Exxon Valdez Oil Spill
Restoration Project Annual Report

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

Restoration Projects 94064 and 94320F
1994 Annual Report

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

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Study History: Restoration Project 94064 continues the study effort initiated under Marine Mammal Study Number 5 (Assessment of Injury to Harbor Seals in Prince William Sound, Alaska, and Adjacent Areas) in 1989 through 1991. The project was reclassified as Restoration Study Number 73 (Harbor Seal Restoration Study) in 1992, and continued as 93046 (Habitat Use, Behavior, and Monitoring of Harbor Seals in Prince William Sound, Alaska) 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. In 1994, an annual report was submitted entitled Habitat Use, Behavior, and Monitoring of Harbor Seals in Prince William Sound: 1994 Annual Report. Fatty acid studies were funded as a pilot project under Restoration Project 94320F (Trophic Interactions of Harbor Seals in Prince William Sound), and are reported here in combination with 94064.

Abstract: Restoration studies of harbor seals, *Phoca vitulina richardsi*, that began in Prince William Sound in 1991 were continued in 1994. Aerial surveys of 25 trend count sites during 1989-1994 showed a continuing decline in the number of seals counted during the molt, and no change during pupping. Statistical analysis showed that the primary factors influencing seal counts were date, time relative to midday, and time relative to low tide. When adjusted for these factors, molting counts showed a highly significant decline of about 6% per year. Power analysis showed that adjusted molting counts have a high likelihood of detecting population recovery if at least 6 replicate counts are made each year over a 5 year period. Twenty-eight seals were captured, sampled, and tagged in 1993, and 36 in 1994. During September 1993-July 1994, seals equipped with satellite-linked time-depth recorders remained within the Sound, mostly near the locations where they were tagged. Dive depth and duration varied by seal and by location. Preliminary analysis of seal blubber showed considerable variation in the distributions of fatty acid types. Viral screening indicated that seals have been exposed to phocine heresvirus and phocine distemper virus.

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

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EXECUTIVE SUMMARY

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

Results of harbor seal restoration studies conducted from 1991 through October 1993 were reported previously. This report describes work done under Restoration Science Study No. 94064 during the period from October 1993 through September 1994. Emphasis is on a detailed analysis of aerial survey data and the methods for monitoring harbor seal recovery, and on analysis of data collected from satellite-tagged seals during September 1993-July 1994. Results from disease studies and preliminary results from fatty acid analyses (Study 94320F) are also presented.

In 1994, aerial surveys were again flown at 25 trend count haulout sites that have been used for NRDA and other studies. Unadjusted molting period counts at all sites combined were 12% lower than in 1993 and 17% lower than in 1989. The overall decline since 1989 was 0% at oiled sites and 23% at unoiled sites. In 1994, unadjusted pupping period counts of non-pups were similar to 1993, but 22% lower than in 1989. Pup counts also were 22% lower in 1994 than in 1989. Pup production at oiled sites was lower in 1994 than in any other year except 1989. Regression analysis of unadjusted count data collected since 1989 showed no significant trend for either molting or pupping counts.

A statistical analysis was done of the effects of date, time, tide, and environmental parameters on seal counts. The primary factors affecting counts were date, time relative to midday, and time relative to low tide. Parameter estimates from a generalized linear model were used to adjust individual daily counts at each location to make them equivalent to counts made in optimum conditions. A linear regression of adjusted counts from 1989-1994 showed a highly significant decline for molting counts, with the average rate of decrease of about 6% per year. Adjusted pupping counts also showed a decline, but it was not statistically significant.

Power analysis was used to examine whether the current survey methods and data analysis protocols will be able to reliably detect population recovery. The analysis indicated that none of the data sets have a reasonable chance of detecting a trend over three survey years. If the number of survey years is increased to five, all pupping counts and unadjusted molting counts still have relatively little power. However, molting counts that have been adjusted for effects of date, time of day, and tide have an 80% or better chance of correctly detecting a 5% annual increase if at least six replicates counts are made each year.

Twenty-eight seals were captured, sampled, and tagged in 1993, and 36 in 1994. Six satellite-linked time-depth recorders (SLTDRs) attached in September 1993 transmitted for 101-310 days. During the tracking period, none of the seals moved out of PWS. Four seals stayed very close to their tagging locations at Seal Island, Bay of Isles, and Channel Island. One made several trips from Seal Island to the north part of Montague Island. One seal ranged widely, moving from Seal Island to the Columbia Glacier and other locations in northwestern PWS. Average daily movements were

significantly less than for seals tagged in spring 1992 and 1993. All six seals were at the locations where they were tagged when their transmitters failed.

Data from SLTDRs attached in September 1993 indicated that seals usually dove to depths of less than 150 m. For five of the six seals, fewer than 4% of the total dives were deeper than 150 m. For one seal which moved between Seal Island, Columbia Bay, and northwestern PWS, 11% of the dives exceeded 150 m. Only 1% of its dives near Seal Island exceeded 150 m, compared to 13% in Columbia Bay and northwestern PWS where bottom depths often exceed 200 m. The shallowest diving seal was at Channel Island, where bottom depths are generally less than 60 m within 5 km of the island. A seal that used both Seal Island and northern Montague Island usually had a bimodal distribution of dives (most <50 m or 100-150 m). However, when it was near Montague during herring spawning in April, and in Stockdale Harbor in February, March and April, almost all of its dives were shallower than 50 m. These results suggest that the seals dove to or nearly to the bottom on most days, and that they did not travel far from their haulouts to feed.

Seal 2287, which retained its SLTDR for 10 months, showed a clear seasonal pattern in diving. It made more deep dives in mid-winter than at any other time of year. In summer, almost no dives were deeper than 20 m. This seal also spent the least amount of time in the water diving during the summer.

Four SLTDRs provided data about the proportion of total time spent in the water versus hauled out. Two seals spent more of their time diving during the day. The other two were more variable, sometimes diving more at night and sometimes during the day. Overall, the four seals spent 66%-77% of their time in the water.

Preliminary analyses of blubber from 40 seals sampled in 1994 showed considerable variability in distributions of fatty acid types. Differences probably relate to geographic, seasonal, age, and/or gender related patterns of feeding. Fatty acids must be analyzed in prey samples and additional statistical analyses conducted before conclusions can be reached regarding food web dependencies. Stable isotope studies being done by other restoration projects will also provide information on harbor seal feeding that will be evaluated in conjunction with results from fatty acids.

Harbor seals sampled in PWS and other locations in Alaska have been exposed to both phocine herpesvirus and phocine distemper virus. There is no evidence that mortality due to either of these viruses has contributed to the decline of harbor seals in some parts of Alaska.

It is essential to continue to monitor the trend in abundance of PWS harbor seals. Surveys conducted during the molt, corrected for the influence of certain factors, have sufficient power to detect a population recovery. Surveys conducted during pupping are too variable, and should be discontinued. In addition, satellite-tagging studies should be continued to learn more about movements, diving behavior, and haulout use of harbor seals in PWS. These studies should be complemented by studies of predation and food availability in order to better understand the potential roles of these factors in limiting the recovery of harbor seals following the spill.

INTRODUCTION

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

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

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

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

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

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

As top level predators, harbor seals are likely to affect, and be affected by, other components of the ecosystem in PWS. Because of the need to understand how harbor seals function in the ecosystem, this restoration study has increasingly emphasized a broad approach to research on the nutrition, energetics, and health of harbor seals. Working in conjunction with researchers at the University of Alaska, Fairbanks, (Dr. Michael Castellini and Brian Fadely) all seals captured have been measured, weighed, and blood-sampled. Blood has been analyzed for a wide variety of hematological and chemical parameters. This component of project 94064 was conducted as a pilot study for project 95001, and preliminary reports have been submitted separately (Fadely et al. 1994*a*,*b*). Vibrissae have been collected and supplied to a study of stable isotopes also being conducted at the University of Alaska, Fairbanks (Dr. Don Schell and Amy Hirons). Stable isotope and condition/nutrition studies are now separate projects (projects 96170 and 96001) supported by the spill restoration program, and the results will be reported separately. Blood serum samples have been screened for disease as part of an ongoing investigation being conducted by ADF&G, and results are included in this report.

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

OBJECTIVES

The objectives of this restoration study have been:

1) to conduct aerial surveys of harbor seals at 25 trend count sites in PWS during pupping and molting;

2) to compare data from current surveys to data collected following the spill to determine whether seal numbers are recovering;

3) to conduct a power analysis of aerial survey data to evaluate the effects of number of replicates and number of survey years on determining trends in abundance;

4) to describe hauling out and diving behavior, and by inference, feeding behavior of satellite-tagged seals in PWS relative to date and time of day;

5) to describe use of haulouts and frequency of movements between haulouts;

6) to determine movement patterns within PWS and between PWS and adjacent areas;

7) to conduct a pilot study investigating the use of fatty acid analysis in comparing diets of harbor seals; and

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

METHODS

Aerial Surveys

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

Survey methods were identical to those used during the NRDA harbor seal study (Frost and Lowry 1994*a*, Frost et al. 1994) and harbor seal restoration studies in 1992-1994 (Frost and Lowry 1994*b*). Surveys were conducted from a single engine fixed-wing aircraft (Cessna 185). Visual counts of seals were made at altitudes of 200-300 m, usually with the aid of 7-power binoculars. Each site was circled until the observer was confident that an accurate count had been made. For larger groups of seals (generally those of 40 or more) photographs were taken using a hand-held 35-mm camera with a 70-210 mm zoom lens and high speed film (ASA 400). Color slides were commercially developed, and seals were counted from images projected on a white surface. During June surveys, separate counts were made of pups and non-pups. Replicate counts (usually 4-10) were made at each site. Counts were usually conducted within two hours before and after low tide.

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

Aerial Survey Trend Analysis

Data were analyzed to determine whether there was an identifiable trend in the counts of harbor seals in PWS since 1989. For each year, daily counts were averaged for each site and then sites were summed to produce yearly estimates for the oiled, unoiled, and total trend count areas. The 95% confidence interval was estimated by bootstrapping (Efron and Tibshirani 1993). The bootstrap method resampled with replacement from the actual daily counts at each haul-out site to produce a new data set with the same sample size (number of counts) for each site in each year. This resampling was done 2000 times for each year's data, and then the 2000 bootstrap estimates were ordered. Ordinarily, the 50th and 1950th ordered bootstrap estimates provide a 95% confidence interval, but as recommended by Efron and Tibshirani (1993), we used a bias-corrected version that slightly adjusted the choice of the ordered bootstrap estimates for the confidence interval endpoints.

A linear regression model was fitted to the 1989-1994 yearly estimates at oiled sites, unoiled sites, and for the trend count area as a whole. This was done for both pupping and molting counts. During the pupping period, only the counts of non-pups were used in the analysis. The regression line for each group took the form,

$$Y = \beta_0 + \beta_1(X)$$

where Y is the mean count/site summed for all sites, β_0 is the y intercept of the line, β_1 is the slope, and X is the year. The significance of regression coefficients was tested using analysis of variance (Snedecor and Cochran 1969).

Analysis of Factors Affecting when Seals are Hauled Out

A Poisson regression was used to analyze the factors that may affect the number of seals hauled out and available to be counted during surveys. This is a generalized linear model (McCullagh and Nelder 1989) with a log link function and a Poisson distribution. To assign an average count to each site in any given year, a model was first used which considered site, year, and the interaction of site by year. Other factors (Table 2) were subsequently added into the model one at a time. If a factor with p parameters increased 2*log-likelihood by more than a χ^2 distribution with p degrees of freedom, then the factor was considered to significantly affect the number of seals counted at haulouts.

For all surveys, data were complete for time of day, time of tide, date, and tide height. Each of these factors was first entered into the model one at a time. The factor with the most significant χ^2-value was retained in the model, and then other factors were again entered into the model one at a time until any remaining factors were insignificant. Time of day and time relative to low tide were analyzed as categorical data. Initially, time increments before and after midday and before and after low tide were placed in six and eight separate categories. Some categories were combined when preliminary analysis indicated that it could be done without changing the fit.

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

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

Trend Analysis of Adjusted Data

A linear regression model was fitted to the 1989-1994 adjusted pupping and molting counts at oiled sites, unoiled sites, and for the trend count area as a whole, as described in the above section "Aerial Survey Trend Analysis." During the pupping period only the counts of non-pups were used in the analysis.

To examine trends in the counts of seal pups during June surveys, the full model was fit to the pup counts using time of day, date up to a third order polynomial, and time relative to low tide. A third order polynomial for date was used to allow more flexibility in the shape of the trend curve. The average proportion of pups was determined relative to 15 June.

Power Analysis

Models - The data consisted of the average counts of seals hauled out during low tide over some fixed time period during the pupping or molting periods. This is an unknown proportion of the true number of seals, but it is assumed to be a constant proportion from year to year. The data on counting seals at haulouts are complicated by the fact that there are two sources of variability. One is due to the variation of replicate counts *within year*. The other is due to variation around some trend line *among years*. When trend among years is modeled linearly, the average number of seals hauled-out in some time period for each year (e.g., during 5 weeks of pupping) does not fall exactly on this trend line, so the deviations from the trend line are modeled as,

$$Y_t \sim N(\beta_o + \beta_1 t,\ \delta^2), \tag{1}$$

where Y_t is a random variable for the average number of seals hauled-out, over some time period in year t, and $N(\beta_o+\beta_1 t,\ \delta^2)$ is the normal distribution with a trending mean $\beta_o+\beta_1 t$ and variance δ^2. Y_t is not actually observed unless a survey is flown every day during the specified time period. Instead, a sample is taken from that time period. Then, the distribution for the number of observed seals on haulouts for replicate flights within a year, conditional on the value Y_t, is,

$$Z_{ti} \mid Y_t \sim f(Z_{ti} \mid Y_t, V),$$

where $f(Z_{ti} \mid Y_t, V)$ is some density function for the ith replicate flight in year t, with mean Y_t and variance V. Using a mean of Y_t implies that Z_{ti} is unbiased for Y_t. However, the replicate flights per year are averaged in an attempt to estimate Y_t. Due to the central limit theorem, we can assume that,

$$Z_{t\bullet} \mid Y_t \sim N(Y_t, V/n_t), \tag{2}$$

where $Z_{t\bullet}$ is the average of the replicate flights per year that will have sampling variance V/n_t. The variance will decrease with the number of replicate flights n_t in year t. This is a specific model of the more general case presented by Link et al. (1994). From (1) and (2), the marginal distribution of $Z_{t\bullet}$ is (Morris 1983),

$$Z_{t\bullet} \sim N(\beta_o + \beta_1 t,\ \delta^2 + V/n_t), \tag{3}$$

and the distribution (3) is used for all inference.

Parameter Estimates - Note that from (3), if it is assumed that $\delta^2 + V/n_t$ is approximately constant for all t, i.e., $\delta^2 + V/n = \sigma^2$, where n is the average number of replicate surveys per year (i.e., assuming n is relatively constant per year), then efficient estimates of the parameters β_o and β_1 are obtained using the yearly means $Z_{t\bullet}$ and the usual least-squares methods without needing to know both variances, δ^2 and V. Then the residuals from the fitted model comprise the mean-square error, which is an estimate for σ^2, call it $\hat{\sigma}^2$. However, for power and the effect of replicate sampling, it is desirable to estimate δ^2 and V. The variance of $Z_{t\bullet}$ was estimated by using resampling methods. We resampled, with replacement, 2000 times from the Z_t; $i = 1,...n_t$, for the tth year, and computed the mean $Z_{t0}^{(k)}$ for the kth resampling. Then $S_t^2 = \sum_{k=1}^{2000}(Z_{t0}^{(k)} - Z_{t0}^{(0)})^2 / 1999$ on the resampled means was used to estimate the sampling variance V/n_t, where $Z_{t0}^{(0)}$ is the average of $Z_{t0}^{(k)}$ over the 2000 iterations. Finally, a simple estimate of V is $\hat{V} = \sum_{t=1}^{T} S_t^2 n_t / T$ and $\hat{\delta}^2 = \hat{\sigma}^2 - \hat{V} / \bar{n}$.

Linear trend: Classical Test of Hypothesis - The usual test of hypothesis under a linear model is given in any text book that includes linear regression. For a linear trend model $X_t = \beta_o + \beta_1 t + \varepsilon_t$, with ε normally distributed with zero mean and some variance, the usual null hypothesis of no trend is H_o: $\beta_1 = 0$. The test may be expressed several ways, but a good heuristic formula is,

$$h = \frac{\hat{\beta}}{s_{\hat{\beta}}} \tag{4}$$

where $\hat{\beta} = \sum_{t=1}^{T}(X_t - \bar{X})(t - \bar{t}) / \sum_{t=1}^{T}(t - \bar{t})^2$ and $s_{\hat{\beta}} = s_{x.t}^2 / \sum_{t=1}^{T}(t - \bar{t})^2$ with $s_{x.t}^2 = \sum_{t=1}^{T}(X_t - \hat{\beta}_0 - \hat{\beta}_1 t)^2 / (T-2)$. Under the null hypothesis, h will have a t-distribution with T - 2 degrees of freedom.

Power - After estimating the parameters, the power of future tests for trend can be estimated, assuming that the classical test (4) is used and the data behave similarly to the past. The effect of the number of replicate surveys per year and the number of years on the ability to detect trends can be examined. Errors about the trend line cannot be controlled, but number of replicates per year can. A power analysis can help choose a design based on realistic cost constraints and can help determine what sort of magnitudes in trend might be detected. Power analysis for a linear trend, where the variance is allowed to change with the mean, was described in Gerrodette (1987). This work was criticized by Link and Hatfield (1990), with a response by Gerrodette (1991). Several issues still need clarification.

Gerrodette (1991) maintained that when there are replicate surveys per year in determining the yearly estimate of abundance, there are increased degrees of freedom above the usual T - 2 based on the number of years. From (3) it is clear that this is not the case. The degrees of freedom should be T - 2, regardless of the number of replicate samples per year.

The second issue is the proper distribution. When the variance is constant (homoskedastic), then the distribution of the test statistic (4) has a non-central t-distribution under the alternative hypothesis (Gerrodette 1991). However, we were unable to show a non-central t-distribution when the variance is proportional to the mean, and it is not likely to be exactly a non-central t-distribution. Nonetheless our simulations confirmed those of Gerrodette (1991), and indicated that the non-central t-distribution works well in practice and gives results quite close to those from Monte Carlo simulations.

Finally, the use of equation (4) may be questioned, especially when the variance changes with the mean (see Gerrodette (1991) for comments on a weighted least squares approach). The use of a weighted least squares statistic would again call into question the power calculations of Gerrodette and the use of a noncentral t-distribution. The use of weighted least squares will give *more* power than one based on the test (4) under a model where the variance changes with the mean, so the calculations we present are *conservative*; i.e., likely there will be more power than indicated assuming the model is heteroskedastic and that weighted least squares is used.

We modified the computer program TRENDS of Gerrodette (1993) to accommodate the two sources of variability δ^2 and V, and to make σ^2 a function of the number of replicate surveys per year by taking $\sigma^2(n) = V/n + \delta^2$. Because our data are counts, a Poisson distribution seemed appropriate, and because the coefficient of variation of $POI(\lambda) = 1/\sqrt{\lambda}$, we used the model in Gerrodette's program where the coefficient of variation is inversely proportional to the square-root of the mean. Notice that $\lim_{n \to \infty} \hat{\sigma}^2(n) = \hat{\delta}^2$, so even with an infinite number of replicate surveys per year it is not possible to obtain a power of 1 for a finite number of years T, unless $\hat{\delta}^2$ is very small.

Capture and Tagging of Seals

Field work was conducted at locations throughout PWS during May and September 1993 and April and September 1994. Personnel were transported from Whittier to the study sites aboard the chartered vessels *Hanna Cove* or *Pacific Star*.

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

In some cases seals could be physically restrained during handling and tagging. Larger animals were sedated with a mixture of ketamine and diazepam administered intramuscularly at standard doses (Geraci et al. 1981). Each seal was weighed, measured, and tagged in the hindflippers with individually numbered plastic tags. Approximately 50 cc of blood was drawn from the extradural intervertebral vein and the following samples were collected: whiskers for stable isotope analysis, flipper-punch skin samples for genetic analysis, and blubber biopsies for fatty acid analysis.

SLTDRs were glued to the mid-dorsal surface of the seal using Devcon quick setting epoxy (Fedak et al. 1984, Stewart et al. 1989). The SLTDRs were manufactured by Wildlife Computers (Redmond, WA), and produced 0.5 watts of power. Most of the units used measured 14.8 x 10.0 x 3.8 cm, weighed about 750 g, and were powered by four lithium C cells. They were attached only to larger seals, generally those weighing more than 40 kg. Beginning in September 1994 we also used a smaller version of the 0.5 watt SLTDR, which measured 11.9 cm x 5.1 cm x 4.5 cm, weighed 385 g, and were powered by six lithium 2/3 A cells. The small SLTDRs were attached to smaller seals, weighing as little as 28 kg.

SLTDRs were equipped with conductivity and pressure sensors, and built-in programmable microprocessors that collected and summarized data for periods when animals were diving and stored it for later transmission, as has been done for spotted seals (*Phoca largha*), crabeater seals (*Lobodon carcinophagus*), and Steller sea lions (*Eumetopias jubatus*) (Lowry et al. 1994*a,b*; Hill et al. 1987; Bengtson et al. 1993; Merrick et al. 1994). Data were stored in six hour blocks (0300-0900 hrs, 0900-1500 hrs, 1500-2100 hrs, and 2100-0300 hrs local time) and transmitted to the satellite once the six hour period was complete. Data from four periods were stored in memory providing at least a 24-hour window for transmission before the data were lost. Two of the fall 1993 SLTDRs summarized dive data as histograms in depth bins of 4-20 m, 21-50 m, 51-100 m, 101-150 m, 151-200 m, and over 200 m, and duration bins of 0-2 minutes, >2-4 minutes, >4-6 minutes, >6-8 minutes, >8-10 minutes and over 10 minutes (software version 3.05). Four of the SLTDRs deployed in September 1993 were equipped with new software (version 3.10) that allowed data to be stored in 10 bins. Settings on those units were: 4-20 m, 21-50 m, 51-75 m, 76-100 m, 101-150 m, 151-200 m, 201-250 m, 251-300 m, 301-350 m, and over 350 m; and 0-2 minutes, >2-4 minutes, >4-6 minutes, >6-8 minutes, >8-10 minutes, >10-12 minutes, >12-14 minutes, >14-16 minutes, >16-18 minutes, and greater than 18 minutes. Version 3.10 software also collects and reports the amount of time in the six hour periods that the seal spent in each of the specified depth ranges. New SLTDR software (version 3.11) became available from Wildlife Computers in 1994 that was designed to collect additional information on haulout behavior. This new feature, called a "timeline", classified sequential 20 minute time segments as dry or wet based on whether the conductivity switch had been dry for more than or less than 50% of the time increment. With each uplink the SLTDR transmitted timeline data for the previous 24 hour periods.

Each SLTDR transmitted information to a National Oceanic and Atmospheric Administration polar-orbiting satellite whenever the seal was hauled out, or when it surfaced sufficiently long for transmission to occur, and the satellite was positioned such that it could receive the signal. Prior to fall 1994, all SLTDRs were programmed to transmit continuously. Based on predictions of satellite passes and the data received from SLTDRs during 1991-1993 we learned that there was effectively no satellite coverage of the PWS region from 2200 to 0200 hours local time. Therefore, the fall 1994 SLTDRs were programmed to not transmit during those time periods. Also, because they had less initial battery power, the small SLTDRs were duty-cycled and alternated with one day transmitting and one day turned off.

Satellite Tag Data Analysis

Data were obtained from Service Argos. The Argos system recorded date and time of each uplink and calculated a location for the SLTDR based on Doppler shift whenever sufficient signals were received during a satellite pass. The accuracy of location calculations varies based in part on the number of uplinks that occur during a satellite pass. Service Argos assigns a quality ranking (called the NQ) to location information. This rank is based on predicted accuracy, which suggests that for the best data (assigned NQ 3) predicted locations are expected to be within 150 m of actual locations 68% of the time. Locations that are based on few uplinks or have other potential problems are assigned NQ 0. For this study, NQ 0 locations were used principally to provide approximate positions of seals on days when no NQ 1-3 fixes were obtained. When only one uplink occurred during a satellite pass, sensor data were recorded but no location was calculated. Fancy et al. (1988), Stewart et al. (1989), and Mate (1987) provide additional description and analysis of the Argos system and its application to marine mammal tracking.

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

Custom computer software was developed for checking, compiling, and analyzing SLTDR data. Initially, inaccurate locations were removed from the database by checking the distances and apparent speeds between adjacent records, as described in Frost and Lowry (1994*b*). We subsequently modified procedures to use a two-step process to screen out inaccurate locations and remove them from the database. First, an error index value was calculated for each record according to the equation described in Keating (1994). This value takes into account the distances and relative directions between sequential location fixes. It is used to identify erroneous locations based on the assumption that records indicating a single, relatively large movement followed immediately by a return to a point near the origin are likely to be in error. As a first step in screening the database we removed all NQ 0 location records that had an error index value greater than 25.

The second step in screening records was to locate and remove erroneous locations based on the apparent speed of the seals. To do this, time, distance, and speed between each sequential pair of fixes were calculated for all location records obtained. A three-stage process was used to flag records that produced improbable movements: 1) apparent speeds of greater than 10 km/hr for a period of greater than 5 minutes; 2) apparent speeds of greater than 100 km/hr for a period of greater than 1 minute; and 3) apparent speeds of greater than 500 km/hr for any length of time. The parameters in 1) are based on the likely sustained swim speeds of harbor seals (Williams and Kooyman 1985), while the latter two identify records that may be erroneous but were too close together in time to be flagged by the first set of criteria. Flagged records were inspected visually, and the locations that were most distant from adjacent records were removed from the database. Numbers of location records referred to in this report include only those records that remained after the complete screening process.

With each transmission, SLTDRs reported the seals as hauled out or at sea based on the status of conductivity sensors. A datafile was created that indicated the times when sensors indicated that haulouts began and ended. The land-sea sensor data were merged with location records to produce a datafile that included SLTDR number, date, time, latitude, longitude, location quality, and whether sensors indicated that the seal was on land or at sea. A computer program was written that calculated from this datafile the average location of the seal during each haulout bout and the average daily position for at sea locations. The program also calculated the distance between each sequential pair of average positions. Only fixes with NQ 1-3 were used in this analysis, and the result was saved as an average position datafile.

The all-location and average-position datafiles were used to produce geographic information system coverages in ARCINFO, and datasets were selected and displayed using ARCVIEW. Figures shown in this report are from the all-location datafiles, and use only locations with NQ 1-3 to reduce clutter. Average position datafiles were used to determine the specific locations where seals hauled out. The locations of haulout bouts were displayed on the screen and each was assigned to the nearest known seal haulout site. If a location plotted more than 5 km from any known haulout, or if it was approximately equidistant between haulouts, the location of that haulout bout was categorized as unknown. Distances moved by seals were calculated by summing the distances between adjacent average daily positions, using only records with NQ 1-3.

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

Fatty Acid Analysis

Blubber samples (50-150 mg) were collected from the hip region of seals using routine biopsy procedures (sterile 6 mm biopsy punches), placed in chloroform/methanol with BHT as an antioxidant, and stored frozen until analyzed. Laboratory analysis and evaluation of data was conducted by Dr. Sara Iverson at Dalhousie University, Nova Scotia. Fatty acids were extracted from seal blubber according to methods described in Iverson (1988). Fatty acid methyl esters were prepared directly from aliquots of the chloroform extract by the addition of borontrifluoride in methanol, sealing under nitrogen, and heating at 100 C for 1 hr. Following transesterification, methyl esters were extracted and purified in hexane. Analysis of fatty acid methyl esters was performed according to Iverson et al. (1992) using temperature programmed capillary gas liquid chromatography on a Perkin Elmer Autosystem II Capillary FID Chromatograph fitted with a 30 mm x 0.25 mm i.d. cyanopropyl polysiloxane column (J&W DB-23) and linked to a computerized integration system (Turbochrom 4 software). Identifications of rare isomers were performed using techniques such as hydrogenation and silver nitrate chromatography (Iverson et al. 1992).

Disease

Serum was collected from each seal that we sampled from 1989-1994. A portion of each sample was archived in ADF&G's serum bank for future testing. An aliquot of serum from each seal was sent to Dr. A. D. M. E. Osterhaus at the National Institute of Public Health and Environmental Health in the Netherlands where it was tested for evidence of exposure to phocine distemper virus (PDV), canine distemper virus (CDV), and phocine herpesvirus (PhHV). For PhHV, a titer of $\geq$20 was considered positive. For PDV and CDV, titers of $\geq$60 were considered indicative of prior exposure (R. Zarnke, pers. commun.).

RESULTS

Molting Period Aerial Surveys - Unadjusted Counts

Molting period surveys were conducted in 1984 and 1988 (Pitcher 1986, 1989), and have been done annually since the spill (Frost and Lowry 1994*a*, *b*). The surveys included 25 major haulout sites in eastern, northern, and central PWS. During 1994, the same 25 sites were surveyed and 7-9 replicate counts were made at each site (Table 3).

At all sites combined there was a 12% decline in unadjusted mean counts from 1993 to 1994 (Table 4). In September 1994, unadjusted counts in the trend count area as a whole were 36% lower than they were in 1988. Since 1989, unadjusted counts for the trend count area as a whole have changed from year to year by 2%-23%, but overall have declined by 17%. This represents an average annual decline of about 4% since 1989. When unadjusted 1994 counts are compared to those in 1989, mean counts at oiled sites were similar and counts at unoiled sites were 23% lower.

Regression analysis of unadjusted counts from the molting period during 1989-1994 indicated no significant trend during this period at either oiled sites ($R^2 = 0.1723$, $P = 0.41$), unoiled sites ($R^2 = 0.2339$, $P = 0.33$), or all sites combined ($R^2 = 0.3395$, $P = 0.22$).

Pupping Period Aerial Surveys - Unadjusted Counts

During 11-18 June 1994, 6-7 replicate counts were made at each trend count site (Table 5). Counts were compared to those made during pupping in 1989-1993 (Frost and Lowry 1994*b*). Unadjusted counts from 1994 indicated that pup production at the oiled sites was lower than in any year except 1989 (Table 6). During 1990-1993, 22.7%-27.1% of the seals counted at oiled sites were pups, compared to 21% in 1989 and 1994. At unoiled sites, production was similar in most years, ranging from 13.7%-17.3% pups.

In the trend count area as a whole during pupping, there has been a 22% decline in unadjusted counts of both non-pup seals and pups from 1989 to 1994 (Table 6). This represents an average annual decline of about 5%. The decline has been greater at unoiled sites than at oiled sites. Unadjusted counts were similar in 1993 and 1994.

Regression analysis of unadjusted counts made during pupping in 1989-1994 indicated no significant trend in the number of non-pups at oiled sites ($R^2 = 0.50$, $P = 0.19$), unoiled sites ($R^2 = 0.61$, $P = 0.07$), or the trend count area as a whole ($R^2 = 0.62$, $P = 0.06$).

Factors Affecting when Seals are Hauled Out - Molting Period

Three primary factors (time of day, date, and time relative to low tide) were found to significantly affect the counts of seals during molting period aerial surveys. Time of day entered the model first as the most significant factor, followed by date, and finally the time of counts relative to low tide ($P < 0.001$ for all three). Tide height was not significant. Time of day was collapsed into four categories and time relative to low tide into three. Categories used in the model and parameter estimates are shown in Table 7.

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

The highest survey counts relative to tidal stage were before 0.5 hour following low tide (Figure 2b). Maximum counts were for the periods 1.0 to 0.5 hour before low tide and from low tide to 0.5 hour after the tide. Counts were substantially lower more than 0.5 hour after the low tide, when 30%-35% fewer seals were counted than during peak times.

Dates for molting surveys during 1989-1994 ranged from 22 August to 16 September. On average, the model indicates that more seals would be counted on 22 August than on later dates, and that in fact the maximum number of seals would be expected in mid-August before any of our surveys began (Figure 3a). The model, which was fit to a quadratic equation, indicated that counts on 1 September would be 15% lower than counts made on 22 August and that counts on 16 September would be 35% lower than counts on 1 September and 44% lower than those on 22 August.

Wind speed had a significant effect on the number of seals counted during surveys ($P < 0.001$). The four categories used in field data collection were collapsed into two categories for the final analysis. The categories "calm" and "light breeze" were combined, as were "light wind" and "windy". Using these two categories, the model predicted that about 14% more seals would be counted on calm days than on windy days. Air temperature was not significant for molting period surveys ($P = 0.08$). Sky conditions had a highly significant effect on the number of seals counted ($P < 0.001$). High overcast, partly cloudy, or clear skies resulted in counts that were about 6% higher than for low overcast, fog, and rain. "Drizzle" conditions resulted in the lowest counts.

Factors Affecting when Seals are Hauled Out - Pupping Period

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

The analysis for time of day indicated that counts during pupping were highest during the 2 hours before midday and lowest more than 4 hours before or after midday, when about 12% fewer non-pup seals were counted (Figure 4a). Peak-period counts were only about 4% higher than any counts within four hours of midday. During mid-June, sunrise occurs at approximately 4:10 am and sunset at about 11:15 p.m., placing midday at 1:40 p.m.. Therefore, the highest counts would be expected between 11:40 am and 1:40 p.m.. Surveys made during the period from 9:40 am to 5:40 p.m. would yield counts within 4% of each other.

The highest survey counts relative to tidal stage were within 1.0 to 0.5 hour before low tide (Figure 4b). Counts in this period were about 9% higher than counts made in the half hour prior or two hours after the actual low tide. Counts were lowest more than 1.5 hrs before or after the tide.

Dates for pupping surveys during 1989-1994 ranged from 7-27 June. The model indicated a 23% greater number of non-pup seals counted on 27 June compared to 7 June (Figure 3b). Counts were relatively consistent from 7 June through 16 or 17 June, with a rapid increase thereafter.

Wind speed had a significant effect ($P < 0.001$) on the number of seals counted during pupping surveys. The four categories used in field data collection were collapsed into two categories for the final analysis. As for molting surveys, the categories "calm" and "light breeze" were combined, as were "light wind" and "windy". Using these two categories, the model predicted that about 22% more seals would be counted on calm days than on windy days. Sky conditions also had a highly significant effect on the number of seals counted ($P < 0.001$). High overcast or partly cloudy skies resulted in counts that were about 11% higher than for low overcast conditions and 18% higher than when there was fog, rain, or drizzle, or when it was clear. Air temperature had a relatively small effect on counts, with only 5% more seals expected at temperatures of 60 degrees than at 40 degrees ($P = 0.03$).

Trend Analysis of Adjusted Counts

Using the model parameter estimates for time of day, date, and time relative to low tide, the expected counts for each site were calculated for the molting and pupping periods.

For molting period surveys, all counts were corrected to 15 August, 2-4 hours before midday, and 1.0 to 0.5 hour before or 0 to 0.5 hour after low tide (Table 9, Appendix A). Once adjusted, the molting-period counts for the trend area as a whole show a very clear, almost perfect linear decrease in numbers (Figure 5). This trend was highly significant ($P = 0.0007$).

For pupping period surveys, the adjusted counts of non-pup seals were corrected to 15 June, 0-2 hours before midday, and 1.0 to 0.5 hour before low tide (Table 10). For all years, the adjusted mean counts were somewhat higher than the unadjusted counts. However, the changes were fairly consistent across years and there were no substantial differences in the shapes of the trend lines for oiled sites, unoiled sites, or for the trend count area as a whole (Figure 6). Although adjusted counts in 1994 were 20% lower than in 1989, the trend was not significant ($P = 0.06$).

To examine trends in the counts of harbor seal pups, the full model with time of day, date up to a third order polynomial, and time relative to low tide was fit to the pup counts. Based on these adjusted pup counts, it appears that the number of pups is relatively stable in early June, and then drops rapidly after about 16 or 17 June (Figure 7). However, none of the polynomial terms for date in the model were significant, even with $\alpha = 0.1$. Therefore, no correction has been made to the annual counts of pups.

Power Analysis

Power analysis was conducted using Gerrodette's (1993) TRENDS program to determine the probability that an increasing trend would be identified using different numbers of survey replicates and years. To use the TRENDS program it is necessary to know the number of years the power analysis will consider, the α-level for the test under the null-hypothesis, the initial population size (since power is lower with lower initial population size), the rate of decline, and the variance. We set initial population size as the mean number of seals counted in 1994 (either unadjusted or adjusted, from Tables 9 and 10), since the decline was continuous through that time. Alpha level was set somewhat conservatively at 0.05, since this is a declining population and we want to be quite confident that we do not incorrectly assume an increasing trend. Power was calculated for 3 or 5 years of surveys, for rates of change from 2% to 10% of the initial population, and for one to an infinite number of replicates.

The analyses used within-year variances derived from the 1989-1994 pupping-period and molting-period data sets for unadjusted counts (Table 11). For molt period surveys, within-year sampling variance for unadjusted counts was lowest in 1989 (S_t^2 = 466; n = 10), and highest in 1994 (S_t^2 = 4,176; n = 9) when counts were conducted during two different tidal cycles over a week apart. For other years, it ranged from S_t^2 = 768 to S_t^2 = 1,486 (n = 7-10). For pupping period surveys, within-year variance was highest in 1989 (S_t^2 = 1,646; n = 9) and 1991 (S_t^2 = 1,923; n = 8) and lowest in 1990 (S_t^2 = 266; n = 10) and 1992 (S_t^2 = 303; n = 4). These within-year variances were used to estimate $\hat{V}$ for the unadjusted counts. For the adjusted counts, we have no independent assessment of $\hat{V}$. However, for the unadjusted counts, $\sigma^2 = V/\bar{n} + \delta^2 = p\sigma^2 + (1-p)\sigma^2$ for some p;0 ≤ p ≤ 1. By assuming that the relationship between the number of replicate samples per year is the same for unadjusted and adjusted counts and using values for $\hat{p}$ from the unadjusted counts ($\hat{p}$ = 0.319 for the molt-period, $\hat{p}$ = 0.093 for pupping), the sample variances for adjusted counts could be estimated.

Power analysis using either unadjusted or adjusted data, any number of replicates, and rates of change from 2% to 10% indicated that there is almost no chance of correctly identifying an increasing trend with only three years of surveys (power < 0.12). When the number of survey years is increased to five, power for all pupping counts and the unadjusted molting counts is still less than 0.5 (i.e., less than 50% chance of correctly identifying a trend) for rates of increase of 2%-10% and up to 14 replicates (Figures 8 and 9). However, for molting counts that have been adjusted for effects of tide, time of day, and date the power increases greatly. Using these adjusted counts, the power analysis predicts an 80% or better chance of detecting a 5% annual increase if surveys are conducted for five years and contain at least six replicates (Figure 9).

Capture and Tagging of Seals

As described in Frost and Lowry (1994*b*), several modifications were made to seal catching procedures and equipment in 1993. The modifications worked well, and as a result 28 seals were caught in 1993 (Table 12) and 36 in 1994 (Table 13).

In 1993, we attached twelve SLTDRs to seals, six in each of spring and fall (Table 12). Seals were tagged at Seal Island (4 in spring and 4 in fall), Applegate Rocks (2 in spring), Bay of Isles (1 in fall), and Channel Island (1 in fall). We attached six SLTDRs to seals caught in spring 1994, and twelve in fall 1994 (Table 13). Seals were tagged at Little Green Island (1 in spring), Port Chalmers (1 in spring and 5 in fall), Stockdale Harbor (4 in spring), Channel Island (5 in fall), and Gravina Island (2 in fall). For the two years combined we tagged 21 males (8 subadults, 13 adults) and 13 females (3 subadults, 10 adults).

SLTDR Performance

The six SLTDRs with version 3.05 and 3.10 software that we attached in fall 1993 worked well. The period of time over which transmissions were received ranged from 101-310 days, and locational information was received on 72%-95% of those days (Table 14). On average, the number of locations per operational day ranged from 2.1-3.9.

The six SLTDRs with version 3.11 software that we attached in spring 1994 all failed after transmitting for less than three days. Those units were replaced by the manufacturer. At the time we prepared for fall 1994 fieldwork there were indications that the problems with the new software had been remedied, but units had not been tested in the field. Therefore, we ordered and attached eight units with 3.10 software, and four units with 3.11 software. The four SLTDRs with 3.11 software again failed after 1-2 days. The eight SLTDRs with 3.10 software transmitted for 40-267 days. Results from those eight will be reported in the 1996 annual progress report.

Movements and Haulout Use

The six SLTDRs attached in September 1993 produced a total of 3,132 location records (Figure 10). All relocations showed the animals within PWS, and there was no indication of movements into adjacent parts of the Gulf of Alaska. All six seals were at the locations where they were captured when their transmitters failed (Table 15).

Two of the four seals tagged at Seal Island (2280 and 2282) remained very near the tagging location, making occasional trips to the vicinity of Applegate Rocks (Figures 11 and 12, Table 15). Seal 2282 made occasional short trips to Applegate Rocks. Seal 2287 stayed near Seal Island during the periods 16 September-16 November and 28 April-22 July. However, during the period from 17 November through 27 April it made a minimum of 12 trips to the north part of Montague Island, each lasting 1-7 days (Figure 13, Table 15). In contrast to the others, seal 2284 ranged widely (Figure 14, Table 15). It was at Seal Island after tagging until 20 September, then moved to the Columbia Glacier and stayed there during 22-25 September. From 27 September through 11 October it was back at Seal Island, then it again moved to the Columbia Glacier. During the period from 14 October through 28 December seal 2284 spend much of its time at the Columbia Glacier, but also made a minimum of four trips to areas to the west and south. On 30 December it moved to the southwest and stayed in the vicinity of Lone and Perry islands until 28 January. On 31 January it was located at the southeast end of Knight Island, and on 1 February it had returned to Seal Island where it remained until the tag failed. Seal 5039 tagged at Bay of Isles and seal 2283 tagged at Channel Island did not move far from their tagging locations (Figures 15 and 16, Table 15).

The distances that seals moved during the period they were tracked ranged from 405 to 1,025 km, with average individual movements of 2.0 to 5.6 km/day (Table 16). These are minimum distances because they are based on straight line distances between haulout locations and average daily positions at sea. The highest daily rate was for seal 2284 that moved between Seal Island, the Columbia Glacier, and Lone Island.

For seals 2280, 2282, and 2287, 96%-98% of recorded haulout bouts were at Seal Island where they were tagged (Table 17). Only 33% of the haulout bouts of seal 2284 were at Seal Island, and most of its recorded haulouts were at the Columbia Glacier (45%). Seal 5039 was recorded hauled out only near the tagging site in Bay of Isles, and on nearby parts of northeastern Knight Island. Seal 2283 hauled out mostly at Channel Island where it was tagged, but also used adjacent areas of Green Island and Montague Island.

Diving Behavior

Depth of dive histogram information was received summarizing 107,823 dives made by instrumented seals from September 1993 to July 1994 (Table 18). For the six seals combined, 39% of the total dives were to depths of 20 m or less and 59% to depths of 50 m or less. Only 4% of the dives were deeper than 150 m. There was considerable variability among seals (Figure 17). For individual seals, 12%-53% of the total dives were to depths of 20 m or less, and 26% to 97% to depths of 50 m or less. From none to 11% of the dives by a seal were deeper than 150 m.

Seal 2287, which retained its SLTDR for 10 months, showed a clear seasonal pattern in the depth of dives (Figure 17). During September and October, 35%-38% of its dives were to depths greater than 100 m, compared to more than 50% during November-January. After January, the proportion of deeper dives decreased steadily and was only 3% in June and 6% in July. For the other five seals, there was no obvious or consistent seasonal pattern in the depths of dives.

Four seals spent the entire time in the same general area where they were tagged. Seal 2283, which spent all of its time near Channel Island, made 97% of its total dives to less than 50 m and no dives deeper than 64 m. Bay of Isles seal 5039 was also a relatively shallow diver, with 76% of its total dives less than 50 m and 95% less than 100 m. Only 23 of more than 20,000 dives by 5039 were deeper than 150 m. In contrast to the seals from Channel Island and Bay of Isles, over 30% of the dives of two seals that remained near Seal Island were deeper than 100 m (34% for 2280 and 31% for 2282). The distribution of dives shallower than 100 m was quite different for these two seals, with 26% of the dives by seal 2280 less than 50 m compared to 56% for seal 2282.

Two seals moved between different areas while they were tagged. Seal 2284, a subadult male tagged at Seal Island, moved between Seal Island, the Columbia Glacier, and northwestern PWS in the Perry- Naked-Fairmount islands area (Table 19). When it was near Seal Island, an average of 86% of its dives were less than 100 m and only 1% were greater than 150 m, with the proportion of dives in the different depth bins quite consistent among periods. In contrast, when 2284 was in Columbia Bay and northwestern PWS, fewer than 70% of its dives were less than 100 m and about 13% were deeper than 150 m. There was variability among periods, but there was always a higher percentage of deep dives than when it was near Seal Island. This seal usually made about 50-70 dives per 6-hr period, with the exception of Seal Island in September when it made about 30 dives per 6-hr period.

Seal 2287, an adult male also tagged at Seal Island, moved between Seal Island, Montague Island, and Stockdale Harbor (Table 20). Near Seal Island, and near Montague during November-February visits, there was a bimodal distribution of dives. Most were less than 50 m or between 100-150 m, with almost none deeper than 150 m. During a single trip to Montague in late April, all dives were less than 50 m. At Stockdale Harbor, over 90% of the total dives were less than 50 m. This seal made many fewer dives per 6-hr period (19-40) than did the subadult male, but the dives were longer.

In general, average durations of dives increased as the depths increased. For all six seals, 70% to 94% of the dives were shorter than six minutes (Figure 18). Durations were shortest for seal 2284, the only subadult, and seal 5039 from Channel Island. Seal 2287 showed a clear seasonal pattern in dive duration. Dives were longest in December and January (50% were longer than six minutes), and progressively shorter after that.

The maximum depths of dive for each seal were summarized by 2-week periods (Table 21). The maximum dive depth recorded for any seal was 380 m, made by seal 2284 (a 45 kg male). It was made on 15 November near Lone and Naked islands. This seal also dove to 300 m or more on 1 December and 2 February, when it was also in the northwestern sound. Dives to maximum depths greater than 200 m were made almost daily by this seal when it was in Columbia Bay and the northwestern sound, but such deep dives were rare when the seal was near Seal Island. The average maximum daily dive depth was significantly less near Seal Island than in either Columbia Bay ($t = 7.96$; $P < 0.001$) or northwestern PWS ($t = 5.66$; $P < 0.001$). Average maximum daily dive depths were not significantly different in Columbia Bay and northwestern PWS ($t = 1.03$; $P > 0.3$). Maximum dives for the other five seals were much shallower, ranging from 64-244 m.

The mean number of dives per 6-hr period and the percent of time spent diving were summarized by month (Table 22). Although some seals made almost twice as many dives per period than others (2284 in all months, 5039 in December-March), the actual amount of time spent in the water was usually quite similar. On a monthly basis, the four seals whose SLTDRs provided time-at-depth information spent 49%-86% of their time in the water. Overall, the four individuals spent 66%-77% of their time in the water. During every month they were tagged, two of the seals (2282 and 2283), spent more of their time in the water during the day (67%-85%) than at night (33%-69%) (Figure 19). Seal 2287 also spent more time in the water during the day in October through January, but from May to July the reverse was true. By July, 80% percent of its time at night was spent in the water, compared to 35% during the day. Unlike the other three, seal 2284 spent more time in the water during the night than during the day in September, October, and March, and about the same amounts of time during day and night in November to February.

Fatty Acids

Fatty acids were extracted from 40 harbor seal blubber samples. For each, 68 fatty acids and isomers were separated and quantified in duplicate analyses. Prey samples were not analyzed in 1994 but will be included as part of this study in the future.

For preliminary analysis, two significant fatty acids which are indicative of diet (since they can only arise directly from the diet) were chosen to illustrate the variability among samples. These were 20:1w11 (indicates foraging on planktivores) and 22:6w3 (indicates foraging on omnivores and piscivores). Fatty acid 20:1w11 varied from 1.6% to 10.5% of total fatty acids, and 22:6w3 from 3.4% to 13.8% of the total. Samples were placed into groups based on the mid-way splits of these two fatty acids. Samples were first divided into two groups at 20:1w11 < 5.0% and > 5.0%. Each of these two groups was then further divided at 22:6w3 < 7.0% and > 7.0% (Table 23).

For the resulting four groups, a subset of results for 12 major fatty acids (Appendix B) was used to examine the data. There were significant differences ($P < 0.04$) in the mean percentages of 9 of the 12 major fatty acids (Figure 20). Group 1 was the most different from other groups, with significant differences in 8 of 12 major fatty acids, while groups 2 and 3 were the most similar. Sample box plots were prepared for several major components, including the two used for group separation, to illustrate these differences (Figure 21). In later stages of this analysis, box plots will be used as a basis for tree regression.

Examination of collection locations for seals within each group indicated geographic differences in where the groups were found. Seals in northern PWS were almost all in group 1, seals at Channel Island were mostly in groups 1 and 4, and all seals but one from Stockdale Harbor and Port Chalmers were in groups 2 and 3 (Figure 22). No group was found in all three areas. Subadults made up 95% (20 of 21) of the seals in groups 1 and 4, and 92% (22 of 24) of the seals in northern PWS and Channel Island where these groups were found. In contrast, adults made up 74% of the seals in groups 2 and 3. Most of these seals were from Stockdale Harbor/Port Chalmers, where 63% of the seals we sampled were adults. The only two adult seals sampled at Channel Island, and one of two adults from northern PWS were in either group 2 or 3.

Disease

Sera from 103 harbor seals captured in PWS and 220 seals from other areas have been tested for exposure to PhHV, PDV, and CDV (Table 24). For most collections, more than 50% of the seals tested positive for PhHV. The prevalence of exposure to PDV was lower, with usually less than 50% of seals showing evidence of exposure. Very few samples tested positive for CDV. There were no obvious geographical or temporal trends in exposure levels.

DISCUSSION

Aerial Survey Methods

We conducted two analyses to test and refine the methods we have been using for aerial surveys of harbor seals in PWS. First, we constructed a model to test the effects that various parameters were having on the counts of seals. All factors except tidal height had some effect on counts of non-pup seals, either during molting or pupping. While there were differences between how some factors affected molting versus pupping counts, in general counts were higher before midday, before and just after low tide, and in calm, partly cloudy, or overcast conditions (Table 25). Perhaps the most surprising finding was the tendency for molting counts to decrease from the earliest survey date throughout the period (Figure 3a), which indicates that peak molting period counts occur earlier in the year than the our surveys have begun. In fact, Pitcher and Calkins (1979) reported that the highest proportion of molting seals in the Gulf of Alaska was found in late July. By the first 10 days in September, only 20% of the seals they examined were classified as molting. Parameter estimates from the model were used to adjust each year's set of counts upward to standard, optimum conditions.

Second, we conducted a power analysis of the aerial survey data, using unadjusted and adjusted counts for both molting and pupping. It was assumed that the goal of PWS harbor seal monitoring is to be able to detect an increase of 5% per year over a five year period with a high degree of confidence that a conclusion of increasing population trend would be correct ($\alpha = 0.05$). Regardless of the number of replicate surveys flown, unadjusted counts during both pupping and molting had very little power to detect trend. Adjusting pupping counts did not improve the situation. However, adjusted molting counts were much superior, and with six replicate surveys the analysis predicts an 80% chance that a trend will be detected (Figure 23).

From these analyses it is evident that aerial surveys, conducted with the methods that have been used in PWS before and since the spill, can be used as a population monitoring tool. However, counts made during pupping are too variable to use for monitoring trend, even if they are adjusted to account for the influence of measurable factors. Counts made during the molting period, after adjustment, provide a very powerful monitoring tool.

Trends in Numbers of Seals

The number of harbor seals on the trend count route in PWS has continued to decline since the spill (Table 26). This decline is shown most clearly in the adjusted total counts for the molting period (Figure 5), which have decreased in an almost perfectly linear fashion. Counts of non-pups during the pupping period have been more variable, and may have been relatively stable since 1991 (Figure 6). Nonetheless, they are considerably lower than they were in 1989. Adjusted non-pup counts were 20% lower in 1994 than in 1989, and pup counts were 22% lower.

The power analysis we conducted clearly shows that adjusted molting counts provide the best measure of the trend in numbers of harbor seals in central and eastern PWS. These counts show that in 1994 seals were 46% less common than they were in 1988 prior to the spill. Their numbers have decreased 28% from 1989 to 1994, and are still declining at an average rate of about 6% per year.

Satellite Tag Performance

We began using Wildlife Computers SLTDRs to study harbor seals in PWS in April 1991. In 1991 we used 1.0 watt units that did not perform reliably (Frost and Lowry 1994*b*). In 1992 and 1993 we used 0.5 watt SLTDRs equipped with software versions 3.05 and 3.10 with very good results. Units attached in the spring transmitted for 39-86 days (Table 14), and the reason that most of them stopped transmitting was probably because they were shed into the water during the seals' annual molt. SLTDRs attached in fall 1993 transmitted for 101-310 days.

In 1994, Wildlife Computers made SLTDRs available with a new software (version 3.11) that was designed to collect additional information about haulout behavior. By monitoring the conductivity switch, this software produced a "timeline" that indicated for each 20 minute segment of the day whether the switch had been mostly wet or mostly dry. In addition to the timeline, the method by which the antenna was attached to the transmitter was also changed for these version 3.11 SLTDRs. In spring we attached six of these units to seals, and they all failed after apparently functioning properly for 1-3 days. Wildlife Computers indicated that they would replace those units, so we had 12 SLTDRs to attach in the fall of 1994. During the summer, Wildlife Computers checked the software code but found no errors that should have caused catastrophic failure, leading to the conclusion that the most likely problem had been with the new method for antenna connection. Units were tested with version 3.11 software and the original antenna connection and seemed to work properly. In fall 1994 we decided to attach eight SLTDRs with version 3.10 software, four with 3.11 software, and all with the original antenna attachment. The four units with 3.11 software again failed after 1-2 days. Of the units with 3.10 software, four that were attached at the same time to seals captured in Port Chalmers transmitted for only 40-93 days, while the other four transmitted for 152-267 days (Table 14). The reason for this curious pattern is unknown.

Recent discussions with Wildlife Computers indicate that they are continuing to try and perfect the SLTDRs with 3.11 software. The software code has been completely rechecked, and again no problems were found. They have been exploring the possibility that radio frequency interference from transmissions might have caused a lock-up in the on-board microprocessor. This could have occurred with the new software because addition of the timeline results in a somewhat longer transmission message. Units have been prepared with shielding for the microprocessor and have worked perfectly in simulations. Those units are now going to be field tested.

Other than the problems discussed above, the SLTDRs we have attached during 1992-1994 have worked very well (Table 14). Most units attached during May have given good information through July, while those attached in September have generally worked through March. For most seals, location information was received on 70%-95% of the days the SLTDRs were operational, and usually an average of 2.5-4.0 locations were received each day. This is similar to the results of Stewart et al. (1989) who put a 1.0 watt Telonics transmitter of a harbor seal at San Nicholas Island, California in April 1988. They received at least one location each day, with an average of 3.4 per day.

Several published studies have used satellite-linked tags to study the behavior of pinnipeds (e.g., Bengtson et al. 1993, Born and Knutsen 1990, Boveng et al. 1989, Heide-Jørgensen et al. 1992*a*, McConnell et al. 1992, Merrick et al. 1994, Stewart et al. 1989, Testa 1994). Most of those have been feasibility studies and/or have used older types of transmitters. The published study most similar to this one was an investigation of spotted seals in the Bering and Chukchi seas. That work began using 1.0 watt transmitters, and had limited success with Wildlife Computers SLTDRs (Lowry et al. 1994*a*). However, 0.5 watt Wildlife Computers SLTDRs generally worked very well, providing data for periods of 32-298 days with seals located on 41%-97% of the operational days and 1.3-7.8 locations received per day (Lowry et al. 1994*b*). That performance is very similar to that for harbor seals tagged in PWS during 1992-1993.

Movement Patterns of Seals

Seals tagged in fall 1993 did not move out of PWS during the period they were tracked. Five of the six remained very close to the location where they were tagged. One ranged more widely, and spent time both at the Columbia Glacier and at land haulouts. The general tendency for seals tracked in spring-summer 1992 and 1993 also was for them to spend most of their time in central PWS (Frost and Lowry 1994*b*). Three of 10 spring-tagged seals moved out of PWS to the south or southwest, but all of them returned. Two spring-tagged seals moved to glaciers in northern PWS. The average distance moved per day for the fall 1993 tagged seals was 3.5 km/day (range for individual seals 2.0-5.6), which was significantly less (t = 5.91, $P < 0.001$) than the average of 8.0 km/day (range 5.4-10.6) for seals tagged in spring 1992 and 1993 (Frost and Lowry 1994*b*).

With the exception of the seal that moved from Seal Island to the Columbia Glacier, the seals tagged in fall 1993 hauled out almost exclusively at the tagging site. All six seals were at the location where they were captured when the last location fix was received. This is a somewhat higher degree of haulout site fidelity than occurred for seals tagged in spring 1992 and 1993, when 7 of 10 hauled out mostly at the location where they were tagged, 1 used the tagging site and another nearby haulout equally, and 2 used only other haulout sites (Frost and Lowry 1994*b*).

As a species, harbor seals have been comparatively well studied, and there have been numerous studies of their movements along the west coast of the United States. Only one movements study has been done in Alaska, by Pitcher and McAllister (1981) who attached very high frequency (VHF) radiotags to 35 harbor seals captured on Tugidak Island in 1988. Tags were monitored daily from land at the Tugidak haulout where seals were captured, and occasional aerial tracking was done over adjacent areas. Most seals showed considerable fidelity to one or two specific haulout sites. The longest documented movement was 194 km, and movement rates up to 27 km/day were recorded. One seal moved across 74 km of open ocean to a haulout on an adjacent island.

Of the published harbor seal studies conducted elsewhere in the western U.S., only two used satellite-linked tags (Boveng et al. 1988, Stewart et al. 1989) and those tracked few animals for relatively short periods of time. Most movement studies have been similar to that of Pitcher and McAllister (1981) in that they used VHF tags that were monitored regularly from ground stations and occasionally from aircraft. Harvey (1987) monitored 26 VHF tagged seals along the Oregon coast during 1983-1985. Tagged seals moved as much as 280 km, but they were located within 8 km of the release site during 92% of the time. Wilson (1993) monitored 21 radiotagged seals along the Oregon coast from May 1992 to May 1993. At least 12 left the Umpqua River tagging site and were relocated elsewhere, with a maximum documented straight line movement of 144 km. Cottrell (1995) put VHF tags on 19 seals in a bay in British Columbia and monitored them from May 1991 to June 1992. He found that seals did not move long distances to follow migrating prey, but rather used prey nearby when they were locally abundant.

Results from studies using VHF and satellite-linked telemetry are not directly comparable because of differences in the way the tags are monitored. VHF tags are generally monitored nearly continuously from on land at specific locations, with occasional broad scale coverage from aircraft. They therefore provide detailed data on the behavior of seals that regularly return to predictable haulouts, but they may miss movements of animals out of the immediate study area. Satellite-linked tags are monitored at intervals throughout the day, and signals can be received wherever the seals are located. Thus, although they do not provide continuous monitoring at any particular haulout, satellite-linked tags are likely to give a more comprehensive picture of movements if seals move long distances either out to sea or to other haulouts.

In spite of the differences in equipment and methods, results of studies of harbor seal movements in the western U.S. have been generally similar. Seals tagged in PWS during 1991-1993 hauled out principally at the location where they were tagged. Although a few ranged widely in PWS or into adjacent parts of the Gulf of Alaska, moving straight line distances of 120-140 km, 16 out of 20 were back at the tagging location when transmissions ended (Frost and Lowry 1994*b*, this report). This pattern of site fidelity and occasional long distance movements is very like that found by Pitcher and McAllister (1981), Harvey (1987), and Stewart and Yochem (1994).

Diving Behavior

Maximum daily dive depths for all seals generally corresponded to maximum available depths in the areas where the seals were found, suggesting that seals commonly dive to the bottom. The maximum dive depth recorded for any seal tagged in September 1993 was 380 m by seal 2284. This dive occurred between Lone and Naked islands, where maximum depths range from 310-860 m. This is similar to the maximum dive depth of 404 m (in Port Wells) for ten seals tagged during May-July 1992-1993 (Frost and Lowry 1994*b*). Stewart and Yochem (1994) reported a maximum dive depth of 446 m for a harbor seal in southern California.

Depth of dive data reported by the SLTDRs indicated that diving behavior varied by geographic location, and that seals often traveled at least several kilometers away from their haulouts to feed. The average maximum daily dive depth for one seal was greater when it was in northwestern PWS (244 m) or Columbia Bay (228 m), where the water was deeper, than when it was near Seal Island (157 m). Average maximum daily dives depths for two other seals that were tagged and stayed near Seal Island in 1993-1994 were also about 150 m and rarely exceeded 200 m, as was the case for seven seals that were tagged and remained near Seal Island in spring 1992 and 1993 (Frost and Lowry 1994*b*). Average bottom depths near Seal Island range from about 110-165 m. A seal would have to travel about 10 km to be in water deeper than 200 m. The deepest dives made by a seal that spent most of its time in Bay of Isles (160-184 m) exceeded maximum bottom depths found within the bay (117 m). The seal would have had to leave Bay of Isles and travel 4-5 km off shore to be in such these depths. However, only 0.1% of the total dives were to depths deeper than those within Bay of Isles.

Although seals dove to maximum depths which seemed to reflect bottom depth in a variety of habitats, the distribution of dives among different depth increments varied considerably by seal and by area. This suggests that although most seals were diving to the bottom each day, they were not necessarily feeding there. One of the Seal Island seals made a similar percentage of dives to <50 m, 50-100 m, and 100-150 m. Two others showed a bimodal pattern when they were diving near Seal Island, with most of the dives either less than 50 m or greater than 100 m. This bimodal pattern was also evident when one of these seals made trips to the north end of Montague Island in November-February. However, when it moved to Stockdale Harbor, or to the north end of Montague in April when the herring were spawning nearshore, almost all of its dives were less than 20 m.

The Seal-Montague-Stockdale seal retained its SLTDR long enough to record data for the spring period (May-July) covered by SLTDRs deployed in 1992-1993. This seal showed a strong seasonal pattern in both the depths to which it dove and the amount of time it spent diving. The percentage of dives shallower than 20 m increased from less than 30% in October-January to 50%-70% in February-May, and over 90% in June and July. This seal was an adult male, and its behavior in June and July may have been related to breeding which occurs at this time. Only one of the seals instrumented during June-July 1992 or 1993 spent as much time in such shallow water. This was an adult, possibly pregnant, female tagged at Seal Island. All of her dives in May and July, and 74% of the dives in June, were less than 20 m (Frost and Lowry 1994*b*). A comparison of June-July 1992-1994 data for three subadult males, two adult females, and six adult males indicated no significant differences in the proportion of dives shallower than 20 m (*t* tests, $P > 0.14$).

Only one seal tagged in September 1993 traveled to Columbia Bay. While it was there, about half of its dives were shallower than 50 m. In contrast, 70%-90% of the dives made by seals using Columbia Bay and College Fiord in May-July 1992-1993 were shallower than 50 m. Without additional data from the fall-winter period, it is not possible to determine whether this is an individual difference or a seasonal difference in diving behavior related to the availability of prey.

SLTDRs deployed in September 1993 provided the first satellite-tag data about the amount of time, and during what part of the day, PWS harbor seals are in the water. Two seals spent more time in the water during the day than at night, while two others were mixed. There was no apparent correlation with geographic location, as one of the daytime-diving seals was from Seal Island and the other from Channel Island. Stewart and Yochem (1994), working in southern California, also found that some seals dove predominantly during the day and hauled out at night, while others dove at night and hauled out during the day.

The four seals carrying these instruments were in the water an average of 66%-77% of the time and hauled out 23%-34% of the time. The least a seal was in the water in any month was 49% of the time (51% hauled out) and the most was 86% (14% hauled out). This compares to an averages measured by VHF tagging of 19% of the time hauled in British Columbia (Cottrell 1995), and 17%-43% in Scotland (Thompson et. al 1989). Stewart and Yochem (1994) found that seals hauled out less in 1983, following the 1982/1983 El Niño Southern Oscillation event, than in 1982 or 1988 and 1989, and suggested this was because food was scarce in 1983 and seals were required to spend more time searching for food. It has been hypothesized that food limitation may be causing harbor seals to decline in PWS and the Gulf of Alaska, while their numbers are stable in southeast Alaska. It may be informative to make comparisons of satellite-tagging data from different parts of Alaska to see if there are differences in the amount of time spent foraging.

Foods and Trophic Relationships

In 1994 we began a study in cooperation with Dr. Sara Iverson of Dalhousie University that will use fatty acid analyses to investigate food web relationships of harbor seals in PWS. The results from that study which are presented in this report are preliminary.

In general, lipid transfer from diet to deposition in tissue is extremely efficient (Iverson 1988, Iverson et al. submitted). Because certain fatty acids cannot be biosynthesized by seals, if they occur in the body they must be of dietary origin. For example, a pair of monosaturates that occurs in one species of copepod acts as a tracer in Atlantic cod (*Gadus morhua*) and herring (*Clupea harengus*) (Ackman 1980). Since most seals undergo seasonal periods of fasting and depletion of fat stores (e.g , during the breeding season or molt) followed by intensive blubber deposition (subsequent to the breeding season or molt), blubber fatty acids usually reflect the integration of diet over a period of several months. In contrast, circulating chylomicrons in blood carry lipids from the last meal. In combination, fatty acids in blubber and blood provide information on both immediate diet and dietary history of the animal. Since many seals tend to feed on only a single or few selected prey species at a given time or season (Pitcher 1980, Bowen 1990), this facilitates the use of fatty acid signatures for prey identification.

Based on initial results, it appears that it will be possible to elucidate dietary differences among seals in PWS using this technique. Preliminary analysis of the 40 samples collected in 1994 indicated substantial individual and geographic variation, suggesting differences in feeding modes. This is unlike harbor seals from Sable Island, Nova Scotia, which show little individual variation within a sampling period (Iverson, pers. commun.). Ratios of particular fatty acids in PWS seals were quite different than ratios found in seals in the Atlantic or sea lions in California. The specificity to which prey can be identified will not be known until analyses of fatty acids in prey from PWS are complete, and regression trees have been developed for the seals and their prey.

It is clear from the preliminary results that seals from northern PWS and Channel Island had eaten different prey than seals from Stockdale Harbor and Port Chalmers. Whether these differences are related to geography or age is not yet known, since most of the seals from Channel Island and the northern sound were subadults and most from Stockdale and Chalmers were adults. It will be necessary to sample a broader range of age classes from each area to resolve this question.

The stable isotope composition of the whiskers of seals in groups 1 and 4 and groups 2 and 3 were often also different along the length of the whisker (A. Hirons, pers. commun.). Whiskers of most seals in groups 2 and 3 (mostly adults) showed large changes in del 13C (-12.5 to -17.5) and del 15N (18 to 13), suggesting changes in diet along the length of the whisker (Hirons, unpubl. data). In contrast, most seals in groups 1 and 4 (over 90% were subadults) appeared to have been eating prey at the same trophic level throughout the period represented by the whisker. If whiskers are replaced annually, these stable isotope data may suggest that adults utilize different prey in winter than at other times of year, or feed in different areas.

The use of fatty acids to elucidate diet and trophic relationships is not a stand-alone method, but neither is any other currently available method for examining marine mammal diets. Stomach contents analysis is limited by the inability to obtain large enough samples, the digestive state of contents, and by the fact that food in a stomach represents only the most recent meal. In PWS, large tidal fluctuations every six hours make it virtually impossible to collect scats from areas where seals haul out. Stable isotopes indicate the trophic level at which seals feed and may show geographical or temporal variations in prey type, but provide limited information on specific prey. Studies of prey availability can establish the "menu" from which seals may choose, but they do not necessarily reflect the availability of prey to seals, and do not account for the energetic costs of capturing different prey. Progress towards answering the question of "Is food limiting harbor seals?" will most likely come through the combination and integration of a variety of approaches, including the description of seal diving behavior; investigations of the distribution and abundance of potential prey; analyses of fatty acids, stable isotopes, and stomach contents; evaluation of body condition and changes in body condition through time; blood chemistry; and analyses of blubber as an energy source. Each of these approaches will provide pieces to a very intricate puzzle, and together they should provide some understanding of the trophic dynamics of seals in PWS.

Factors Affecting Population Recovery

The mortality caused by the *Exxon Valdez* oil spill reduced seal numbers in part of PWS (Frost et al. 1994), and will most likely have the effect of increasing the time required for the number of seals to recover, once other factors limiting population growth are controlled. Unfortunately, at the present time there is little understanding of the factors that may be adversely affecting harbor seals in this area.

Recent epidemics and mass mortality caused by PDV in the eastern North Atlantic have highlighted the possible role of disease in population declines (Heide-Jørgensen et al. 1992*b*, Thompson and Hall 1993). However, the limited data available suggest that disease has not been responsible for the decline in Alaskan harbor seals (Pitcher 1990, Sease 1992, this study). Since 1989, as part of this and other harbor seal studies, ADF&G has collected serum samples from PWS, the Gulf of Alaska/Kodiak area, and southeast Alaska. In addition, samples from the Pribilof Islands, the north side of the Alaska Peninsula, and the Gulf of Alaska that were stored in ADF&G's serum bank have been analyzed. For all the samples screened for PhHV, the overall prevalence was 65% (R. Zarnke, pers. commun.). There were no major differences in prevalence between the Bering Sea (56%), the Gulf of Alaska (75%), PWS (58%), or southeast Alaska (71%). Samples tested for PDV indicated a lower prevalence than for PhHV. For southeast Alaska, 17% of all samples that were tested were positive, compared to 20% in PWS, 20% in the Gulf of Alaska, and 13% at the Pribilof Islands. Very few samples tested positive for CDV, and those were most likely a result of cross-reaction with antibodies produced in response to PDV infection (R. Zarnke, pers. commun).

This serologic survey has indicated that PhHV and PDV are enzootic in healthy seals from around Alaska. There were no obvious differences by geographic area that would help explain ongoing population declines in the Gulf of Alaska and PWS and stable populations in southeast Alaska and the Bering Sea. To date, no clinical signs of disease indicative of a PDV infection have been reported from seals in Alaska. At this time it appears unlikely that disease is responsible for the ongoing decline of seals in PWS and the Gulf of Alaska. However, we will continue to collect samples, conduct some analyses, and archive serum.

CONCLUSIONS

1. In 1994, unadjusted counts of harbor seals on the PWS trend route were 12% lower during molting than in 1993. Pupping counts were similar in the two years. Although both molting and

pupping counts have shown substantial declines since 1989 (17% and 22% respectively), neither decline is statistically significant based on unadjusted counts.

2. Counts of harbor seals made during molting and pupping are affected principally by date, time of day, and time relative to low tide. General linear model estimates of parameters can be used to adjust counts and take into account variability in those factors among survey years.

3. When raw counts of seals are adjusted for the effects of date, time, and tide, molting counts showed a highly significant decline during 1989-1994 at a rate of about 6% per year. The decline in adjusted pupping counts was not significant.

4. Power analysis showed that adjusted or unadjusted pupping counts and unadjusted molting counts have little power to detect population recovery. Molting counts that have been adjusted to account for the effects of date, time of day, and tide have an 80% or better chance of correctly detecting a 5% annual increase if at least 6 replicate counts are made each year over a 5 year period.

5. Six seals tagged with SLTDRs in September 1993 remained within PWS during the 101-310 day periods that they were tracked. They mostly stayed close to the locations where they were captured and tagged. Average daily movements were significantly less than for seals tagged in spring 1992 and 1993.

6. Dive data from seals tagged in September 1993 showed harbor seals in PWS spend an average of 66%-77% of their time diving, almost all of it at depths less than 150 m. Maximum dive depths appear to vary according to water depth in a particular region, but the proportion of dives to different depths varies by individual and by season, apparently independent of water depth.

7. Preliminary analysis of fatty acids in blubber of 40 seals sampled in 1994 showed considerable variability that is likely due to differences in feeding. Due to unequal age distribution of samples among groups, it could not be determined whether differences in fatty acids were due to age, sample location, or a combination of both. Prey sample analyses must be done before the fatty acid results can be interpreted completely.

8. Harbor seals in PWS and other parts of Alaska have been exposed to phocine herpesvirus and phocine distemper virus. There is no evidence that either of these diseases has been responsible for the decline in harbor seal numbers in some areas.

9. It is essential to continue to monitor the trend in abundance of PWS harbor seals. Surveys conducted during the molt, corrected for the influence of certain factors, have sufficient power to detect a population recovery. Surveys conducted during pupping are too variable, and should be discontinued. In addition, satellite-tagging studies should be continued to learn more about movements, diving behavior, and haulout use of harbor seals in PWS. Those studies should be complimented by studies of predation and food availability, in order to better understand the possible roles of those factors in limiting the recovery of harbor seals following the spill.

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

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

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

Factor	Type	Description
Location	categorical	25 sites
Year	categorical	6 years, 1989-1994 for pupping surveys
		8 years, 1984 and 1988-1994 for molting surveys
Time of day	categorical	before (midday - 4 hours)
		(midday - 4 hours) to (midday - 2 hours)
		(midday - 2 hours) to (midday)
		(midday) to (midday +2 hours)
		(midday + 2) to (midday + 4 hours)
		after (midday + 4 hours)
Date	continuous	in days beginning with 1 June
Time relative to low tide	categorical	before (lowtide - 1.5 hours)
		(lowtide - 1.5 hours) to (lowtide - 1 hour)
		(lowtide - 1 hour) to (lowtide - 0.5 hour)
		(lowtide - 0.5 hour) to (lowtide)
		(lowtide) to (lowtide + 0.5 hour)
		(lowtide + 0.5 hour) to (lowtide + 1 hour)
		(lowtide + 1 hour) to (lowtide + 1.5 hours)
		after (lowtide + 1.5 hours)
Tide height	continuous	deviations from low tide, in feet
Wind	categorical	CA = calm
		LB = light breeze
		LW = light wind
		WI - windy
Air temperature	continuous	in degrees Fahrenheit
Sky conditions	categorical	CL = cloudy
		DR = drizzle
		FO = fog
		HO = high overcast
		LO = low overcast
		PC = partly cloudy
		RN = rain

Table 3. Number of counts (n), mean (μ), and maximum (max) number of harbor seals counted during aerial surveys in Prince William Sound, August-September 1989-1994.

	1989			1990			1991			1992			1993			1994		
Site	n	μ	max	n	μ	max	n	μ	max	n	μ	max	n	μ	max	n	μ	max
1	8	0	0	8	<1	2	9	1	4	10	<1	1	6	4	22	7	0	0
2	5	20	54	8	5	13	10	13	28	10	24	41	4	16	28	7	9	23
3	8	33	50	7	21	37	10	27	38	10	31	42	5	38	44	7	59	70
4	7	43	66	8	69	104	10	80	125	10	41	76	6	73	86	7	49	65
5	7	7	13	8	1	4	10	14	21	9	8	20	7	3	67	7	1	3
6	8	33	53	8	22	43	8	17	26	8	12	17	7	20	26	7	2	8
7	8	2	4	8	4	13	9	5	11	9	<1	1	7	<1	1	8	<1	1
8	8	7	13	8	10	17	9	10	16	9	4	8	7	2	8	8	4	11
9	8	24	32	8	23	33	8	23	29	9	13	17	7	10	15	8	<1	3
10	8	23	27	8	15	23	8	10	15	9	7	9	7	3	8	8	0	0
11	8	3	10	8	3	10	9	<1	2	9	<1	1	7	<1	2	8	<1	1
12	8	35	60	8	36	50	8	39	61	9	45	61	7	22	50	8	36	60
13	7	22	40	8	29	43	10	25	28	9	33	41	7	24	37	8	29	42
14	6	41	52	7	30	40	9	33	42	9	44	53	7	36	48	8	40	59
15	7	36	59	6	39	50	7	63	78	8	52	71	7	41	49	9	43	68
16	4	83	103	7	115	151	9	106	169	8	65	108	5	54	74	9	64	84
17	7	18	32	8	23	47	8	25	40	9	37	49	6	28	52	9	25	44
18	1	116	116	2	41	45	8	105	235	8	78	119	6	118	213	9	56	108
19	3	32	47	5	28	46	8	15	34	8	56	71	5	48	58	9	30	48
20	5	61	78	5	104	131	8	109	152	9	62	83	6	114	127	9	77	117
21	6	44	63	8	49	59	8	47	57	9	42	54	6	14	19	9	35	48
22	7	37	48	8	36	49	9	28	34	9	10	22	6	1	4	9	6	11
23	8	11	19	8	11	18	9	21	28	9	24	30	6	22	34	9	40	58
24	8	59	87	8	43	58	9	56	81	9	57	67	5	61	87	9	31	66
25	9	19	71	8	23	61	8	51	104	10	25	54	5	21	41	9	41	56

Table 4. Unadjusted mean counts and annual percent change for harbor seals at oiled and unoiled trend count sites in Prince William Sound, August-September 1988-1994.

	Oiled (n=7)		Unoiled (n=18)		All (n=25)	
Year	mean[a]	annual % change	mean[a]	annual % change	mean[a]	annual % change
1988	418		639		1057	
1989	238	-43	576	-10	815	-23
1990	278	-17	504	+12	779	-4
1991	290	+4	631	+25	920	+18
1992	267	-8	492	-22	760	-17
1993	206	-23	568	+15	774	+2
1994	237	+15	441	-22	678	-12
Overall declines						
1988-1994		-43		-31		-36
1989-1994		0		-23		-17

[a]Mean values may vary slightly from those presented in previous reports (Frost and Lowry 1994a,b; Frost et al. 1994) because of random variations in the actual values selected by bootstrapping when calculations are done.

Table 5. Number of counts (n), mean, and maximum (max) number of harbor seals and harbor seal pups counted during aerial surveys in Prince William Sound, June 1989-1994. Data for 1992 are from National Marine Mammal Laboratory (unpublished).

	1989		1990		1991		1992		1993		1994	
	non-pups/pups		non-pups/pups		non-pups/pups		non-pups/pups		non-pups/pups		non-pups/pups	
Site	mean	max	mean	max	mean	max	mean	max	mean	max	mean	max
1	0/ 0	0/ 0	2/ 0	4/ 0	0/ 0	1/ 0	3/ 1	8/ 1	10/ 0	19/ 1	<1/<1	1/ 1
2	3/ 0	19/ 1	11/ 0	18/ 0	3/ 0	11/ 1	2/ 0	6/ 0	6/ 0	14/ 1	12/ 0	30/ 0
3	5/ 0	13/ 1	5/ 1	9/ 1	1/ 0	4/ 1	9/ 0	10/ 0	9/ 1	16/ 3	3/<1	10/ 1
4	68/16	88/25	55/21	69/33	23/11	46/15	25/ 9	32/17	35/9	47/11	35/11	48/15
5	9/ 2	24/ 4	2/ 1	3/ 1	7/ 2	12/ 4	2/ 0	3/ 1	3/ 0	9/ 0	<1/ 0	2/ 0
6	17/ 5	29/ 9	10/ 4	17/ 9	11/ 4	17/ 6	16/ 4	23/ 6	14/ 3	25/ 3	10/ 1	19/ 3
7	4/ 3	11/10	0/ 0	1/ 1	4/ 1	8/ 2	3/ 0	8/ 1	4/ 1	8/ 2	<1/<1	2/ 1
8	10/ 2	17/ 4	3/ 1	6/ 1	3/ 1	7/ 2	1/ 1	1/ 1	6/ 2	11/ 3	2/ 1	7/ 2
9	11/ 3	18/ 5	8/ 1	10/ 2	3/ 0	8/ 0	5/ 0	6/ 1	6/ 0	14/ 1	7/<1	9/ 2
10	3/ 0	6/ 1	1/ 0	3/ 0	3/ 0	7/ 1	1/ 0	1/ 0	0/ 0	0/ 0	0/ 0	0/ 0
11	3/ 0	8/ 1	5/ 1	8/ 3	1/ 0	1/ 1	1/ 0	3/ 0	1/ 0	3/ 1	1/ 0	2/ 1
12	29/ 9	34/13	43/15	54/18	40/14	52/17	40/13	50/16	33/ 9	45/10	29/ 9	38/ 10
13	11/ 3	36/ 9	19/ 6	25/11	14/ 7	19/ 8	13/ 5	17/ 6	20/ 5	31/ 9	12/ 6	19/10
14	18/ 7	28/13	18/ 5	24/11	24/ 5	32/ 7	15/ 4	20/ 5	12/ 5	16/ 8	18/ 9	25/10
15	46/14	68/23	47/20	54/23	71/29	87/39	46/22	54/30	42/14	49/19	55/13	67/18
16	151/31	199/56	137/36	158/43	143/45	177/54	84/36	104/45	108/31	132/46	119/28	146/41
17	22/ 8	32/11	28/16	33/22	25/11	36/15	50/13	61/19	48/13	58/18	49/10	59/13
18	91/12	152/20	73/ 3	96/ 5	61/ 3	94/ 5	69/ 8	78/19	53/ 1	110/ 2	60/ 4	127/ 7
19	88/15	118/30	68/ 6	100/ 9	45/ 6	62/ 9	36/ 7	50/10	40/ 6	49/ 8	40/ 6	53/ 9
20	75/19	104/23	95/24	110/30	66/18	94/28	38/14	62/24	81/18	113/29	73/22	84/25
21	20/ 4	32/ 9	28/ 0	37/ 0	13/ 0	24/ 0	6/ 1	18/ 3	1/ 0	3/ 1	2/<1	6/ 1
22	15/ 4	32/ 8	23/ 1	28/ 2	16/ 1	20/ 2	13/ 1	16/ 2	5/ 1	9/ 2	16/ 3	19/ 4
23	25/ 8	32/11	21/ 6	28/ 7	19/ 5	27/ 8	10/ 3	14/ 6	18/ 4	26/ 7	22/ 5	26/ 6
24	29/ 6	54/10	25/ 3	42/ 5	24/ 3	39/ 4	30/ 6	38/ 8	20/ 4	29/ 5	24/ 4	30/ 6
25	0/ 0	1/ 0	1/ 1	3/ 2	1/ 1	5/ 1	0/ 0	1/ 0	0/ 0	0/ 0	0/ 0	0/ 0

Table 6. Unadjusted mean counts of harbor seals and harbor seal pups at oiled and unoiled trend count sites in Prince William Sound, June 1989-1994.

	Oiled (n=7)			Unoiled (n=18)			Combined (n=25)		
	non-pups[a]	pups	percent pups	non-pups[a]	pups	percent pups	non-pups[a]	pups	percent pups
1989	278	72	20.6	471	98	17.3	749	170	18.5
1990	291	99	25.4	435	72	14.2	727	171	19.1
1991	307	111	26.6	292	56	16.1	599	167	21.8
1992	248	92	27.1	267	55	17.0	516	147	22.2
1993	263	77	22.7	310	49	13.7	573	126	18.0
1994	282	75	21.0	304	57	15.8	586	132	18.4

[a]Mean values may vary slightly from those presented in previous reports (Frost and Lowry 1994a,b; Frost et al. 1994) because of random variations in the actual values selected by bootstrapping when calculations are done.

Table 7. Parameter estimates for factors affecting molt period counts of hauled out seals made during aerial surveys of Prince William Sound, August-September 1984-1994.

Factor	Category	Parameter estimate
Tide of day	before (midday - 4 hr)	0.2389
	(midday - 4 hr) to (midday - 2 hr)	0.2820
	(midday - 2 hr) to (midday + 2 hr) and after (midday + 4 hr)	0.1656
	(midday + 2 hr) to (midday + 4 hr)	0.0
Date	date since June 30	0.0720
	$date^2$ since June 30	-0.0005
Time of tide	< -1 hr or -0.5 hr to 0 hr from low tide	0.2656
	-1 hr to -0.5 hr or 0 hr to 0.5 hr from low tide	0.3652
	0.5 hr to +1.5 hr from low tide	-0.0875
	> 1.5 hr from low tide	0.0
Wind speed	calm/light breeze	0.1323
	light wind/windy	0.0
Sky conditions	drizzle	-0.2236
	low overcast, fog, or rain	0.0
	clear, high overcast, or partly cloudy	0.0557

Table 8. Parameter estimates for factors affecting pupping period counts of hauled out seals made during aerial surveys of Prince William Sound, June 1989-1994.

Factor	Category	Parameter estimate
Tide of day	before (midday - 4 hr) and after (midday + 4 hr)	-0.1240
	(midday - 4 hr) to (midday - 2 hr) and (midday) to (midday + 4 hr)	-0.0381
	(midday - 2 hr) to (midday)	0.0
Date	date since June 1	-0.0202
	$date^2$ since June 1	0.0009
Time of tide	|low tide - survey time| > 1.5 hr	-0.1873
	-1.5 hr to -1.0 hr from low tide, or -0.5 hr to +1.5 hr from low tide	-0.0875
	-1.0 hr to -0.5 hr from low tide	0.0
Wind speed	calm/light breeze	0.1960
	light wind/windy	0.0
Air temperature	airtemp	0.0223
	$airtemp^2$	-0.0002
Sky conditions	clear, drizzle, fog, or rain	-0.1660
	low overcast	-0.1060
	high overcast, partly cloudy	0.0

Table 9. Adjusted mean counts and annual percent change for harbor seals at oiled and unoiled trend count sites in Prince William Sound, based on surveys during August-September 1988-1994.

	Oiled (n=7)		Unoiled (n=18)		All (n=25)	
Year	mean	annual % change	mean	annual % change	mean	annual % change
1988	553		878		1431	
1989	317	-43	753	-14	1070	-25
1990	336	+ 6	620	-18	956	-11
1991	293	-13	624	+ 1	917	- 4
1992	297	+ 1	557	-11	854	- 7
1993	197	-34	635	+14	831	- 3
1994	269	+37	497	-22	767	-8
Overall changes						
1988-1994		-51		-43		-46
1989-1994		-15		-34		- 28

Table 10. Adjusted mean counts and annual percent change for non-pup harbor seals at oiled and unoiled trend count sites in Prince William Sound, based on surveys during June 1989-1994.

	Oiled (n=7)		Unoiled (n=18)		All (n=25)	
Year	mean	annual % change	mean	annual % change	mean	annual % change
1989	285		505		790	
1990	341	+20	496	-2	837	+6
1991	353	+4	333	-33	686	-18
1992	271	-23	300	-10	571	-17
1993	292	+8	337	+12	669	+18
1994	308	+5	321	-5	629	-6
Overall change 1989-1994		+8		-36		-20

Table 11. Summary of parameters for molting and pupping period data used in the power analysis for Prince William Sound harbor seal trend count surveys.

	Molting Period		Pupping Period	
	unadjusted	adjusted	unadjusted	adjusted
$\hat{V}$	14,604.3	1,690.1	2,827.4	3,606.8
$\hat{V} / \bar{n}$	1,653.9	191.4	377.0	480.9
$\hat{\beta}_0$	49,892	112.025	78.009	81,723
$\hat{\beta}_1$	-24.7	-55.8	-38.9	-40.7
$\hat{\sigma}^2$	5,175.5	600.0	4,034.8	5,171.4
$\hat{\delta}^2$	3,524.5	408.6	3,657.8	4,690.5

Table 12. Harbor seals captured, sampled, and tagged with SLTDRs during field activities conducted in Prince William Sound, 1993.

Specimen Number	Capture Date	Capture Location	Sex	Age Class	SLTDR Number	Standard Length (cm)	Axillary Girth (cm)	Weight (kg)
PWSHS-1-93	5/7/93	Seal Island	M	adult	2287	147.0	105.5	83.5
PWSHS-2-93	5/7/93	Seal Island	F	subadult	none	103.0	72.7	28.9
PWSHS-3-93	5/7/93	Seal Island	M	adult	2282	138.5	107.5	87.1
PWSHS-4-93	5/7/93	Applegate Rocks	M	adult	2283	121.5	102.2	59.4
PWSHS-5-93	5/7/93	Applegate Rocks	F	subadult	none	101.0	83.0	31.7
PWSHS-6-93	5/8/93	Seal Island	F	subadult	none	107.0	86.0	38.7
PWSHS-7-93	5/8/93	Seal Island	F	adult	11040	140.0	103.4	65.0
PWSHS-8-93	5/8/93	Applegate Rocks	M	subadult	none	103.0	91.0	37.0
PWSHS-9-93	5/8/93	Applegate Rocks	M	adult	2240	135.0	100.1	66.2
PWSHS-10-93	5/8/93	Applegate Rocks	M	subadult	none	112.0	76.5	31.9
PWSHS-11-93	5/9/93	Seal Island	M	adult	11042	148.5	113.0	87.3
PWSHS-12-93	5/9/93	Seal Island	M	subadult	none	107.5	80.5	31.4
PWSHS-13-93	5/9/93	Seal Island	F	subadult	none	105.0	84.0	32.4
PWSHS-20-93	9/15/93	Seal Island	F	adult	2282	122.0	118.0	84.1
PWSHS-21-93	9/15/93	Seal Island	M	subadult	none	117.0	88.5	35.5
PWSHS-22-93	9/15/93	Seal Island	M	subadult	none	107.0	87.0	40.0
PWSHS-23-93	9/15/93	Seal Island	M	adult	2287	139.0	102.0	65.0
PWSHS-24-93	9/15/93	Seal Island	M	subadult	2284	112.0	96.0	47.7
PWSHS-25-93	9/15/93	Seal Island	M	subadult	none	114.0	85.0	40.9
PWSHS-26-93	9/15/93	Seal Island	M	pup	none	101.0	76.0	25.9
PWSHS-27-93	9/15/93	Seal Island	F	pup	none	92.0	74.5	24.1
PWSHS-28-93	9/16/93	Bay of Isles	M	adult	5039	134.0	106.5	84.1

Table 12. Continued.

Specimen Number	Capture Date	Capture Location	Sex	Age Class	SLTDR Number	Standard Length (cm)	Axillary Girth (cm)	Weight (kg)
PWSHS-29-93	9/18/93	Seal Island	M	adult	2280	136.0	96.0	61.4
PWSHS-30-93	9/18/93	Seal Island	F	subadult	none	118.0	77.0	34.1
PWSHS-31-93	9/18/93	Applegate Rocks	M	pup	none	99.0	73.0	23.6
PWSHS-32-93	9/18/93	Channel Island	M	adult	2283	144.0	104.0	81.7
PWSHS-33-93	9/18/93	Channel Island	M	subadult	none	108.0	81.0	38.6
PWSHS-34-93	9/18/93	Channel Island	F	subadult	none	100.0	84.0	34.1

Table 13. Harbor seals captured, sampled, and tagged with SLTDRs during field activities conducted in Prince William Sound, 1994.

Specimen Number	Capture Date	Capture Location	Sex	Age Class	SLTDR Number	Standard Length (cm)	Axillary Girth (cm)	Weight (kg)
PWSHS-1-94	4/26/94	Green Island	F	subadult	none	114.0	79.0	37.0
PWSHS-2-94	4/27/94	Little Green I	M	subadult	failed	112.0	85.0	44.0
PWSHS-3-94	4/27/94	Port Chalmers	F	adult	failed	135.0	117.0	119.0
PWSHS-4-94	4/27/94	Port Chalmers	M	subadult	none	114.0	90.0	47.0
PWSHS-5-94	4/27/94	Stockdale Harbor	M	adult	failed	136.0	---	69.0
PWSHS-6-94	4/28/94	Stockdale Harbor	M	adult	failed	140.0	108.0	77.0
PWSHS-7-94	4/28/94	Stockdale Harbor	F	adult	failed	146.0	113.0	118.0
PWSHS-8-94	4/28/94	Stockdale Harbor	M	adult?	none	122.0	97.0	61.0
PWSHS-9-94	4/28/94	Stockdale Harbor	M	subadult	none	113.0	91.0	52.0
PWSHS-10-94	4/28/94	Stockdale Harbor	M	adult	failed	152.0	111.0	92.0
PWSHS-11-94	9/18/94	Channel Island	F	adult	failed	117.0	98.0	61.6
PWSHS-12-94	9/18/94	Channel Island	F	subadult	2286	102.0	71.5	27.9
PWSHS-13-94	9/18/94	Channel Island	M	subadult	none	108.0	78.7	36.2
PWSHS-14-94	9/18/94	Channel Island	M	subadult	2282	121.0	97.7	56.9
PWSHS-15-94	9/18/94	Channel Island	F	subadult	none	106.0	79.0	30.3
PWSHS-16-94	9/18/94	Channel Island	F	subadult	none	118.0	78.0	33.8
PWSHS-17-94	9/18/94	Channel Island	M	subadult	none	117.0	90.0	42.3
PWSHS-18-94	9/18/94	Channel Island	M	subadult	none	120.0	83.8	43.8
PWSHS-19-94	9/18/94	Channel Island	M	subadult	none	128.0	83.0	44.5
PWSHS-20-94	9/18/94	Channel Island	F	subadult	none	95.0	76.0	28.9
PWSHS-21-94	9/18/94	Channel Island	M	subadult	failed	110.0	82.0	35.7

Table 13. Continued.

Specimen Number	Capture Date	Capture Location	Sex	Age Class	SLTDR Number	Standard Length (cm)	Axillary Girth (cm)	Weight (kg)
PWSHS-22-94	9/18/94	Channel Island	M	subadult	none	107.0	72.0	34.2
PWSHS-23-94	9/18/94	Channel Island	M	adult	2280	143.0	94.8	62.4
PWSHS-24-94	9/19/94	Gravina Island	F	adult	failed	131.0	97.0	64.9
PWSHS-25-94	9/19/94	Gravina Island	F	pup	none	96.3	73.5	25.7
PWSHS-26-94	9/19/94	Gravina Island	M	subadult	11042	121.5	78.0	36.1
PWSHS-27-94	9/22/94	Port Chalmers	F	adult	2281	141.0	104.0	72.6
PWSHS-28-94	9/22/94	Port Chalmers	M	adult	none	141.0	125.0	105.7
PWSHS-29-94	9/22/94	Port Chalmers	M	pup	none	103.0	70.0	17.0
PWSHS-30-94	9/22/94	Port Chalmers	F	adult	11039	141.0	113.0	71.6
PWSHS-31-94	9/22/94	Port Chalmers	F.	subadult	failed	120.0	87.0	37.5
PWSHS-32-94	9/22/94	Port Chalmers	F	adult	none	132.0	109.9	72.7
PWSHS-33-94	9/22/94	Port Chalmers	F	subadult	2283	119.0	85.0	40.5
PWSHS-34-94	9/22/94	Port Chalmers	M	adult	none	132.0	99.0	70.0
PWSHS-35-94	9/22/94	Port Chalmers	F	adult	2284	129.0	102.0	55.4
PWSHS-36-94	9/22/94	Port Chalmers	M	adult	none	154.0	121.0	111.8

Table 14. Performance of satellite-linked SLTDRs attached to harbor seals in Prince William Sound, 1991-1994. Does not include units with version 3.11 software.

SLTDR	Date Attached	Date of Last Transmission	Total Days Operational	No. Days w/ Locations[a]	Total No. Locations[a]
1991					
14096	4/19/91	6/25/91	68	9	14
14097	4/19/91	4/26/91	8	4	20
11466	9/14/91	9/14/91	4	1	8
11467	9/11/91	10/8/91	28	22	85
1992					
3086	5/17/92	7/7/92	52	44	137
3087	5/17/92	7/11/92	56	44	147
3088	5/17/92	7/19/92	64	40	244
3089	5/17/92	7/24/92	69	30	89
1993-spring					
2282	5/7/93	7/28/93	83	77	318
2283	5/7/93	7/21/93	76	71	302
2287	5/7/93	6/14/93	39	39	188
2240	5/8/93	8/1/93	86	53	224
11040	5/8/93	7/8/93	62	44	209
11042	5/9/93	7/25/93	78	61	202
1993-fall					
2282	9/15/93	12/25/93	101	96	392
2284	9/15/93	3/17/94	183	131	402
2287	9/15/93	7/22/94	310	266	960
5039	9/16/93	3/11/94	176	130	370
2280	9/18/93	3/10/94	173	146	585
2283	9/18/93	2/11/94	146	133	423

[a]Figures for 1991, 1992 and spring 1993 may vary slightly from those reported in Frost and Lowry (1994b) due to changes in procedures for screening records (see methods).

Table 14. Continued.

SLTDR	Date Attached	Date of Last Transmission	Total Days Operational	No. Days w/ Locations[b]	Total No. Locations[b]
1994					
2280	9/18/94	2/27/95	162		
2282	9/18/94	6/12/95	267		
2286	9/18/94	3/3/95	166		
11042	9/19/94	2/18/95	152		
2281	9/22/94	12/6/94	75		
2283	9/22/94	12/21/94	90		
2284	9/22/94	12/24/94	93		
11039	9/22/94	11/1/94	40		

[b]Location data for these SLTDRs have not yet been analyzed, and will be presented in the 1996 annual report.

Table 15. Summary of movements of satellite-tagged harbor seals in Prince William Sound, September1993-July 1994.

SLTDR	Location and Date Tagged	Other Major Areas and Dates of Use	Location/Date of Last Location Fix
2282	Seal Island-9/15/93	Applegate Rocks-9/16; 10/1,12,14	Seal Island-12/25/93
2284	Seal Island-9/15/93	Columbia Glacier-9/22-25; 10/14; 10/17-11/12; 11/18-29;12/3-9; 12/14-28 College Fiord-10/15-10/16 Fairmount Island area-11/29; 12/1-2;12/10-13 Lone Island-11/13-16; 11/30-12/1; 12/30-1/28 SE Knight Island-1/31	Seal Island-3/17/94
2287	Seal Island-9/15/93	N. Montague Island-11/17; 12/27; 1/25-27; 2/2; 2/5-6; 2/11-12; 2/25-28; 3/7; 3/14-16; 4/4; 4/8-10; 4/20-27	Seal Island-7/22/94
5039	Bay of Isles-9/16/93		Bay of Isles-3/11/94
2280	Seal Island-9/18/93		Seal Island-3/10/94
2283	Channel Island-9/18/93		Channel Island-2/11/94

Table 16. Distances moved by satellite-tagged harbor seals in Prince William Sound, September 1993-July 1994.

SLTDR Number	Dates Tracked	Distance moved (km) Total	per Day
2282	9/15/93-12/25/93	405	4.0
2284	9/15/93-3/17/94	1,025	5.6
2287	9/15/93-7/22/94	846	2.7
5039	9/16/93-3/11/94	554	3.1
2280	9/18/93-3/10/94	654	3.7
2283	9/18/93-2/11/94	295	2.0

Table 17. Use of haulout sites by satellite-tagged harbor seals in Prince William Sound, September 1993-July 1994. Numbers indicate the number of haulout bouts that occurred at each site based on location and land-sea sensor data (see Methods).

	SLTDR Number/Tagging Site					
Location	2282 Seal Island	2284 Seal Island	2287 Seal Island	5039 Bay of Isles	2280 Seal Island	2283 Channel Island
Seal Island	60	32	186	--	88	--
Applegate Rocks	--	1	--	4	--	
NW Montague Island	--	--	4	--	--	--
Columbia Glacier	--	43	--	--	--	--
Lone Island	--	16	--	--	--	--
Perry Island	--	1	--	--	--	--
Fairmont Island	--	3	--	--	--	--
Channel Island	--	--	--	--	--	41
Green Island	--	--	--	--	--	7
Port Chalmers	--	--	--	--	--	6
Bay of Isles	--	--	--	79	--	--
NE Knight Island	--	--	--	9	--	--
SE Knight Island	--	1	--	--	--	--
TOTAL KNOWN	61	96	191	88	92	54
Unknown	1	--	2	2	8	--
TOTAL	62	96	193	90	100	54

Table 18. Depth distribution of dives (m) for six satellite-tagged harbor seals in Prince William Sound, September 1993-July 1994.

Location/ Dates	Percent of Total Dives				Total # of Dives
	<50	>50-100	>100-150	>150	
2280					
Sep	30	37	32	1	1,237
Oct	36	46	16	2	3,099
Nov	22	36	38	4	2,723
Dec	25	33	38	4	2,697
Jan	24	45	29	2	2,801
Feb	21	42	36	<1	2,404
Mar	20	27	53	<1	816
Overall	**26**	**40**	**32**	**2**	**15,777**
2282					
Sep	67	8	16	9	1,682
Oct	48	15	33	4	2,709
Nov	65	12	22	1	2,456
Dec	45	16	33	6	1.994
Overall	**56**	**13**	**27**	**4**	**8,841**
2283					
Sep	99	1	0	0	891
Oct	98	2	0	0	2,698
Nov	99	1	0	0	2,594
Dec	100	<1	0	0	2,941
Jan	90	10	0	0	1,848
Feb	98	2	0	0	593
Overall	**93**	**3**	**0**	**0**	**11,565**
2284					
Sep	59	24	8	9	1,770
Oct	54	18	15	13	5,692
Nov	51	14	18	17	6,868
Dec	48	22	24	6	4,527
Jan	40	14	28	18	2,640
Feb	42	41	15	11	2,573
Mar	54	36	10	<1	2,466
Overall	**50**	**21**	**18**	**11**	**26,536**

Table 18. Continued.

Location/ Dates	Percent of Total Dives <50	>50-100	>100-150	>150	Total # of Dives
<u>2287</u>					
Sep	51	11	38	<1	1,052
Oct	48	17	34	1	2,768
Nov	29	15	55	1	1,944
Dec	31	19	50	<1	2,850
Jan	38	12	49	1	2,169
Feb	53	7	38	2	2,341
Mar	66	10	22	1	2,038
Apr	63	11	26	0	2,213
May	74	6	20	0	3,173
Jun	95	2	3	0	2,140
Jul	92	2	6	0	2,145
Overall	**58**	**10**	**31**	**1**	**24,833**
<u>5039</u>					
Sep	76	19	5	0	1,655
Oct	71	23	6	<1	2,897
Nov	67	27	6	0	3,466
Dec	79	16	5	<1	4,553
Jan	81	14	5	<1	3,851
Feb	78	16	6	<1	2,713
Mar	83	13	4	<1	1,136
Overall	**76**	**18**	**5**	**0**	**20,271**

Table 19. Depth distribution of dives (m) for seal number 2284 in three regions of Prince William Sound, September 1993-March 1994.

Location/ Dates	Percent of Total Dive <50	>50-100	>100-150	>150	Total # of Dives	Dives per 6 hr Period
Seal Island						
9/16-9/20	59	27	13	1	435	33
9/27-10/11	43	42	13	1	1,193	28
2/1-2/16	43	32	23	2	1,286	44
2/21-3/12	45	44	10	<1	2,133	65
3/15-3/17	59	34	7	0	694	77
Overall	**47**	**39**	**13**	**1**	**5,741**	**46**
Columbia Bay						
9/22-9/25	69	9	4	18	789	66
10/14	75	17	5	3	539	108
10/17-11/12	53	13	14	20	7,174	74
11/18-11/29	44	20	27	9	2,508	68
12/3-12/9	49	21	25	5	1,313	57
12/14-12/28	46	24	24	6	1,757	58
Overall	**52**	**16**	**18**	**14**	**14,080**	**69**
Lone-Storey Is.						
11/13-11/16	47	18	15	19	516	74
11/28-12/1	53	12	28	7	1,026	73
12/10-12/13	46	30	20	4	444	56
12/30-1/28	39	14	29	17	2,872	50
3/13-3/14	59	27	14	<1	263	44
Overall	**44**	**16**	**26**	**13**	**5,121**	**56**

Table 20. Depth distribution of dives (m) for seal number 2287 in three regions of Prince William Sound, September 1993-July 1994.

Location/ Dates	Percent of Total Dives <50	>50-100	>100-150	>150	Total # of Dives	Dives per 6 hr Period
Seal Island						
9/16-11/16	45	15	39	<1	4,858	26
11/18-12/26	31	19	50	<1	3,256	29
12/28-1/24	34	12	52	1	1,908	30
1/28-2/5	28	10	60	2	716	26
2/8-2/10	45	9	46	0	229	38
2/14-2/22	34	12	45	10	452	41
3/1-3/6	72	7	19	2	594	31
3/9-3/11	39	20	40	<1	215	27
3/17-4/3	60	12	27	1	1,103	24
4/4-4/7	29	16	55	0	176	22
4/11-28	48	16	36	0	862	28
Overall 9/16-4/28	**41**	**15**	**43**	**1**	**14,369**	**28**
5/1-5/31	74	6	20	0	3,173	28
6/1-6/30	95	2	3	0	2,140	19
7/1-7/22	92	2	6	0	2,145	30
N. Montague I.						
11/17, 12/27	36	14	50	0	110	6
1/25-1/27	43	16	38	1	273	34
2/5-2/6	37	6	57	0	113	19
2/11-2/12	40	13	47	0	314	35
4/20-27	100	0	0	0	364	21
Overall	**59**	**9**	**32**	**<1**	**1,174**	**26**
Stockdale Hbr.						
2/25-2/28	100	0	0	0	496	35
3/14-3/16	88	4	8	0	413	41
4/8-4/10	82	3	15	0	236	30
Overall	**92**	**2**	**6**	**0**	**1,145**	**36**

Table 21. Maximum dive depths (m) for six satellite-tagged harbor seals in Prince William Sound for bimonthly periods, September 1993 -July 1994.

	SLTDR Number/Tagging Location/Age/Sex					
	2282 Seal I. adult F	2284 Seal I. subadult M	2287 Seal I. adult M	5039 Bay of Isles adult M	2280 Seal I. adult M	2283 Channel I. adult M
September 15-30	172	284	152	140	196	48
October 1-15	144	236	144	158	160	56
October 16-31	144	248	172	136	184	56
November 1-15	152	380	148	146	212	52
November 16-30	168	280	164	162	216	60
December 1-15	172	332	144	162	244	48
December 16-31	168	224	152	166	212	48
January 1-15	---	216	152	174	228	64
January 16-31	---	292	152	154	152	64
February 1-15	---	300	156	158	152	56
February 16-28	---	160	152	124	136	---
March 1-15	---	164	164	162	152	---
March 16-31	---	136	152	---	---	---
April 1-15	---	---	148	---	---	---
April 16-30	---	---	148	---	---	---
May 1-15	---	---	152	---	---	---
May 16-31	---	---	156	---	---	---
June 1-15	---	---	144	---	---	---
June 16-30	---	---	156	---	---	---
July 1-21	---	---	156	---	---	---
Mean	160	242	153	154	187	55
Range	144-172	136-332	144-172	124-174	136-244	48-64

Table 22. Mean number of dives per six hour period and percent of time the SLTDR was wet for six satellite-tagged harbor seals in Prince William Sound, September 1993 -July 1994.

	SLTDR Number/Tagging Location/Age/Sex					
	2282 Seal I. adult F	2284 Seal I. subadult M	2287 Seal I. adult M	5039[a] Bay of Isles adult M	2280[a] Seal I. adult M	2283 Channel I. adult M
Number of dives						
September 15-30	26	42	21	32	27	19
October	24	61	27	25	27	32
November	24	71	26	34	30	33
December	34	59	31	62	37	36
January	---	51	30	53	26	19
February	---	53	36	56	28	16
March	---	67	25	52	22	---
April	---	---	27	32	27	---
May	---	---	28	---	---	---
June	---	---	19	---	---	---
July 1-21	---	---	30	---	---	---
Percent of time wet						
September 15-30	72	71	72	---	---	77
October	71	73	65	---	---	79
November	49	80	65	---	---	77
December	73	76	70	---	---	77
January	---	78	78	---	---	72
February	---	80	86	---	---	72
March	---	74	81	---	---	---
April	---	---	79	---	---	---
May	---	---	66	---	---	---
June	---	---	69	---	---	---
July 1-21	---	---	57	---	---	---

[a] Time at depth bins were not included in the programming for these SLTDRs.

Table 23. Prince William Sound harbor seals grouped by the presence of two important dietary fatty acids, 20:1w11 and 22:6w3, in blubber. All samples were collected in 1994. (Sub = subadult, Ad = adult)

Group1 20:1w11 < 5.0% 22:6w3 < 7.0%			Group 2 20:1w11 < 5.0% 22:6w3 > 7.0%			Group 3 20:1w11 > 5.0% 22:6w3 > 7.0%			Group 4 20:1w11 > 5.0% 22:6w3 < 7.0%		
Sample	Location	Age	Sample	Location	Age	Sample	Location	Age	Sample	Location	Age
PWS-2	L Green	Sub	PWS-3	Chalmers	Ad	PWS-6	Stockdale	Ad	PWS-4	Chalmers	Sub
PWS-13	Channel	Sub	PWS-7	Stockdale	Ad	PWS-11	Channel	Ad	PWS-12	Channel	Sub
PWS-20	Channel	Sub	PWS-8	Stockdale	Ad	PWS-21	Channel	Sub	PWS-14	Channel	Sub
PWS-22	Channel	Sub	PWS-9	Stockdale	Sub	PWS-23	Channel	Ad	PWS-15	Channel	Sub
PWS-24	Gravina	Ad	PWS-10	Stockdale	Ad	PWS-29	Chalmers	Sub	PWS-16	Channel	Sub
PWS-25	Gravina	Sub	PWS-27	Chalmers	Ad	PWS-34	Chalmers	Ad	PWS-17	Channel	Sub
PWS-26	Gravina	Sub	PWS-28	Chalmers	Ad				PWS-18	Channel	Sub
TAT-1	Fidalgo	Sub	PWS-30	Chalmers	Ad				PWS-19	Channel	Sub
TAT-2	Glacier	Sub	PWS-31	Chalmers	Sub						
TAT-4	Outpost	Sub	PWS-32	Chalmers	As						
TAT-5	Fairmount	Sub	PWS-33	Chalmers	Sub						
TAT-6	Fish Bay	Sub	PWS-35	Chalmers	Ad						
TAT-7	Fidalgo	Sub	TAT-3	Long Bay	Ad						

Table 24. Summary of serologic testing of harbor seals in Alaska, 1979-1994. Prevalence values are in percent.

Location	Year	n	Phocine herpesvirus		Phocine distemper virus		Canine distemper virus	
			negative	positive	negative	positive	negative	positive
Pribilof Islands	1979	15	7	93	87	13	100	0
Alaska Peninsula	1981	27	15	85	-	-	-	-
(north side)	1985	24	100	0	-	-	-	-
Gulf of Alaska	1978	71	21	79	83	17	99	1
	1989	6	50	50	100	0	100	
	1993	5	20	80	40	60	100	0
	1994	10	40	60	50	50	100	0
Prince William Sound	1989	14	50	50	100	0	100	0
	1990	7	71	29	100	0	100	0
	1991	8	25	75	57	43	87	13
	1992	8	13	87	80	20	100	0
	1993	28	43	57	77	23	89	11
	1994	38	42	58	75	25	100	0
Southeast Alaska	1990	2	0	100	100	0	100	0
	1993	18	33	67	80	20	89	11
	1994	42	29	71	83	17	100	0

Table 25. Summary of the influence of various factors on counts of harbor seals in Prince William Sound during molting and pupping periods. Pupping period analyses pertain only to non-pups.

Factor	Molting Period	Pupping Period
Date	counts decreasing throughout the survey period, starting 15 August	counts similar 7-17 June, the increasing steadily through 27 June
Time of Day	highest counts more than 2 hrs before midday; lowest counts 2-4 hrs after midday	highest counts 2 hrs before midday to midday; lowest counts more than 4 hrs before or after midday
Time of Tide	highest counts from low tide to 0.5 hrs after and 0.5-1.0 hrs before low; counts much lower more than 0.5 hrs after low	highest counts 0.5 hrs before low tide to low tide; lowest counts more than 1.5 hrs before or after low tide
Tide Height	not significant	not significant
Wind Speed	higher counts in calm or light breeze	higher counts in calm or light breeze
Sky Conditions	higher counts in clear, high overcast or partly cloudy conditions; lowest in drizzle	higher counts in high overcast and partly cloudy conditions; lowest in fog, rain, drizzle, and clear
Air Temperature	not significant	higher counts at 60°F than at 40°F

Table 26. Adjusted mean counts of harbor seals during pupping and molting periods, 1988-1994. Pup counts are not adjusted.

Year	Pupping Period		Molting Period
	Non-Pups	Pups	
1988	---	---	1,431
1989	790	170	1,070
1990	837	171	956
1991	686	167	917
1992	571	147	854
1993	669	126	831
1994	629	132	767

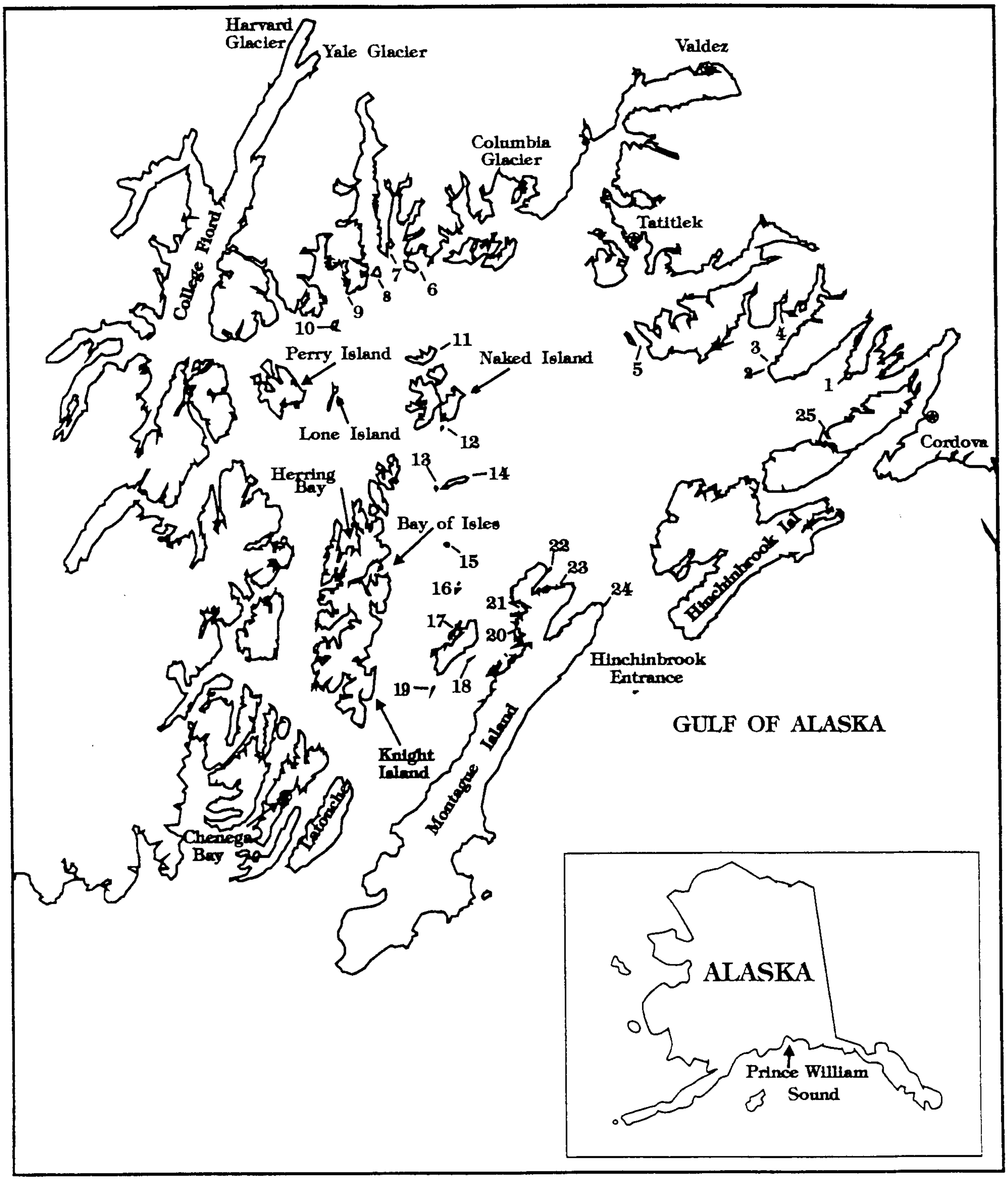


Figure 1. Map of the Prince William Sound study area showing oiled and unoiled trend count sites.

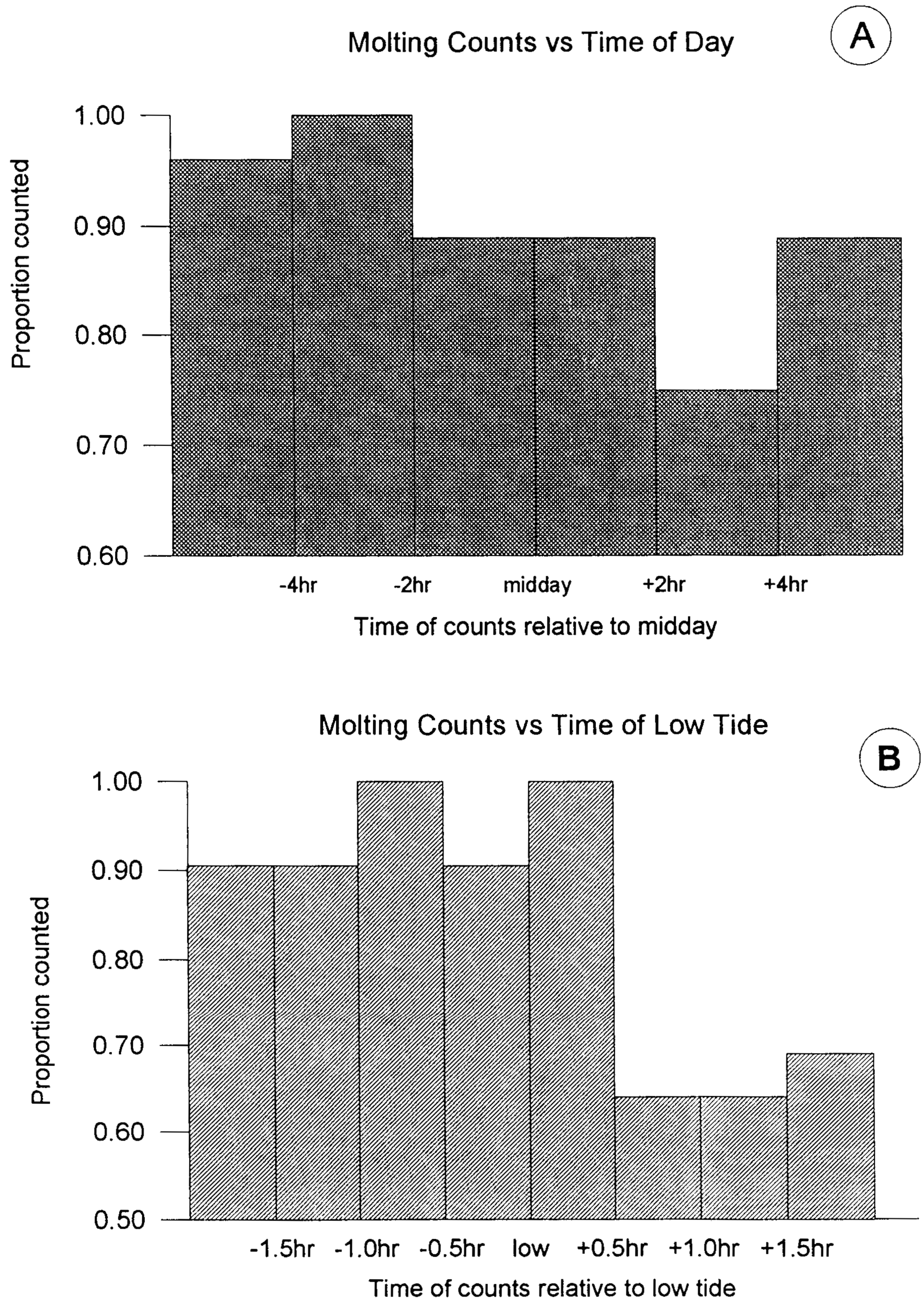


Figure 2. Effect of time of day (A) and time relative to low tide (B) on counts of harbor seals in Prince William Sound, August-September 1983-1994.

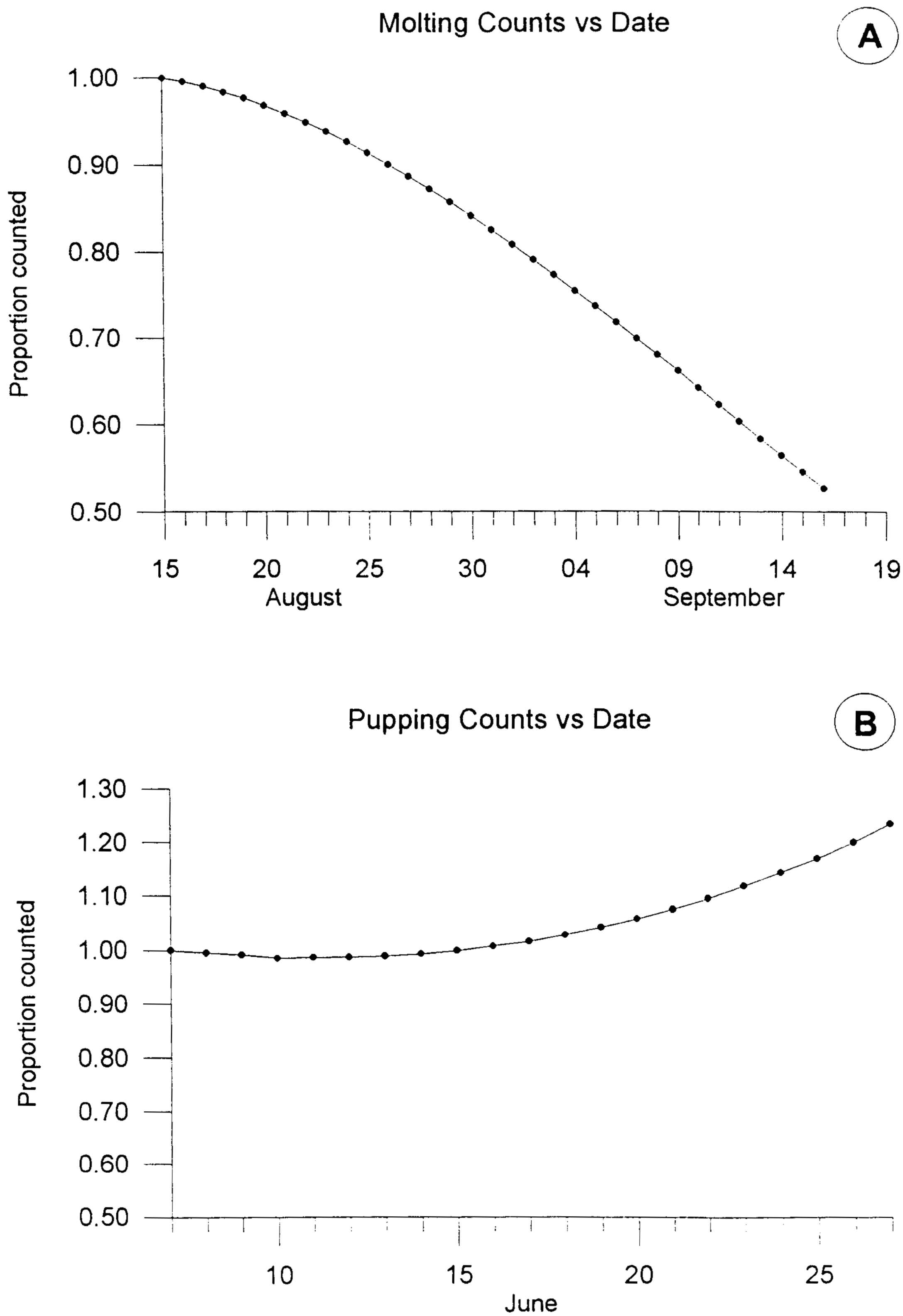


Figure 3. Effect of date on counts of harbor seals in Prince William made during molting (A) and pupping (B) periods.

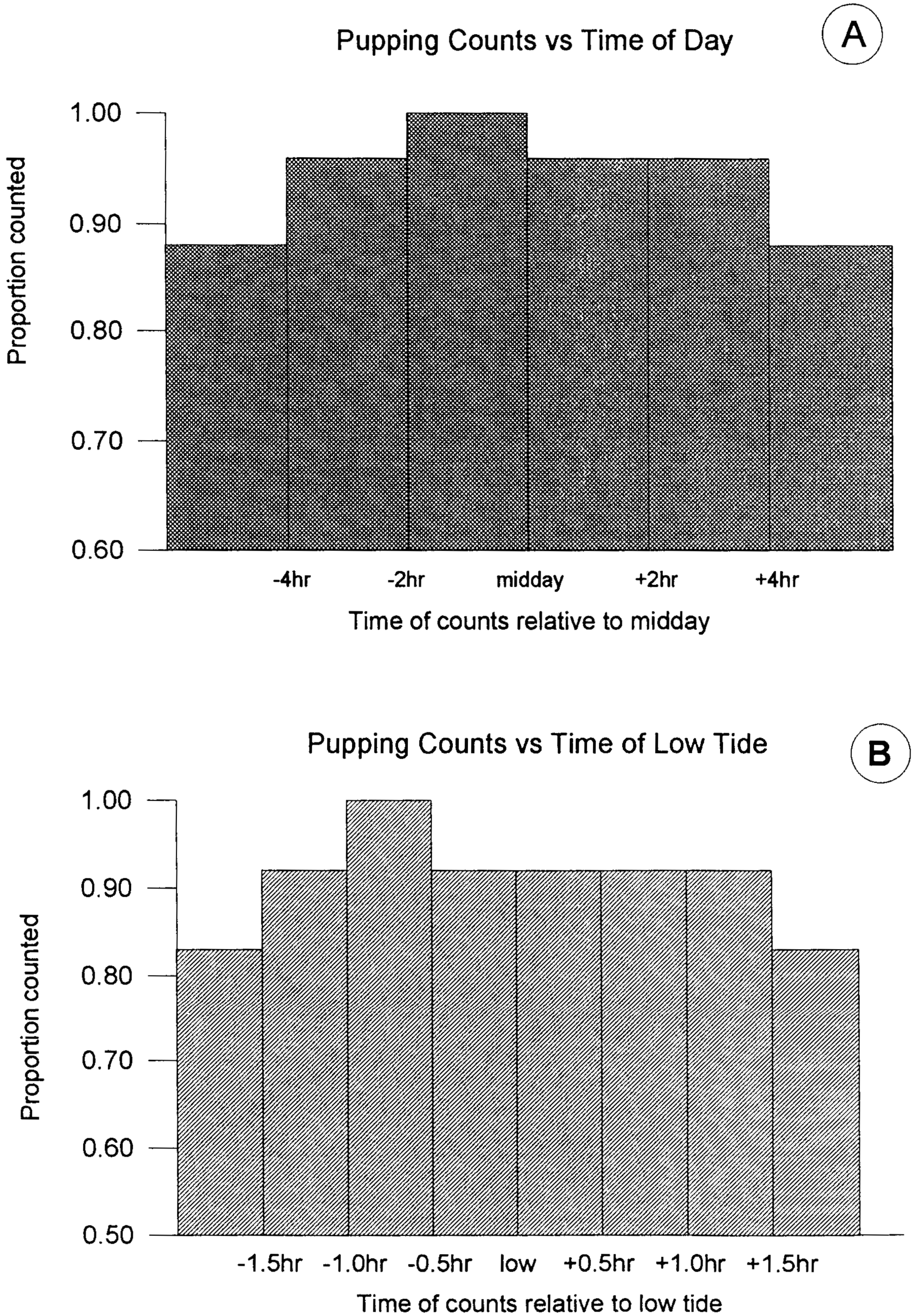


Figure 4. Effect of time of day (A) and time relative to low tide (B) on counts of harbor seals in Prince William Sound, June 1989-1994.

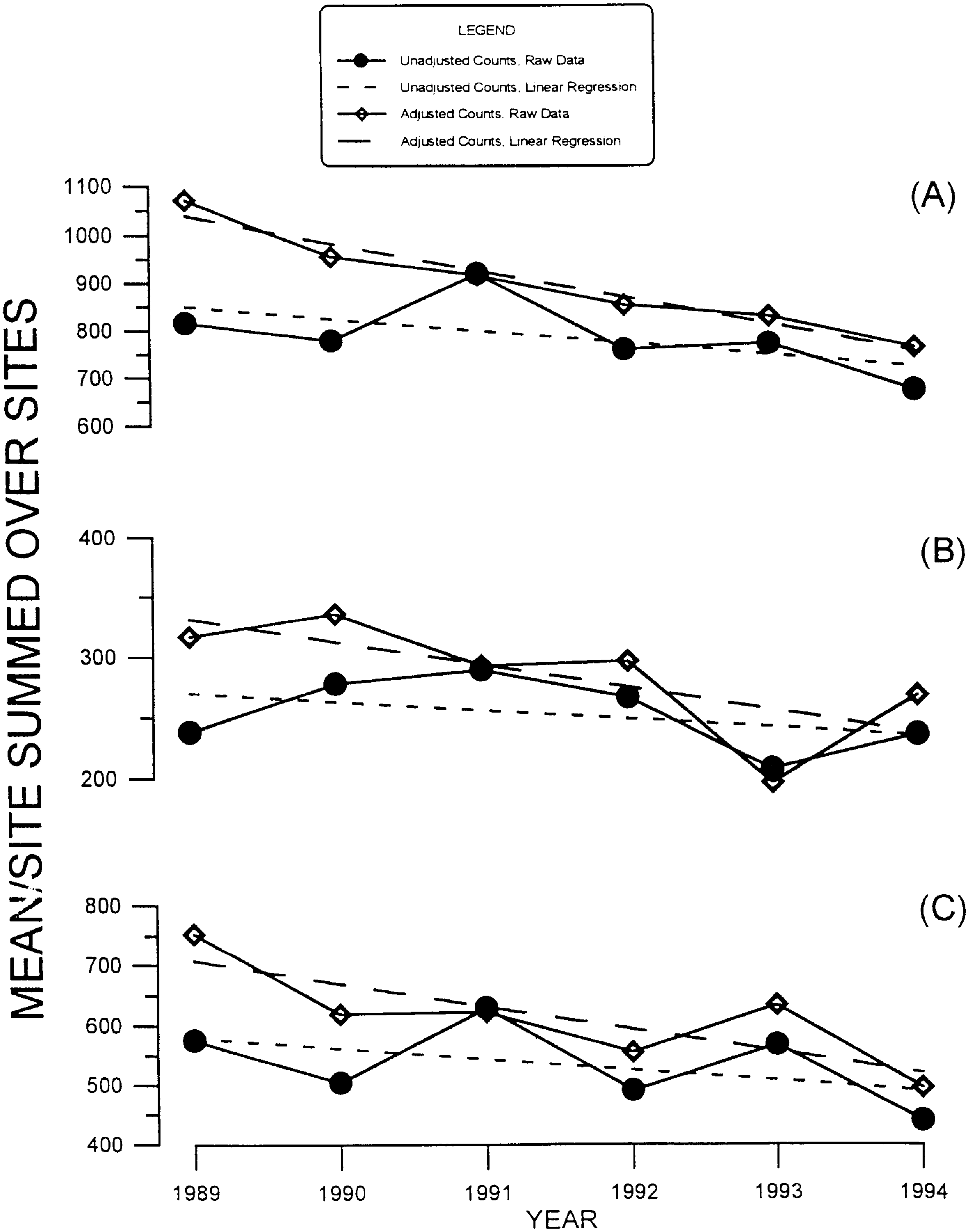


Figure 5. Trend in numbers of harbor seals in Prince William Sound based on unadjusted and adjusted counts made during August-September 1989-1994 (A - all; B - oiled; C - unoiled).

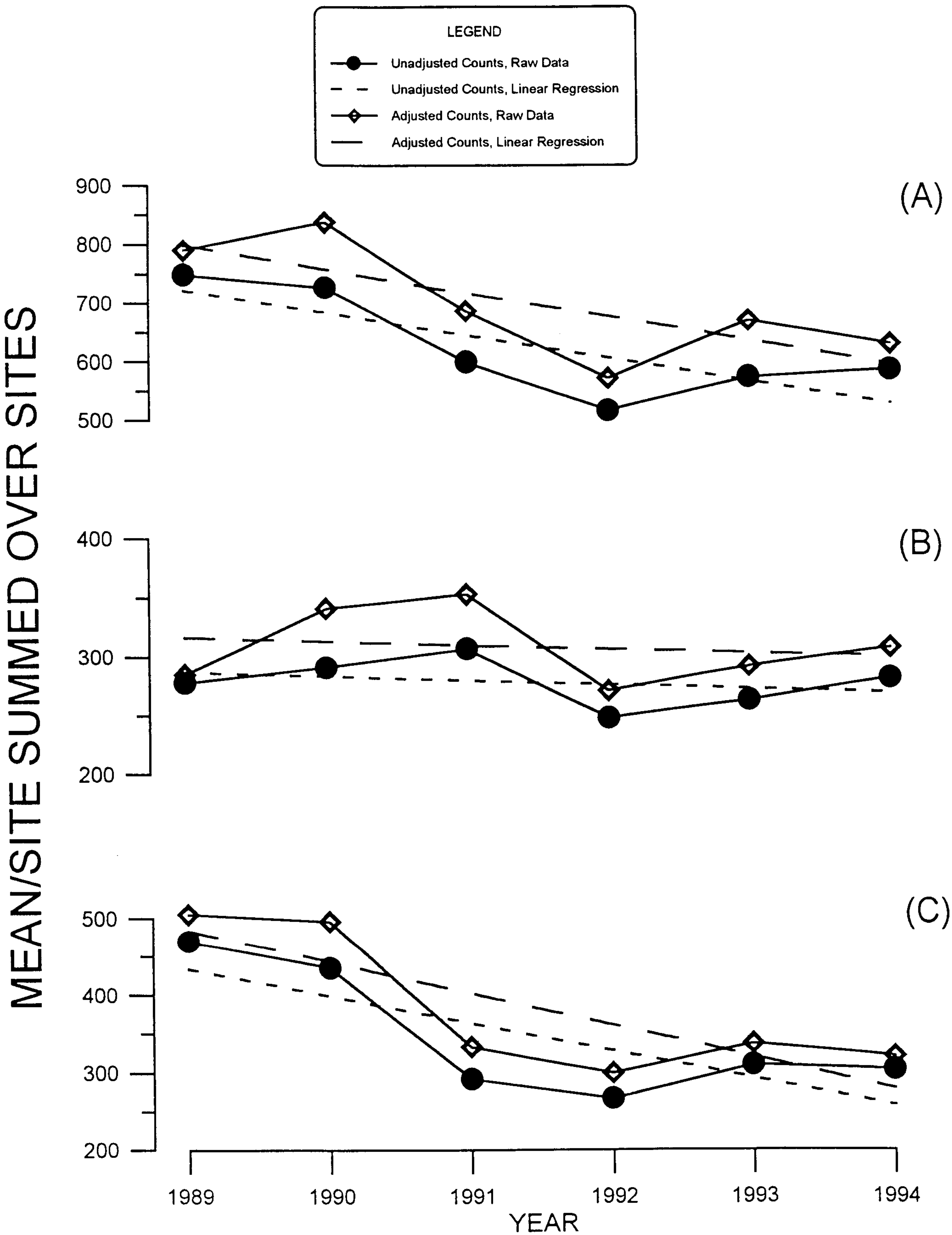


Figure 6. Trend in numbers of harbor seals in Prince William Sound based on unadjusted and adjusted counts made during June 1983-1994 (A - all sites; B - oiled; C - unoiled).

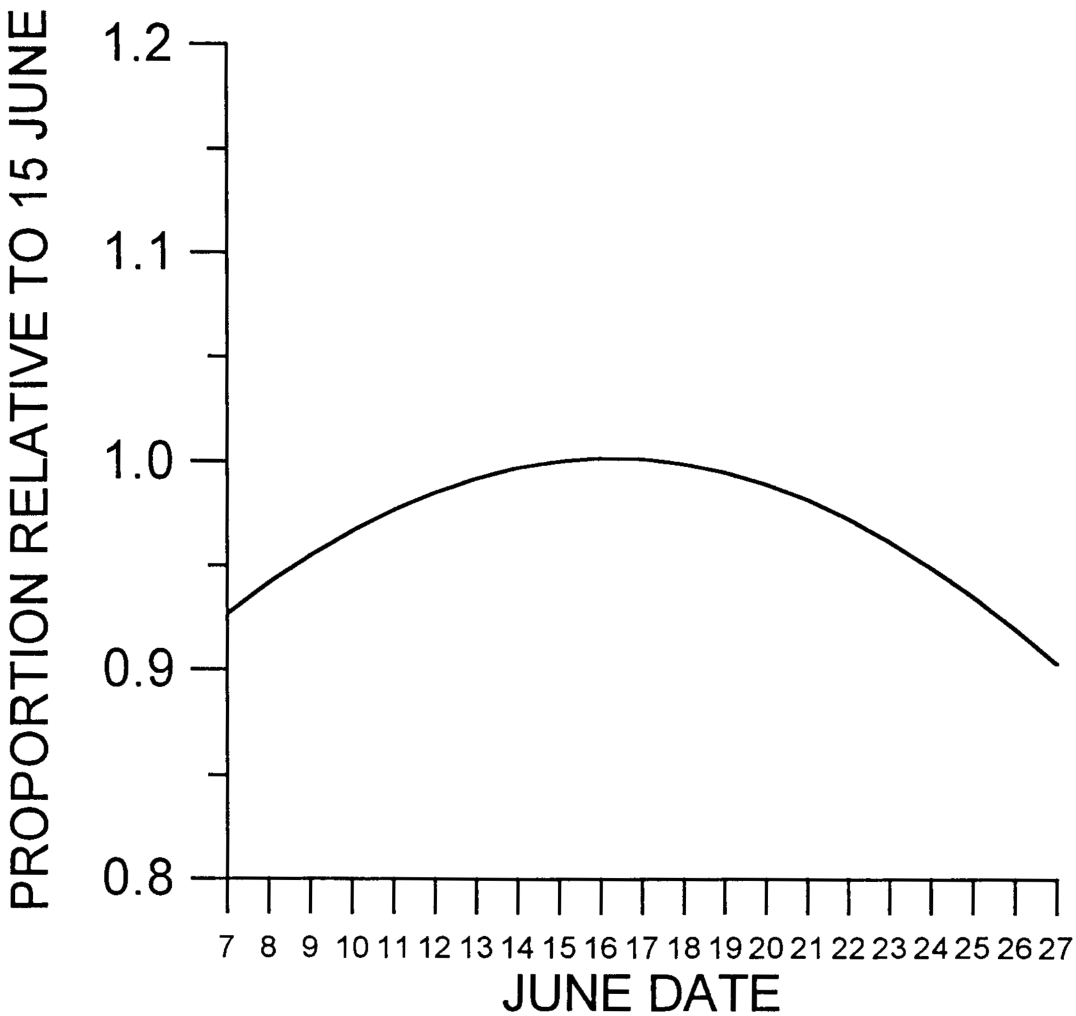


Figure 7. Effect of date on counts of harbor seals pups in Prince William Sound, June 1989-1994.

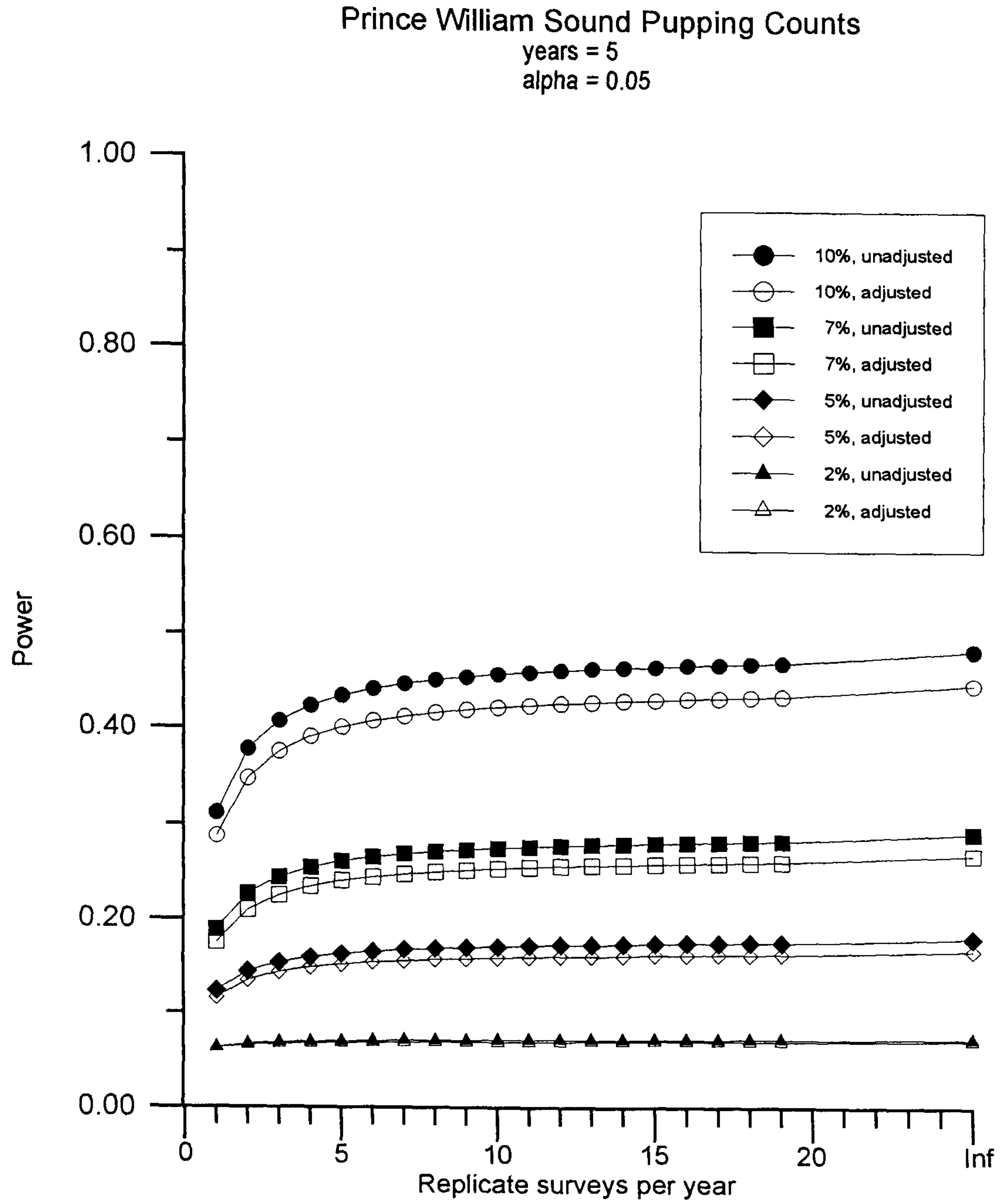


Figure 8. Power analysis for aerial surveys of harbor seals in Prince William Sound based on data collected during pupping surveys, June 1989-1994.

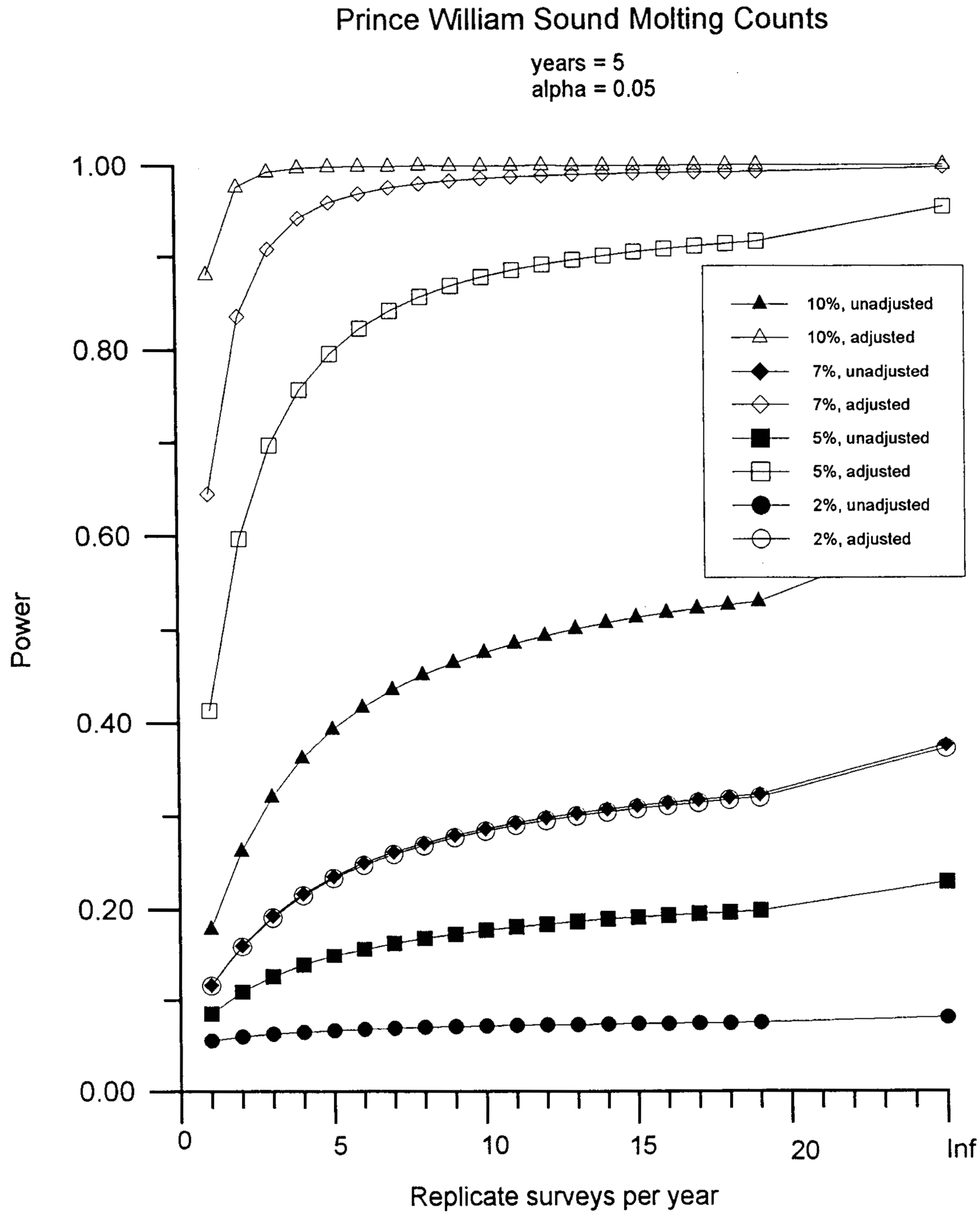


Figure 9. Power analysis for aerial surveys of harbor seals in Prince William Sound based on data collected during molting surveys, August-September 1983-1994.

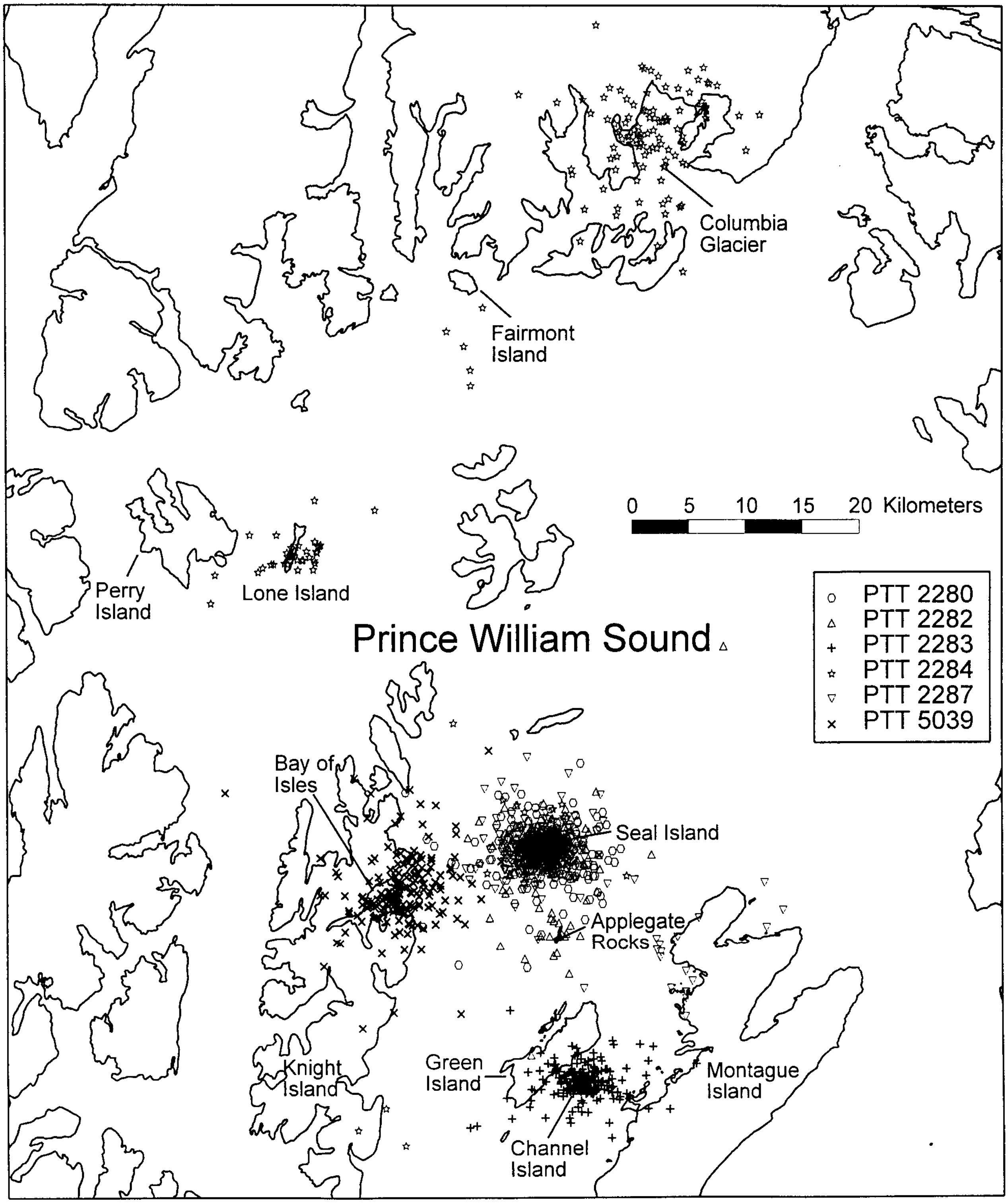


Figure 10. Map of Prince William Sound showing locations of satellite tagged seals during September 1993-July 1994.

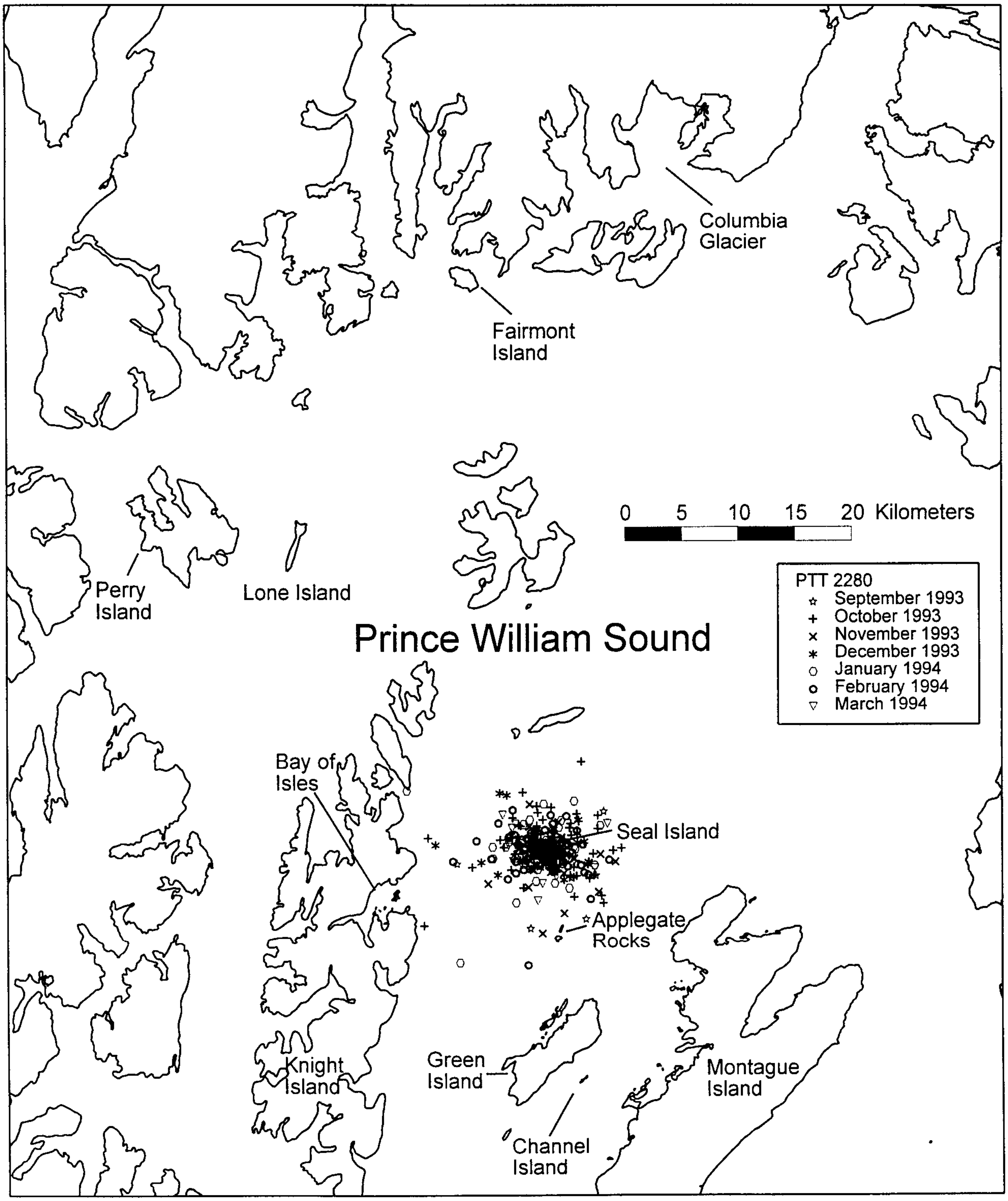


Figure 11. Map of Prince William Sound showing locations of satellite tagged seal 2280, 18 September 1993-10 March 1994.

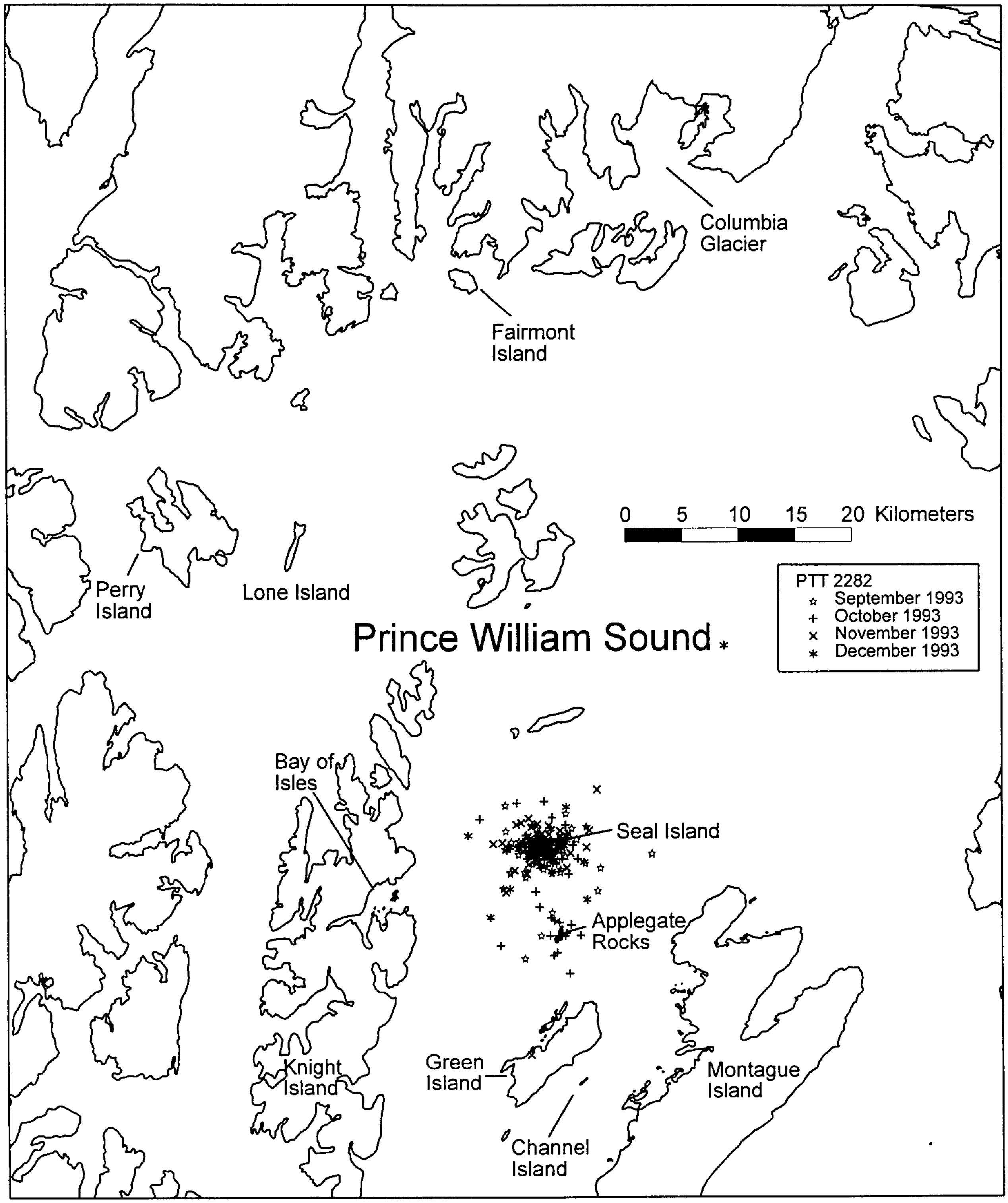


Figure 12. Map of Prince William Sound showing locations of satellite tagged seal 2282, 15 September-25 December 1993.

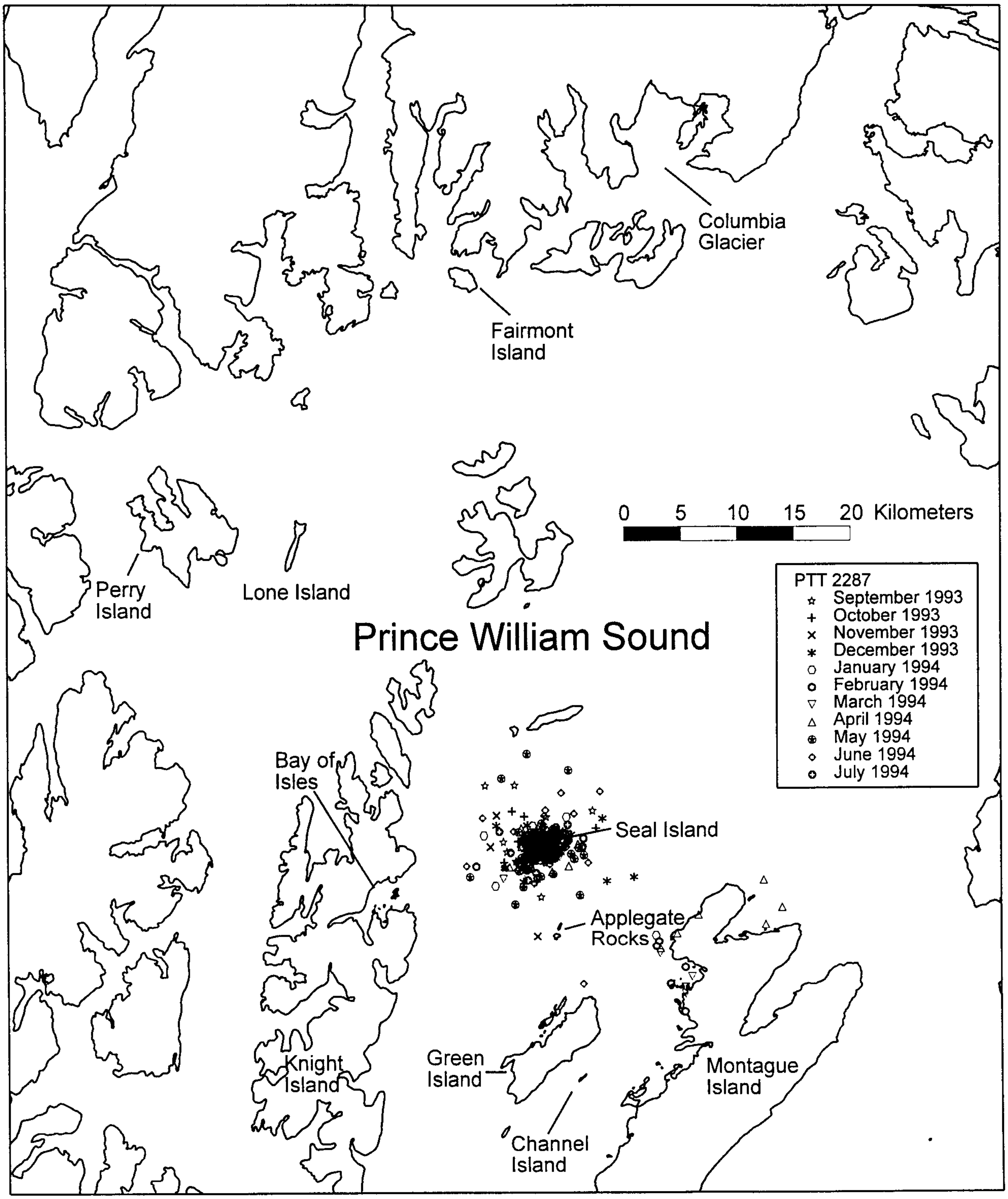


Figure 13. Map of Prince William Sound showing locations of satellite tagged seal 2287, 15 September 1993-22 July 1994.

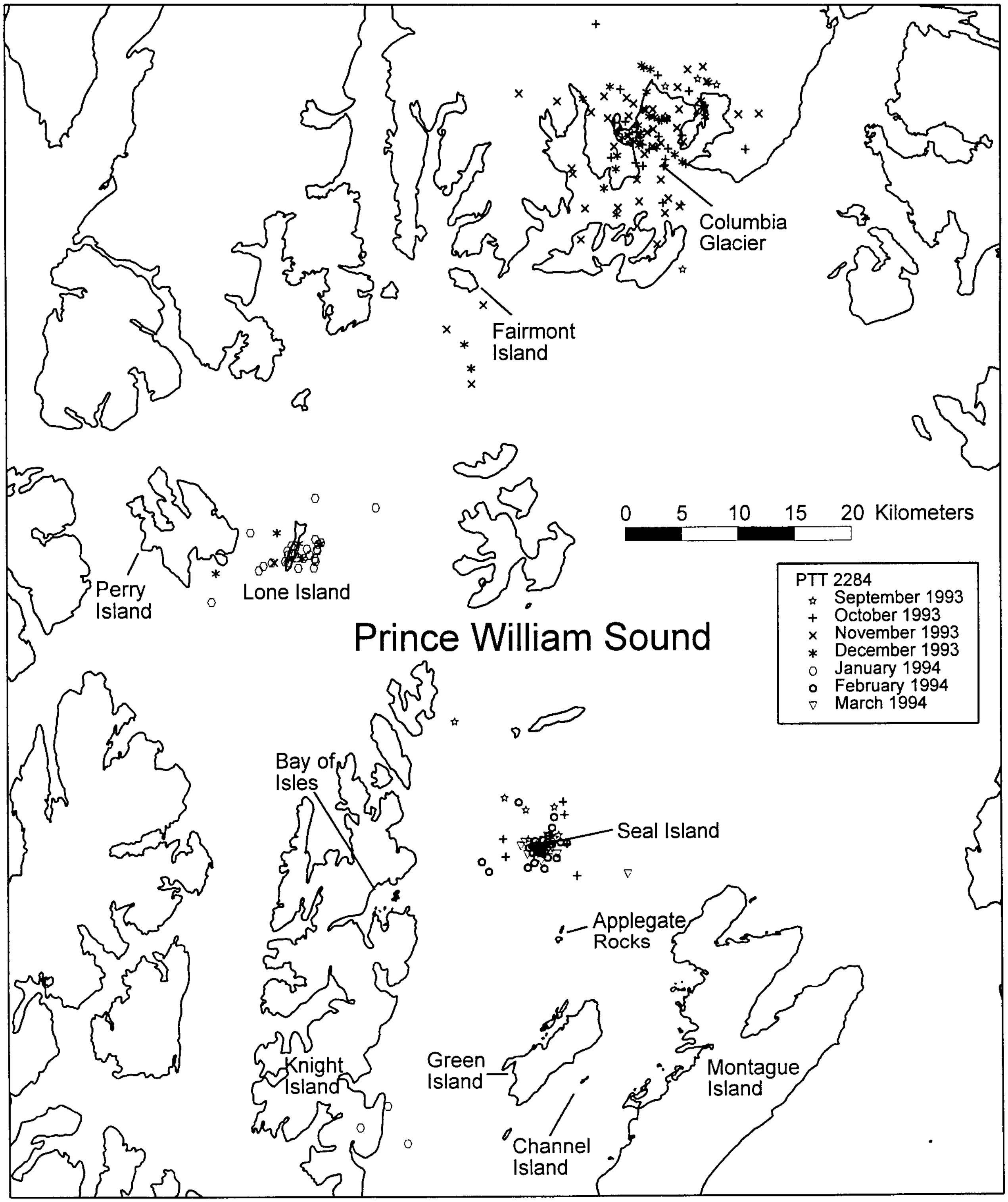


Figure 14. Map of Prince William Sound showing locations of satellite tagged seal 2284, 15 September 1993-17 March 1994.

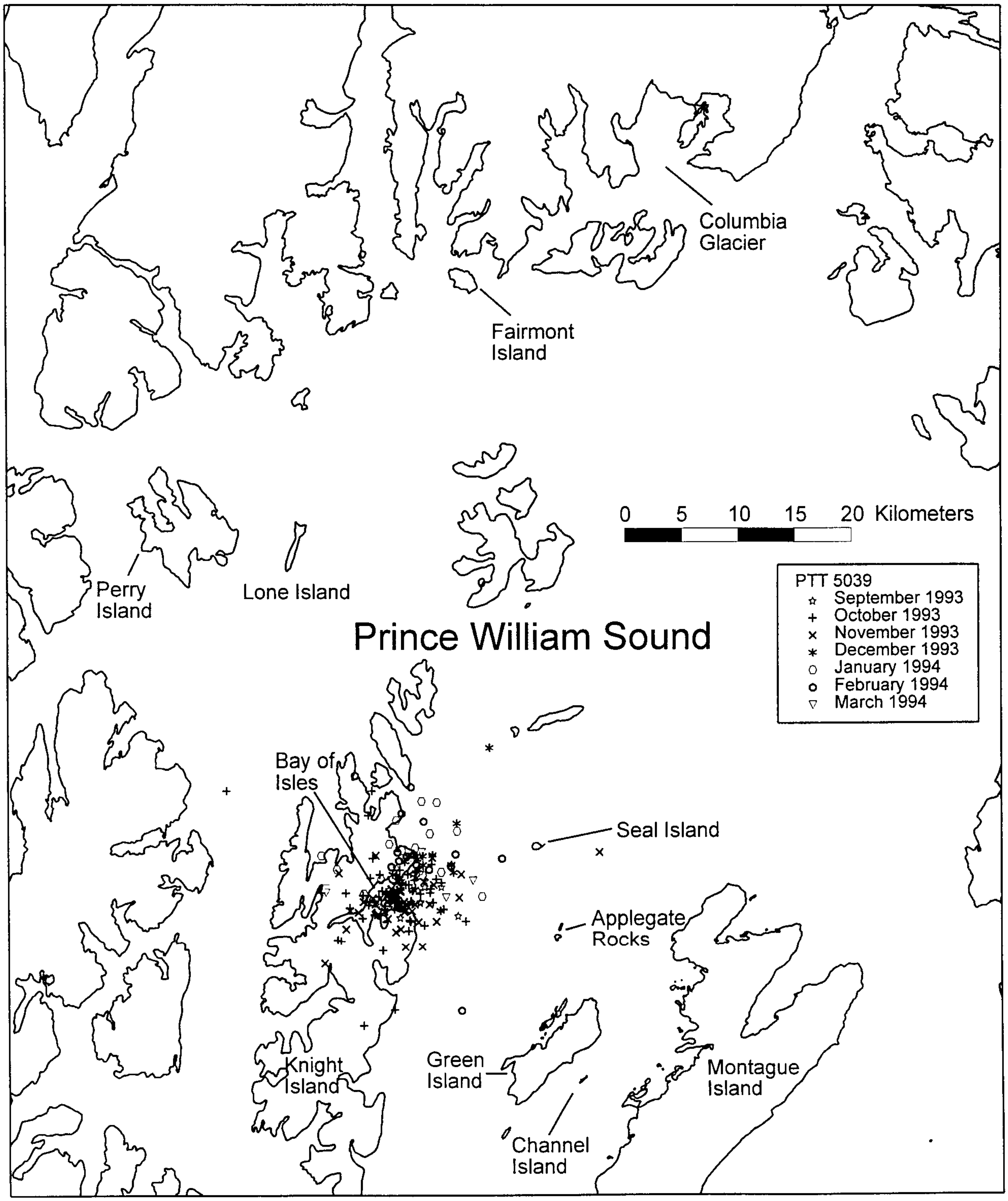


Figure 15. Map of Prince William Sound showing locations of satellite tagged seal 5039, 16 September 1993-11 March 1994.

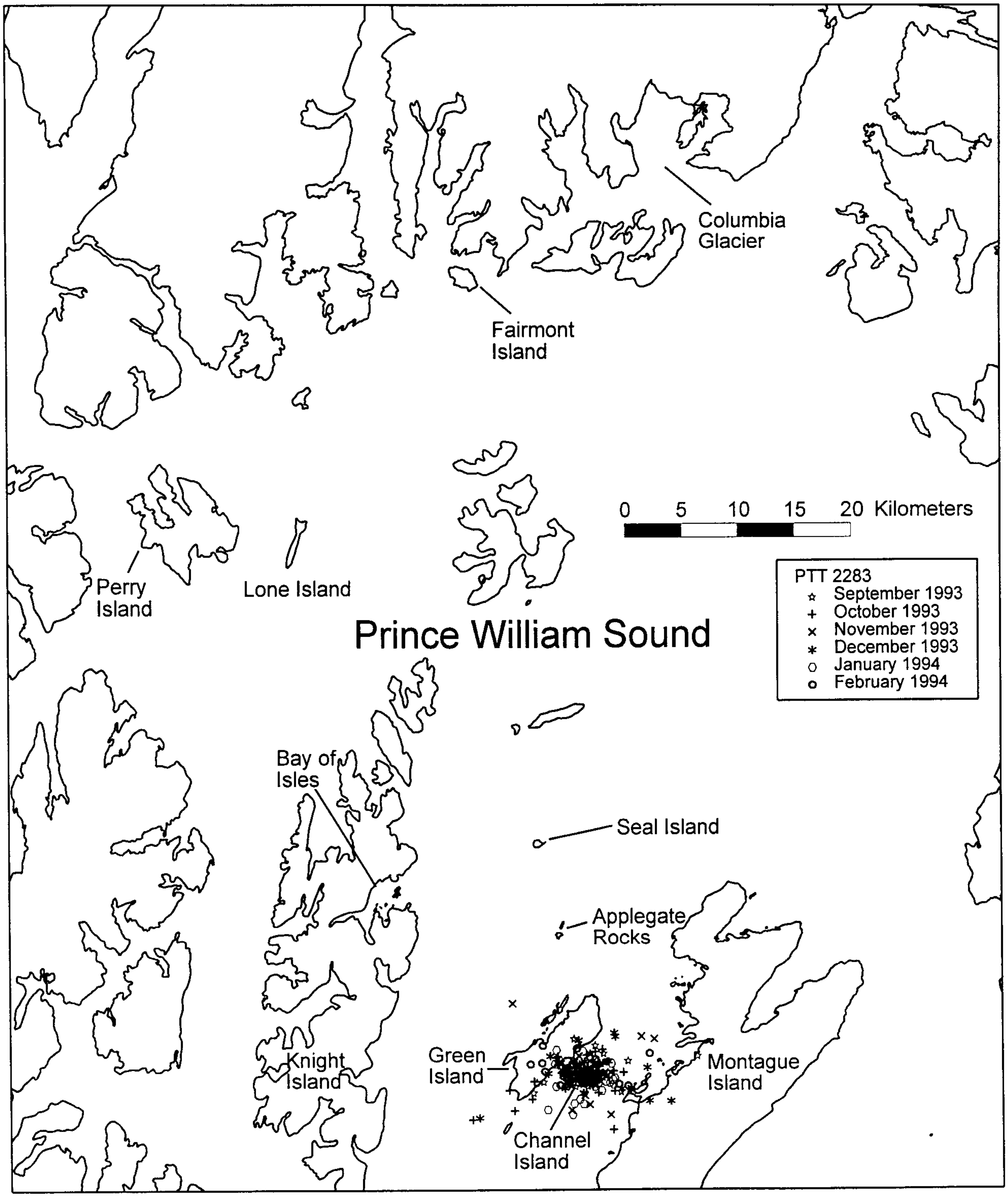


Figure 16. Map of Prince William Sound showing locations of satellite tagged seal 2283, 18 September 1993-11 February 1994.

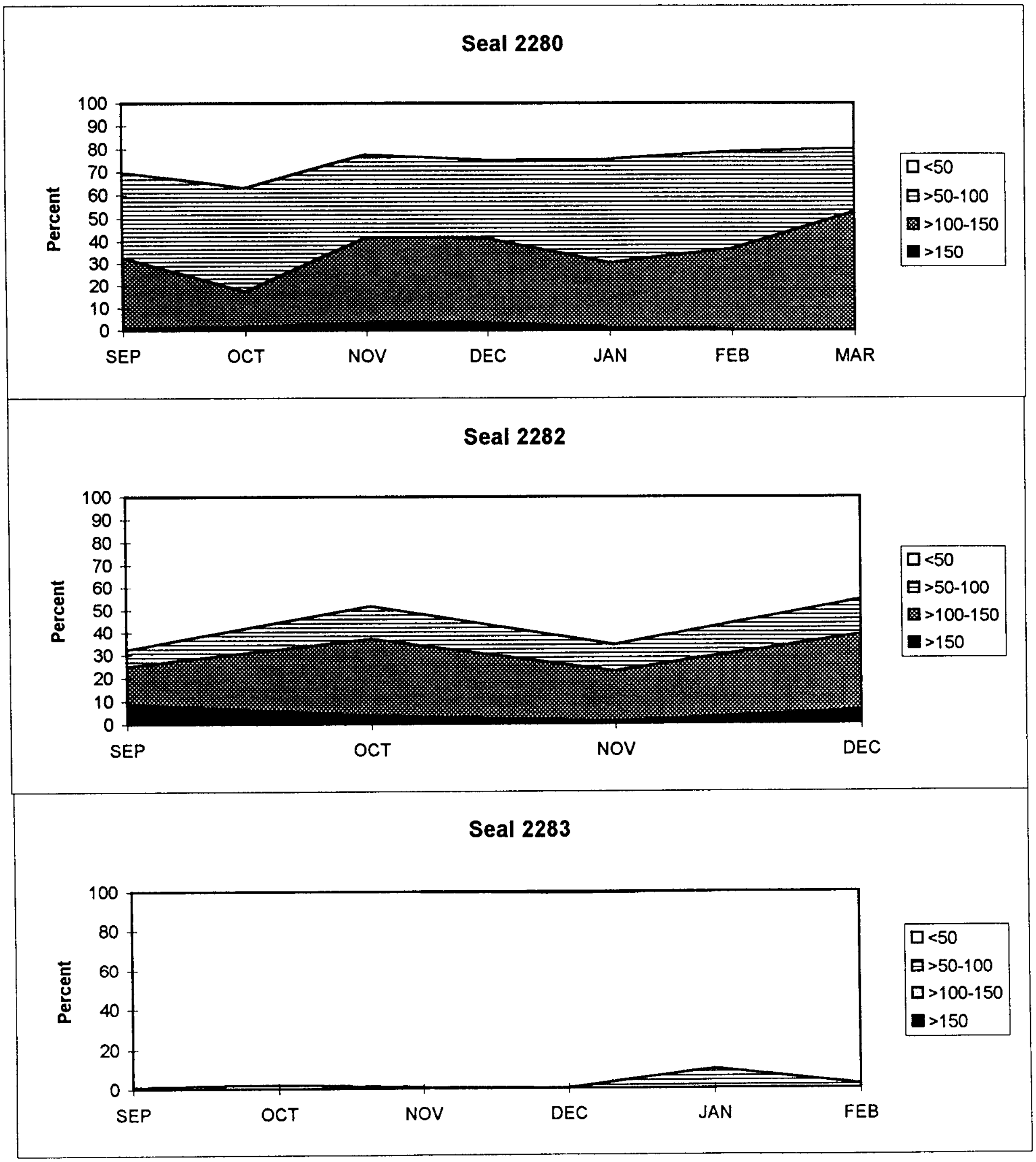


Figure 17. Monthly distribution of dives by depth (m) for six satellite-tagged harbor seals in Prince William Sound, September 1993-July 1994.

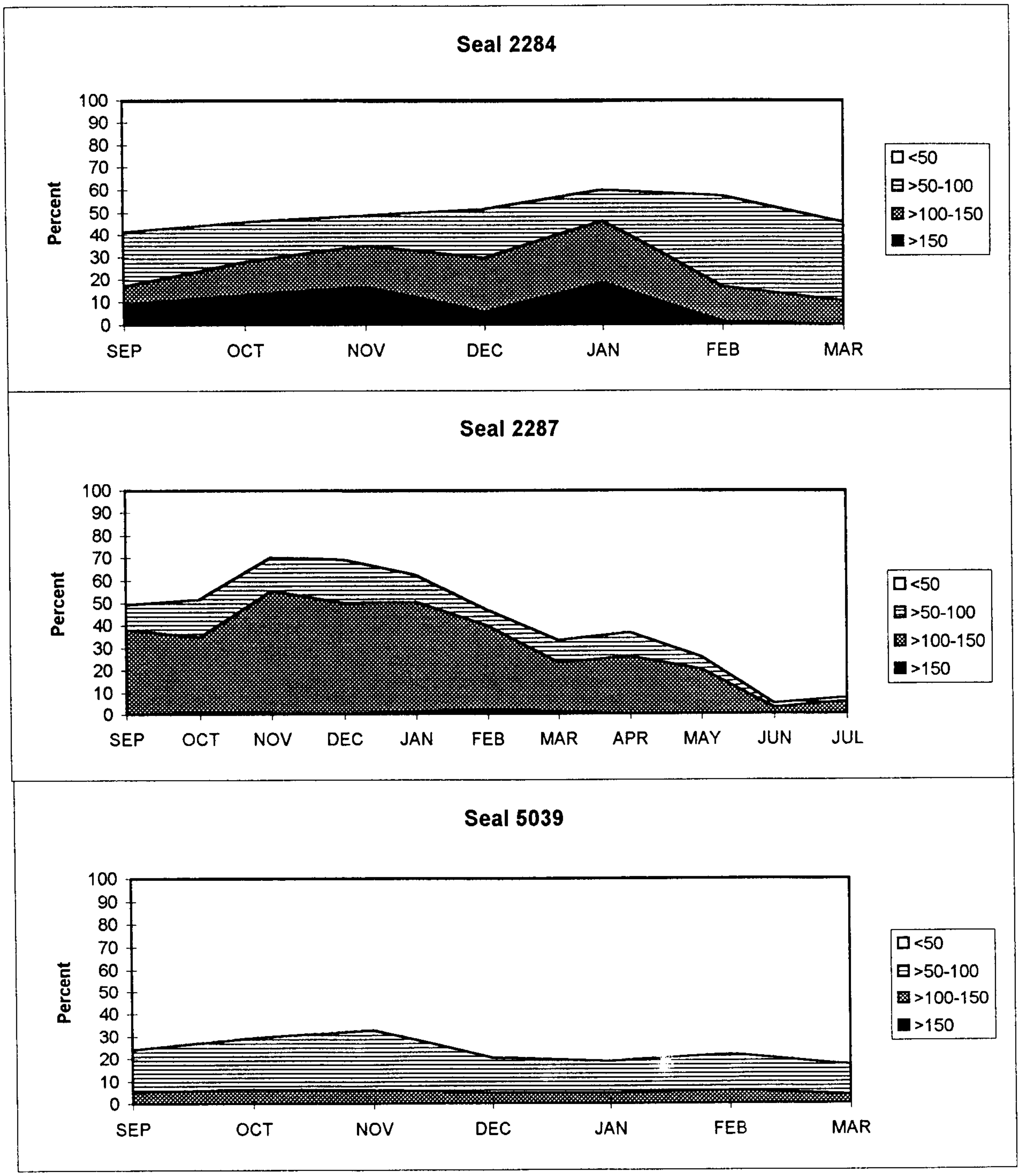


Figure 17. Continued.

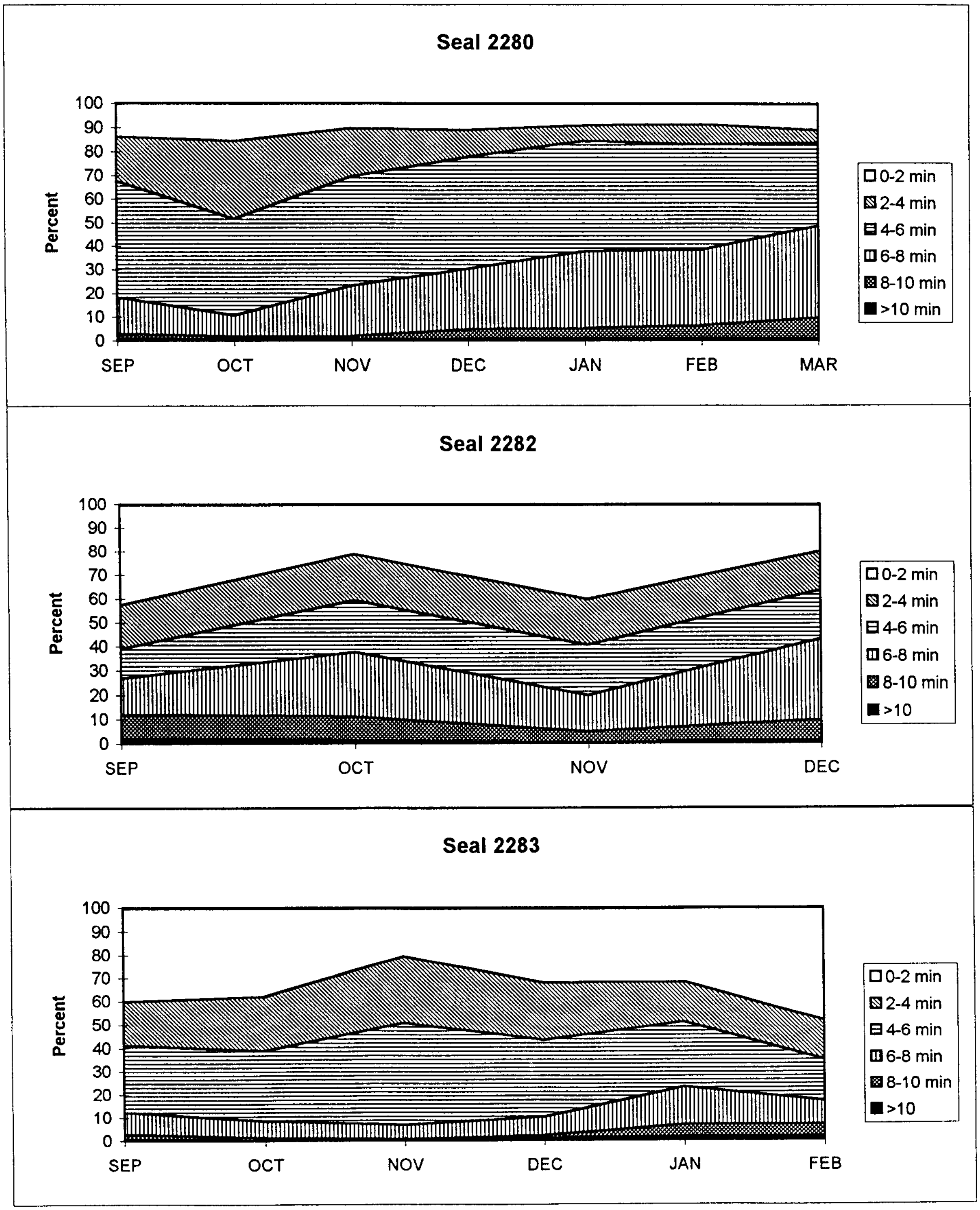


Figure 18. Monthly distribution of dives by duration (minutes) for six satellite-tagged harbor seals in Prince William Sound, September 1993-July 1994.

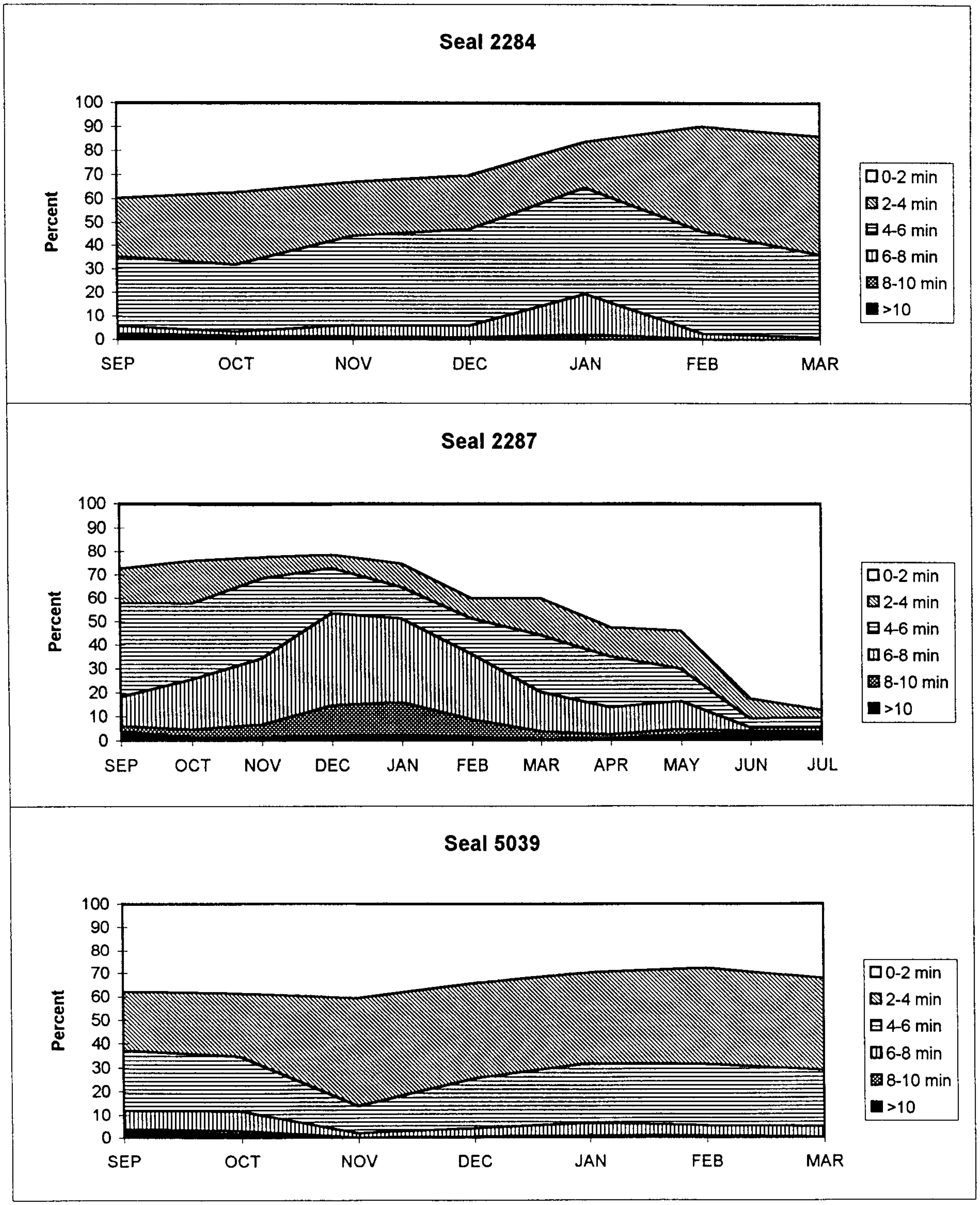


Figure 18. Continued.

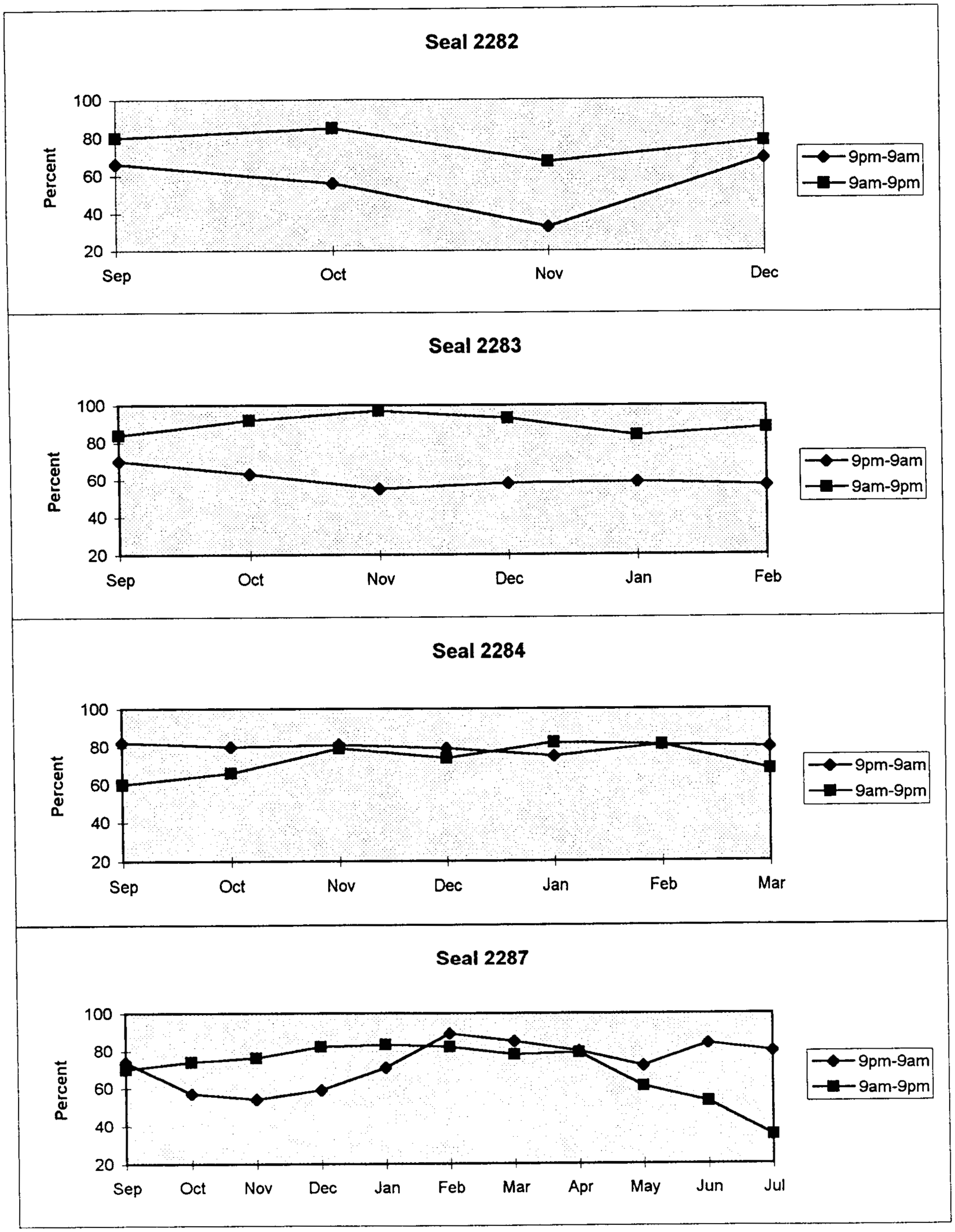
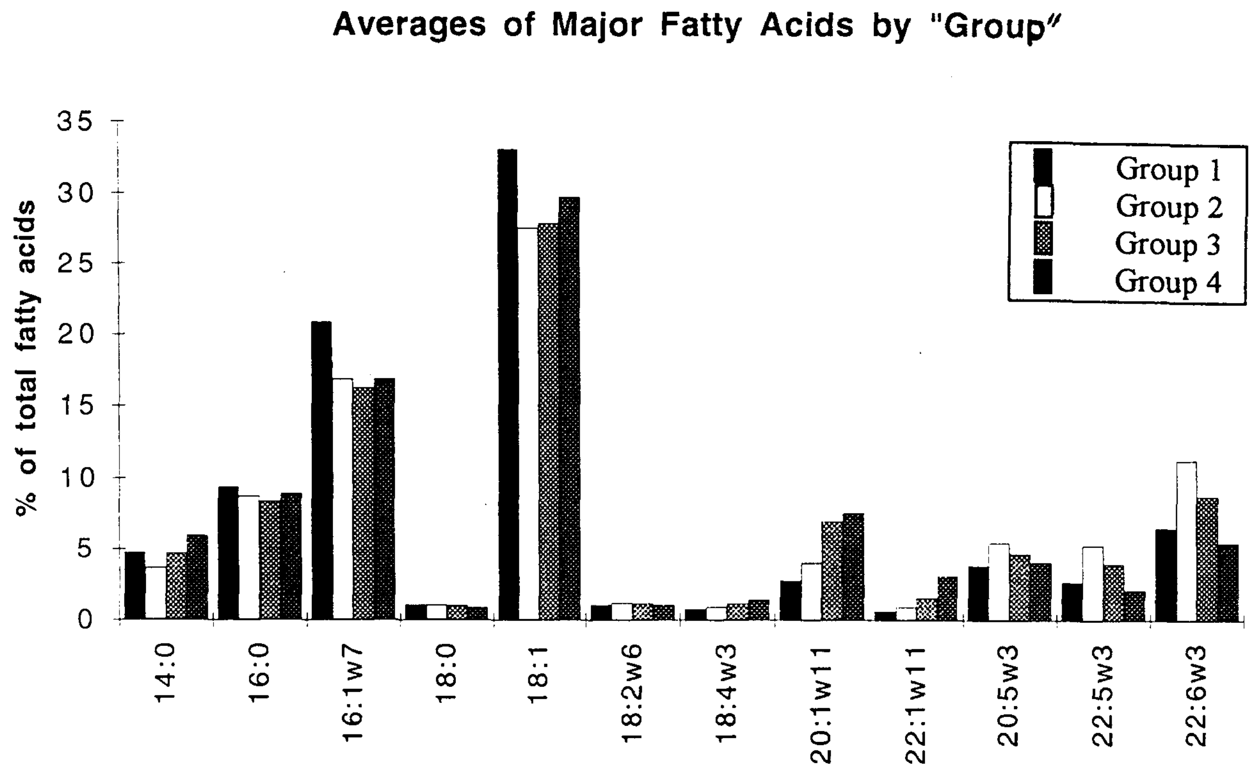


Figure 19. Monthly distribution of the percent of time spent diving for four satellite-tagged harbor seals in Prince William Sound, September 1993-July 1994.



p<	0.001	ns	0.004	ns	0.038	ns	0.001	0.001	0.001	0.001	0.001	0.001
	1≠2,4		1≠2,3,4		1≠2,3		all	1≠2,3,4	1≠3,4	1≠2	1≠2,3	1≠2,3
	2≠4						diff	2≠3,4	2≠4	2≠4	2≠3,4	2≠3,4
	3≠4								3≠4		3≠4	3≠4

Figure 20. Occurrence of 12 types of fatty acids, by group, in blubber from harbor seals sampled in Prince William Sound during 1994.

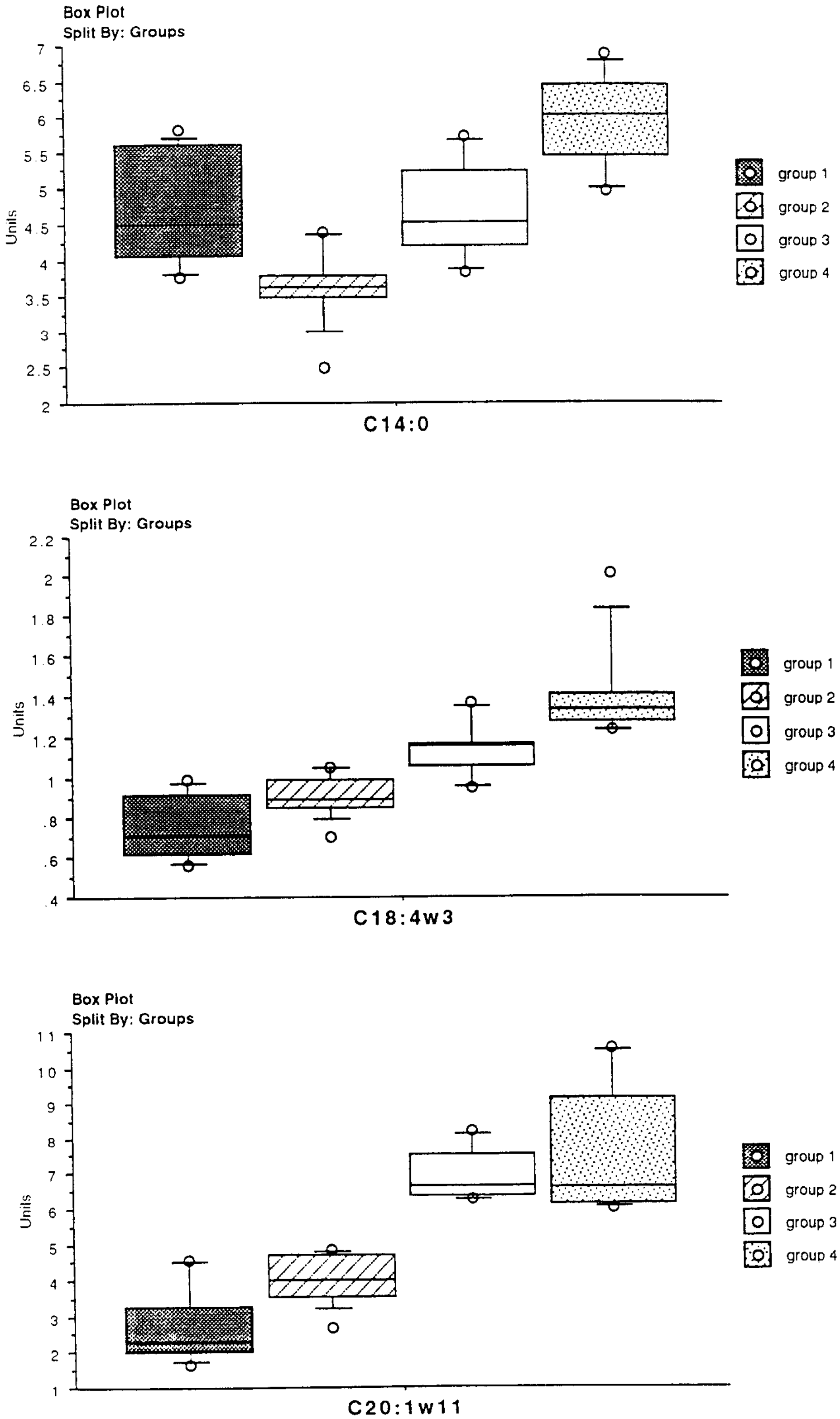
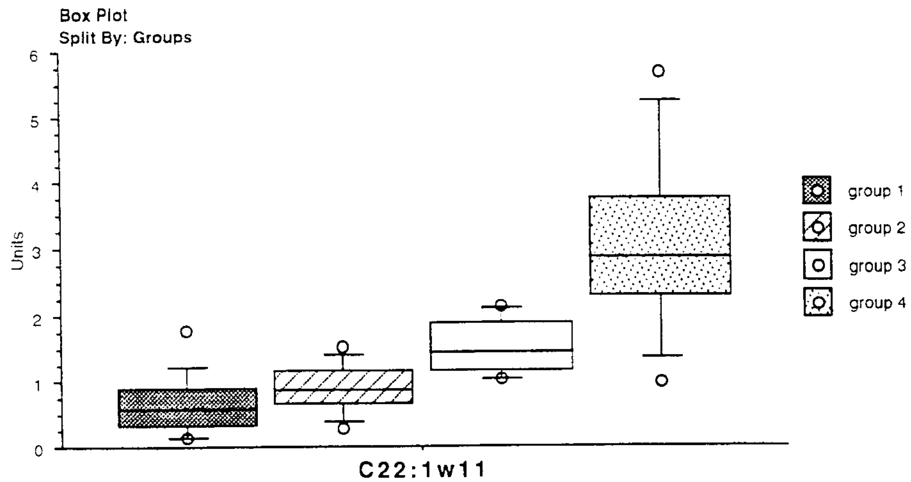
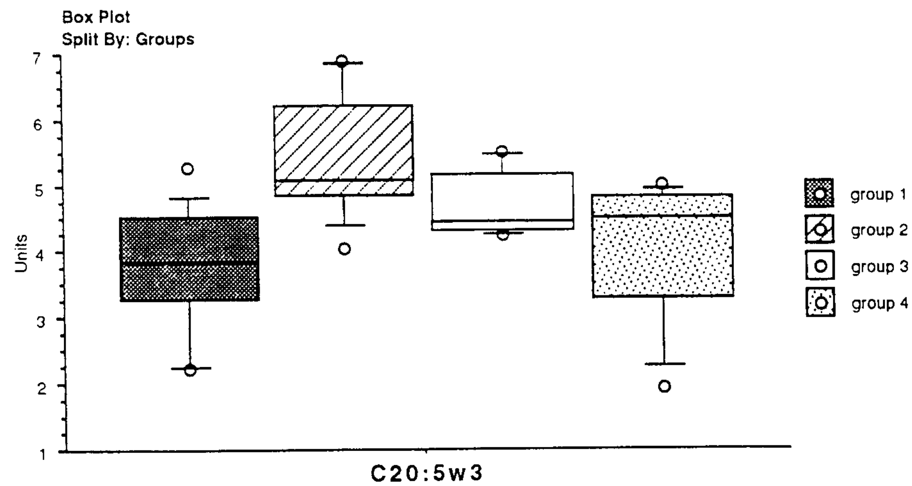


Figure 21. Box plots showing the occurrence of six types of fatty acids, by group, in blubber from harbor seals sampled in Prince William Sound during 1994.





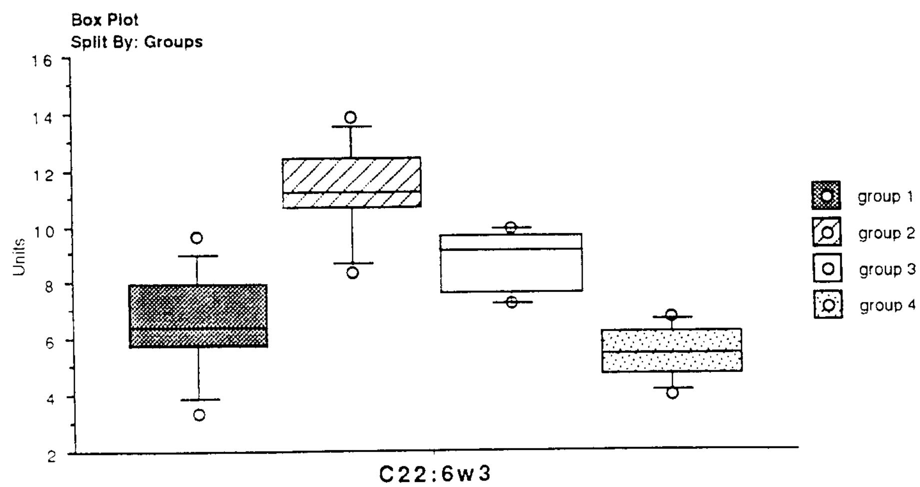


Figure 21. Continued.

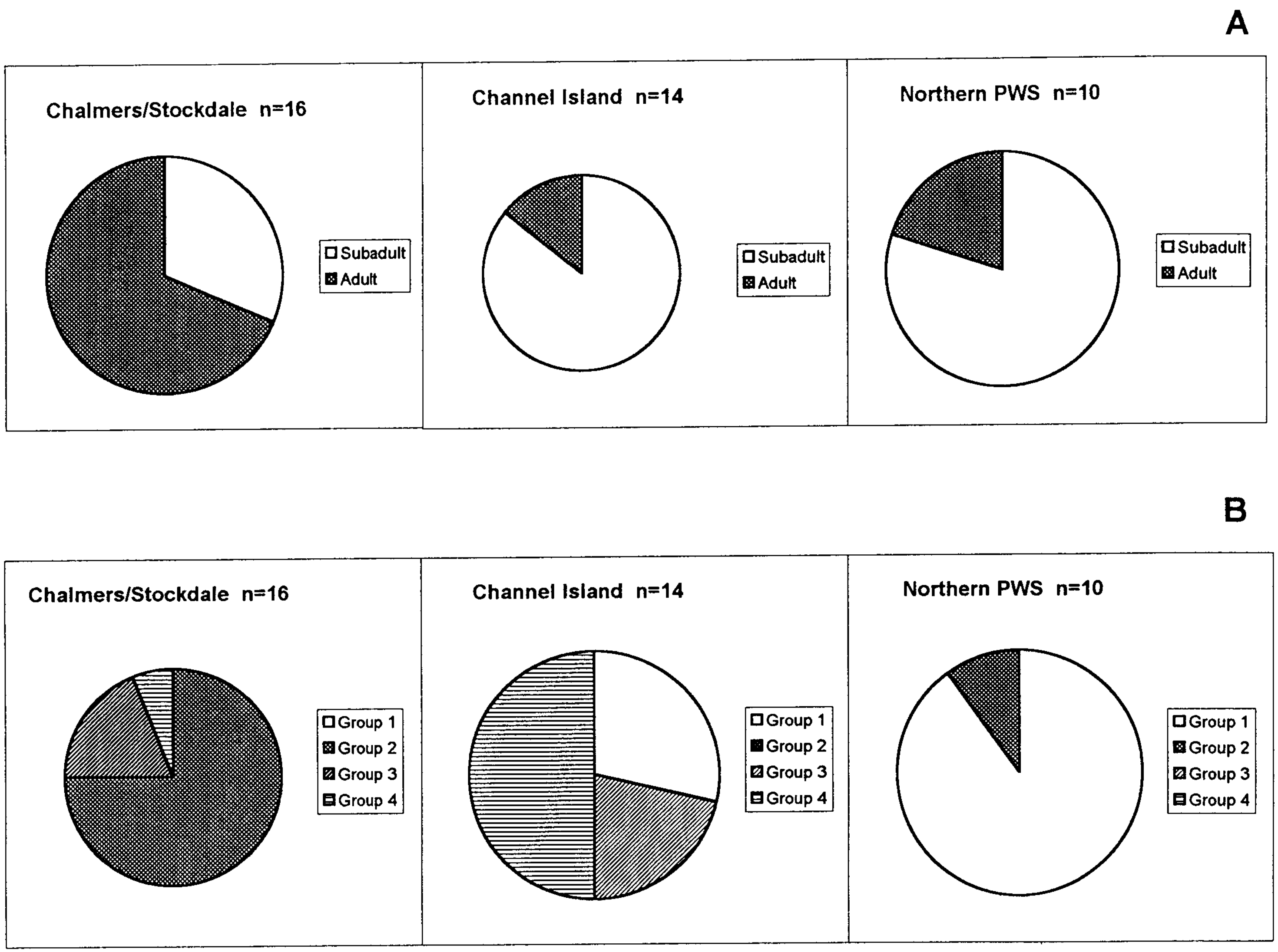


Figure 22. Percent of samples analyzed for fatty acids in three geographical regions of Prince William Sound. A. By age class. B. By fatty acid group

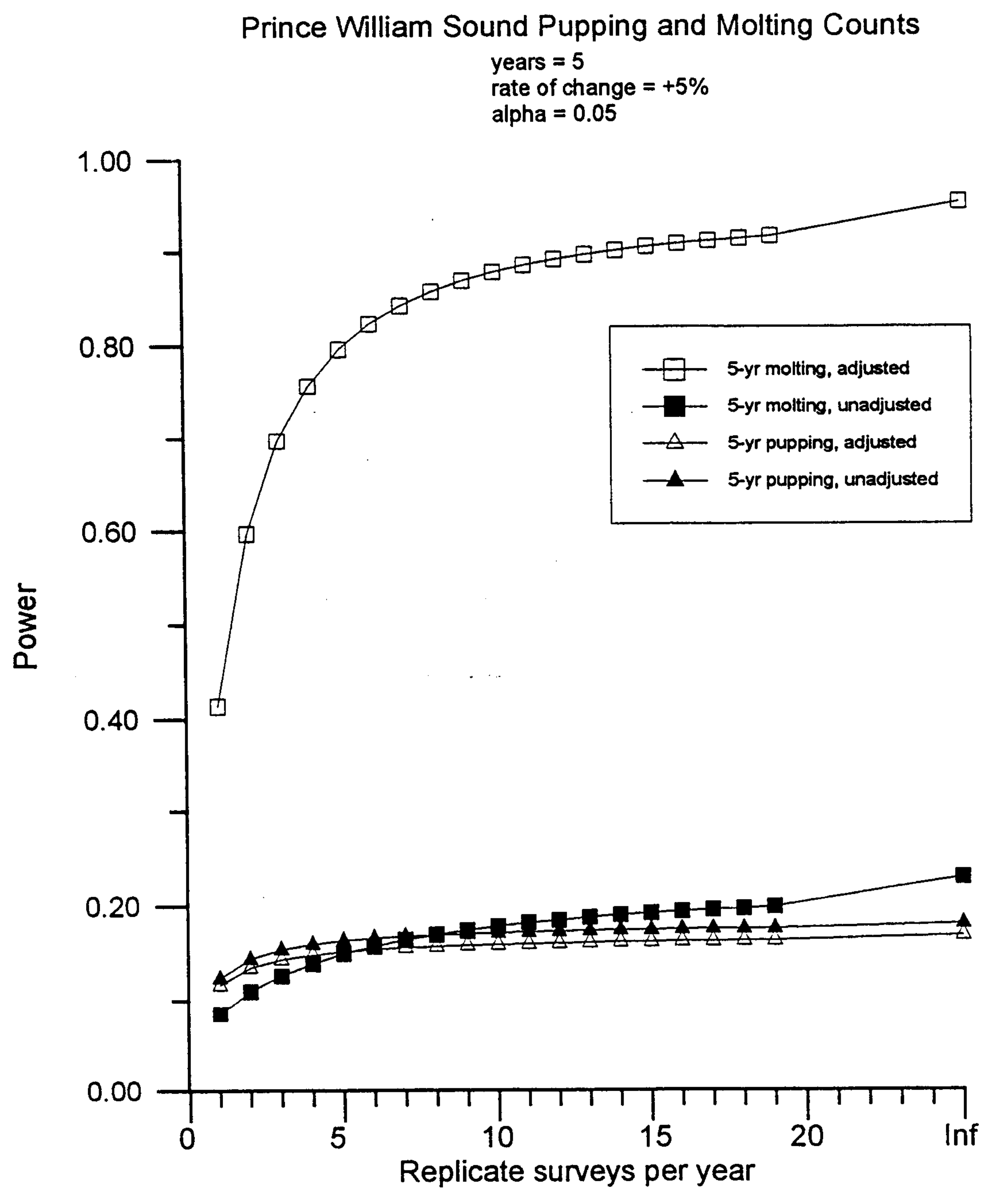


Figure 23. Power analysis for aerial surveys of harbor seals in Prince William Sound based on unadjusted and adjusted counts made during molting and pupping.

Appendix A. Adjusted estimates for the average number of seals at each trend count site during the molting period for each year, 1984 and 1988-1994. The counts are adjusted to 15 August, for the 2- 4 hours before midday time period, and for times from 1.0 to 0.5 hour before or 0 to 0.5 hour after low tide.

Site	1984	1988	1989	1990	1991	1992	1993	1994
1	64	17	0	<1	1	<1	5	0
2	37	17	27	7	14	27	18	11
3	63	58	46	27	28	34	45	65
4	212	1-5	57	90	84	46	81	54
5	43	5	9	1	15	8	2	1
6	136	52	45	27	17	13	20	2
7	17	2	2	5	5	<1	<1	<1
8	56	15	10	12	10	5	2	5
9	33	25	32	27	23	14	11	<1
10	39	23	31	18	10	7	3	0
11	16	6	4	3	<1	<1	<1	0
12	115	48	45	44	39	48	24	42
13	111	40	28	35	25	35	27	32
14	138	101	52	35	34	47	39	48
15	160	95	47	46	64	55	53	48
16	321	203	117	142	106	69	22	71
17	87	59	23	30	25	41	31	29
18	391	118	123	46	101	89	131	73
19	85	71	41	37	15	61	52	32
20	100	100	88	122	105	71	127	83
21	49	64	60	58	45	49	16	37
22	65	45	47	44	27	11	1	7
23	52	15	25	13	20	27	24	45
24	101	91	80	55	54	65	72	38
25	19	54	28	30	51	29	24	44

Appendix B. Percent of 12 fatty acids or fatty acid groups in blubber samples from 40 harbor seals captured in Prince William Sound during 1994.

Seal	14:0	16:0	16:1w7	18:0	18:1	18:2w6	18:4w3	20:1w11	20:5w3	22:1w11	22:5w3	22:6w3
2	5.7	9.7	14.1	1.3	41.7	1.2	0.9	4.5	2.3	1.8	1.4	3.4
3	3.5	10.0	16.6	1.1	24.2	1.0	1.0	3.7	6.2	1.2	5.5	11.5
4	5.0	7.6	20.5	0.7	30.0	0.9	1.4	6.7	5.0	1.0	2.8	6.6
6	4.7	6.6	14.4	0.8	40.1	1.2	1.1	7.5	4.3	1.2	3.9	7.6
7	3.4	8.2	14.7	1.0	25.7	1.2	1.0	4.7	5.9	1.2	6.3	12.6
8	4.2	6.8	19.1	0.7	40.0	1.2	0.9	4.7	4.7	0.7	3.8	8.7
9	3.8	6.0	22.9	0.6	26.8	1.3	1.1	4.8	5.1	0.7	4.2	8.3
10	2.5	4.4	15.2	0.6	35.3	1.5	0.7	4.8	4.0	0.4	6.3	10.9
11	4.4	7.9	14.4	1.1	29.1	1.2	1.2	6.3	5.2	1.7	4.7	9.1
12	6.0	8.0	17.7	0.7	35.4	1.1	1.3	6.0	3.0	2.6	1.4	4.0
13	4.8	8.3	25.1	0.8	24.5	0.9	0.9	4.6	4.3	0.9	2.6	6.5
14	6.9	9.1	12.6	0.8	25.8	1.1	2.0	10.4	4.9	5.7	1.7	5.4
15	6.5	11.9	15.9	1.2	27.1	0.9	1.3	6.1	4.5	3.2	2.5	5.5
16	5.1	7.8	16.5	0.8	35.3	1.1	1.2	7.9	1.9	3.3	1.8	4.9
17	6.1	8.7	15.9	0.8	21.9	1.0	1.4	10.5	4.8	4.3	2.5	5.8
18	5.8	8.9	20.3	0.7	26.7	1.1	1.3	6.6	4.5	2.3	2.5	6.7
19	6.4	9.1	15.5	0.9	35.2	1.0	1.2	6.2	3.6	2.3	1.7	4.6
20	5.6	9.1	18.2	0.9	41.6	1.0	0.7	3.2	2.2	0.9	1.3	3.9
21	5.2	9.1	16.4	1.1	26.3	1.2	1.4	6.8	4.6	2.1	3.1	9.1
22	5.7	11.2	24.7	1.0	26.4	0.8	0.7	3.8	3.7	0.6	2.7	6.2
23	4.2	8.2	16.4	0.9	26.9	1.2	1.1	8.2	4.3	1.9	3.6	9.9
24	5.8	10.8	14.8	1.2	41.8	0.9	0.7	2.9	3.2	1.2	1.6	4.2
25	4.1	11.1	22.9	1.4	23.6	1.0	0.9	2.2	4.5	0.7	4.4	8.0
26	4.5	8.8	19.6	0.9	35.0	1.2	1.0	1.9	4.1	0.6	2.5	7.4
27	3.0	8.2	14.2	1.2	27.3	1.1	0.9	4.1	6.6	0.8	6.5	12.4

Appendix B. Continued.

Seal	14:0	16:0	16:1w7	18:0	18:1	18:2w6	18:4w3	20:1w11	20:5w3	22:1w11	22:5w3	22:6w3
28	3.7	12.6	13.8	1.6	24.2	1.1	0.9	4.1	5.1	1.5	5.6	13.5
29	5.7	11.2	21.6	1.0	25.7	0.9	1.2	6.4	4.2	1.2	2.8	7.2
30	3.6	11.6	15.0	1.4	23.7	1.1	0.9	2.7	6.9	0.9	5.9	13.8
31	4.4	8.3	18.8	1.1	27.6	1.2	1.0	4.7	4.4	1.1	4.3	9.2
32	3.7	11.1	16.1	1.3	23.5	1.1	1.0	3.5	6.9	1.4	5.4	12.2
33	3.7	8.5	18.9	1.1	28.7	1.2	0.9	3.4	5.0	0.7	4.6	10.7
34	3.8	7.1	14.1	1.2	28.0	1.2	0.9	6.4	5.5	1.0	5.6	9.6
35	3.5	8.3	16.0	1.1	29.1	1.2	0.9	3.5	5.4	0.9	5.4	12.2
Tat1	4.6	10.7	17.4	1.6	28.0	1.1	1.0	2.3	5.3	0.6	3.3	8.9
Tat2	5.1	9.1	15.9	1.2	42.5	1.1	0.7	1.7	3.4	0.6	1.8	6.4
Tat3	4.4	11.4	16.0	1.3	26.6	0.9	0.8	4.0	5.1	0.7	4.7	10.8
Tat4	3.8	7.5	26.2	0.7	33.1	1.2	0.6	2.0	3.7	0.1	2.5	6.0
Tat5	3.9	6.8	23.0	0.6	32.5	1.2	0.8	1.8	4.8	0.1	3.2	8.4
Tat6	4.5	9.1	22.2	0.9	34.6	0.9	0.6	2.4	3.3	0.2	2.8	5.8
Tat7	4.1	10.9	24.1	1.1	23.9	0.8	0.6	2.3	4.6	0.4	3.6	9.6