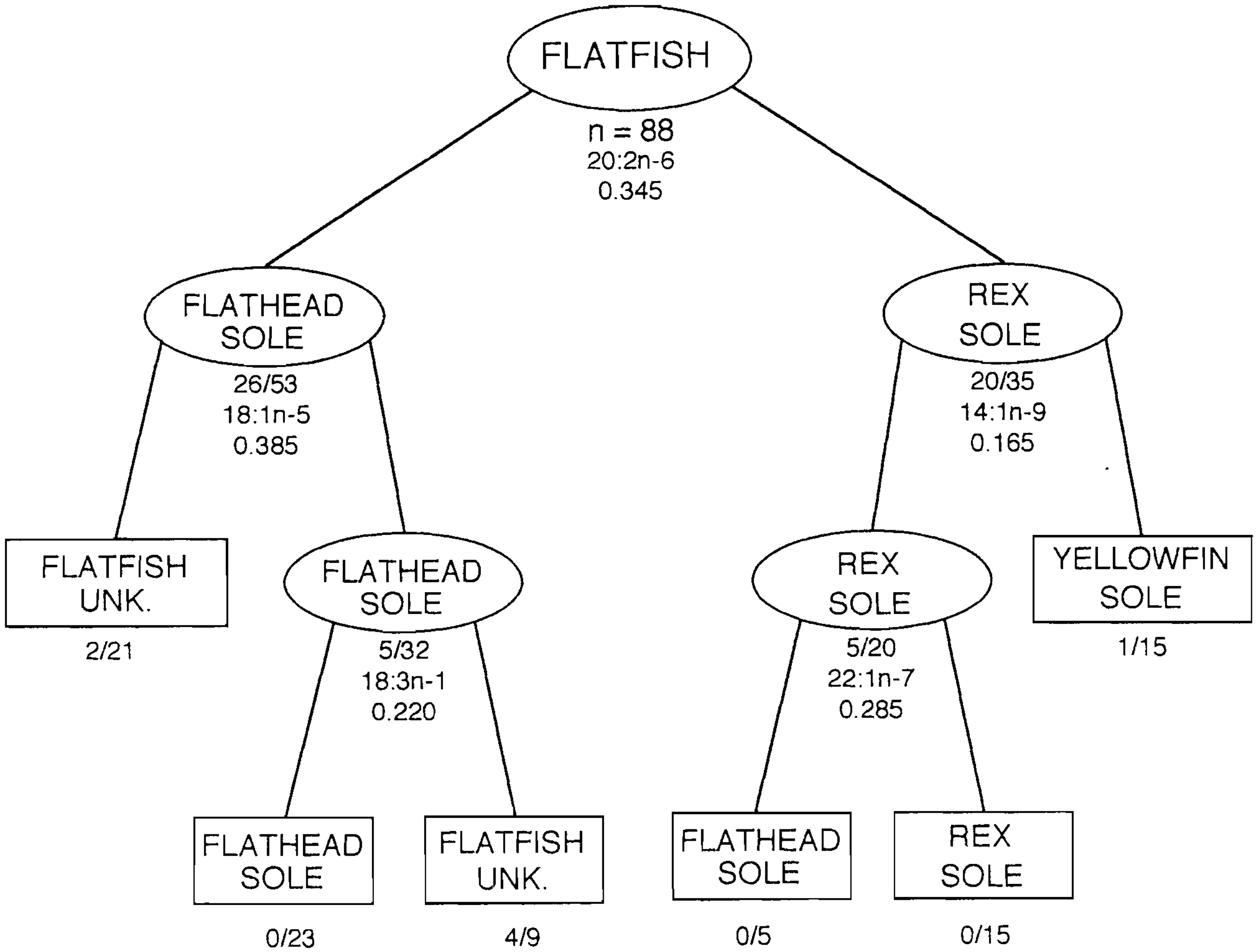
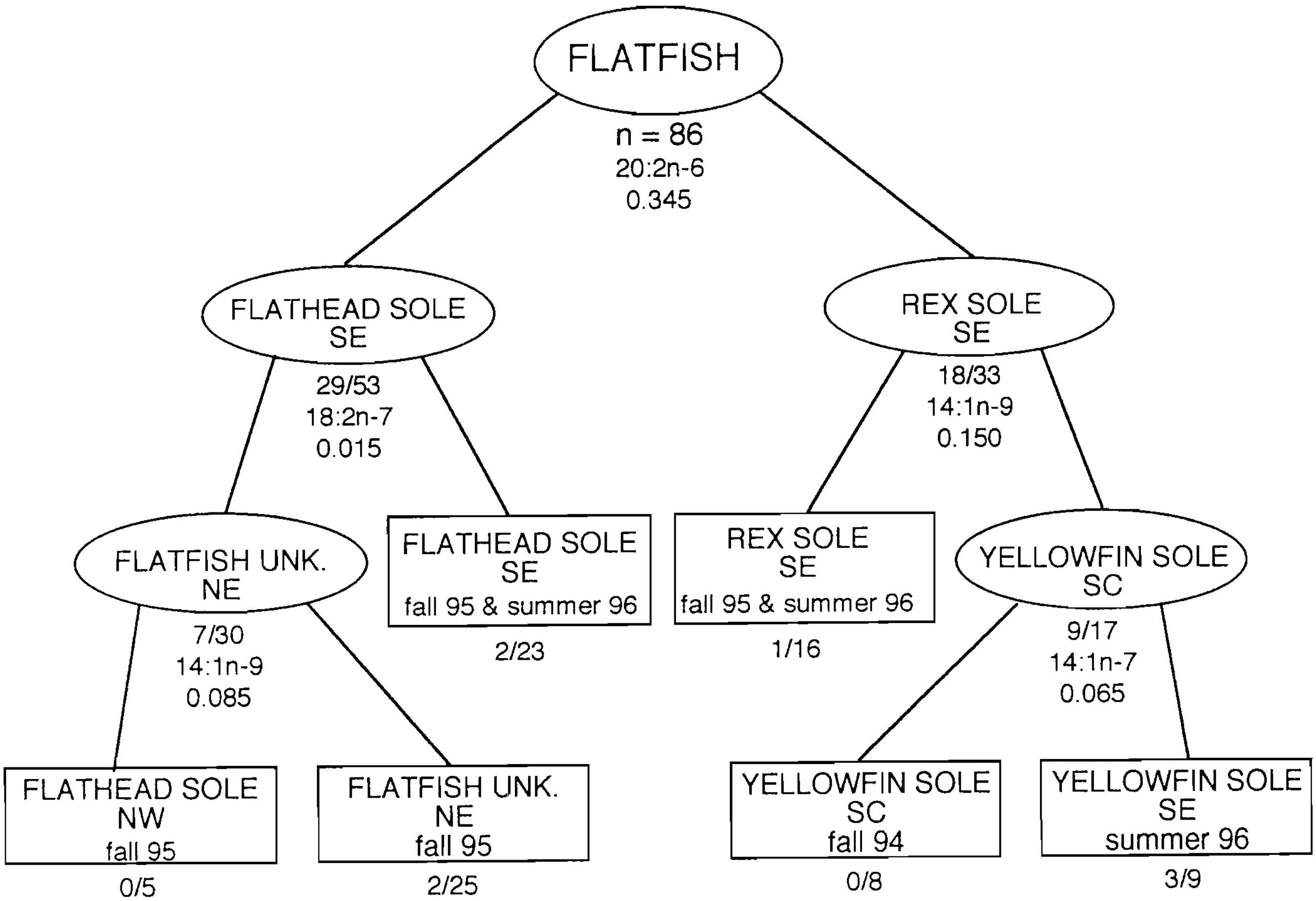


Figure 3. Variation in selected fatty acids (mean + SEM) in flatfish (n = 86) as a function of species and area of collection within Prince William Sound.



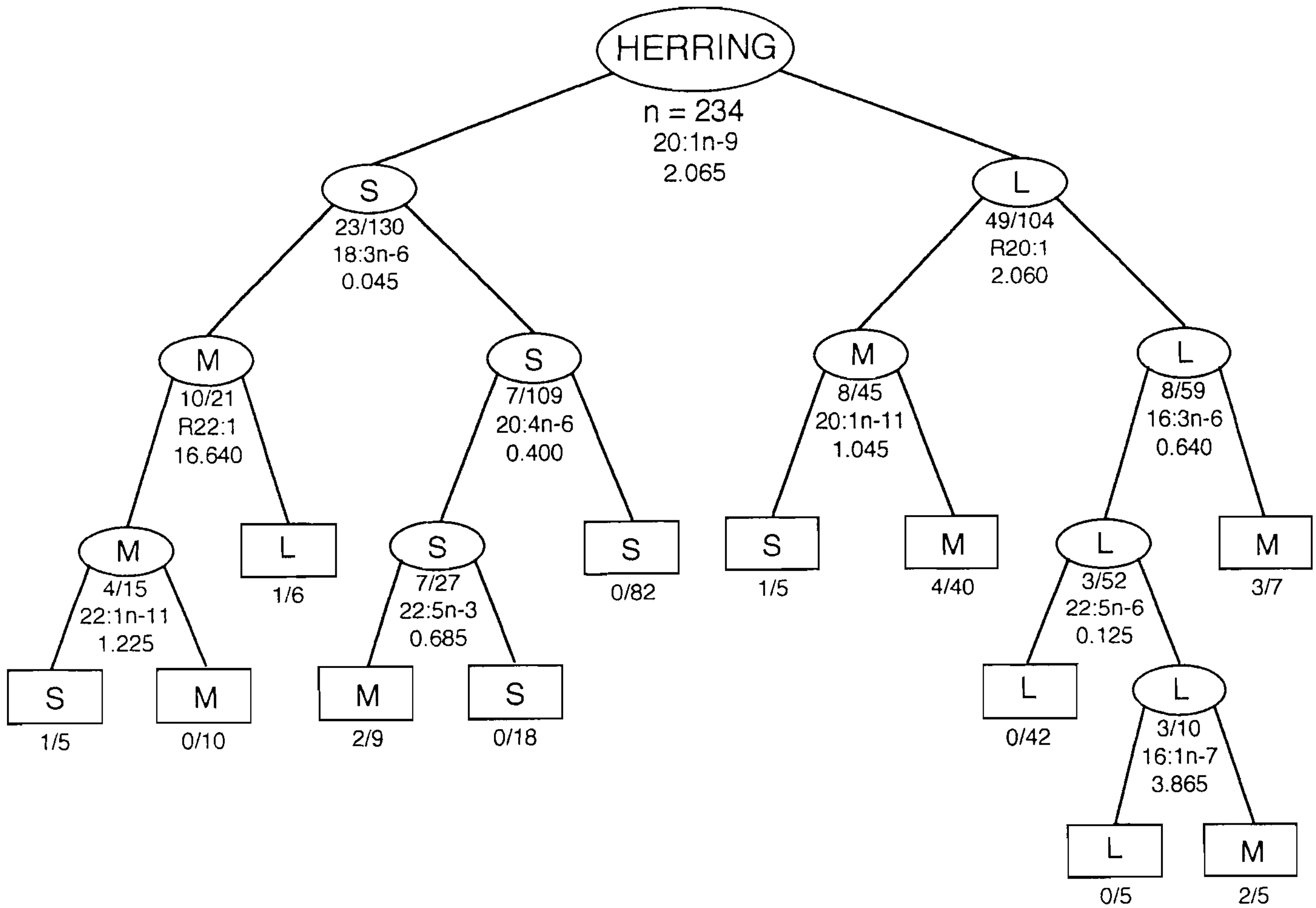
SUMMARY:	correct/total	
Flathead Sole	28/33	84.8%
Flatfish unk. sp.	24/24	100%
Rex Sole	15/15	100%
Yellowfin Sole	14/16	87.5%
Total:	81/88	92.0%
Misclassified:		7

Figure 4: Classification tree of flatfish species within PWS. See Fig. 2 legend for explanation of tree.



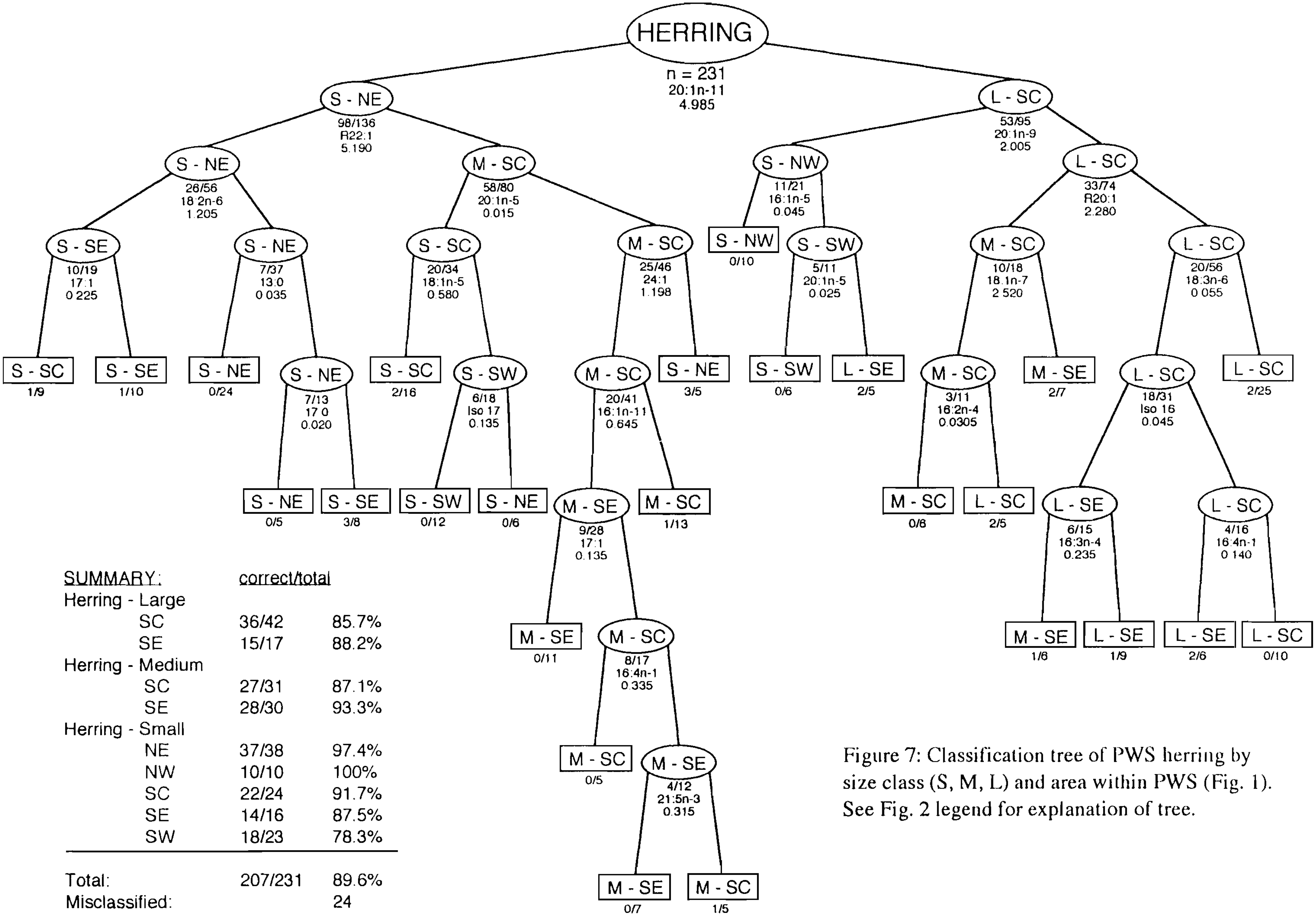
SUMMARY:	correct/total	
Flathead Sole		
NW	5/5	100%
SE	21/26	80.8%
Flatfish unk. sp. - NE	23/24	95.8%
Rex Sole - SE	15/15	100%
Yellowfin Sole		
SC	8/8	100%
SE	6/8	75.0%
Total:	78/86	90.7%
Misclassified:		8

Figure 5: Classification tree of flatfish species by location within PWS (Fig. 1). Season and year of collection are listed with locations, given there potential confounding influence. See Fig. 2 legend for explanation of tree.



SUMMARY:	correct/total	
Herring - Large	52/60	86.7%
Herring - Medium	60/62	96.8%
Herring - Small	108/112	96.4%
Total:	220/234	94.0%
Misclassified:		14

Figure 6: Classification tree of PWS herring by size classes: small (S), medium (M) and large (L). See Fig. 2 legend for explanation of tree.



SUMMARY:		correct/total	
Herring - Large			
	SC	36/42	85.7%
	SE	15/17	88.2%
Herring - Medium			
	SC	27/31	87.1%
	SE	28/30	93.3%
Herring - Small			
	NE	37/38	97.4%
	NW	10/10	100%
	SC	22/24	91.7%
	SE	14/16	87.5%
	SW	18/23	78.3%
Total:		207/231	89.6%
Misclassified:			24

Figure 7: Classification tree of PWS herring by size class (S, M, L) and area within PWS (Fig. 1). See Fig. 2 legend for explanation of tree.

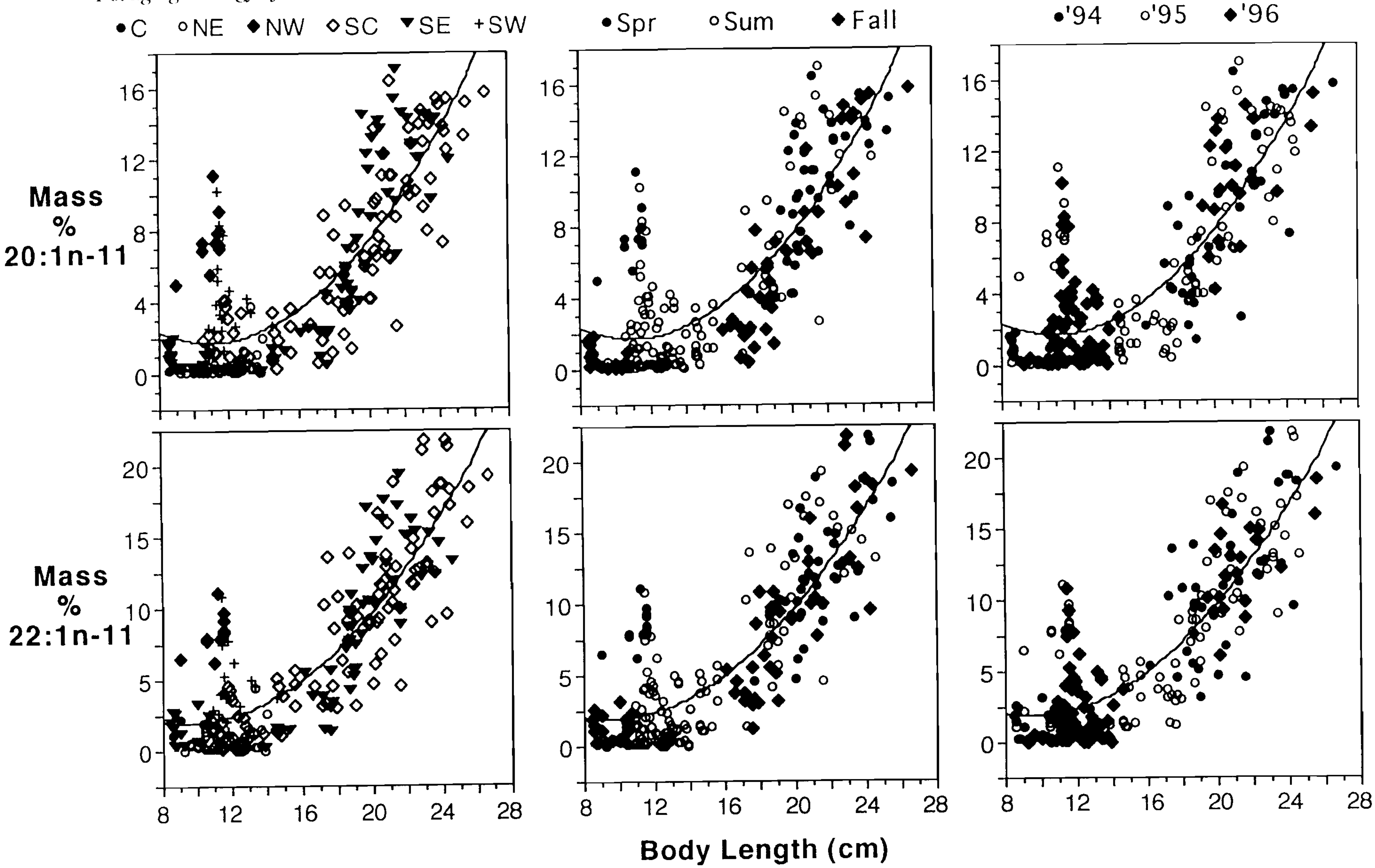


Figure 8. Variation in fatty acids 20:1n-11 and 22:1n-11 in herring (n = 236) as a function of body length and illustrating distribution of points across location within Prince William Sound, across seasons, and across years. Body length alone explained 67.5% and 72.0% of the variation in 20:1n-11 and 22:1n-11, respectively (P <0.001).

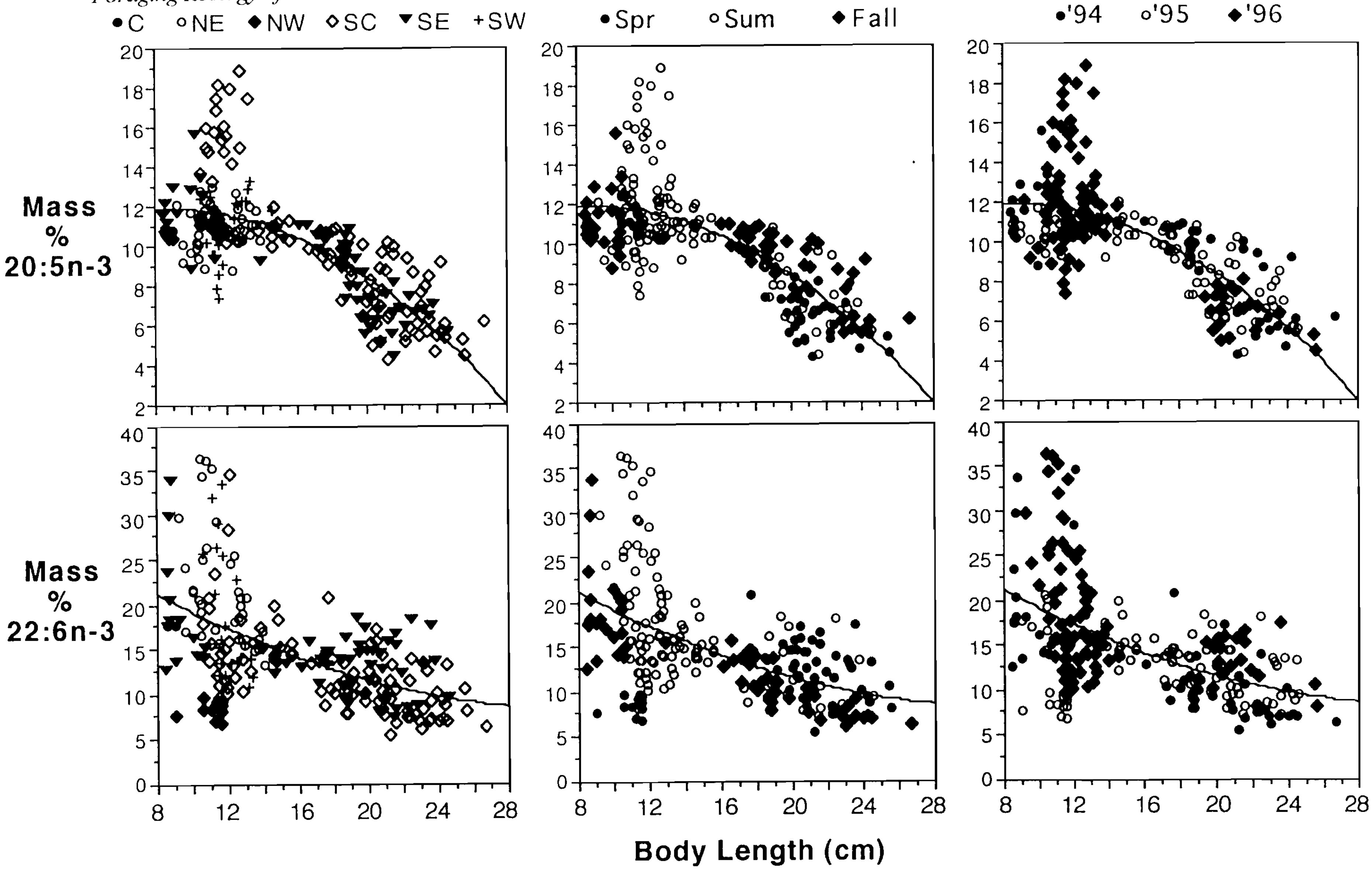


Figure 9. Variation in fatty acids 20:5n-3 and 22:6n-3 in herring (n = 236) as a function of body length and illustrating distribution of points across location within Prince William Sound, across seasons, and across years. Body length alone explained 55.9% and 29.6% of the variation in 20:5n-3 and 22:6n-3, respectively ($P < 0.001$).

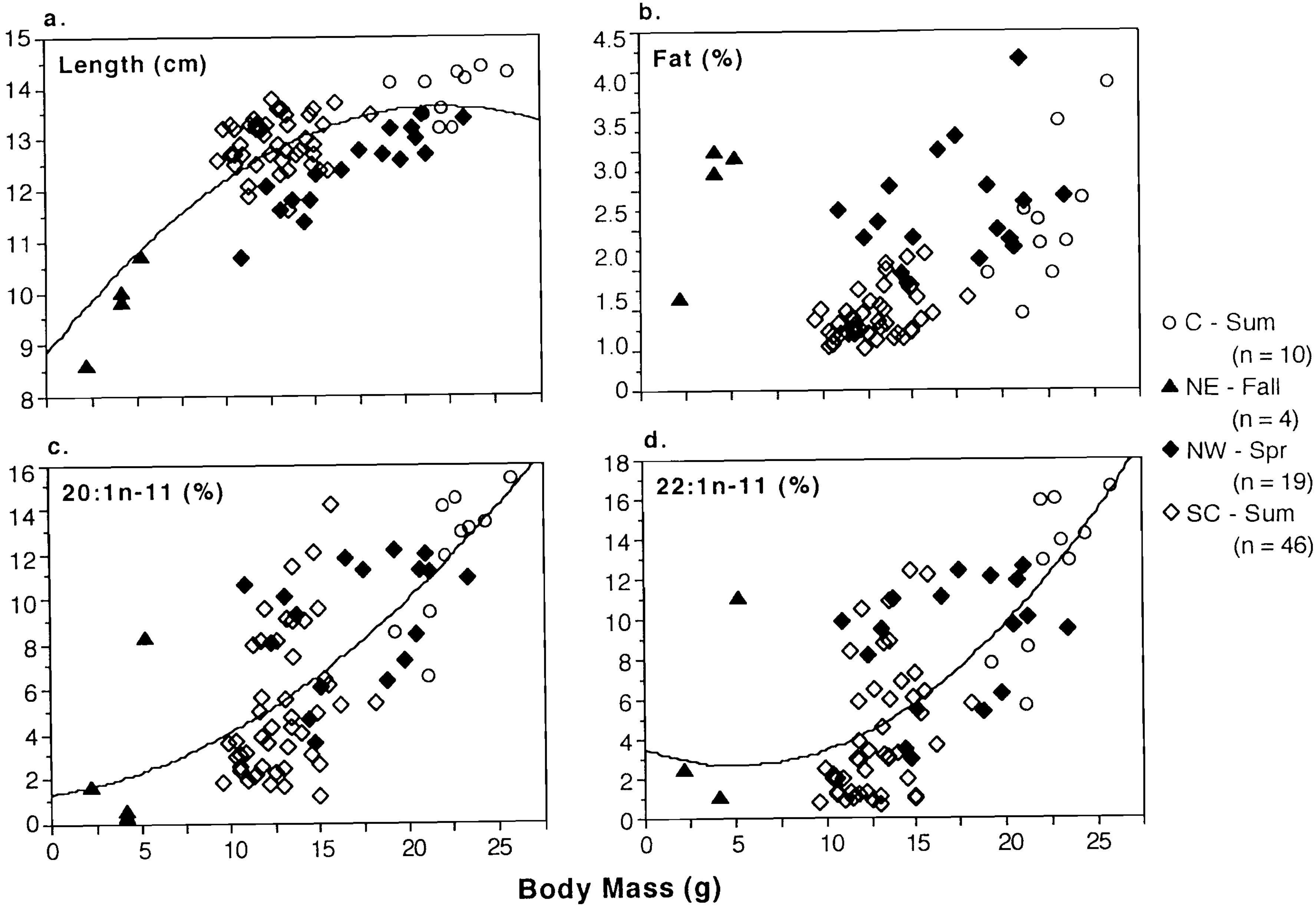


Figure 10. Selected characteristics of capelin (n = 79) collected in Prince William Sound ay various locations and seasons. Although body length was strongly correlated with mass (a. r2 = 0.532), mass was a better predictor of other variables. Body length alone explained 50.9% and 50.2% of the variation in 20:1n-11 (c.) and 22:1n-11 (d.), respectively (P <0.001).

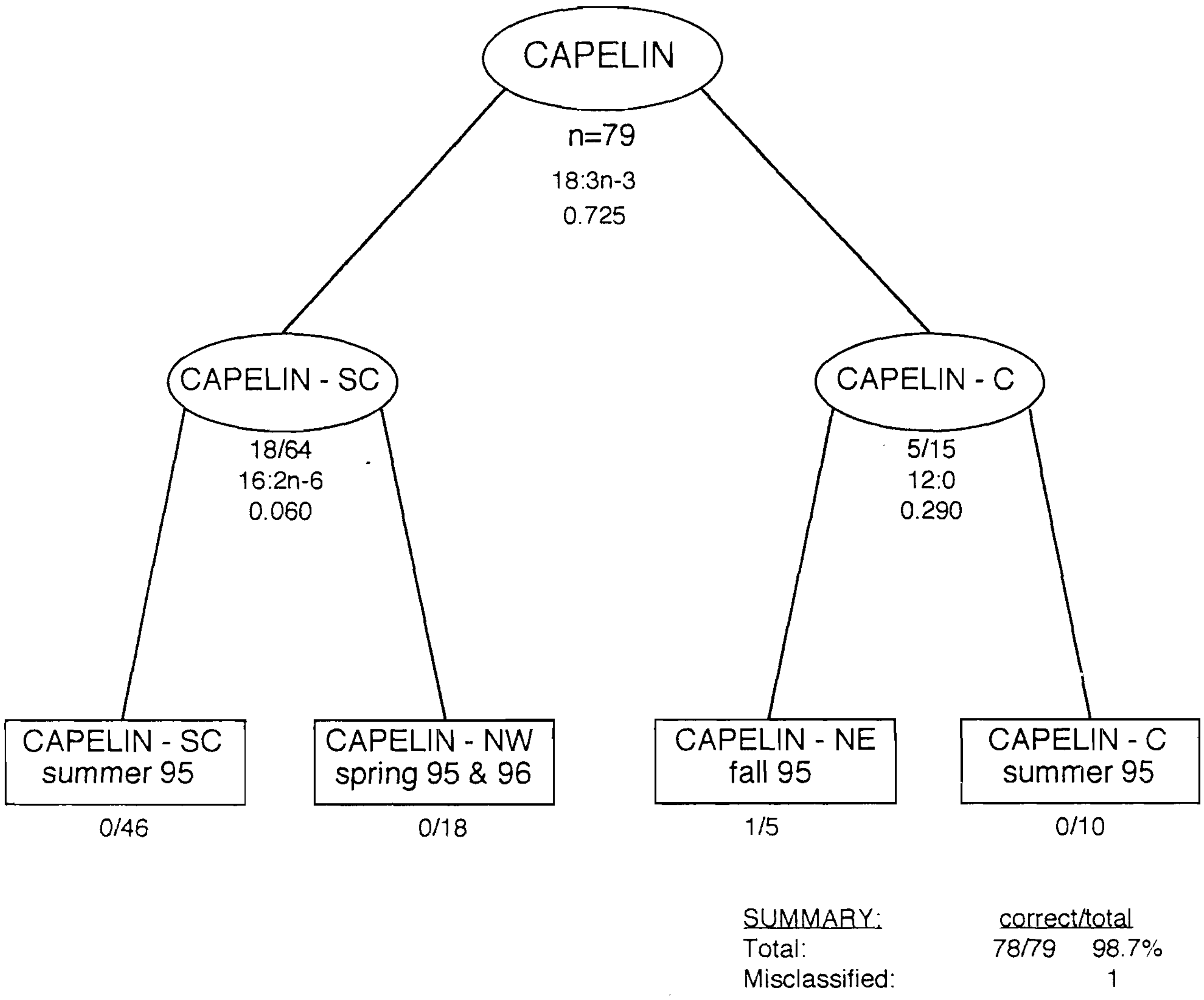


Figure 11: Classification tree of capelin across locations within PWS (Fig. 1). See Fig. 2 legend for explanation of tree.

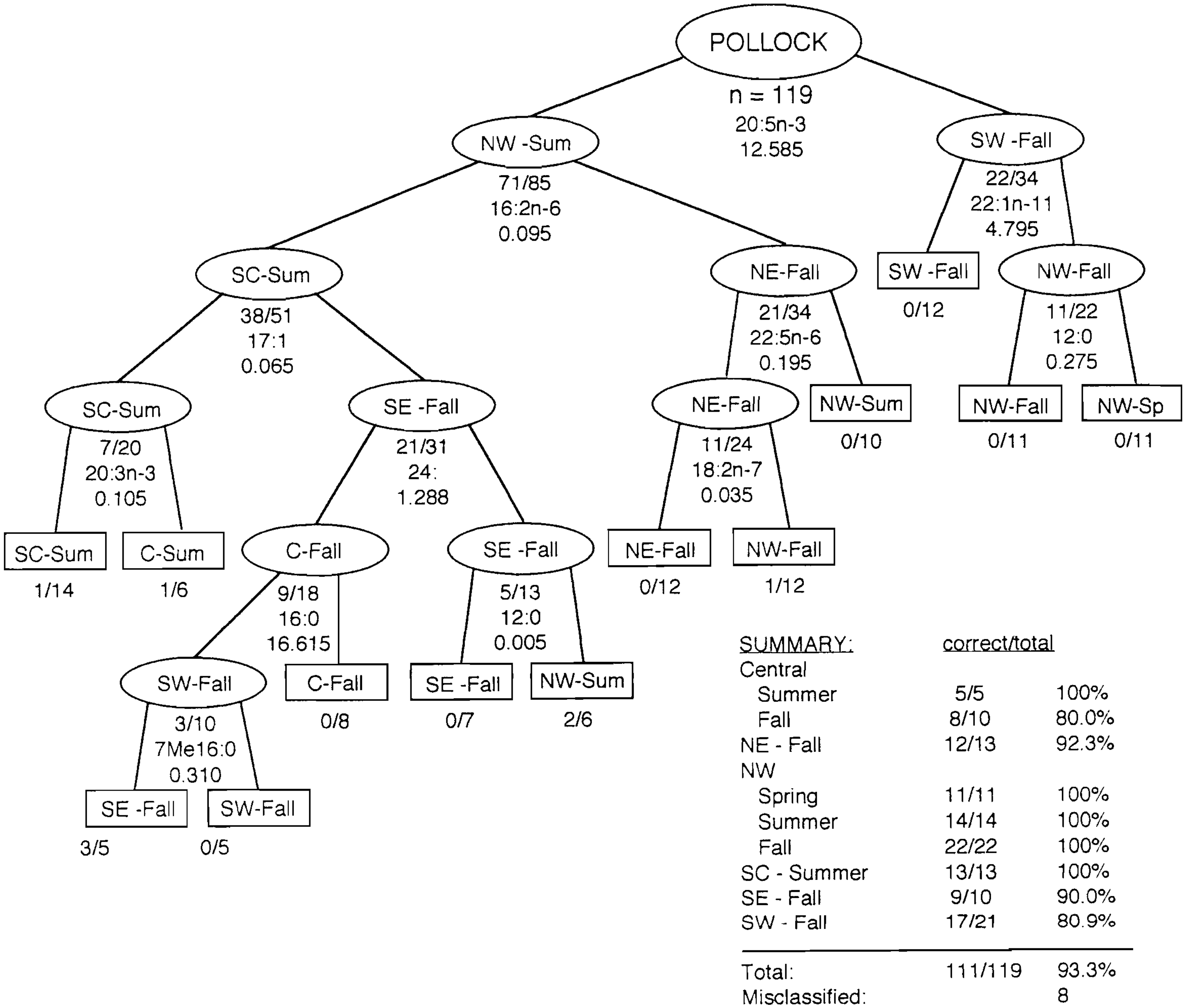


Figure 12: Classification tree of pollock from 1995 across locations and seasons within PWS (Fig. 1). See Fig. 2 legend for explanation of tree.

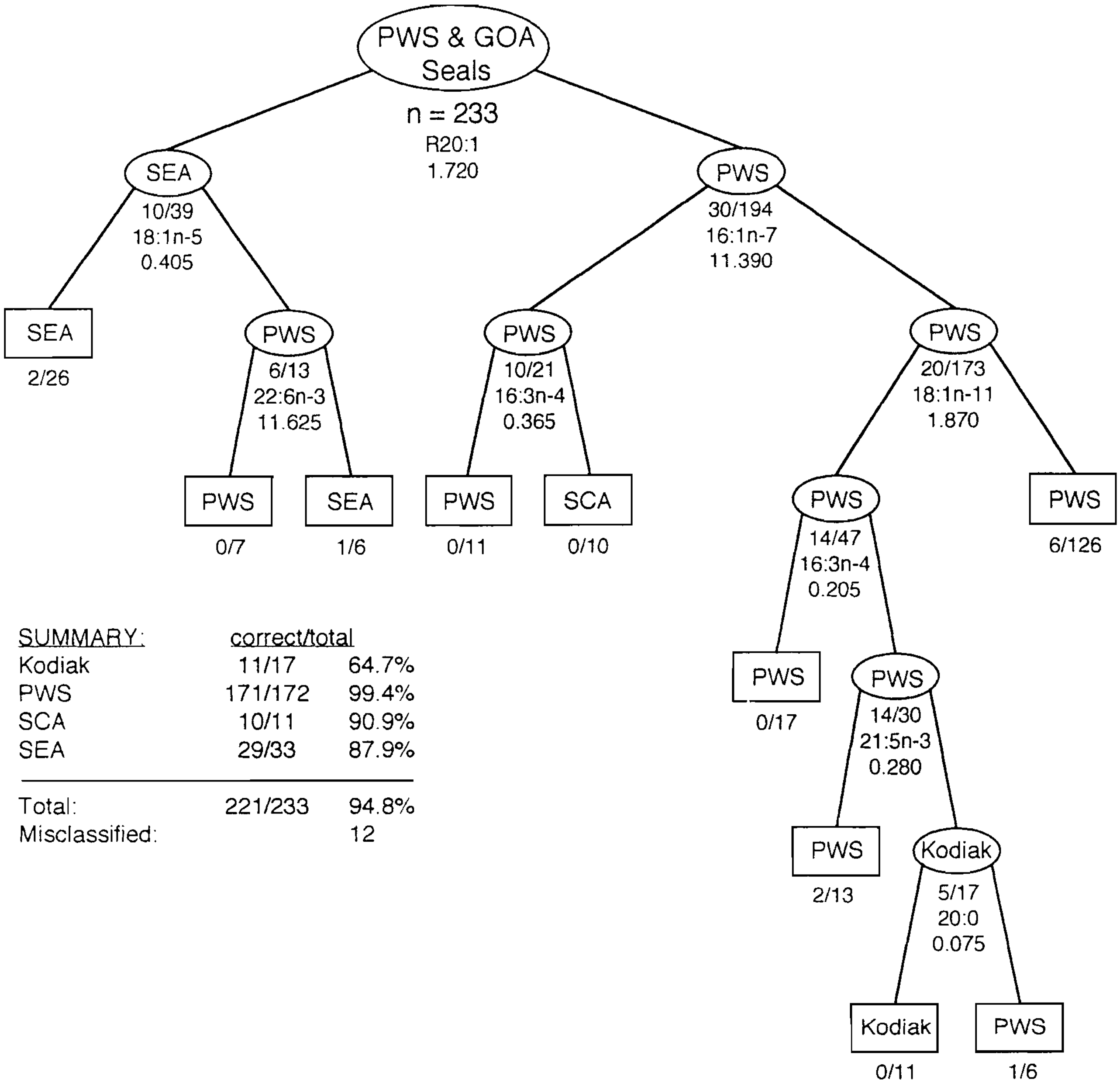
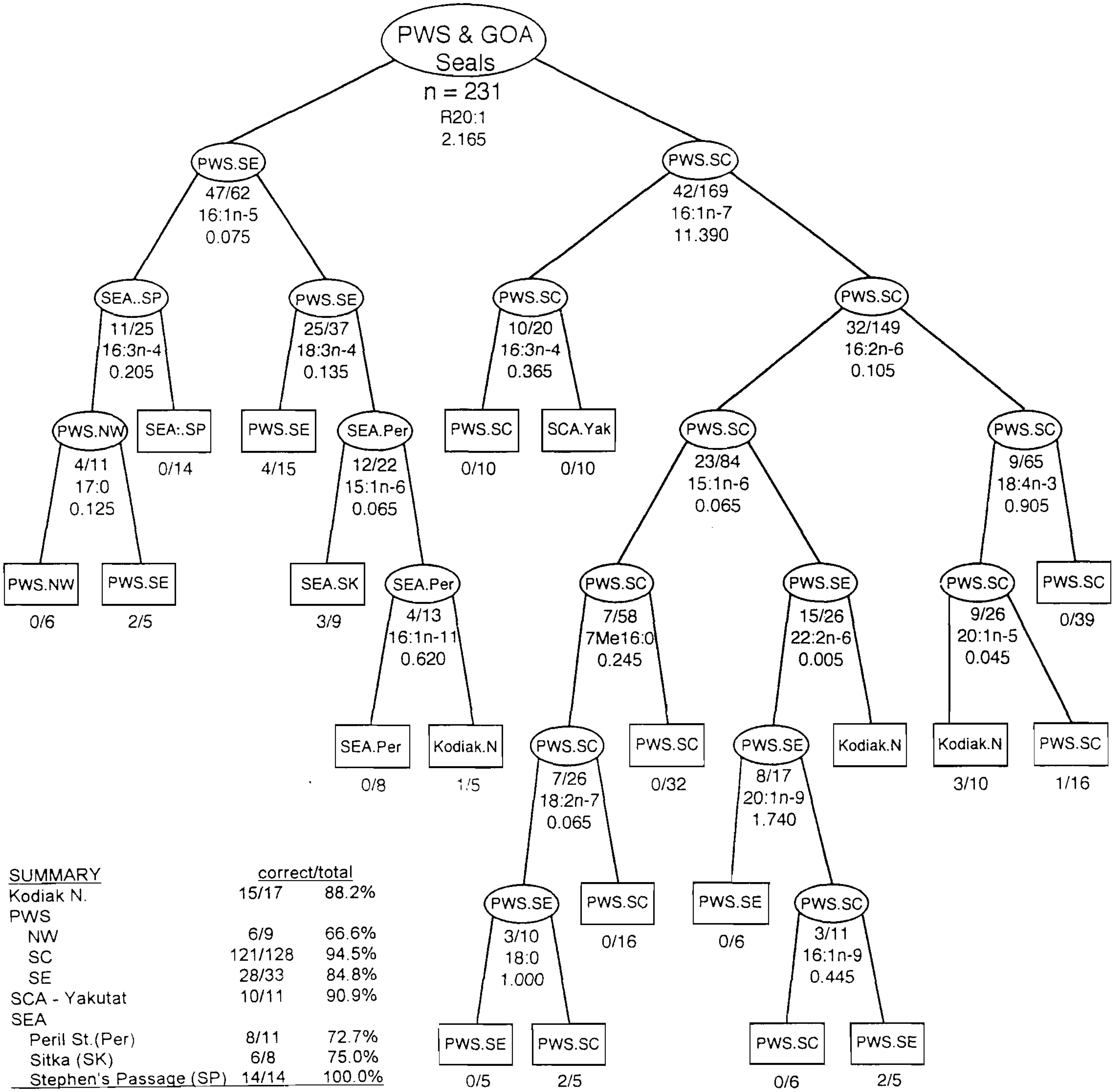


Figure 13: Classification tree of harbor seals from PWS and GOA by major area. Analysis includes all adults and subadults; pups and half year olds excluded. See Fig. 2 legend for explanation of tree.



SUMMARY	correct/total	
Kodiak N.	15/17	88.2%
PWS		
NW	6/9	66.6%
SC	121/128	94.5%
SE	28/33	84.8%
SCA - Yakutat	10/11	90.9%
SEA		
Peril St.(Per)	8/11	72.7%
Sitka (SK)	6/8	75.0%
Stephen's Passage (SP)	14/14	100.0%
Total correct	208/231	90.0%
Misclassified	23/231	10.0%

Figure 14: Classification tree of harbor seals from PWS and GOA by specific location within PWS and the GOA. Analysis includes all adults and subadults where sampling location contains 4 or more individuals. See Fig. 2 legend for explanation of tree.

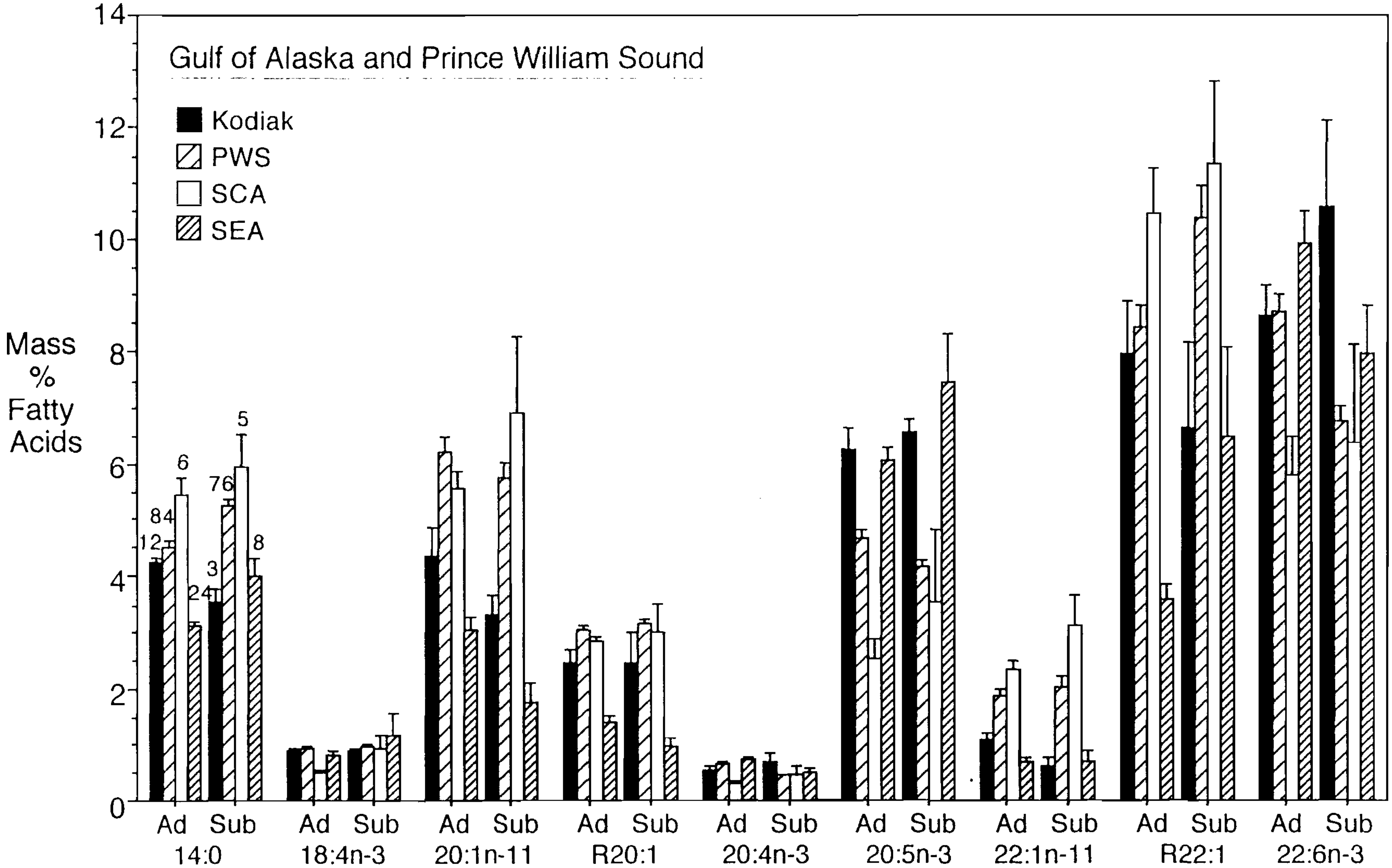


Figure 15. Variation (mean + SEM) in selected fatty acids in seals among age classes and locations in the Gulf of Alaska and Prince William Sound (n = 218). Numbers above bars in first plot indicate sample size for each group. SCA (South Central at Yakutat). Age class differences (excluding yearlings, half-year-olds and pups due to sample size) were found for 18:4n-3 and 20:5n-3 ($P < 0.01$); location differences were found for all components ($P < 0.001$, 2-way ANOVA).

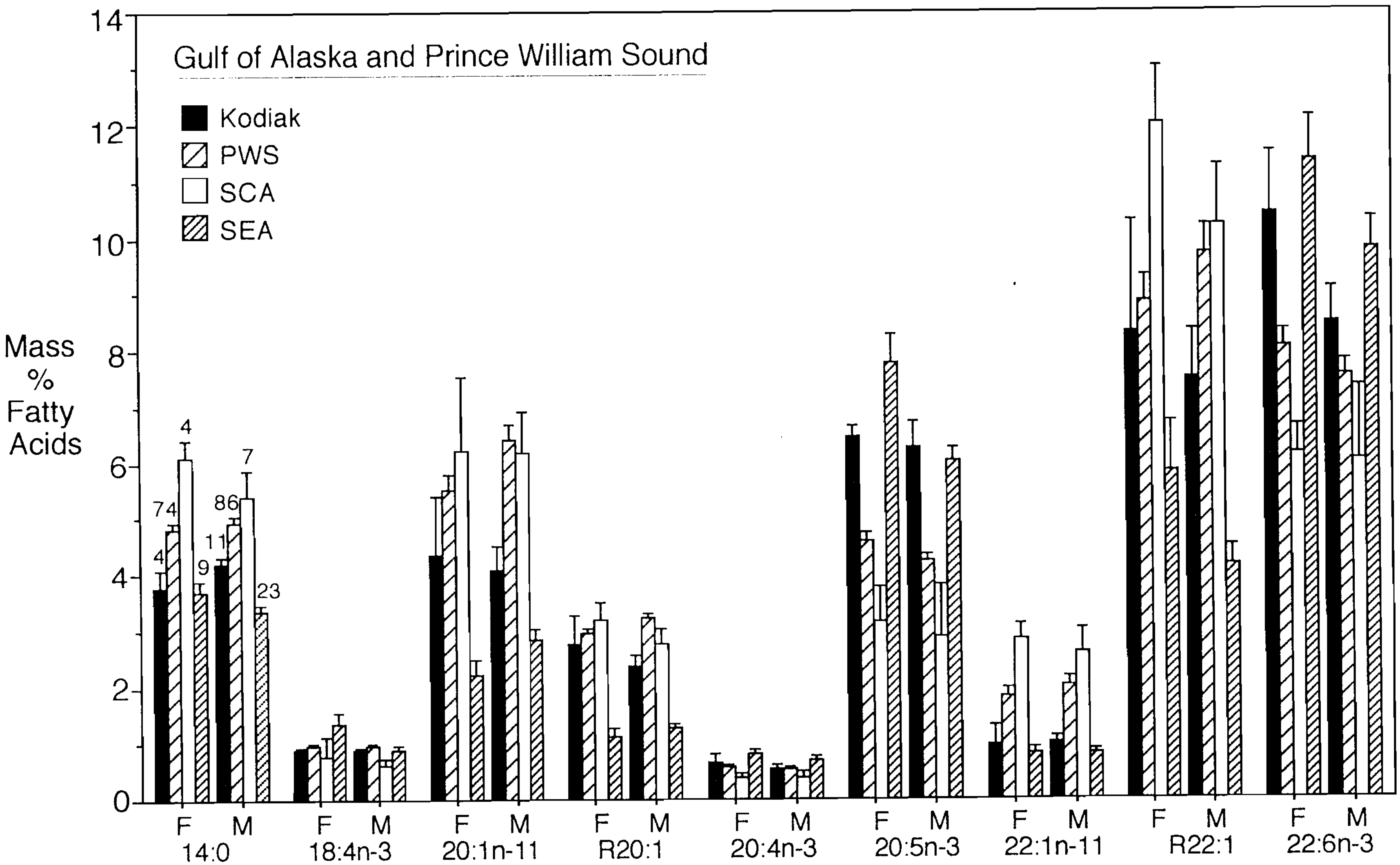


Figure 16. Variation (mean + SEM) in selected fatty acids in seals among females (F) and males (M) and locations in the Gulf of Alaska and Prince William Sound (n = 218). Numbers above bars in first plot indicate sample size for each group. Adults and subadults were included and combined, given sometimes small group sample size; see Fig. 15 for distribution of these age classes. SCA (South Central at Yakutat). Sex differences were found for 18:4n-3 and 20:5n-3 ($P < 0.05$); location differences were found for all components ($P < 0.001$, 2-way ANOVA).

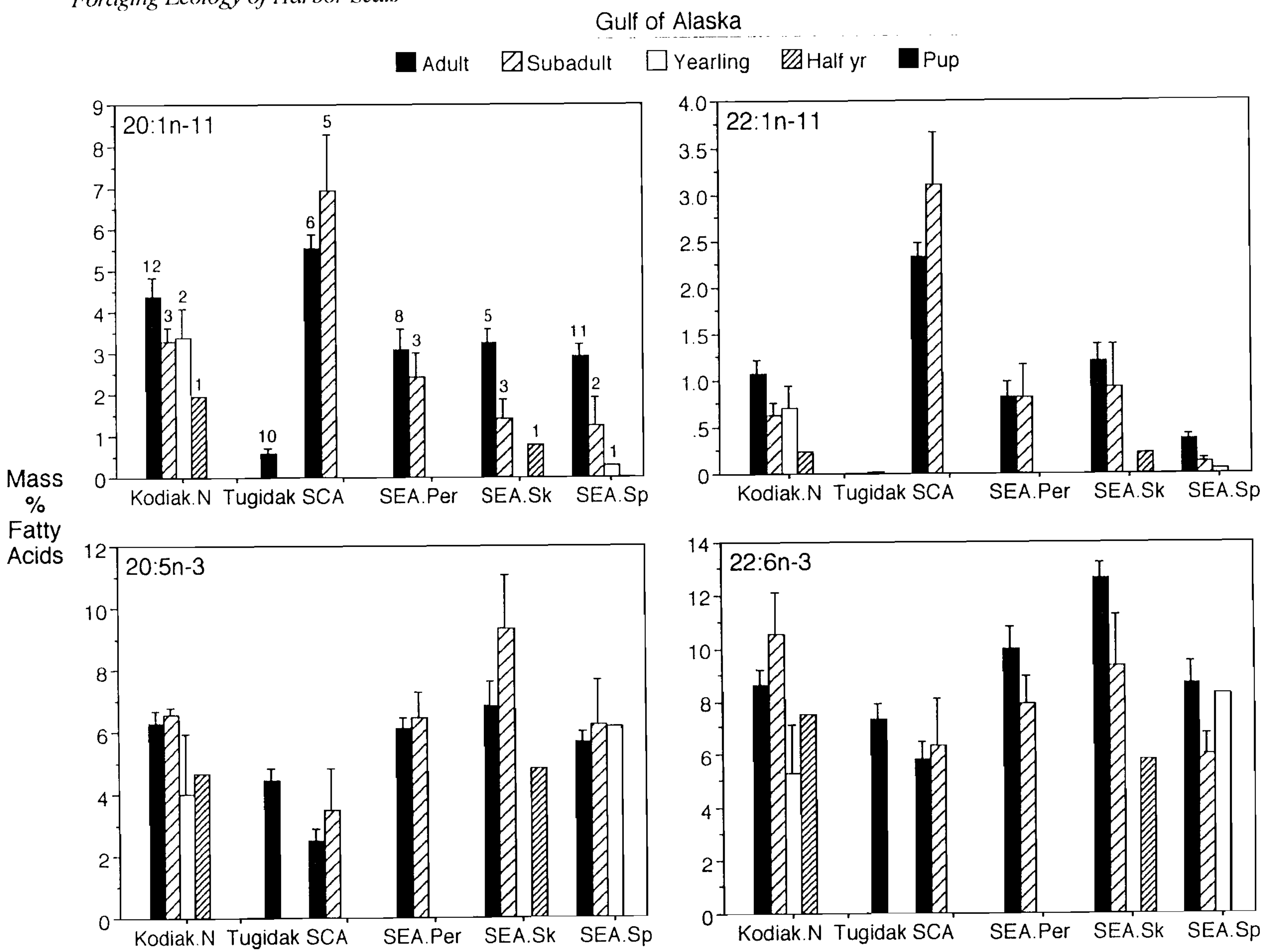


Figure 17. Variation (mean + SEM) in selected dietary fatty acids in seals among age classes and locations in the Gulf of Alaska ($n = 76$). Numbers above bars in first plot indicate sample size for each group. SCA (South Central at Yakutat), SEA.Per (Southeast Alaska at Peril Straight), SEA.Sk (at Sitka), Sp (at Stephens Passage). Age class differences (excluding yearlings, half year olds and pups due to sample size) were found for all components ($P < 0.01$); location differences were found for 20:1n-11 and 20:5n-3 ($P < 0.05$, 2-way ANOVA).

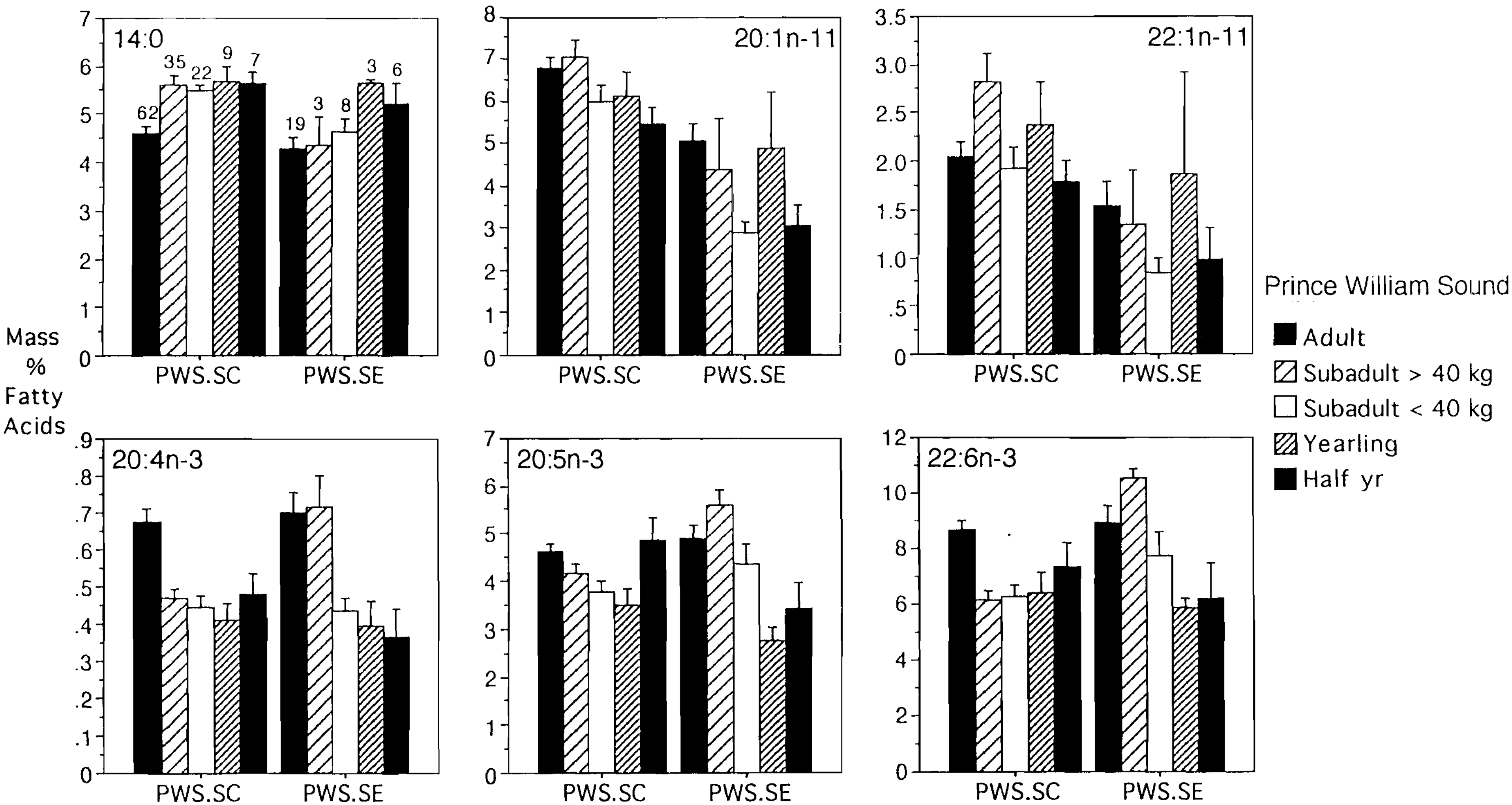


Figure 18. Variation (mean + SEM) in selected fatty acids in seals among two major locations in Prince William Sound by age class (n = 174, no pups). Subadults are divided into those > and < 40 kg. Numbers above bars in first plot indicate sample size for each group. Location differences were apparent for 14:0, 20:1n-11, and 22:1n-11; age class differences were apparent for all except 22:1n-11 ($P < 0.05$, 2-way ANOVA). Means comparisons tests revealed these differences to be attributable mostly to differences between adults and all other age classes, although some differences separated half year-olds and yearlings from older age-classes.

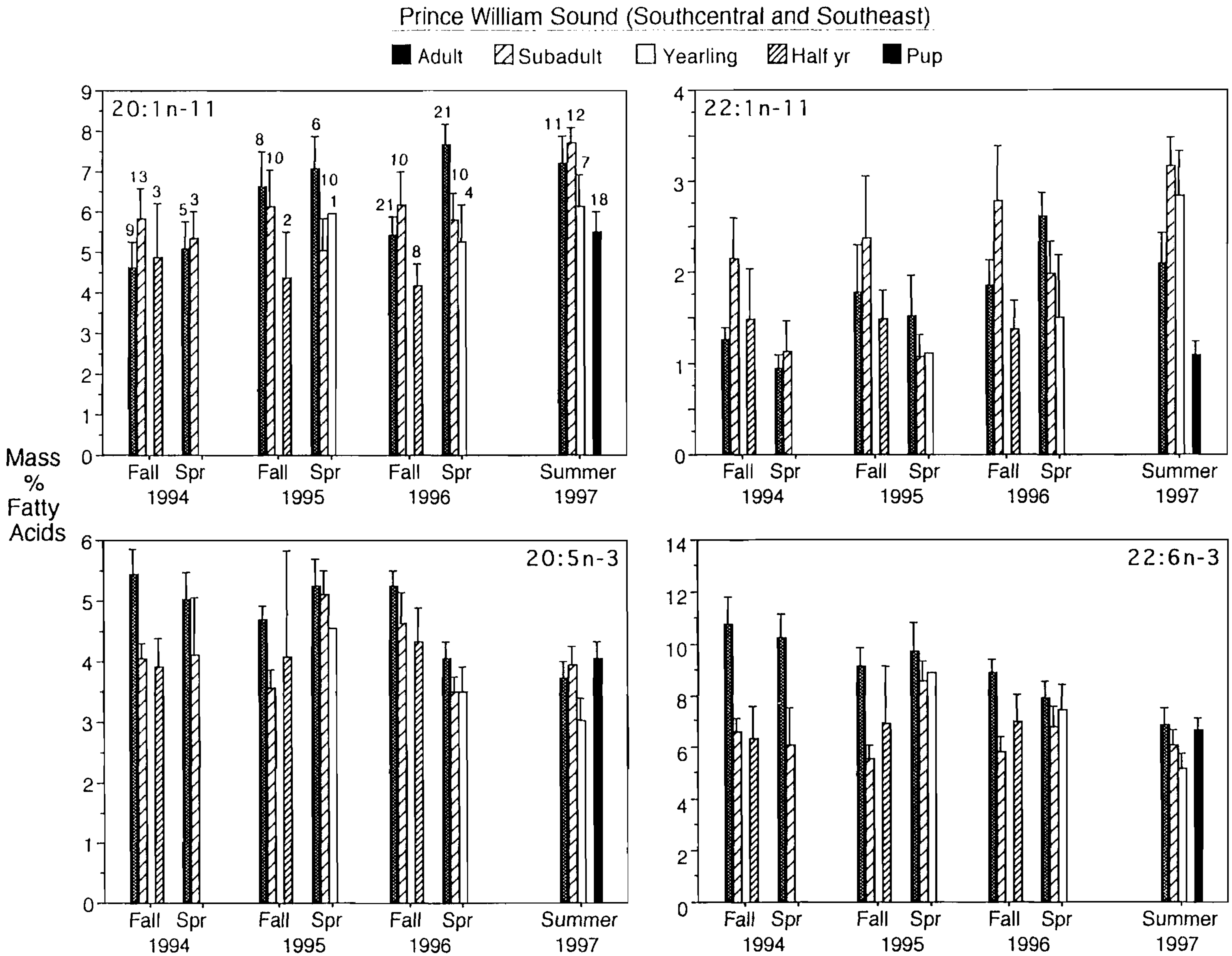
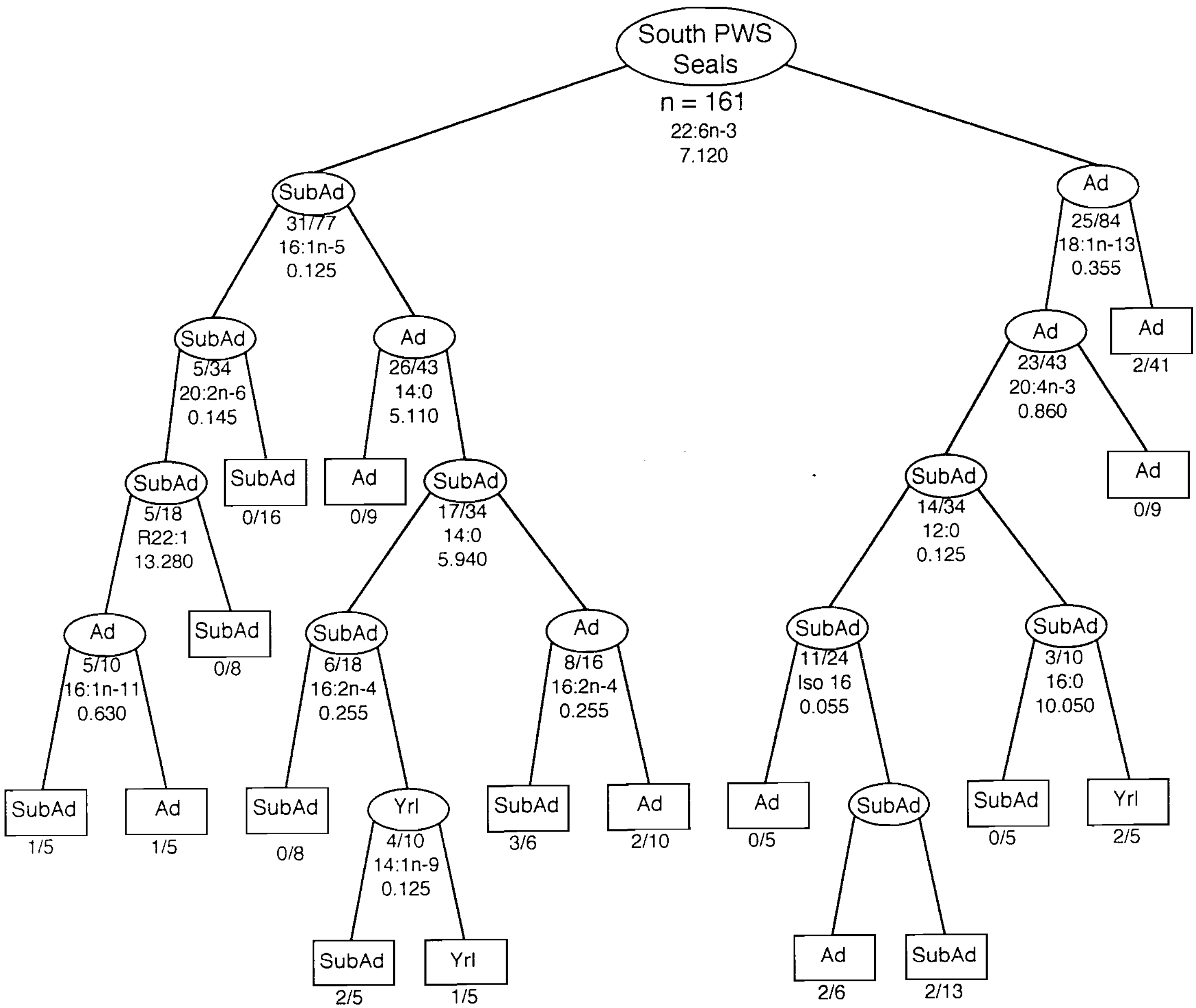
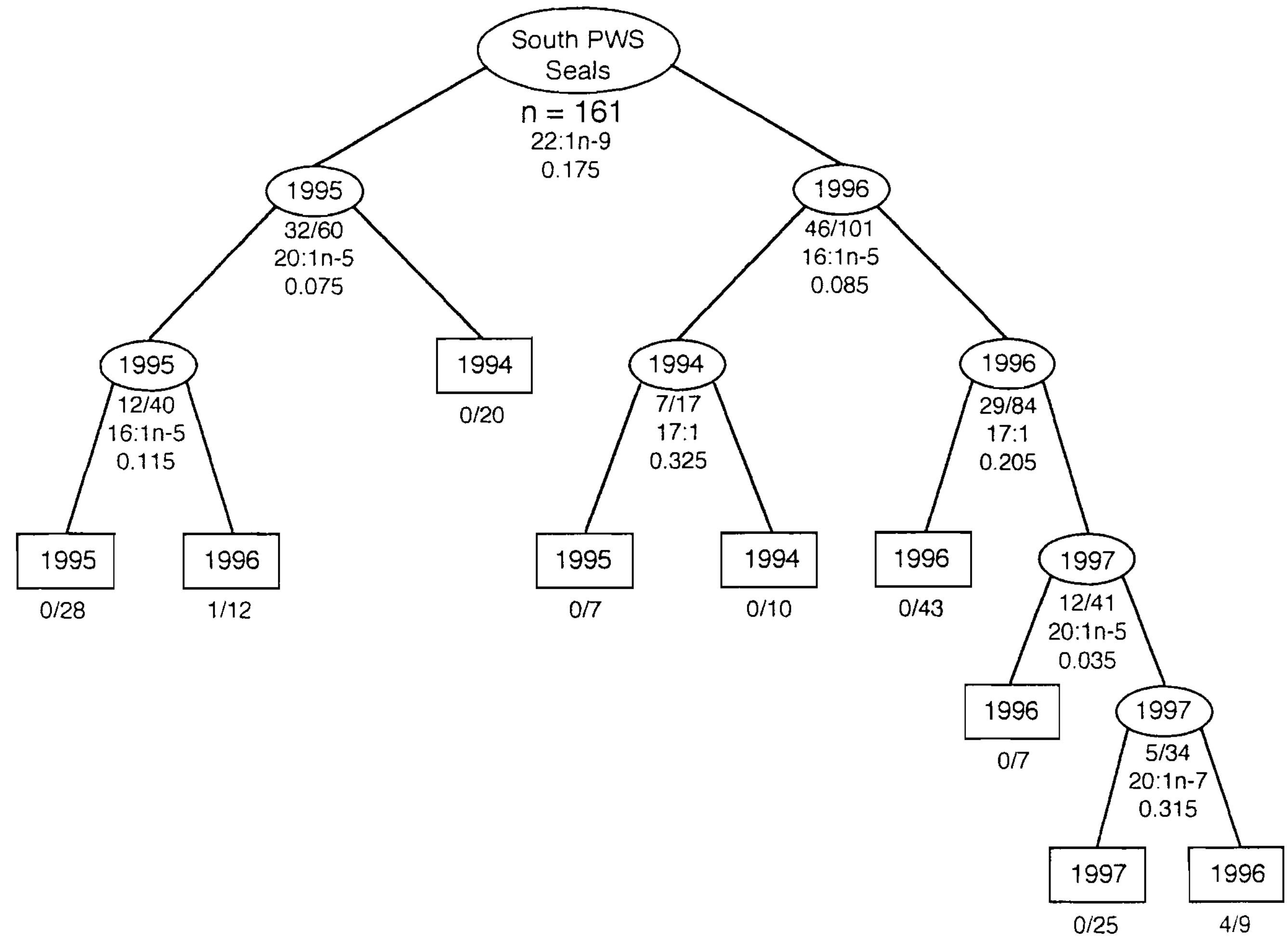


Figure 19. Variation (mean + SEM) in selected dietary fatty acids in seals among age classes, seasons and years in southcentral and southeast Prince William Sound (n = 196). Numbers above bars in first plot indicate sample size for each group; data were tested by 2-way ANOVAs, ommitting summer 1997. Generally, differences were not found across years. Only 20:1n-11 differed between spring and fall ($P = 0.0347$). Age classes differed significantly ($P < 0.05$) in all components expect for 22:1n-11; means comparisons tests revealed these differences to be attributable mostly to differences between adults and all other age classses



<u>SUMMARY:</u>	<u>correct/total</u>	
Adult	78/81	96.3%
Sub Adult	58/58	85.3%
Yearling	7/12	58.3%
Total:	143/161	88.8%
Misclassified:		18

Figure 20: Classification tree of harbor seals from South (SC & SE) PWS by age class (half year olds and pups excluded). See Fig. 2 legend for explanation of tree.



SUMMARY:	correct/total	
1994	30/30	100%
1995	35/35	100%
1996	66/66	100%
1997	25/30	83.3%
Total:	156/161	96.9%
Misclassified:		5

Figure 21: Classification tree of harbor seals from SC and SE PWS by year. Adults, subadults and yearlings included. See Fig. 2 for explanation of tree.

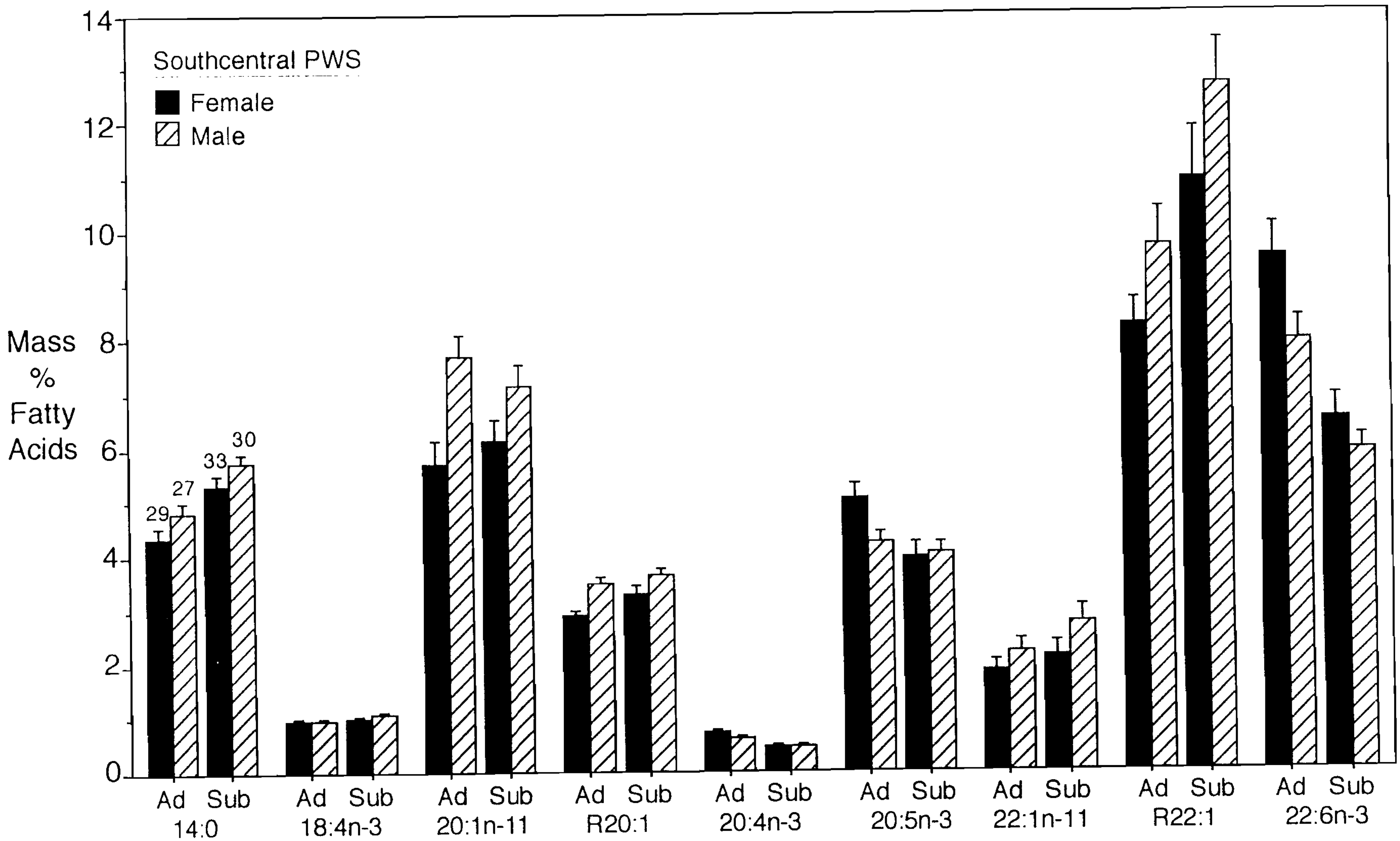


Figure 22. Selected fatty acids (mean + SEM) in seals from southcentral Prince William Sound (near Montague Island) as a function of age class (adults and subadults only) and sex. Numbers above bars in first plot indicate sample size for each group. Age class differences were found for all components except 18:4n-3, 20:1n-11 and 22:1n-11; sex differences were found for all components except 18:4n-3, 20:4n-3, and 20:5n-3 ($P < 0.05$, 2-way ANOVA).

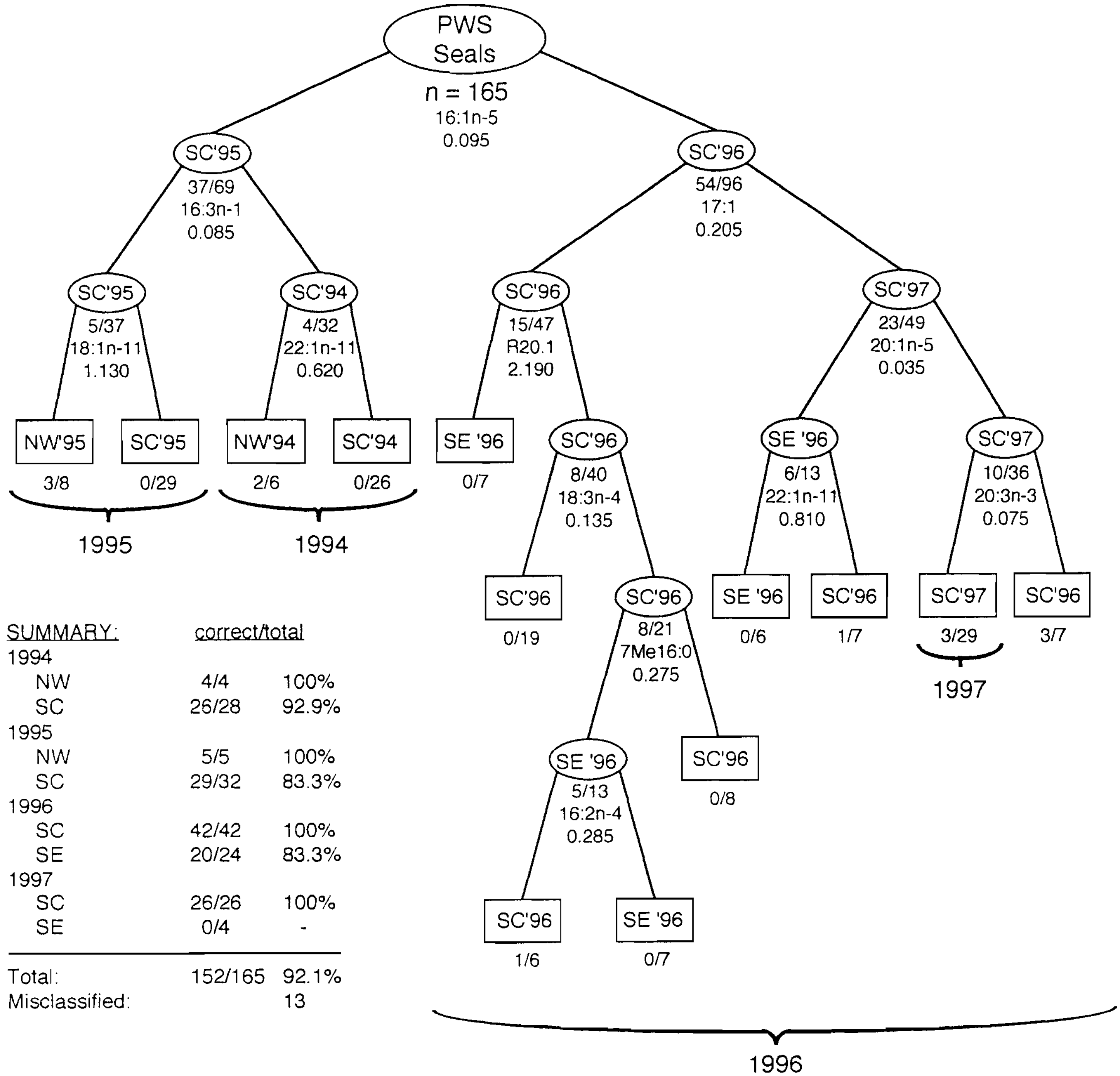


Figure 23: Classification tree of harbor seals from PWS by area and year. Adults, subadults and yearlings included. See Fig. 2 for explanation of tree.

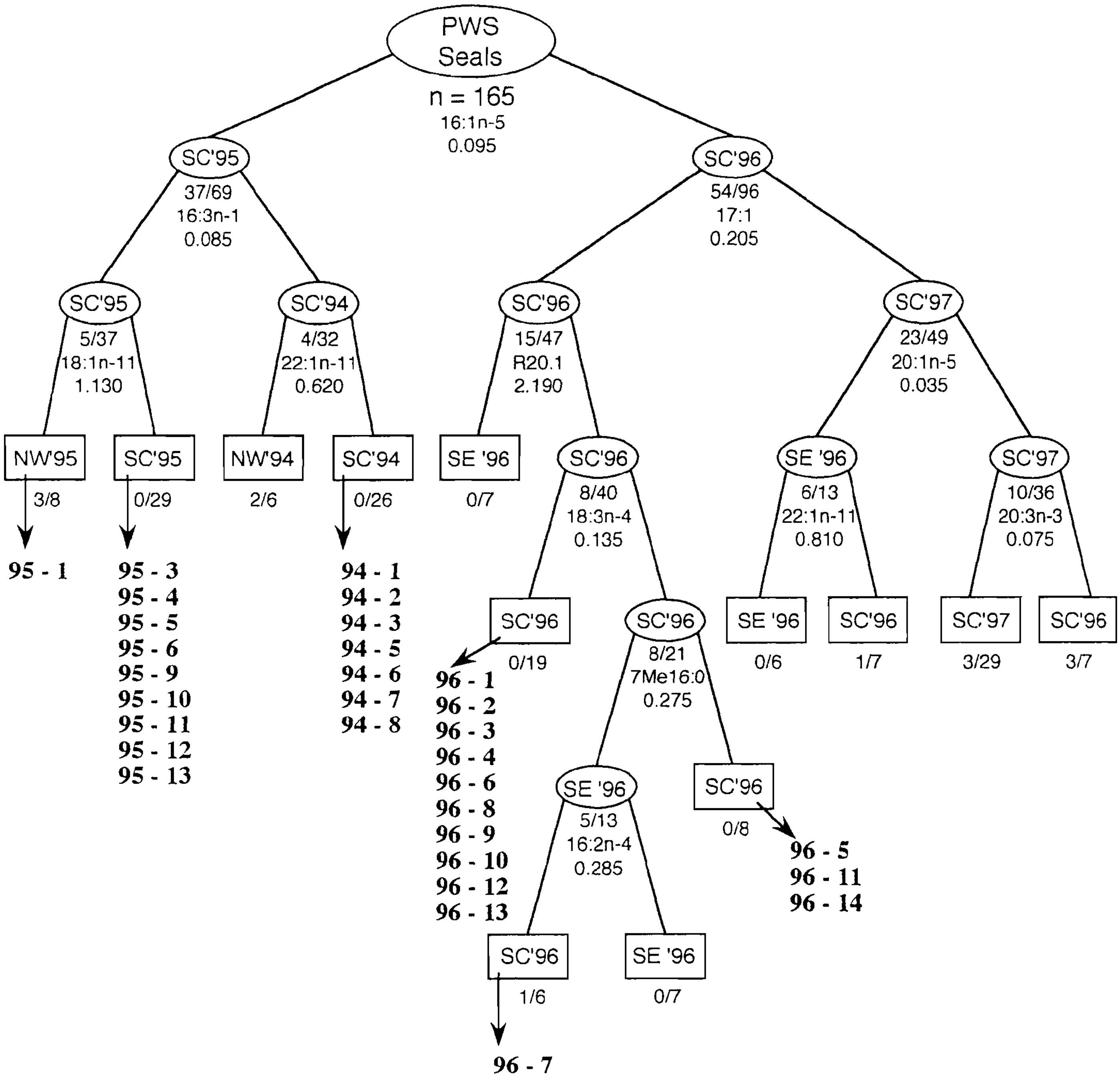


Figure 24: Classification tree of harbor seals from PWS by area and year (see Fig. 23) with identification of satellite tagged animals located in tree. All tagged animals (n = 31) were correctly identified to location.

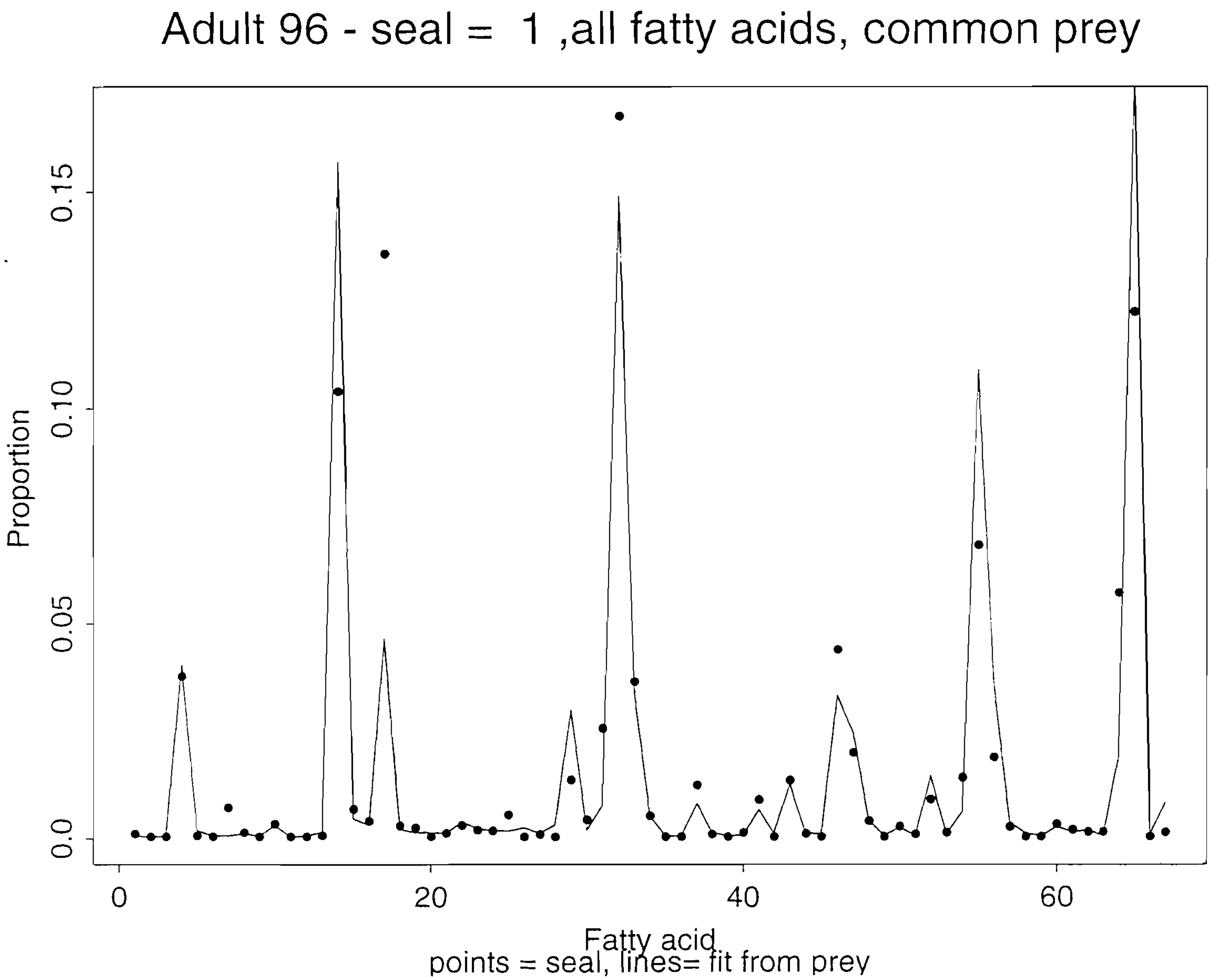


Figure 25. Plot of an individual PWS seal (points) and the best fitting combination of prey (lines), using all fatty acids in the model. The x-axis represents the fatty acid number (in consecutive order beginning with 12:0, i.e. see Tables 2 and 4) and the y-axis represents the relative contribution of each fatty acid.

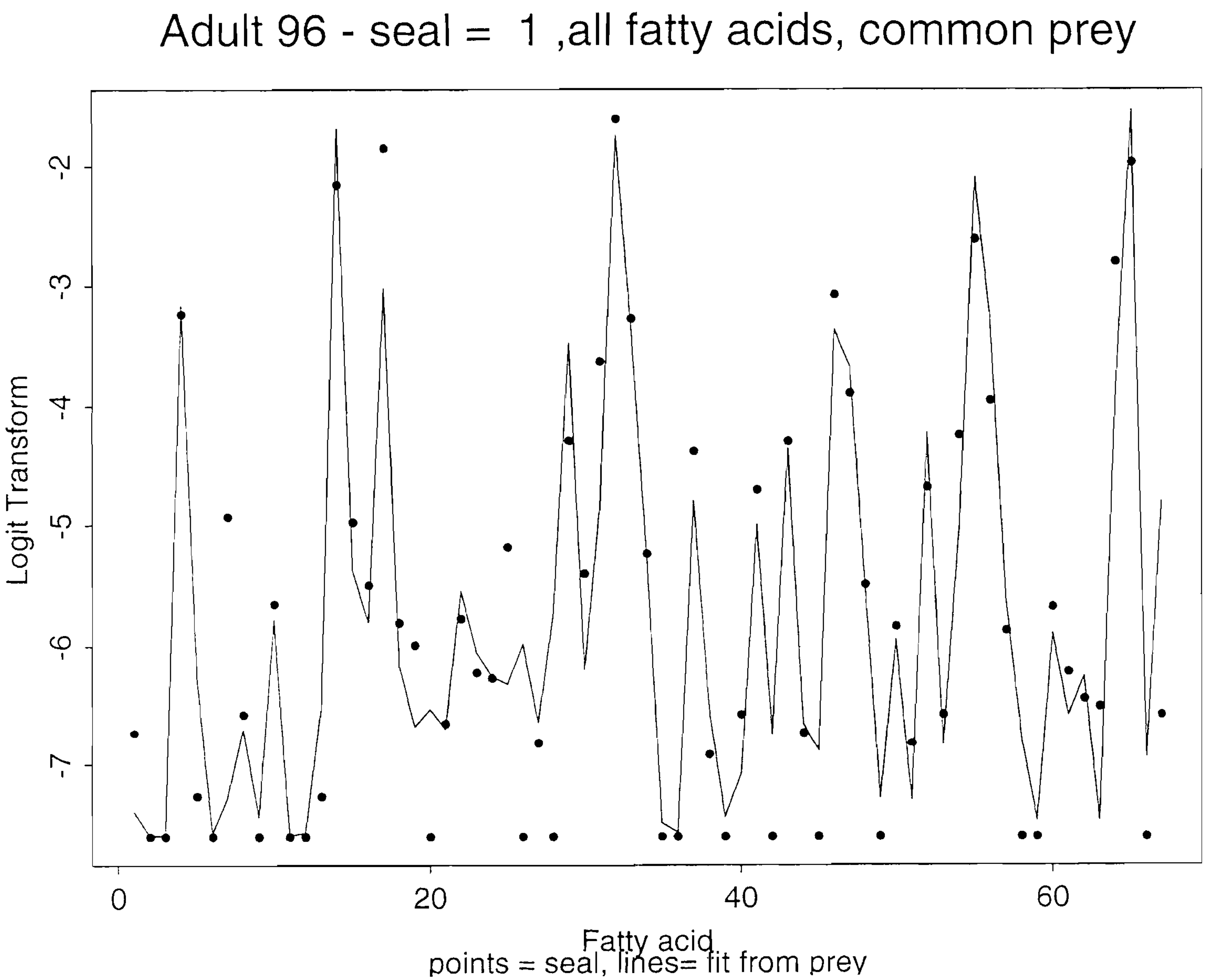


Figure 26. Plot of an individual PWS seal (points) and the best fitting combination of prey (lines), using all fatty acids in the model. The x-axis represents the fatty acid number (in consecutive order beginning with 12:0) and the y-axis represents the logit transform of the relative contribution of each fatty acid (that is, if y_t is the contribution of the t fatty acid then the logit transform is $\log(y_t/1-y_t)$) in order to equally view minor and abundant fatty acids.

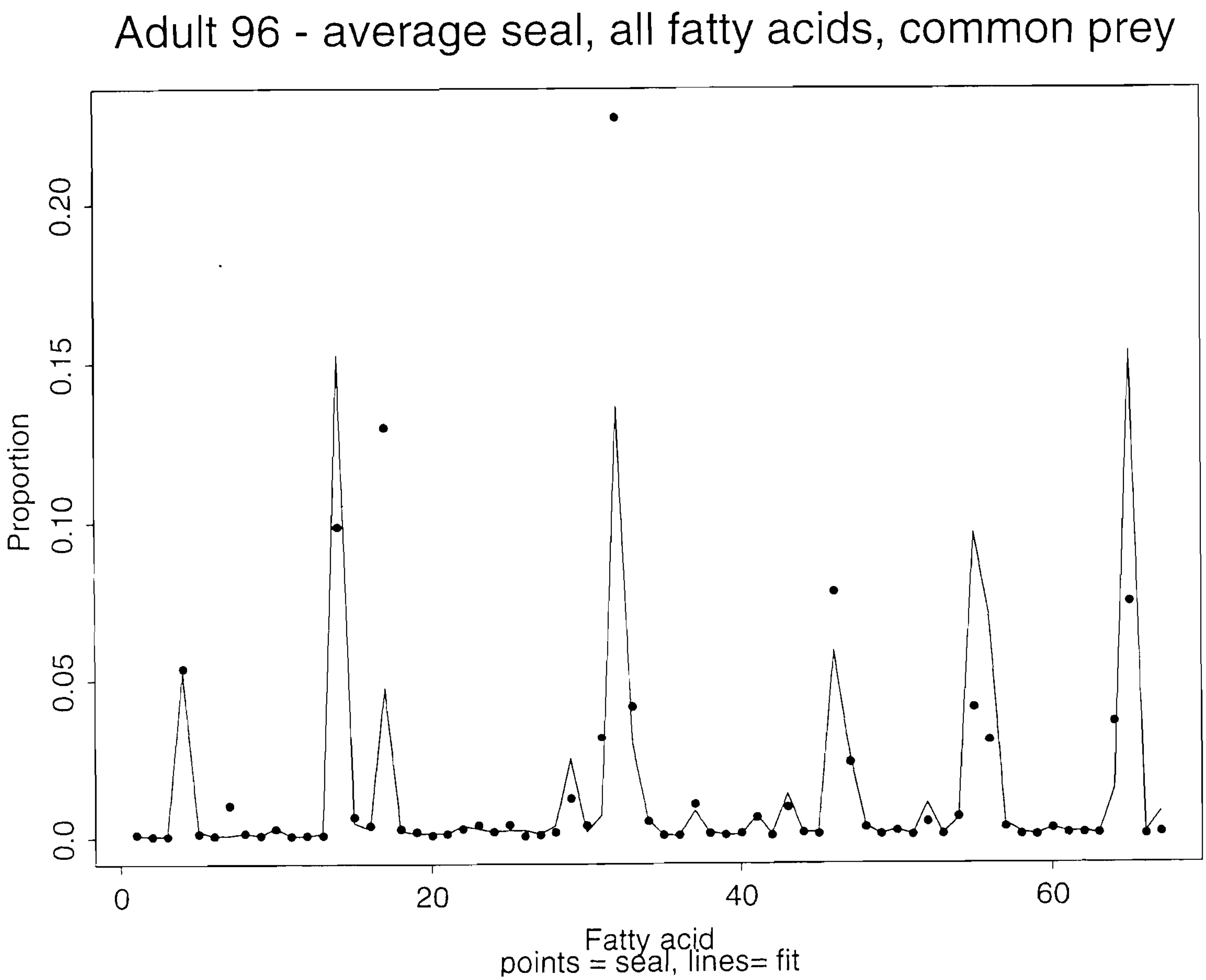


Figure 27. Plot of the average of the 16 PWS seals (points) and the best fitting combination of prey (lines), using all fatty acids in the model. The x-axis represents the fatty acid number (in consecutive order beginning with 12:0) and the y-axis represents the relative contribution of each fatty acid.

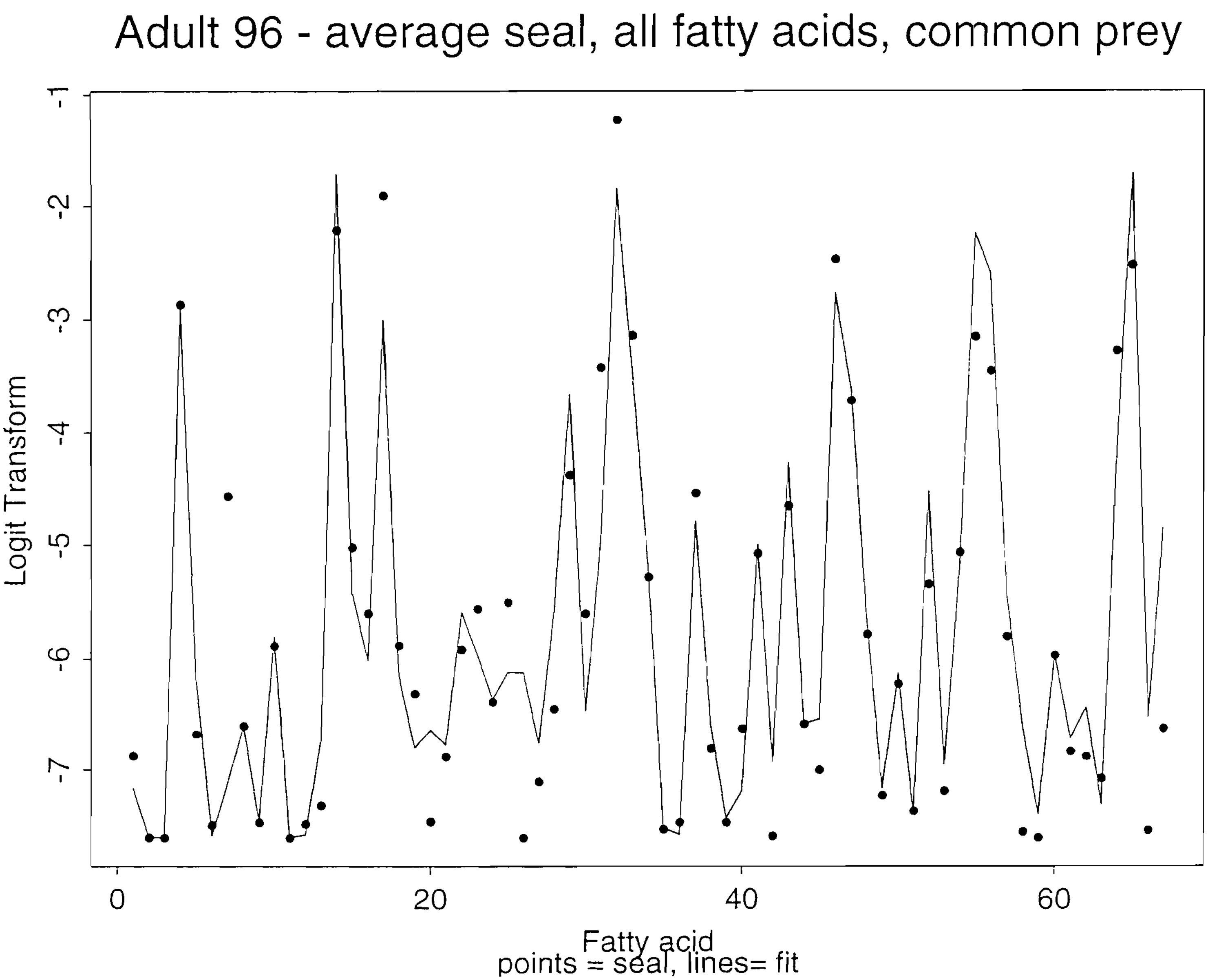


Figure 28. Plot of the average of the 16 PWS seals (points) and the best fitting combination of prey (lines), using all fatty acids in the model. The x-axis represents the fatty acid number (in consecutive order beginning with 12:0) and the y-axis represents the logit transform of the relative contribution of each fatty acid (that is, if y_t is the contribution of the t fatty acid then the logit transform is $\log(y_t/1-y_t)$) in order to equally view minor and abundant fatty acids.

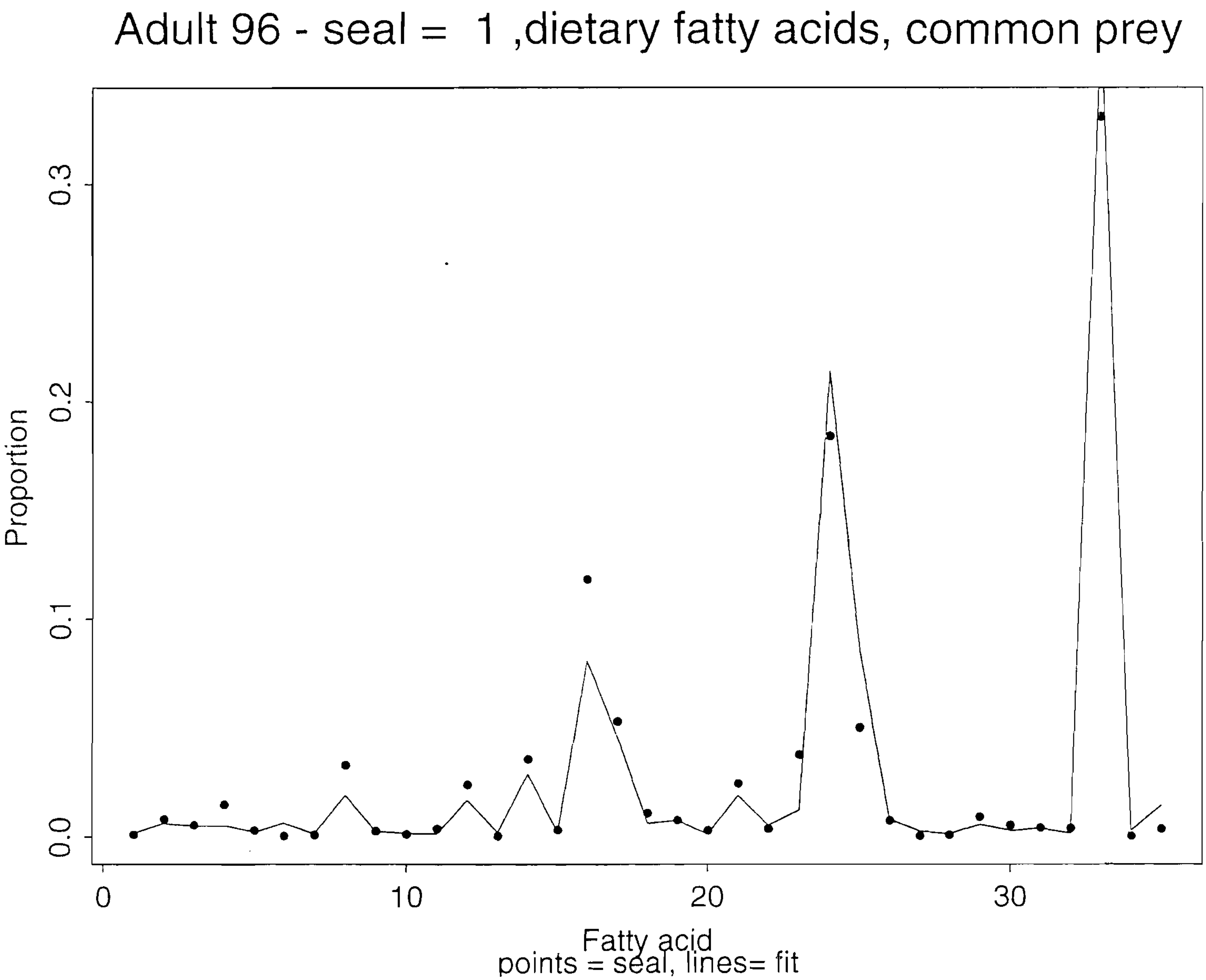


Figure 29. Plot of an individual PWS seal (points) and the best fitting combination of prey (lines), using only dietary fatty acids in the model. The x-axis represents the fatty acid number (in consecutive order beginning with 18:2n-6) and the y-axis represents the relative contribution of each fatty acid.

Adult 96 - seal = 1 ,dietary fatty acids, common prey

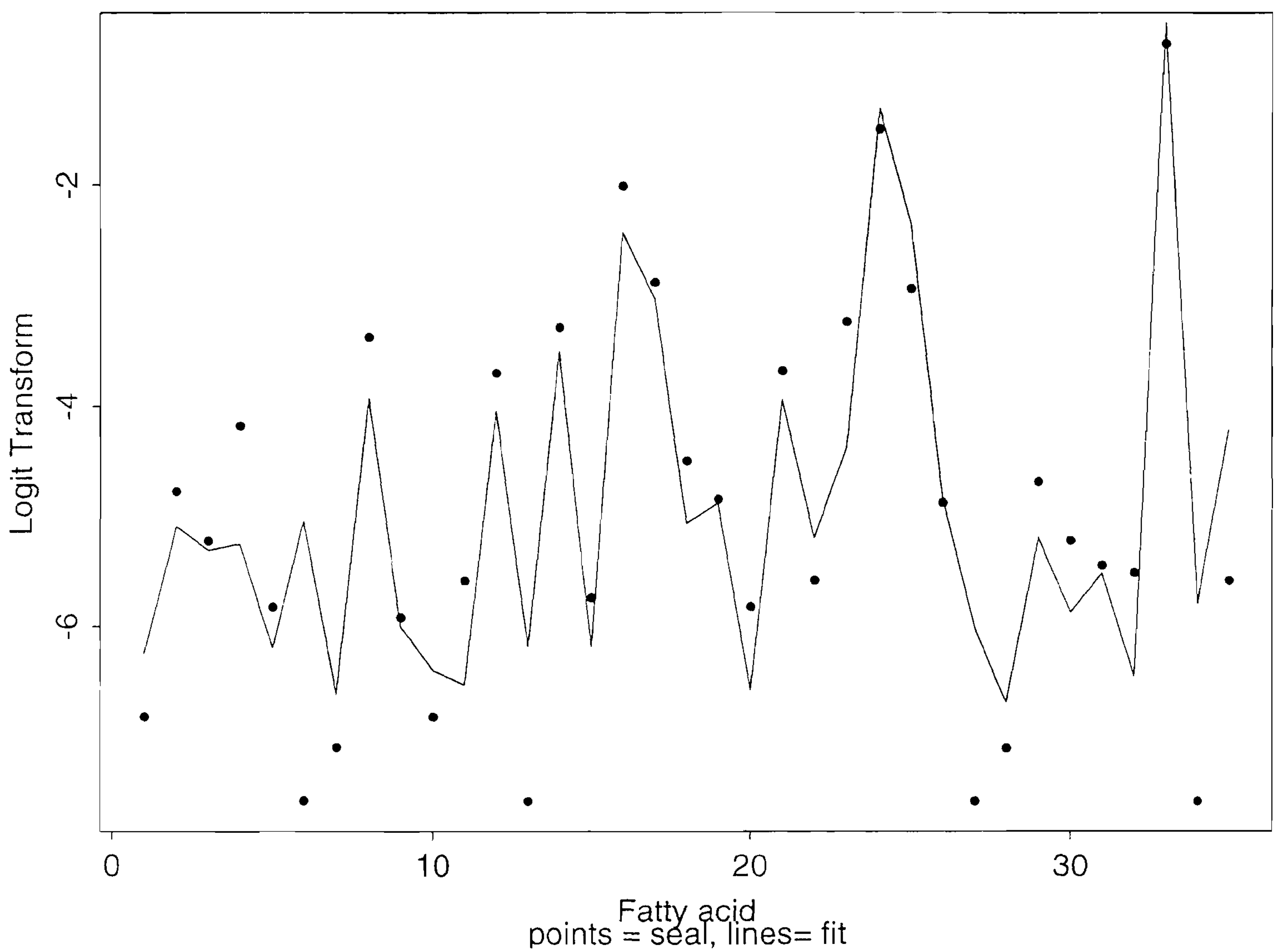


Figure 30. Plot of an individual PWS seal (points) and the best fitting combination of prey (lines), using only dietary fatty acids in the model. The x-axis represents the fatty acid number (in consecutive order beginning with 18:2n-6) and the y-axis represents the logit transform of the relative contribution of each fatty acid (that is, if y_t is the contribution of the t fatty acid then the logit transform is $\log(y_t / 1 - y_t)$) in order to equally view minor and abundant fatty acids.

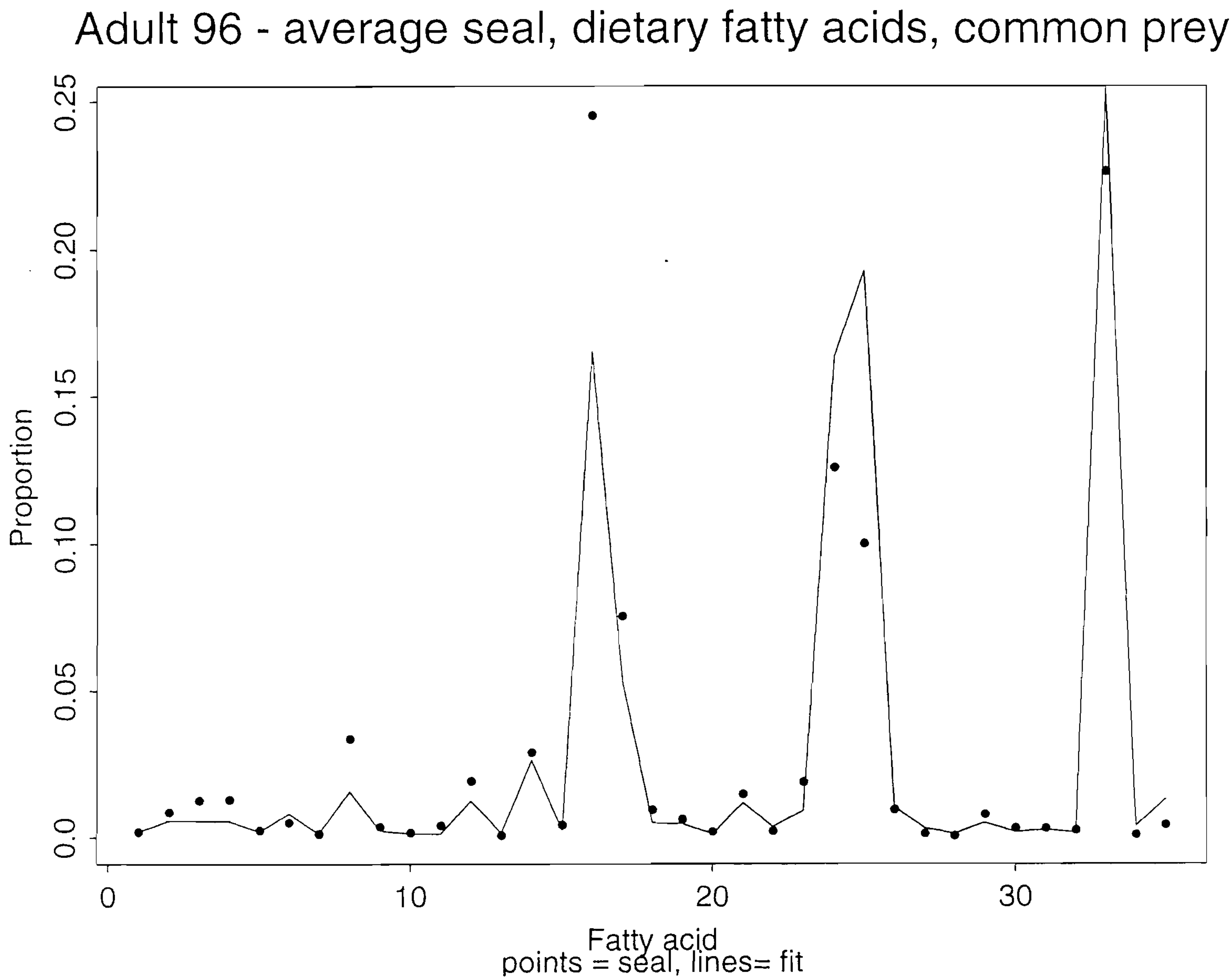


Figure 31. Plot of the average of the 16 PWS seals (points) and the best fitting combination of prey (lines), using only dietary fatty acids in the model. The x-axis represents the fatty acid number (in consecutive order beginning with 18:2n-6) and the y-axis represents the relative contribution of each fatty acid.

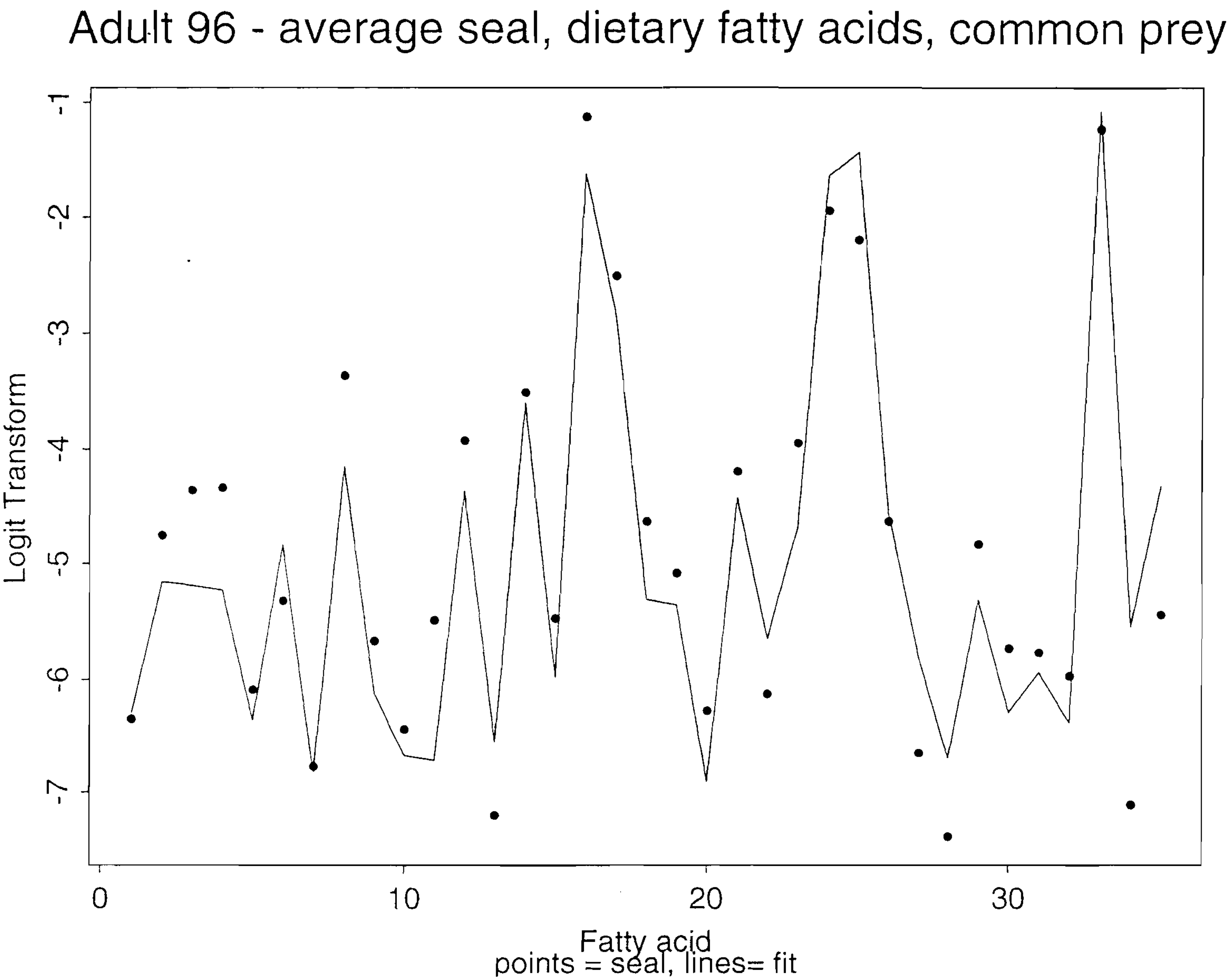


Figure 32. Plot of the average of the 16 PWS seals (points) and the best fitting combination of prey (lines), using only dietary fatty acids in the model. The x-axis represents the fatty acid number (in consecutive order beginning with 18:2n-6) and the y-axis represents the logit transform of the relative contribution of each fatty acid (that is, if y_t is the contribution of the t fatty acid then the logit transform is $\log(y_t/1-y_t)$) in order to equally view minor and abundant fatty acids.

CHAPTER FOUR

DIVING BEHAVIOR OF HARBOR SEALS IN SOUTHCENTRAL PRINCE WILLIAM SOUND, 1994-1997

Tracey Gotthardt
Environment and Natural Resources Institute
University of Alaska Anchorage
707 A Street
Anchorage, Alaska, USA 99501

OBJECTIVE 8

Determine foraging range and diving behavior of harbor seal pups and juveniles and compare to similar information for other age groups.

This report to be cited as:

Gotthardt, T. 1998. Diving behavior of harbor seals in southcentral Prince William Sound, 1994-1997. Pages 118-147 *in* Monitoring, habitat use, and trophic interactions of harbor seals in Prince William Sound, Alaska. Annual Report to the *Exxon Valdez* Oil Spill Trustee Council. Restoration Study 97064. Alaska Department of Fish and Game, Division of Wildlife Conservation, Fairbanks, AK.

DIVING BEHAVIOR OF HARBOR SEALS IN SOUTHCENTRAL PRINCE WILLIAM SOUND, 1994-1997

Tracey Gotthardt
Environment and Natural Resources Institute
University of Alaska Anchorage
707 A Street
Anchorage, Alaska, USA 99501

ABSTRACT

Harbor seal, *Phoca vitulina richardsi*, populations have been declining in Prince William Sound (PWS), Alaska, for the past twenty years for unknown reasons. Since 1993, Frost et al. have affixed satellite-linked depth recorders (SDR's) to the backs of 63 harbor seals to monitor their diving behavior and habitat use in an effort to understand the cause of the decline. Satellite data from 14 of these - seven adult females and seven subadults tagged in the southcentral region of PWS during fall 1994-1996 - were investigated in this study. The project objective was to determine if patterns existed in harbor seal movements and diving behavior at different spatial and temporal scales, and also between age classes of seals. Results indicate that the movements and diving behavior of individual seals varied widely, but, overall, seals from the southcentral region of PWS made relatively shallow dives (less than 150 m) of short duration (less than 4 min). Patterns in foraging behavior were obvious when data were broken down by age class. Adult female seals displayed strong fidelity to their haulout sites, seldom traveled, and their diving behavior was characterized by relatively short and shallow dives (20-40 m). Subadults tended to travel greater distances both within and outside of PWS, made deeper and longer dives, and overall, utilized a greater variety of depths when diving. It appears that harbor seals are diving more actively and making longer dives during the winter; however, results indicate that dive depth appears to be more closely associated with geographic location than it is with season.

Key words: diving, foraging behavior, harbor seal, *Phoca vitulina richardsi*, Prince William Sound, satellite tagging

NOTE: This is an early draft of a thesis chapter for Ms. Gotthardt's Master of Science project at University of Alaska, Anchorage, entitled "Harbor Seal Foraging Ecology in Prince William Sound." Completion of this Master's project is expected by December 1998.

INTRODUCTION

Harbor seals, *Phoca vitulina richardsi*, are medium sized earless seals belonging to the family Phocidae (Hoover-Miller 1994; Frost et al. 1997). They inhabit temperate and subarctic coastal waters of the North Pacific, North Atlantic, and contiguous seas, and are among the most commonly seen seals along the shores of the Northern Hemisphere (Hoover-Miller 1994). In Alaska harbor seals are found from the Southeast, into the Gulf of Alaska and Prince William Sound, as far west as the Pribilof and Aleutian islands, and into the Kuskokwim Bay-Nunivak Island region. They haul out on rocks, reefs, beaches, and drifting glacial ice, and feed in marine, estuarine, and occasionally fresh waters (Hoover-Miller 1994; Frost et al. 1994a, b; Small and DeMaster 1995). Telemetry studies suggest that harbor seals are generally non-migratory, and their local movements are associated with such factors as tides, food availability, reproduction and season (Pitcher and McAllister 1981; Small and DeMaster 1995), although some long distance movement of tagged seals in Alaska has been recorded (Pitcher and Calkins 1979; Frost et al. 1995, 1996, 1997).

In Prince William Sound (PWS), Alaska, harbor seals are one of the most abundant and widely distributed marine mammals, hauling out and/or breeding at more than fifty sites (Frost et al. 1995, 1996, 1997). Harbor seal populations within PWS have declined by approximately 60% between 1984-1997 (Pitcher 1989; Frost and Lowry 1994; Frost et al. 1994-1997) for unknown reasons.

In 1989 the *Exxon Valdez* oil tanker spilled 11 million gallons of crude oil into the PWS, damaging critical haulout areas and having numerous short and long term repercussions on an ecosystem wide level. It was estimated that as a result of the spill 300 seals died from oil-related causes (Frost et al. 1994a). Although the overall harbor seal decline is not directly attributable to the oil spill, the spill may have exacerbated an already failing population trend The most recent trend analysis data indicate that molt counts were 15% lower in 1996 than 1995, representing the lowest counts since monitoring began in 1988 (Frost et al. 1997).

The Alaska harbor seal decline has not been isolated to just within Prince William Sound but has also occurred in adjacent waters (Frost et al. 1995, 1996, 1997; Iverson et al. 1997; Pitcher 1990). On Tugidak Island, located in the Gulf of Alaska, formerly one of the largest concentrations of harbor seals in the world, population counts declined by 85% between 1976 and 1988 (Pitcher 1990), and continued to decline by 33% between 1988-1994 (Small and DeMaster 1995). Parallel population declines within the same geographic region have also been documented for Steller sea lions (*Eumetopias jubatus*), and several species of piscivorous seabirds (i.e. pigeon guillemots, black-legged kittiwakes, and murres) (Pitcher 1990; Loughlin et al. 1992; Duffy 1997; Piatt and Anderson 1996). Although the reasons for these declines are not well understood, their coincidence may indicate some ecosystem-wide phenomena is contributing to these declining populations.

Anderson *et al.* (1997) noted that over the last 15 to 20 years an abrupt shift has occurred in the marine ecosystem of the Gulf of Alaska. This shift has been manifested by changes in the distribution, composition, and abundance of certain forage species such as capelin (*Mallotus villosus*), juvenile walleye pollock (*Theragra chalcogramma*), and sandlance (*Ammodytes hexapterus*) (Anderson et al. 1997; Piatt and Anderson 1996). In view of the fact that both sea bird and marine mammals, which rely on forage fish for a major part of their diets, have failed to recover, one of the leading theories that has emerged is that food availability, and hence, the quality (or amount) of the food available, may be limiting these populations.

The distribution, movements, and foraging activity of harbor seals are poorly understood, particularly because they have been difficult to observe offshore and in rough waters (Hoover-Miller 1994; Frost et al. 1997). VHF and satellite telemetry studies have recently allowed researchers to track seasonal movements of marine mammals by monitoring their diving behavior and have provided an enhanced understanding of seal foraging strategies (Pitcher and McAllister 1981; Stewart et al. 1989; Thompson and Miller 1990; Thompson et al. 1991, 1994; Frost et al. 1995, 1996, 1997; Tollit and Thomspon 1996; Swain et al. 1996). Bjorge (1995) used VHF recorders to track free ranging harbor and grey seals to determine habitat use and foraging behavior in western Norway. VHF investigations in the Moray Firth, Scotland, have documented the summer and winter foraging activity areas and patterns of common seals (Tollit et al. 1998; Thompson et al. 1991).

Satellite-linked depth recorders (SDR's) have provided researchers with more sophisticated technology and the ability to monitor marine mammal movements for longer periods and at greater distances. Lowry et al. (1998) attached SDR's to four spotted seals in the Bering and Chukchi seas between 1991-1994, to monitor seal movements and behavior. Stewart et al. (1996) documented the movements and dive patterns of four juvenile Baikal seals from autumn through spring. In Alaska, Swain and Small (1996; 1997) have been using SDR's to investigate differences in foraging activity between seals around Kodiak Island and Southeast, Alaska.

When attempting to address the restoration of harbor seals in Prince William Sound, it is important to understand harbor seal habitat usage and how that relates to their foraging activity. In 1992, Frost et al., as part of a project funded by the EVOS Trustee Council (Monitoring, Habitat Use, and Trophic Interactions of Harbor Seals in Prince William Sound, Alaska; Restoration Project /064) began placing satellite telemetry recorders on the backs of harbor seals in Prince William Sound, Alaska, to record and track seal movements and monitor their diving behavior. From 1992-1997, 51 harbor seals were outfitted with SDR's, providing a database of long-term, year-round harbor seal habitat use.

The goal of this study was to enhance our understanding of the foraging ecology of harbor seals in PWS, analyzing harbor seal diving behavior and location data on temporal and spatial scales to determine if patterns exist in seal distribution and foraging strategies within PWS and between PWS and adjacent waters.

METHODS

Trend count survey data indicate that haulouts in the southcentral region of PWS (i.e. = Port Chalmers, Stockdale Harbor, Little Green Island, Channel Island areas) are the largest non-glacial harbor seal haulouts in PWS (Figure 1) (Frost et al. 1997). Due to the large sample size of seals tagged between 1994-1996, we limited the scope of our project to only seals which were tagged in southcentral PWS.

From within southcentral PWS, 14 seals were tagged with SDR's during fall 1994-1996. These seals include seven adult females (ID#s 94-5, 94-6, 94-8, 95-9, 95-10, 96-9, and 96-13; Table 1), and seven subadults seals (ID#s 94-1, 94-7, 95-13, 96-10, 96-11, 96-12; Table 2). The time period for which data were received from the SDR's ranged from 42 to 300 days.

Capture and Tagging of Seals

Harbor seals in Prince William Sound were tagged with SDR's. Field work was conducted by Frost et al. at various locations throughout Prince William Sound, Alaska, during September 1994, and in May and September 1995-1996. A more detailed description of capture and tagging of seals can be found in Frost et al. (1995, 1996, 1997).

SDR's are programmable microprocessors, equipped with conductivity and pressure sensors which transmit seal location and diving information to a National Oceanic and Atmospheric Administration polar-orbiting satellite (Frost et al. 1996). Between 1994-1996, two types of SDR's were used to monitor seals diving behavior. Most of the units measured 14.8 x 10.0 x 3.8 cm, weighed approximately 750 g and were powered by four lithium C cells. These units were attached to larger seals which weighed more than 40 kg. Smaller seals were outfitted with SDR's which measured 11.9 x 5.1 x 4.5 cm, weighed 385 g and were powered by six lithium 2/3 A cells (Frost et al. 1995, 1996). SDR's were programmed as described in Frost et al. (1996). The smaller units were duty cycled (1994 = one day on/one day off; 1995-1996 = one day on/two days off) to prolong battery life and extend the transmission period.

Whenever the SDR's antennas broke the surface (or when the seal was on land) and there was satellite passage, an "uplink" was created and data were transmitted. Data included the seal's position when the uplink was created and all dive data stored from the previous 24 hours (Frost et al. 1995, 1996, 1997).

For periods when seals were diving, data collected from SDR's were summarized into three "type" categories: dive depth, dive duration, and the amount of time spent at depth. Data were stored in 6-hour blocks (period 0 = 0300-0900 hrs local time, period 1= 0900-1500 hrs, period 2 = 1500-2100 hrs, and period 3 = 2100-0300 hrs). Dive depth data were stored and categorized into 10 depth bins: 4-20 m, 21-50 m, 51-75 m, 76-100 m, 101-150 m, 151-200m, 201-250m, 251-300m, 301-350m, and >350m. Dive duration data were into 10 bins in 2-minute increments as follows: 0-2, >2-4, >4-6, > 6-8, >8-10, >10-12, >12-14, >14-16, and >18 minutes (Frost et al. 1995, 1996, 1997).

Satellite Tag Data Analysis

Data from satellite tagged seals was obtained from Kathryn J. Frost and Lloyd Lowry (ADF&G) after Service Argos had downloaded the data from the satellite. A computer program was used to calculate the average location for each seal by integrating latitude, longitude, time, date, and location quality from individual location records for a 24 hour period. Methodology developed by Frost et al. (1995, 1996) was used to identify and eliminate erroneous location records. A more detailed description of satellite tag analysis is available in Frost et al. (1995, 1996, 1997).

Harbor seal average-daily-position files, generated by Lloyd Lowry (ADF&G), were used to produce geographic information system coverages in ArcInfo and Infocad (GIS softwares). Once coverages were built they were imported and displayed thematically in ArcView, a desktop mapping/GIS program (See Appendix 1 for GIS Spatial Analysis Procedures). Location data used in this report represent the average daily position files. In an attempt to eliminate most erroneous location files, location data is assigned a quality ranking (scale of -4 to 4). Only location data of quality > 0 were used in this report.

Foraging/ Diving Behavior

Individual seals were tracked through time to determine the range of their daily movements and habitat use. Tracking was accomplished by observing average locations chronologically in ArcView.

The maximum dive that each seal dove in a 24-hour period was recorded as a component of the dive data histograms. The maximum depth that each seal dove by day was graphed and examined for patterns. The mean maximum depth for the entire tagging period (by individual seal) was calculated. Maximum dive depth files were integrated with average daily location files, which were displayed thematically in ArcView. In addition, this integrated location/maximum dive depth file was compared to the corresponding bathymetry to determine if maximum dive depth was positively correlated with the ocean floor.

Dive depth and duration data were displayed in histograms, sorted by date and period. Dive data were further analyzed by month and cumulatively for the entire tagging period (Frost et al. 1996, 1997). The SDR dive data for individual seals, adult female seals, and subadult seals tagged in southcentral PWS were graphed with respect to season, time of day, and geographic location and examined visually for patterns (Frost et al. 1996, 1997). Harbor seal dive profiles were compared with positional data to determine whether temporal patterns were relevant at different spatial scales. This analysis was performed for individual seals as well as for different sex and age classes (adult females and subadults).

RESULTS

Movements and Foraging Trips

The movements of 14 harbor seals tagged in fall 1994-1996 are shown in Figures 2A-D and summarized in Table 1 (adult females) and Table 2 (subadults).

Adult female harbor seals did not range as widely as subadult seals. Five of the seven adult females not only stayed within the boundaries of PWS, but they seldom traveled further than 25 km from the area where they were tagged (Figures 2A-C).

Seals 95-10 and 96-13 were the only adult female seals to make foraging trips outside of PWS. Seal 95-10 made 4 trips to Middleton Island, a distance of 115 km (one-way), between September and March. After a 2-5 day stopover at Middleton Island, this seal would repeatedly return to Stockdale Harbor or Port Etches within PWS. This same seal also made two trips to the Copper River Delta (CRD). Adult female seal 96-13 left PWS in early October, traveling 200 km to Kayak Island where it foraged in the Northern Gulf of Alaska until returning to PWS, to spend May and June in Icy Bay (SW PWS). Seals 95-10 and 96-13 were both at the CRD during the months of March - May.

Subadults tagged in the central region ranged quite widely both within and outside of PWS. Of 7 subadult seals wearing SDR's, only one seal (94-7) remained in PWS for the full duration of its tagging period (Figures 2A and 2D). Even this seal (94-7) traveled extensively throughout PWS, making a circuit originating in Stockdale Harbor in September, Unakwik Bay (Nov. 8 - 11), Columbia Bay (Nov. 26-27), and back to Stockdale Harbor (Dec. 6) where it remained until December 20 when transmission ceased.

Six of the 7 subadult seals left on foraging trips outside of PWS (Table 2, Figures 2A and D). Of these six seals, 5 were beyond the boundaries of PWS when satellite transmission ceased. Seal 95-13 left PWS for the Copper River Delta (CRD) during October 15 - November 5 and was moving back in the direction of PWS when transmission stopped on November 8. Four of the six seals which left PWS traveled to the Copper River Delta, a distance of approximately 120 km. Seal 96-11 arrived in the CRD on March 7, after spending September - February foraging within PWS. Seal 96-10 foraged until May 3 in PWS then moved into the CRD between May 3 and June 2, en-route to the Icy Bay/Yakutat Area. Subadult male 96-12 remained in the central region of PWS until January 24, when it traveled to the Bering River, and then moved between the CRD and Northern Gulf of Alaska during February 2 - 6, when transmissions ceased.

Subadult seals 94-1, 96-7, and 96-10 traveled the farthest outside of PWS. Subadults 94-1 and 96-10 moved towards the southeast, as far as Yakutat and Icy Bay, distances of 502 km and 360 km, respectively (Figure 2D). Seal 94-1 left PWS in early November and remained in the Yakutat Bay area during November 10 - February 11 when its tag stopped transmitting. Seal 96-10 left the CRD on June 2, traveling towards the Yakutat Area (June 11-27) when transmissions were lost. Subadult female 96-7 left PWS and traveled westward into Cook Inlet, stopping at Augustine Island, before arriving in Chinitna Bay on Dec. 25, a distance of 472 km. This seal remained foraging in Cook Inlet until transmissions ceased in March.

<u>Diving Behavior - Maximum Depth</u>

The maximum daily dive depths for individual seals are summarized in Tables 3 and 4. Maximum dive depths varied significantly between adult females and subadults, but within age classes obvious patterns arose.

Adult female maximum dives and mean maximum dives were considerably shallower than dives made by subadults. Mean maximum dive depths for adult females ranged from 14-81 m, with actual maximum dives from 28-290 m. Of the seven adult females, five never left PWS for the entire transmission period, and never dove deeper than 72 m (four of these seals diving less than 40 m). Two adult females, 95-10 and 96-13, which left PWS during their transmission period, had maximum dive depths of 280 and 236 m, and mean maximum dive depths of 69 m and 81 m, respectively.

Subadult seals made deeper dives than did adult females, and greater inter-age class variability existed in maximum dive depth profiles for juveniles. Mean maximum dive depths ranged from 73 - 145 m, with maximum depths between 124 - 360 m. With the exception of seal 95-13 whose deepest dive was 124 m (from limited data set, n = 7), the six remaining juveniles maximum dive depths were 232 m or deeper. Six of the seven juveniles left PWS at one time or another while their SDR's were transmitting, yet five of these seals made their deepest dives while within PWS. This contrasts to adult females, who dove the deepest dives outside of PWS.

Collectively, four seals (adult females 95-10 and 96-13; juveniles 94-1 and 96-12) made their deepest dives outside of PWS while traveling in the northern Gulf of Alaska. Although the locations of these deep dives were similar, there is no relation in the depth of dives.

For both subadults and adults the timing of the deepest dives fell into three distinct time periods: October - mid. November, December 1 - December 14, and January 30 - mid. February (Tables 3 and 4). Nine of 14 seals made their deepest dives between October - November. Two seals dove the deepest during December, and four seals made their maximum dives during January - February (note: adult female 95-9 is represented in both the October and January time categories). No obvious patterns existed in the locations of these dives within said time periods. (Note: SDR transmission periods varied for all seals: 5 of 14 seals ceased to transmit after December 25, and these time categories may simply be an artifact of a reduced sample size during the spring months).

Each seal's daily maximum dive depth and its corresponding average location were compared to the underlying bathymetry, using point files in ArcView. In most cases, maximum depth indicated that seals were diving to the bottom. Unfortunately, this analysis was confounded by the gross scale of the digital bathymetry and lack of location precision associated with using a seals average location over a 24 hour period. As a result, maximum dive depths were sometimes deeper than the bottom profile.

Diving Behavior - Dive Depth Histograms

Dive depth histogram information summarized 85,756 dives for the seven subadult seals and 129,668 dives for the seven adult female seals. Dive data analysis revealed patterns in seal diving behavior within age classes and differences between subadults and adult females. Subadult seals consistently dove deeper, dove deep more often, and exhibited a much more varied diving profile than did adult female seals.

As a group, adult females dove to fairly shallow depths, with over 80% of their dives less than 20 m, and 88% of their dives less than 50 m (Figure 3). On an individual basis, 5 of the 7 adult female seals tagged (94-5, 6, 8, and 95-9, 96-9) never dove deeper than 50 m, diving between 4 and 20 m 80% of the time (Figure 4). Seals 95-10 and 96-13 exhibited more variable diving profiles. Seal 95-10 was most actively diving in December (96% of dives 4-20 m), and was diving the deepest (deeper than 150 m) during February and March (Figure 4). Seal 96-13 was most actively diving during February and May. In February, 70% of this seals dives were less than 20 m, and in May, 80% of its dives were shallow (< 20 m). From October - March, this same seal spent 10-15% of its dives deeper than 150 m (Figure 4).

Dive depth histograms for seven adult female seals were summarized by month (Figures 5 and 6). As a group, adult females made 75% or more of all dives in water less than 20 m from September to May (Figure 5). Adult female seals dived the deepest from January - March and were making the greatest number of dives between October and January (Figure 6). In January, 13% of total dives were 20-50 m. For all other months 9% or less of dives were 20-50 m. Adult females dove the deepest in February, when 6% of their dives were greater than 200 m.

Unlike adult females, which exhibited strong inter age-class patterns, considerable variation occurred in the diving profiles of subadult seals (Figure 7). Seals 94-1 and 95-13 were making the most dives during October and utilized a variety of depths ranging from 4-200 m. Seal 94-7 made the most dives of all subadult seals and 70% or more of these dives were less than 20 m deep. Subadult 96-7 was diving most actively during January and February, when 50%-90% of its dives were less than 50 m. This seal dove the deepest during November and December, with 40%-50% of its dives > 50 m. Subadult male, 96-10, made the most dives in

October and April (in October 10% of dives were 50 - 100 m, 50 % were less than 20 m and in April 95% of dives were less than 20 m). This seal made its deepest dives during the winter, particularly in February and March, when over 40 % of dives were 100 - 150 m. Subadult male 96-11 was also diving the most during the winter months. During September through January, between 35%- 60 % of this seals dives were deeper than 50 m. During February and March, this seal began to spend more time (90%) in shallow water of less than 50 m. Overall, seal 96-11 seldom dove deeper than 100 m. Subadult male 96-12 dove the most during October and December. This seal consistently dove deeper than 50 m, and made its deepest dives (> 150 m) during January and February.

For the 7 subadults, 55 % of their total dives were less than 20 m, 23 % ranged from 20 - 50 m, and 20 % of their dives exceeded 100 m (Figure 3). Dive data for 7 subadult seals are summarized by month in Figures 4 and 5. Like the 7 adult female seals, subadults were diving the most during October through January, with dive numbers starting to taper off toward spring (Figure 6).

Overall, subadult seals made the greatest percentage of their dives (over 40 %) in shallow water between 4 - 20 m (Figure 5). During October - February, 20 % or more of total dives were between 20 - 50 m, and from September - January, 15% or greater of total dives ranged from 50 -100 m. Dives which exceeded 150 m were made during October - January, the same months that subadults were also making the most dives.

Diving Behavior - Dive Duration

Duration histogram data were collected for 132,040 dives made by adult females and 84,379 dives for subadults. Most dives were short: 41% were less than 2 min., 37% were between 2-4 min., and 18% were 4-6 min. for the 7 subadult seals (Figure 8). Adult females also made short dives: 48% of total dives were less then 2 min., 27 % were 2-4 min., and 15% were 4-6 min. (Figure 8). Only 2% of subadult dives exceeded 6 min., compared to 9% for adult females.

Dive duration corresponded directly with dive depth in the distribution and proportion of dives in the various depth and duration categories (Figures 5 and 9). Adult female seals with a high proportion of shallow dives similarly had a high proportion of short dives. Subadult duration histograms directly mirrored their dive depth histograms. During October - January, when subadult seals were making the deepest dives they were also making the longest dives (Figures 5 and 9). Dive duration appeared to be more consistent for subadult seals throughout the year. Both subadults and adult females made longer dives (greater than 6 min.) during the winter months and began to make shorter dives in the spring (March - May). During January, 40 % of all dives ranged from 2-4 minutes for both subadults and adult females. This was also the same month that the greatest proportion of dives was the deepest for both age classes.

DISCUSSION

Investigations of 14 harbor seals tagged with SDR's within the Southcentral region of PWS revealed that different age classes of seals, adult females and subadults, exhibited differences in their foraging strategies and diving behavior. Subadult seals tended to travel greater distances and to utilize a greater variety of depths when diving. Adult female seals displayed greater fidelity to their haulout sites, traveled less, and their diving behavior was characterized by relatively short and shallow dives.

Movements and Foraging Trips

Considerable variability in the range of harbor seal movements was noted between the two age classes, subadults and adult females. Adult females exhibited the greatest fidelity to the areas where they were tagged. Six of the seven adult female seals tagged in the central region were within PWS when their transmitters ceased. Five of these seals never left PWS, seldom traveling distances greater than 25 km, and were at their capture location when their SDR's stopped transmitting. These results are in agreement with previous VHF and SDR studies which suggest that harbor seals exhibit fidelity to their haulout area and do not range far from home to forage (Thompson et al. 1990, 1991; Frost et al. 1995; 1996; Swain et al. 1996; Tollit et al. 1998). Thompson et al. (1990, 1991) found that seals in the Moray Firth, Scotland, traveled up to 45 km from their haulout sites on foraging trips of up to 6 days during the summer, and winter feeding trips found seals closer inshore. More recent investigations of harbor seal movements in the Moray Firth (Tollit et al. 1998) found that a majority of 31 seals tagged foraged within 30 km of their haulout site. Investigations of harbor seal movements in Alaska also suggest strong fidelity of harbor seals to areas where they were captured and tagged in Kodiak Island waters and in Southeast, Alaska (Swain and Small 1997).

Subadult harbor seals tagged in PWS exhibited vastly different foraging strategies and a greater range of movement than did adult females. Six of the seven subadults moved outside of PWS to forage at one time or another while their SDR's were transmitting, and 5 of these seals were beyond the boundaries of PWS when transmissions ceased. Individual subadult seals traveled as far as Yakutat Bay, 500 km to the southeast of PWS, 472 km to the west into Cook Inlet, and 120 km to the Copper River Delta.

Frost et al. (1997) suggests that some harbor seals in PWS must move substantial distances to feed during the winter - spring months. This is particularly true for subadult seals as they ranged widely outside of PWS during this time period. Frost et al. (1997) reported that over the 4 years of the PWS harbor seal SDR study (Restoration Study No. 94-97064), there appeared to have been a change in the feeding locations of seals during the winter - spring period. Prior to the fall of 1995, only 2 of 30 seals had gone to the Copper River Delta. Of the 14 seals under investigation in this study, 5 seals (1 adult female and 4 subadults) tagged in the fall of 1995 or 1996 made trips to the Copper River Delta, mostly between March - May. The five seals which were tagged during fall 1994 did not travel to the CRD.

Diving Behavior

As with movement/location data, analysis of maximum dive depths also revealed patterns within age classes of seals, but varied between subadults and adult females as well as with geographic location. Adult seals which never left the Port Chalmers area had maximum dives consistently of 28-40 m, which reflects the bottom bathymetry for that area. Swain and Small (1997) also found that harbor seals which exhibited very little movement had consistent daily dive depths. Adult females which traveled had considerably more variation in their daily maximum dives, and their deepest dives were made outside of PWS.

Subadult seals traveled further than did adult females, had more variability in their maximum dive depth profile, and made deeper dives, ranging from 124-360 m. Six of these seals had maximum dive depths of 232 m or deeper. Unlike the two adult female seals which dove the deepest outside of PWS, 5 of 7 subadults made their deepest dives while foraging at various geographic locations within PWS.

Not only did some harbor seals in PWS move considerable distances to feed during the winter months, they also dove deeper during the winter, probably in response to available forage. Four seals (2 adult females and 2 subadults) made their deepest dives while traveling in the Northern Gulf of Alaska during November - February. For both age classes combined, the deepest maximum dives occurred between October - February.

When maximum dive data were compared with location data they indicated that diving behavior varied by geographic location. Seals that never left the Port Chalmers/Stockdale Harbor area consistently dove from 20-40m, which is indicative of the bottom. A subadult male (96-12) dove between 40-70 m when in the Montague Straits area (i.e. Channel Island, Central-western Montague Island). However, when this seal moved out of PWS into the deeper waters of the Gulf of Alaska in late January, its maximum dive depths ranged from 210-230 m. Similarly, subadult seal 96-11 dove consistently between 50-120m while foraging in the southcentral region of PWS, but when it moved into Zaikof Bay at the northern end of Montague Island, maximum dive depths ranged from 200-360 m. Deeper dives were also associated with seals that moved into the bays of northern PWS, Unakwik and Columbia, where dives of deeper than 100 m were recorded.

When maximum dive depth was looked at in relation to location and bathymetry the majority of maximum dives reflected the bottom profile of the ocean, suggesting that seals dive to the bottom at least once a day. Unfortunately, due to the variability associated with both the location data and the bathymetry, this generalization should be approached with caution.

CONCLUSIONS

Seals tagged in PWS with SDR's showed considerable individual variability in how deep they dove and where they dove, although patterns were discernable between age classes. Overall, the diving behavior of the 14 harbor seals under investigation was characterized by relatively short and shallow dives. Harbor seals seldom dove deeper than 150 m, with 5% or less of all dives to greater depths. Correspondingly, most dives were short, with 75% or more of all dives less than 4 minutes in duration. Of the 14 SDR tagged seals, only 4 seals spent any significant amount of time diving deeper than 150 m, and these dives occurred while seals were foraging in the Gulf of Alaska during the winter. These findings are similar to those of other harbor seal investigations which suggest that harbor seals are shallow water feeders (Tollit et al. 1998; Frost et al. 1994, 1995, 1996, 1997; Swain and Small 1997).

There are differences in the diving behavior of subadult and adult female seals. Adult females consistently made shallow dives, with 88% of total dives less than 50 m deep. Adult females which exhibited a high proportion of shallow dives, similarly, had a high proportion of short dives (less than 4 minutes). Subadults utilized a greater variety of depth strata, with 20% of total dives deeper than 100m. Although subadults, as a whole, made relatively short dives, the proportion of dives between 2-6 minutes is greater than adult female, who had a greater proportion of dives < 2 min. The greater diversity in subadult diving patterns, along with greater movements and longer dives, may be characteristic of the investigative nature of young seals as they learn to forage (Swain and Small 1997).

Seasonal patterns were evident from the dive data but should be approached with caution. Variation existed in the amount of time a seal was tagged with an SDR , dependent upon battery life which resulted in unequal transmission periods. Overall, it appears that harbor seals are diving the deepest and making the most dives during the winter. At the same time, they are also making the longest dives (> 2 minutes). This is probably in relation to a reduced prey base as fish move out of PWS to overwinter in the Gulf of Alaska, or deep overwintering of herring, or offshore benthic fish, to name a few examples. However, diving behavior appears to be most influenced by geographic location although seasonal trends based on location data are more difficult to discern. It appears that seals, particularly subadults are leaving PWS during the winter, making deeper dives while in the Gulf of Alaska, probably in search of food, and some, but not all, are returning to PWS in the spring.

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Table 1. Summary of movements of satellite tagged adult female harbor seals in Prince William Sound, Fall 1994-1997. AF = Adult Female (Adapted from Frost et al. 1997.)

ID#	Age/ Sex	Location and Date Tagged	Other Major Areas and Dates of Use	Location and Date of Last Location Fix
94-5	AF	Port Chalmers 9/22/94		Stockdale Harbor 12/5/94
94-6	AF	Port Chalmers 9/22/94	Stockdale Harbor 9/23-10/29	Rocky Bay 10/30/94
94-8	AF	Port Chalmers 9/22/94		Port Chalmers 12/24/94
95-9	AF	Port Chalmers 9/26/95		Port Chlamers 2/9/96
95-10	AF	Port Chalmers 9/26/95	Middleton I. 9/30-10/7, 11/6-13, 12/5-7, 2/10-14 Port Etches 10/14-11/3, 11/15-30, 12/11-1/28, 3/12 SE Montague I. 2/2,2/18-3/8; Rocky Bay 4/16-21 Copper River Delta 3/14-4/3,4/22-5/17	Copper River Delta 5/17/96
96-9	AF	Port Chalmers 9/27/96	Port Chlamers 10/4-12, 11/22-28,1/23-2/11, 2/20-3/3, 312-3/21 Montague Straits 10/22-11/14,12/8-1/20, 2/27, 3/25 Stockdale Harbor 11//18,1/21, 3/4 Zaikof Bay 4/1	Port Chalmers 6/10/97
96-13	AF	Channel Island 9/27/96	Kayak Island 10/8-12/16,12/18-1/31,2/7-8, Grass Island Bar 12/16, 2/9-18,2/21-3/12,3/19-5/21 N.GOA 2/5-2/6, 2/20, 3/17 Icy Bay 5/26-6/16	Icy Bay 6/16/97

Table 2. Summary of movements of satellite tagged juvenile harbor seals in Prince William Sound, September 1994 - June 1997. JM = Juvenile Male, JF = Juvenile Female (Adapted from Frost et al. 1997.)

ID#	Age/ Sex	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, 2/2-21; 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
94-7	JF	Port Chalmers 9/22/94	Stockdale Harbor 9/26-10/23, 12/6-21 Unakwik Inlet 11/8-13; Columbia Bay 11/26-27	Port Chalmers 12/21/94
95-13	JF	Port Chalmers 9/27/95	SE Montague 10/6; Copper River Delta 10/15-11/15	Orca Inlet 11/8/95
96-7	JF	Channel Island 9/27/96	Seal Island 9/30, 10/12; Green Island 10/3-11, 11/19 Applegate Rocks 10/17-11/17; Augustine Island 12/16 Chinitna Bay (Cook Inlet) 12/25-3/8	Chinitna Bay 3/8/97 (Cook Inlet)
96-10	JM	Stockdale Harbor 9/27/96	Stockdale Harbor 9/30, 11/23-2/26, 3/13-4/27; Columbia Bay 10/18-24, 11/7-13; Glacier Island 11/1 Rocky Bay 3/7; Copper River Delta 5/3, 6/2; Icy Bay 6/9-27	Icy Bay 6/27/97
96-11	JM	Channel Island 9/27/96	W. Montague Island 9/30, 12/7; Channel Island 10/2, 10/6, 10/24, 11/28, 12/5, 12/14-23; Applegate Rocks 10/9-11, 10/18, 10/26, 11/11-13, 12/26,1/3-4, 1/30; Green Island 10/21-15, 10/21, 11/10, 11/19, 12/1-2, Copper River Delta 1/10, 3/7	Copper River D 3/7/97
96-12	JM	Channel Island 9/27/96	W. Montague I. 9/29-10/2, 10/8, 10/24, 11/7, 11/20, 12/17, 1/6; Channel Is. 10/3-5, 10/9-14, 10/18-21, 10/27-11/2, 11/8, 11/14-17, 12/19-12/31; Port Chalmers 10/15; SE Montague 12/2-12/11; Bering River 1/24-1/31 Copper River Delta 2/2-6	N. GOA 2/6/97

Table 3. Maximum daily dive depth (m) for seven SDR-tagged adult female harbor seals, September 1994 - June 1997.

ID Number	Age/ Sex[a]	Deployment Dates	n[b]	Max Depth	Mean Max Depth	Max Depth Date	Comments
94-5	AF	9/23/94 - 5/12/94	66	44	33.03	10/29/94	Max. depth consistently 20 - 40 m for entire tagging period.
94-6	AF	9/23/94 - 10/30/94	36	28	17.77	9/23/94 10/30/94	Max. depths consistent between 8-28m for entire tagging period.
94-8	AF	9/19/94 - 12/25/94	52	32	14.23	11/11/94	Max. depth highly variable between 0-32m.
95-9	AF	9/27/95 - 9/2/96	114	40	29.98	3/10/95 5/10/95 1/30/95 5/2/95	Nov. - Feb. max. depth ranged from 16-32m.
95-10	AF	9/26/95 - 5/18/96	164	280	69.29	1/30/96	Max. depths highly variable; dives either >128m or <8m. Deepest dives during Feb. and Mar. >208m, when seal was travelling between Box Point, Middleton I., and N.GOA.
96-9	AF	9/18/96 - 10/6/97	230	72	31.23	12/14/96	Max. depths from 8-64m for entire tagging period. Dives >60m occurred Dec. - Jan.
96-13	AF	9/27/96 - 6/17/97	180	236	81.51	6/11/96 10/11/96	Deepest dives made en-route to Bering River. Max. depths highly variable

[a] AF = Adult Female, JF = Juvenile Female, JM = Juvenile Male
[b] The number of days with maximum dive depths

Table 4. Maximum daily dive depth (m) for seven SDR tagged juvenile harbor seals, September 1994 - June 1997.

ID Number	Age/ Sex[a]	Deployment Dates	n[b]	Max Depth	Mean Max Depth	Max Depth Date	Comments
94-1	JF	9/20/94 - 2/15/95	67	252	145.37	5/12/94	9 dives > 200m in N. GOA, Oct. - Jan. All other dives highly variable.
94-7	JF	9/24/94 - 12/21/94	54	252	90.44	11/11/94	2 deepest dives (228 & 252m) in Unakwik Bay in Nov.; Max. depth < 50 m between Sept. and Oct. 15, Oct. 16-Dec. max. depth between 100-150m .
95-13	JF	9/24/95 - 8/11/95	7	124	72.57	8/11/95	Data set too limited for comparisons.
96-7	JF	9/30/96 - 8/3/97	33	264	109.94	10/27/96	Max. depths highly variable.
96-10	JM	9/30/96 - 6/27/97	57	232	95.86	10/15/96	Deepest dive in Columbia Bay. During Jan. - Mar. consistent max. depths of 96-148m. April-May, max. depth avg. 46m, while seal is at the Copper River Delta.
96-11	JM	9/27/96 - 2/6/97	48	360	89.17	12/2/97	Nov. - Jan. dove consistently to 84-112m. 3 deepest dives (> 208 m) were in Zaikof Bay.
96-12	JM	9/30/96 - 2/6/97	35	232	78.51	6/2/97	Max. depths for Sep.-Jan. range from 28-84m with the exception of max. depth 136m at Box Point in late Nov. Deepest dives were in Feb., > 220m while seal was travelling to the Bering River and N. GOA.

[a] AF = Adult Female, JF = Juvenile Female, JM = Juvenile Male

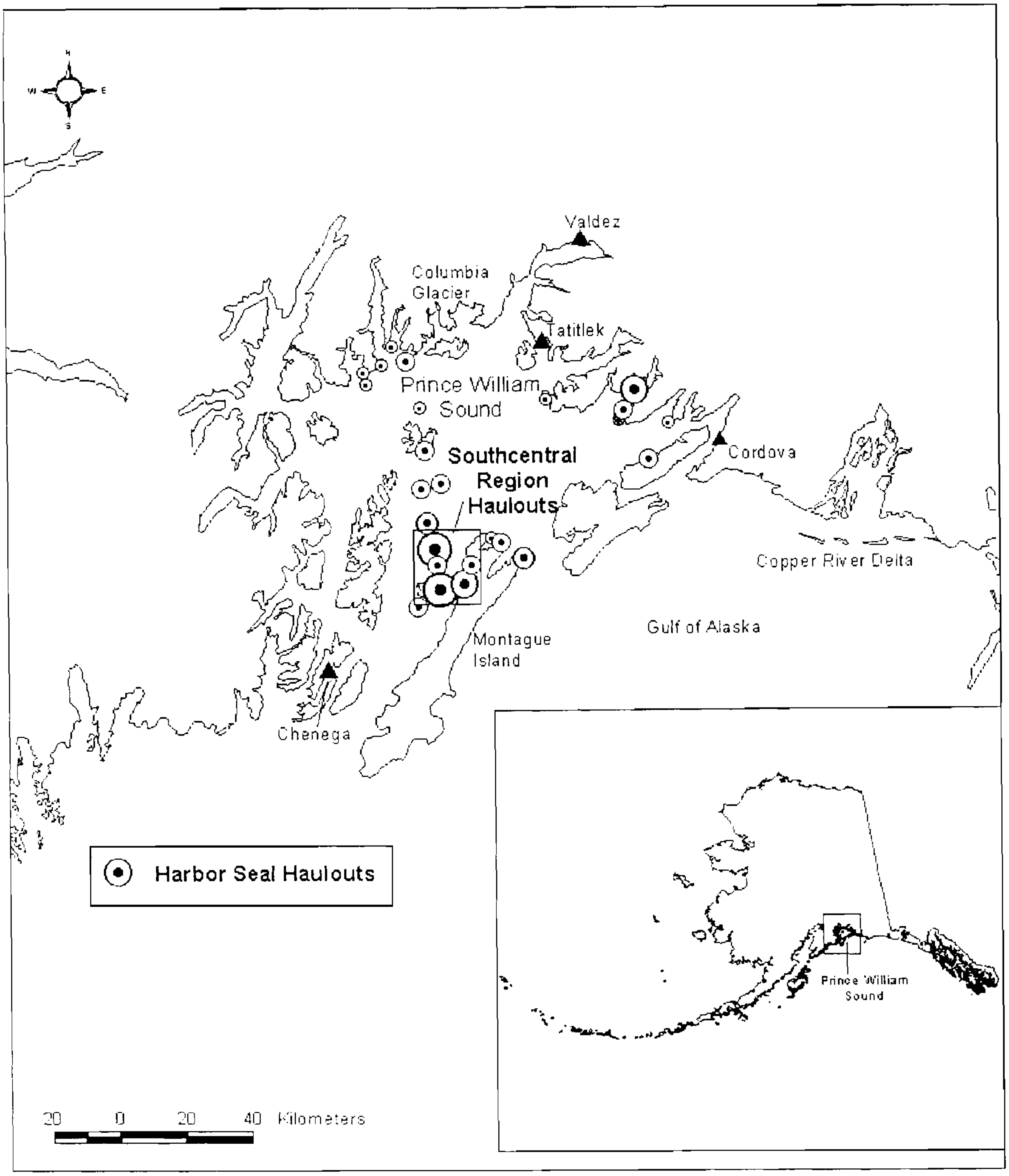


Figure 1. Map of Prince William Sound showing harbor seal haulouts used for trend analysis. Haulouts are represented according to size.

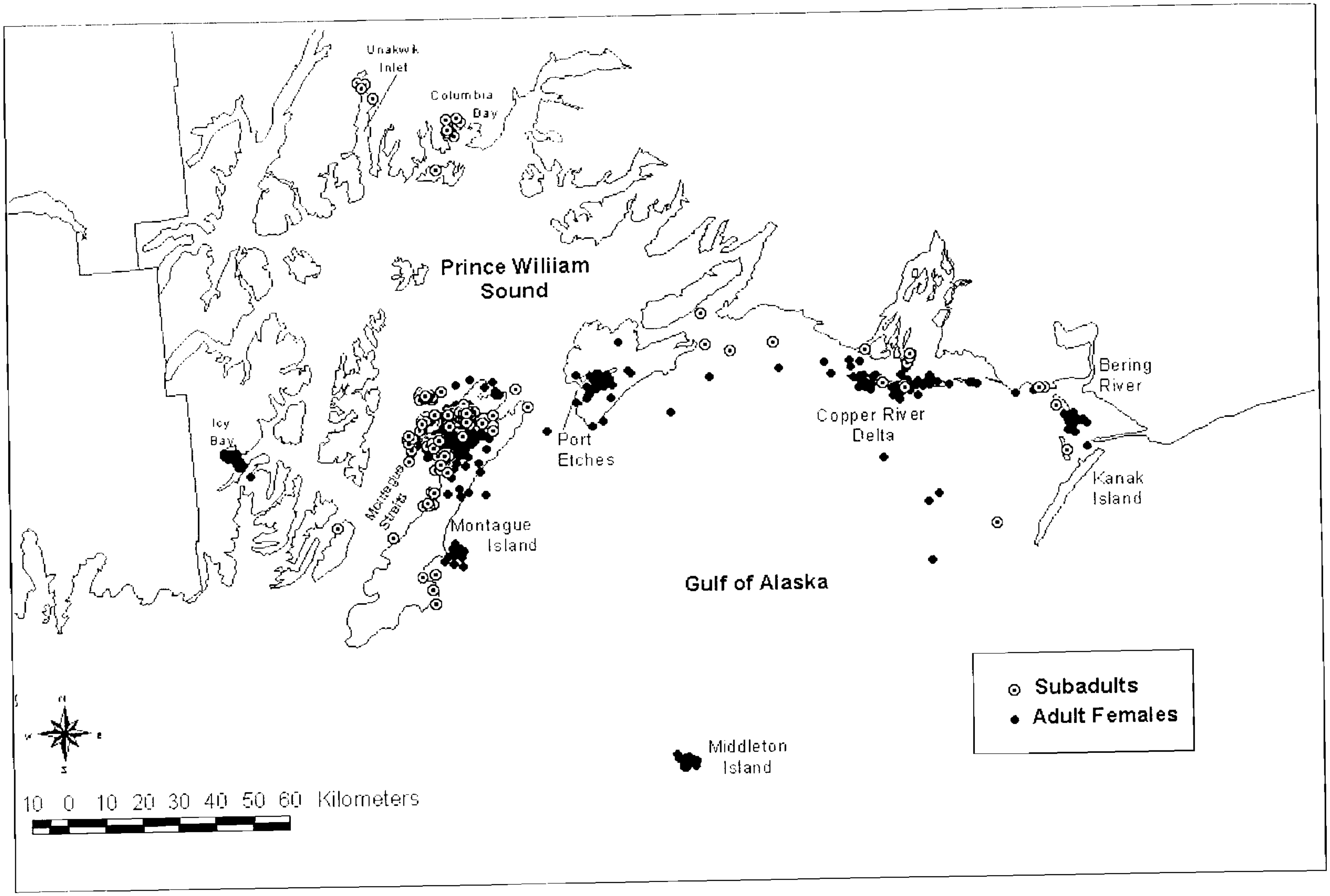


Figure 2a. Map of Prince William Sound showing the average daily locations of subadult and adult female seals tagged with SDR's during sptember 1994 - June 1997.

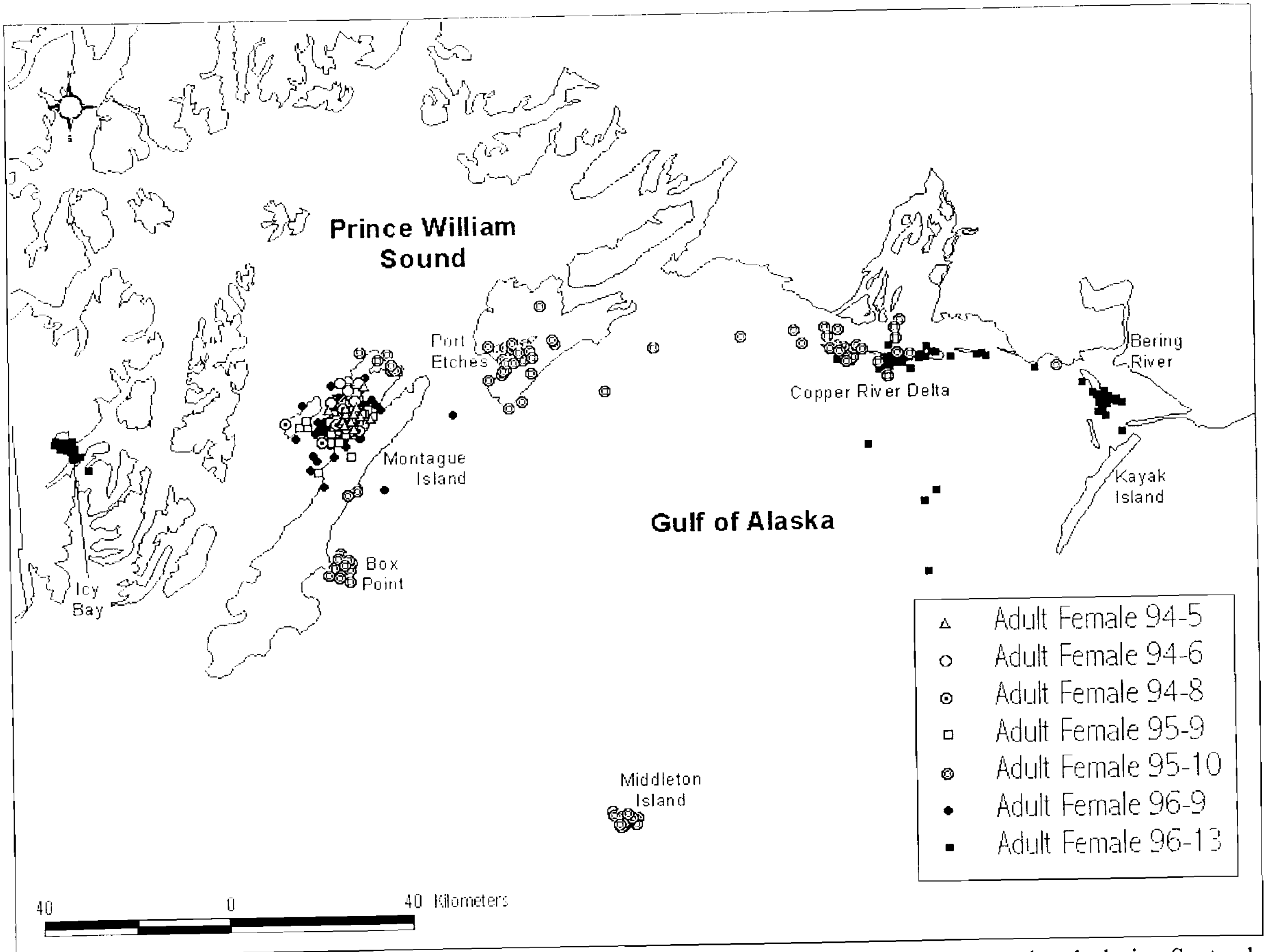


Figure 2b. Map of Prince William Sound showing average daily locations of adult female satellite tagged seals during September 1994 - June 1997.

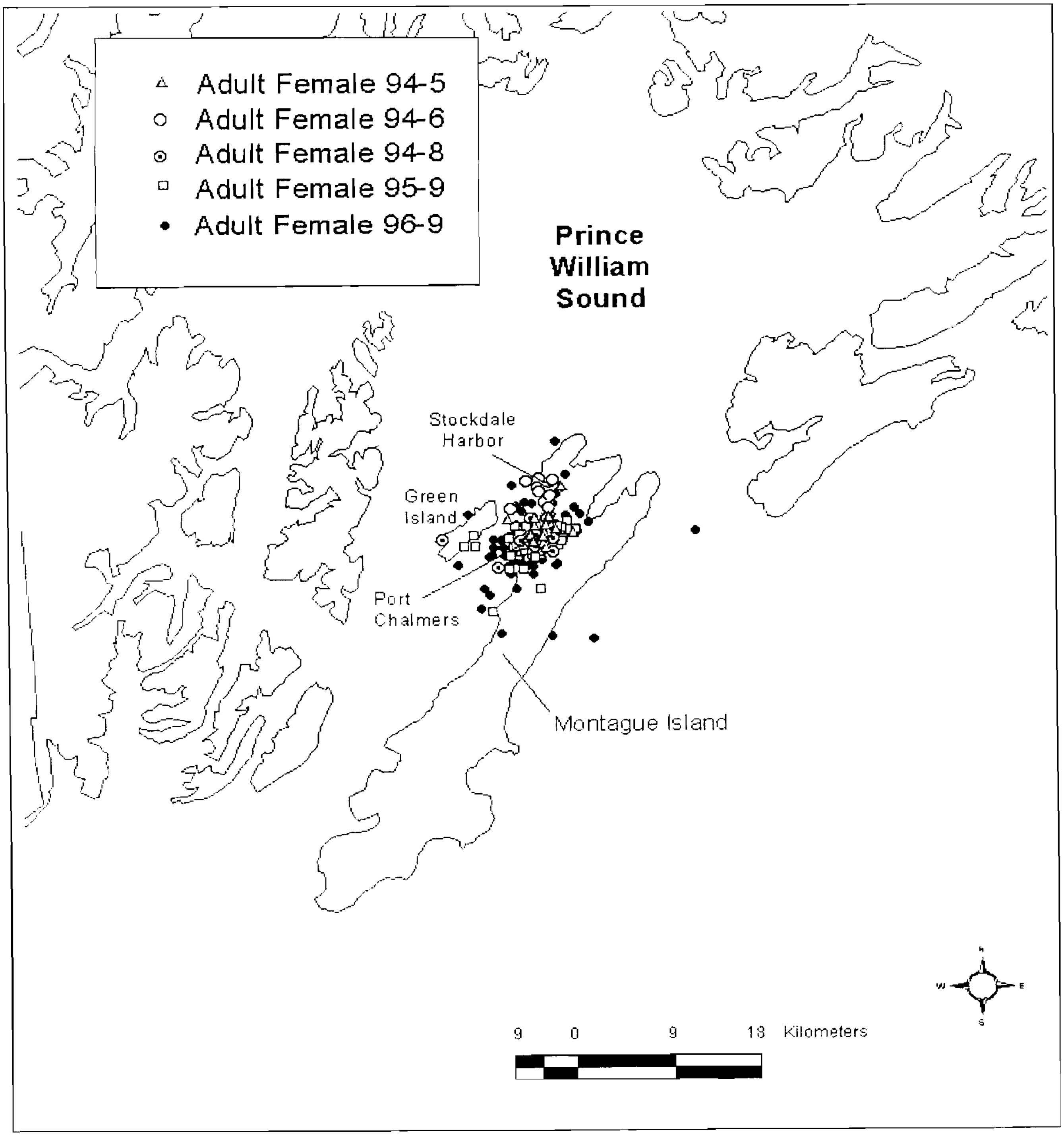


Figure 2C. Map showing the average daily location of 5 adult female satellite tagged harbor seals in southcentral Prince William Sound. Seals tagged September 1994, 1995, and 1996.

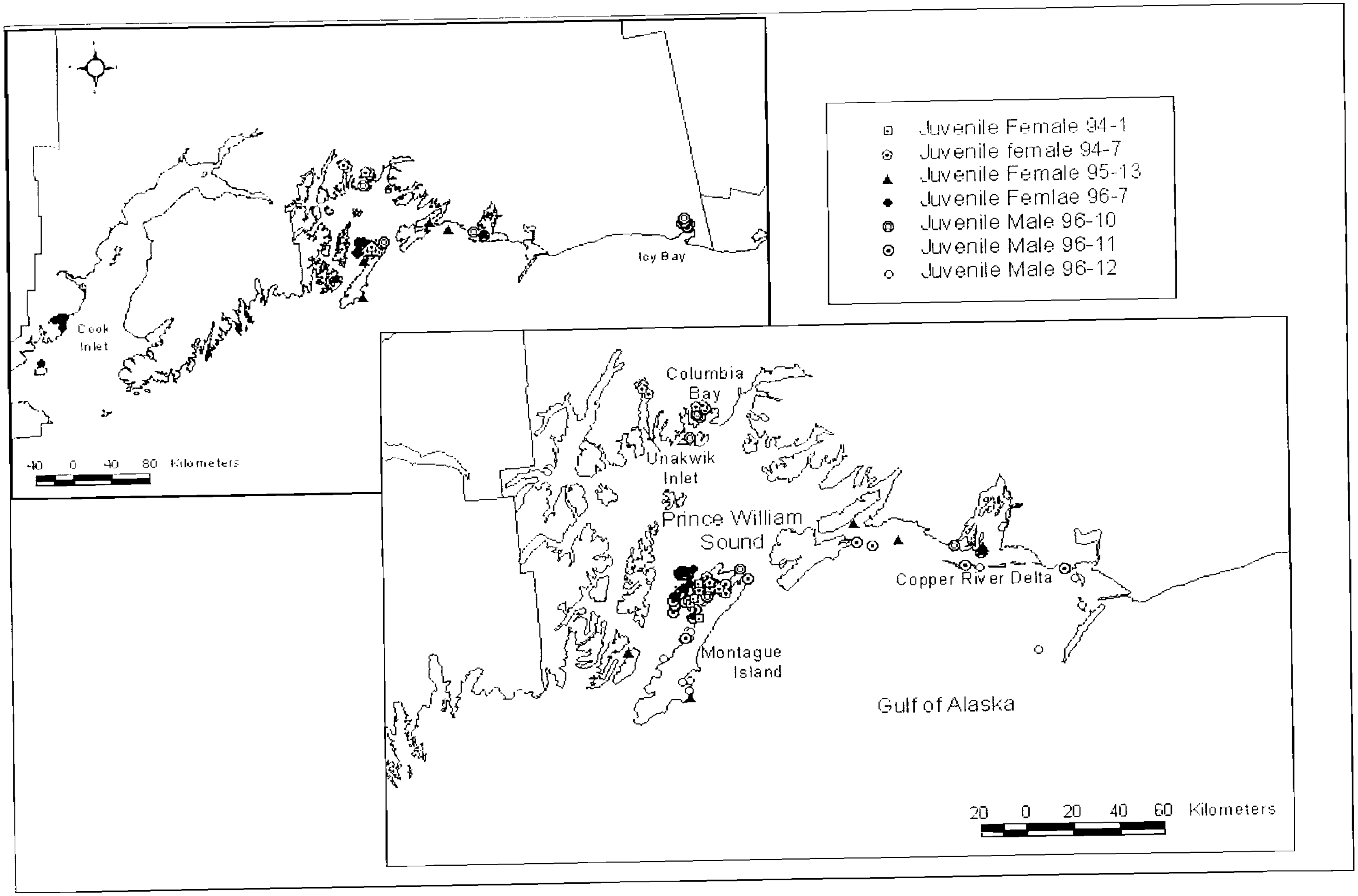
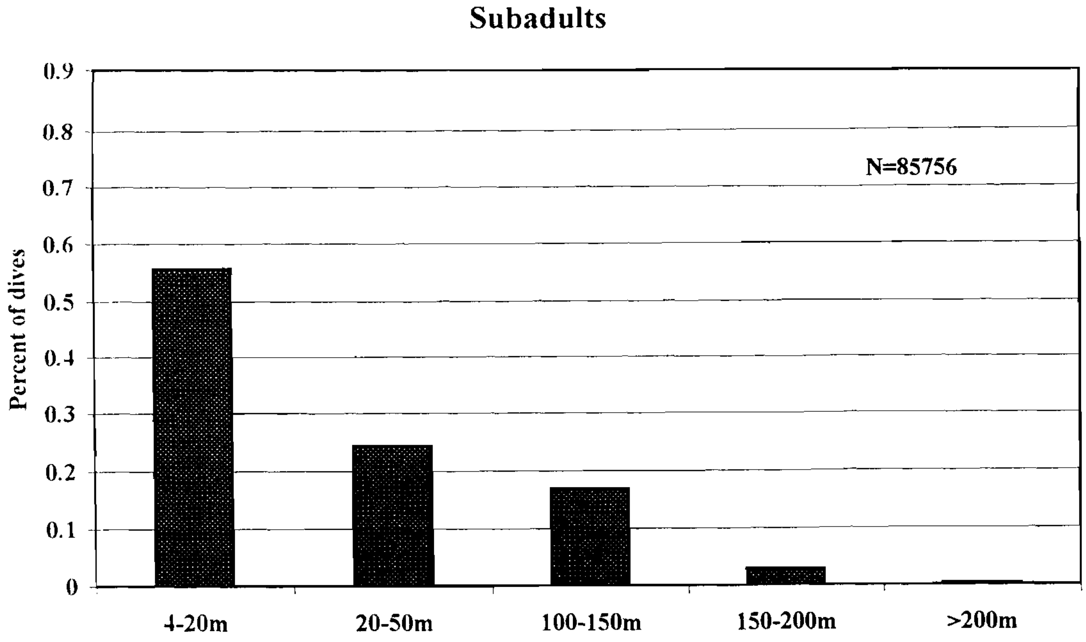


Figure 2d. Map of Prince William Sound showing average daily locations and range of movement of seven SDR tagged subadult harbor seals during September 1994 - June 1997.



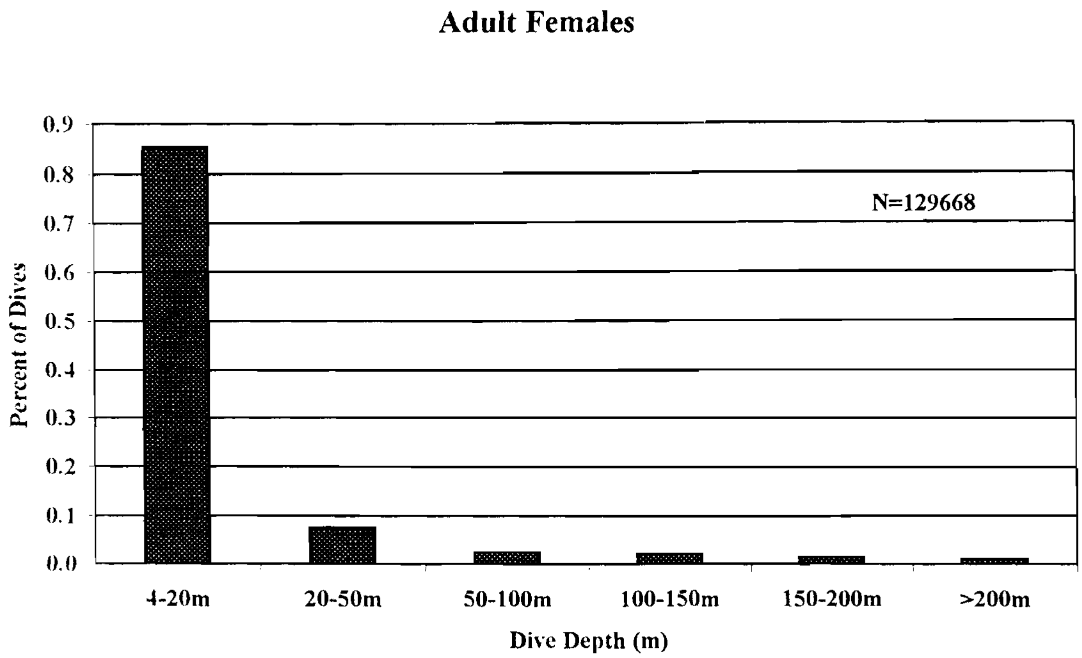


Figure 3. Percentage of all dives by depth category (bin) for 7 adult female and 7 subadult harbor seals tagged with SDR's from central Prince William Sound, September 1994-June 1997.

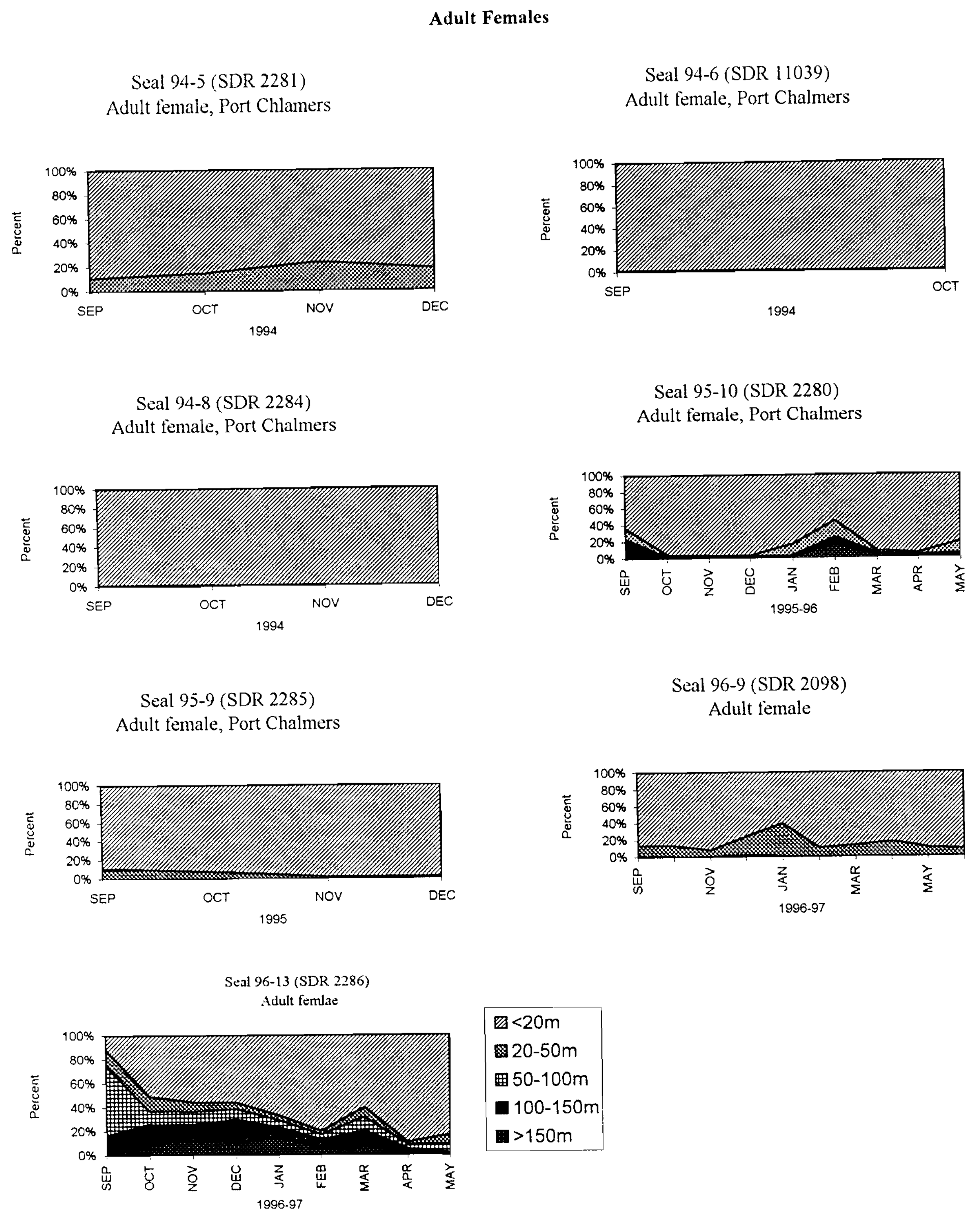
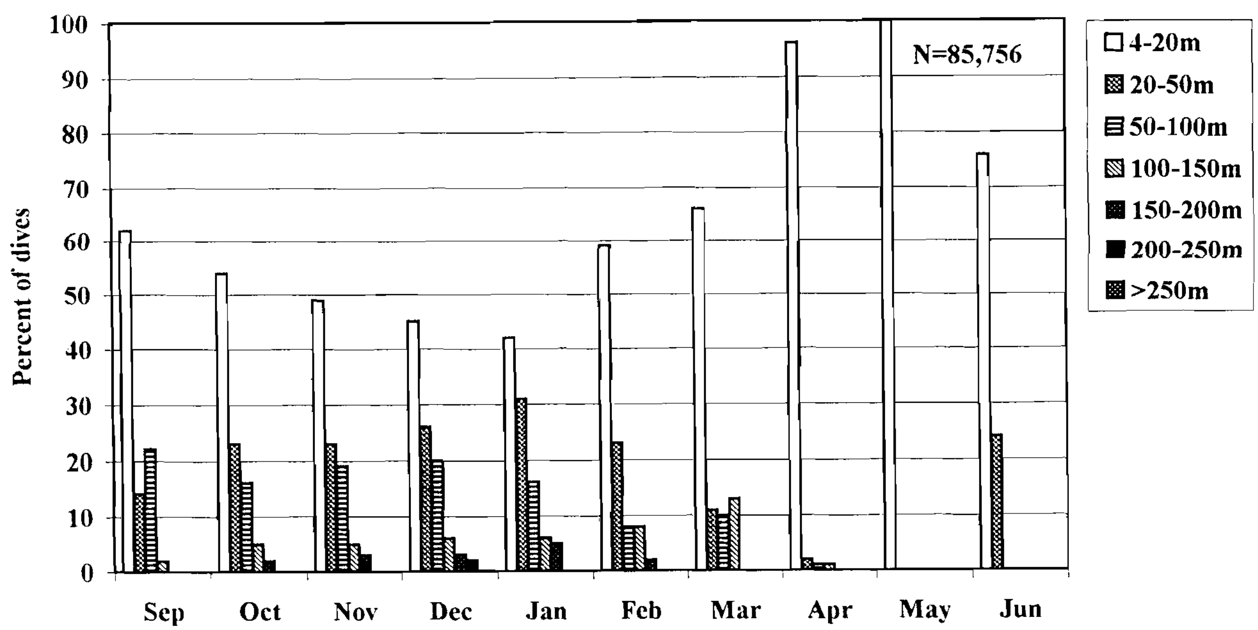


Figure 4. Monthly dive distribution summary for seven adult female harbor seals with satellite tags from the central region of Prince William Sound, September 1994 - June 1996.

Subadults Monthly Dive Depth Summary



Adult Females Monthly Dive Depth Summary

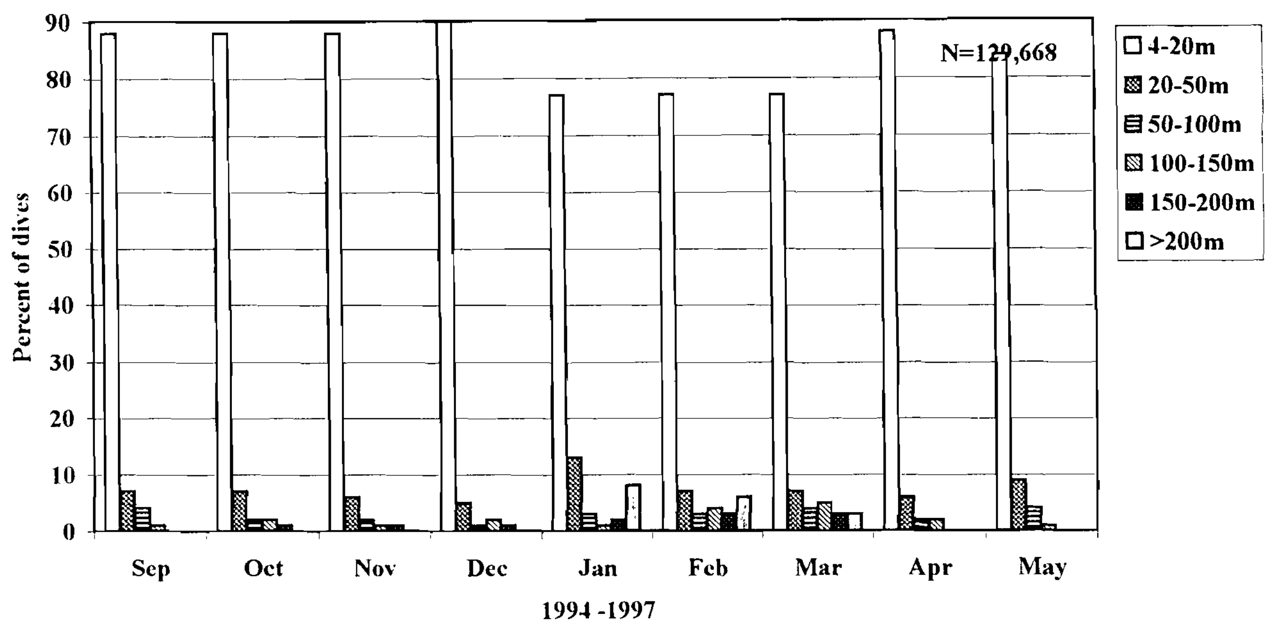
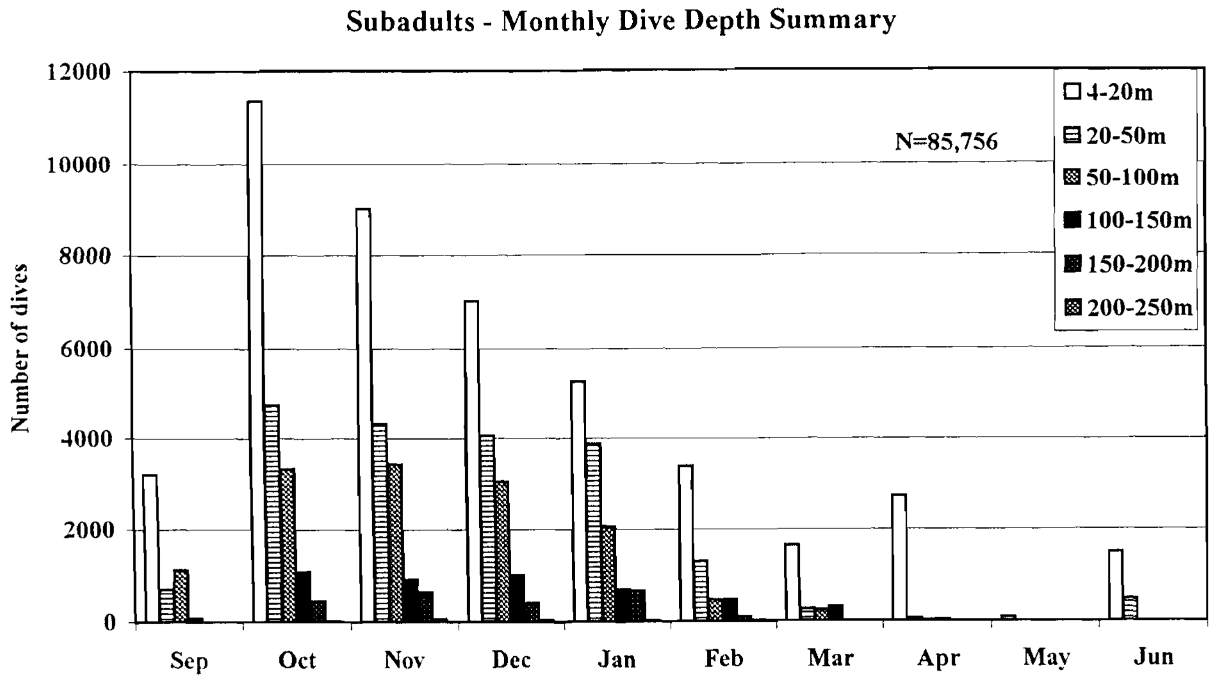


Figure 5. Percentage of all dives by dive depth for 7 subadult and 7 adult female SDR - tagged harbor seals in Prince William Sound, September 1994 - June 1997.



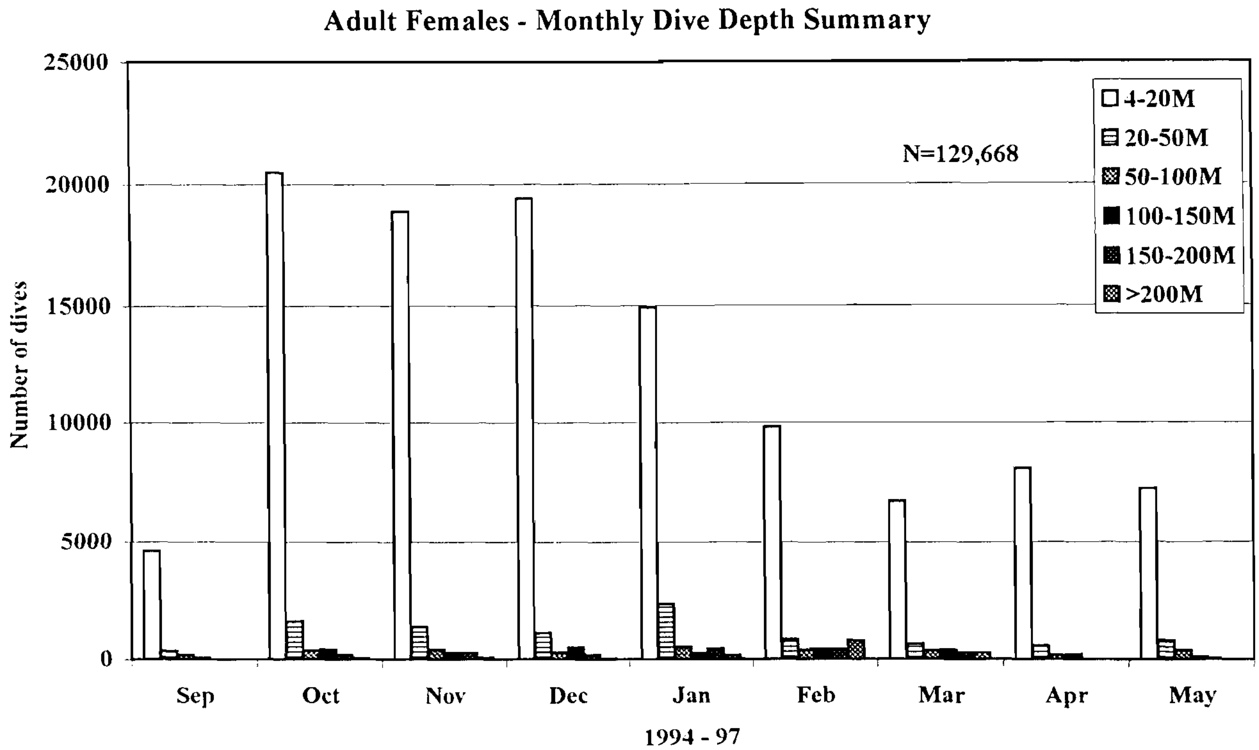


Figure 6. Total number of all dives by dive depth for 7 subadult and 7 adult female SDR - tagged harbor seals in Prince William Sound, September 1994 - June 1997.

Subadult seals

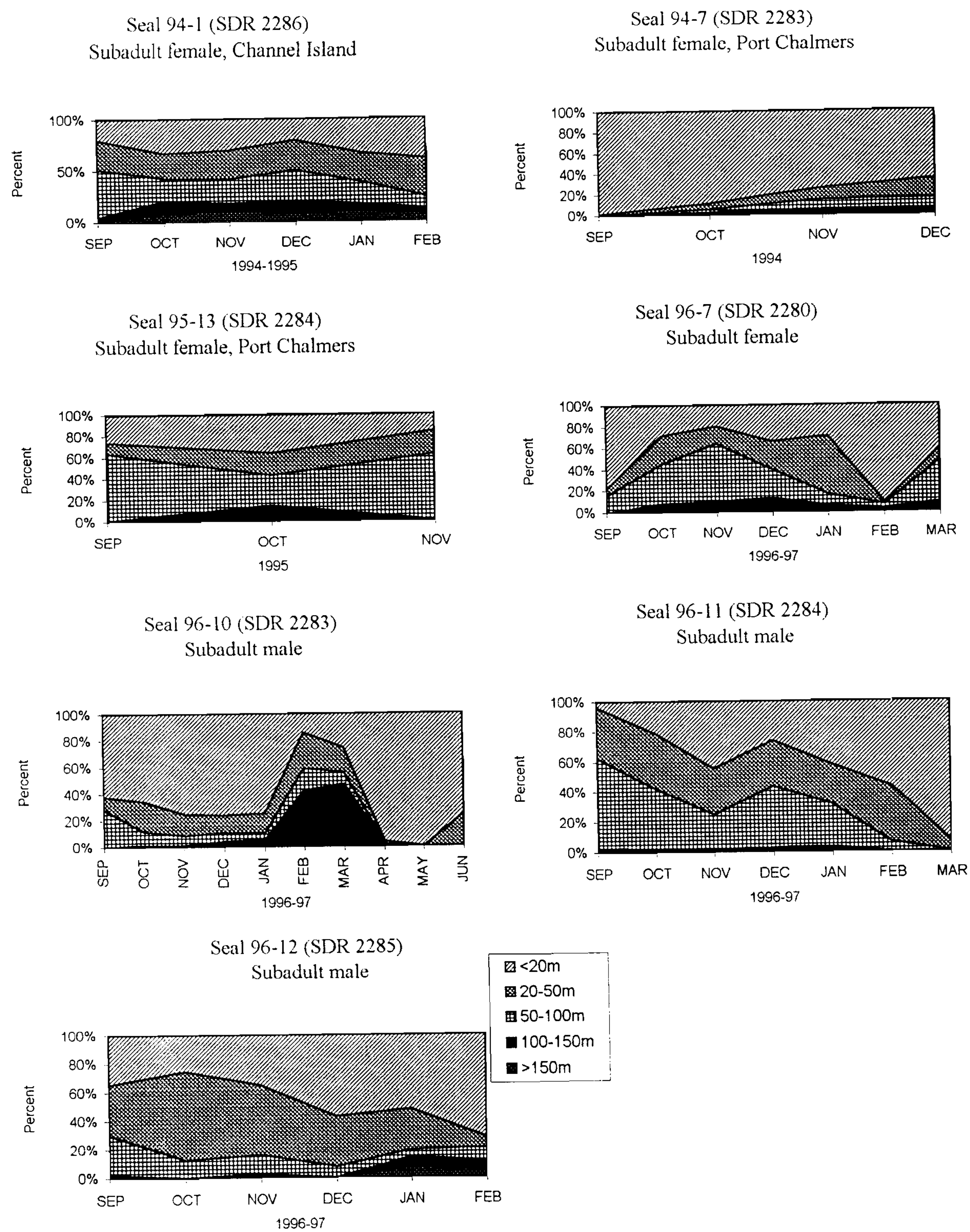


Figure 7. Monthly dive distribution summary for seven subadult harbor seals with satellite tags from the central region of Prince William Sound, September 1994-May 1997.

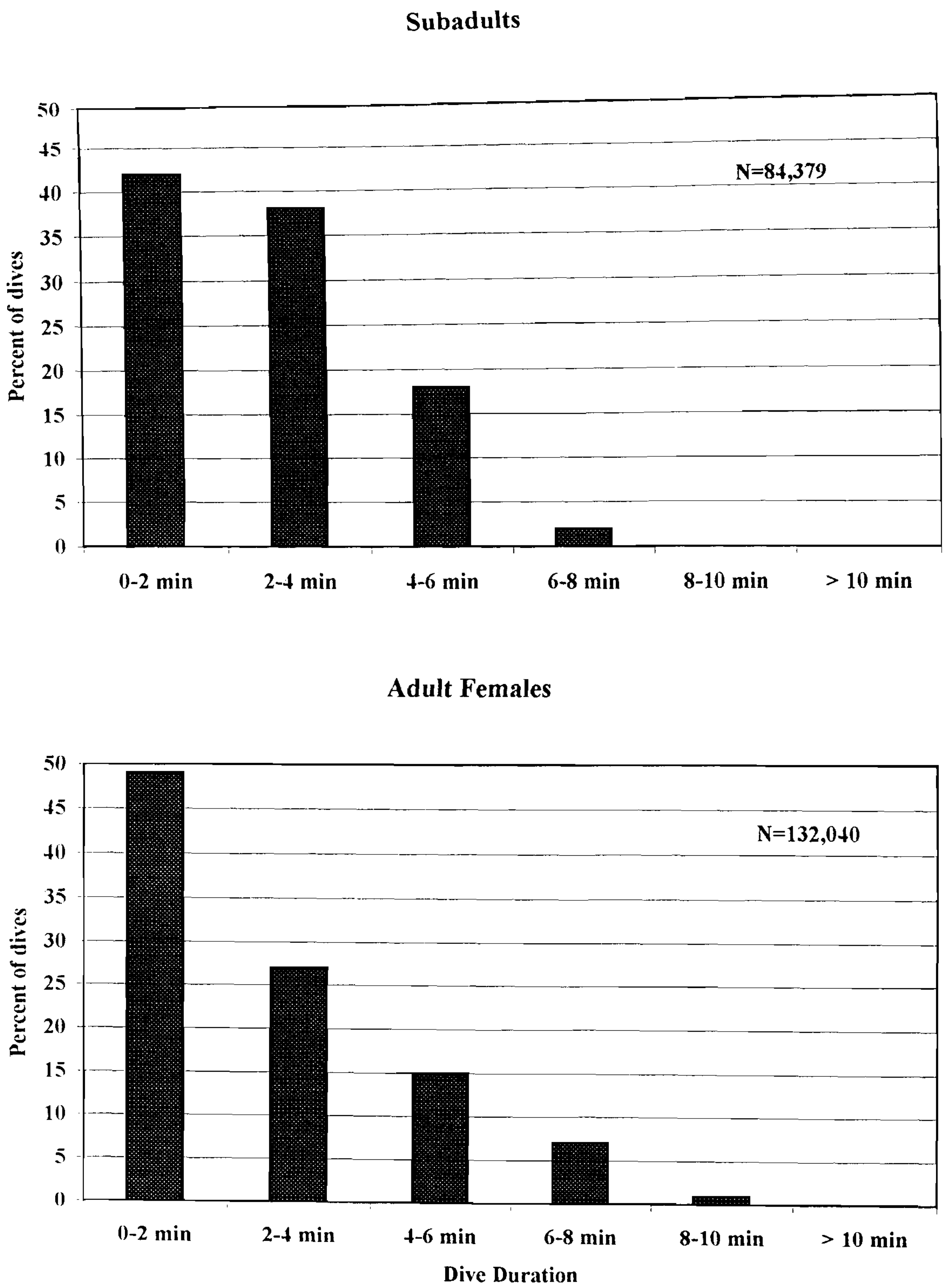
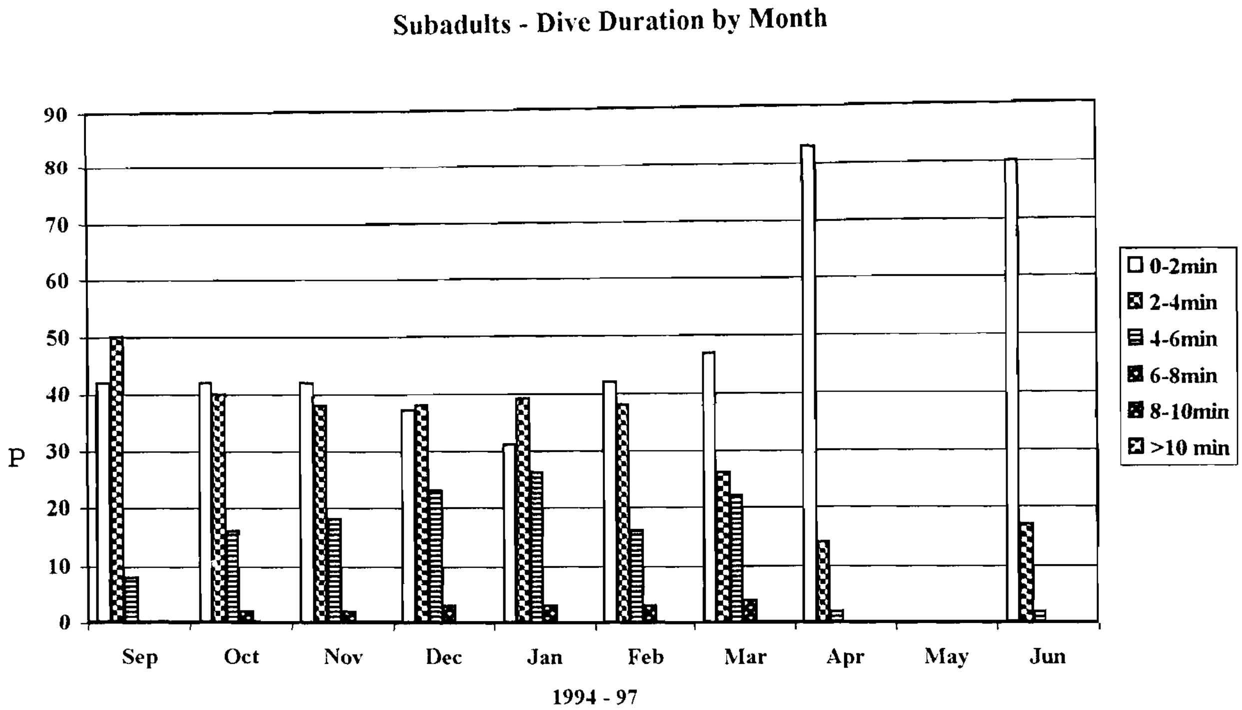


Figure 8. Percentage of all dives by duration bin for 7 adult female and 7 subadult SDR-tagged harbor seals in Prince william Sound, Sept. 1994 - June 1997.



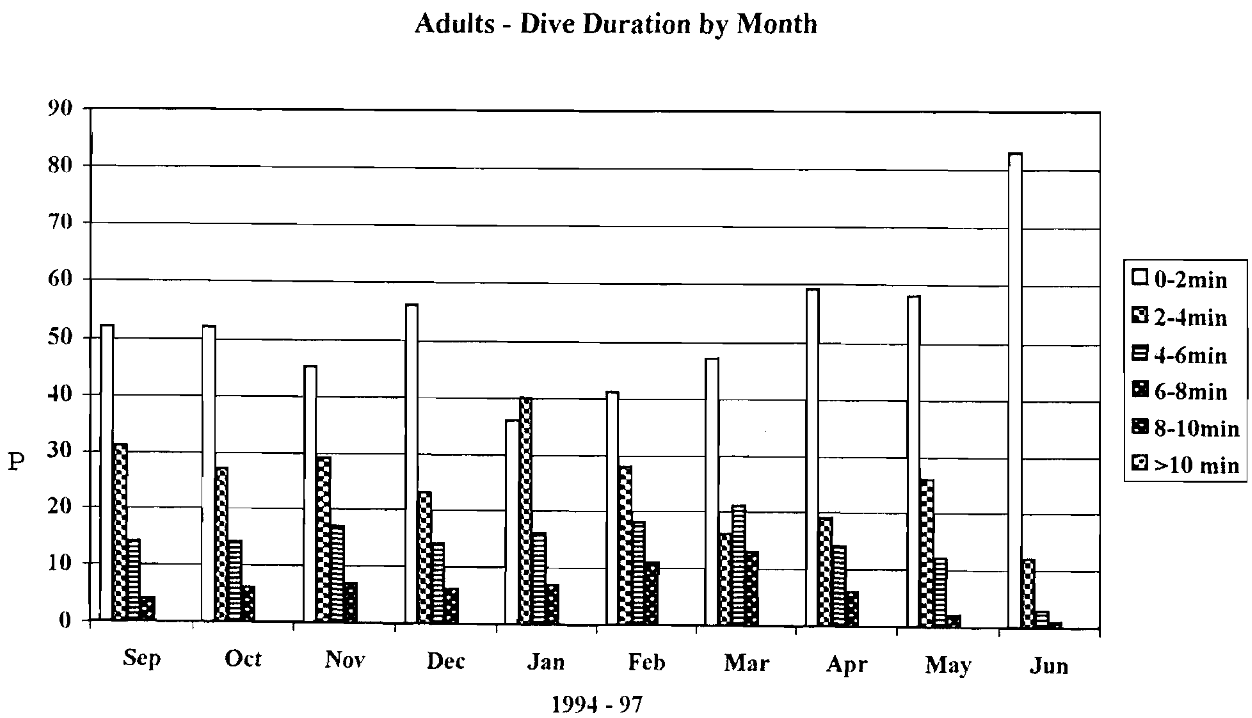


Figure 9. Seasonal distribution of percentage of all dives by duration for 7 adult female and 7 subadult SDR tagged harbor seals from Prince William Sound, September 1994 - June 1997.