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

Boat-based Population Surveys of Sea Otters (*Enhydra lutris*) in Prince William Sound, Alaska, following the *Exxon Valdez* Oil Spill

Marine Mammal Study 6-6
Final Report

Douglas M. Burn

U.S. Fish and Wildlife Service
Marine Mammals Management
1011 East Tudor Road
Anchorage, Alaska 99503

October 1994

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

Boat-based Population Surveys of Sea Otters (*Enhydra lutris*) in Prince William Sound, Alaska, following the *Exxon Valdez* Oil Spill

Marine Mammal Study 6-6
Final Report

Douglas M. Burn

U.S. Fish and Wildlife Service
Marine Mammals Management
1011 East Tudor Road
Anchorage, Alaska 99503

October 1994

Boat-based Population Surveys of Sea Otters (*Enhydra lutris*)
in Prince William Sound, Alaska, following the *Exxon Valdez* Oil Spill

Marine Mammal Study 6-6
Final Report

Study History: Marine Mammal Study 6 (MM6), titled *Assessment of the Magnitude, Extent and Duration of Oil Spill Impacts on Sea Otter Populations in Alaska*, was initiated in 1989 as part of the Natural Resource Damage Assessment (NRDA). The Study had a broad scope, involving more than 20 scientists over a three year period. Final results are presented in a series of 19 reports that address the various project components.

Abstract: Following the *Exxon Valdez* oil spill, boat-based population surveys of marine birds and sea otters were periodically conducted within Prince William Sound, Alaska, between June 1989 and July 1991. The purpose of this research was to estimate post-spill sea otter density and abundance for comparison with pre-spill data in order to determine the injury to the population. Within the oiled area, sea otter density within shoreline stratum (defined as a 200m-wide strip adjacent to the shore) was 35% lower than the pre-spill density, suggesting a significant oil effect. Sea otter density in the shoreline stratum of unoiled areas was not significantly different than pre-spill density. Declines in shoreline sea otter density between 1989 and 1990 in both oiled and unoiled areas suggested a possible Sound-wide decline in the sea otter population. However, comparison of abundance estimates of all survey strata combined showed that the sea otter population in both oiled and unoiled areas of Prince William Sound were not significantly different between July of 1989, 1990, and 1991. Direct loss to the sea otter population in the immediate aftermath of the spill was estimated to be 2,800 individuals. Population and density estimates were not corrected for the number of otters missed by observers, and may underestimate absolute population and density by as much as 30%.

Key Words: Boat-based surveys, *Enhydra lutris, Exxon Valdez*, oil spill, population estimation, Prince William Sound, sea otter.

Citation: Burn, D. M. 1994. Boat-based population surveys of sea otters (*Enhydra lutris*) in Prince William Sound, Alaska, *Exxon Valdez* Oil Spill State/Federal Natural Resource Damage Assessment Final Report (Marine Mammal Study 6-6), U.S. Fish and Wildlife Service, Anchorage, Alaska.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

As part of the Natural Resources Damage Assessment effort following the *Exxon Valdez* oil spill, boat-based population surveys of marine birds and sea otters were periodically conducted within Prince William Sound, Alaska, between June 1989 and July 1991. The purpose of this research was to estimate post-spill sea otter density and abundance for comparison with pre-spill data in order to determine the injury to the population. Within the oiled area, sea otter density within the shoreline stratum (defined as a 200m-wide strip adjacent to the shore) was 35% lower than the pre-spill density, suggesting a significant oil effect. Sea otter density in the shoreline stratum of unoiled areas was not significantly different than pre-spill density. Declines in shoreline sea otter density between 1989 and 1990 in both oiled and unoiled areas suggested a possible Sound-wide decline in the sea otter population. However, comparison of abundance estimates of all survey strata combined showed that the sea otter population in both oiled and unoiled areas of Prince William Sound were not significantly different between July of 1989, 1990, and 1991. Direct loss to the sea otter population in the immediate aftermath of the spill was estimated to be 2,800 individuals. Population and density estimates were not corrected for the number of otters missed by observers, and may underestimate absolute population and density by as much as 30%.

ACKNOWLEDGEMENTS

I thank the following persons for their assistance in preparation of this report: T. Jennings, B. Boyle, R. Slothower, G. Balogh, and H. Buckholtz provided GIS support. D. Bowden and S. Klosiewski, provided statistical advice. Damage assessment surveys were designed by S. Klosiewski. He and K. Laing served as project coordinators and were instrumental in getting this effort into the field. I also thank D. Irons for providing the pre-spill data set for comparative analysis. I thank B. Ballachey, D. Bowden, T. DeGange, T. Evans, R. Garrott, K. Oakley, and two anonymous reviewers for providing comments on the manuscript.

INTRODUCTION

Within the first few weeks of the 1989 *Exxon Valdez* oil spill, the sea otter quickly became the most vivid symbol of the damage to wildlife in Prince William Sound, Alaska (Batten 1990). With the recovery of hundreds of carcasses, the fact that sea otters suffered considerable injury due to the spill was clear.

Historically, sea otters in Alaska had been commercially exploited from the time of Vitus Bering's voyage of 1741, until they were granted protection under the North Pacific Fur Seal Convention in 1911 (Rotterman and Simon-Jackson 1988). Sea otters were extirpated throughout much of their range, with only a few small remnant populations surviving. The present sea otter population in Prince William Sound is believed to be derived from one such remnant population that persisted in the southwestern portion of the Sound (Lensink 1962). Surveys conducted in the 1960's and 1970's documented the northeastward expansion into unoccupied areas of the Sound (Pitcher 1975). By the mid-1980's, sea otters had recolonized most of the Sound, but likely had not reached carrying capacity in some areas (Irons et al. 1988). At the time of the *Exxon Valdez* oil spill, the size of the Prince William Sound sea otter population was not well known, but was believed to number between 5,000 and 10,000 individuals.

The number of carcasses recovered could only produce a minimal estimate of the injury to the Prince William Sound sea otter population. Carcass recovery rates have been determined, and used to calculate an estimate of total spill-related mortality (Doroff and DeGange ms). Another means of determining the extent of the injury was comparison of pre- and post-spill population estimates. This study reports the results of 9 post-spill sea otter population surveys conducted in Prince William Sound between June 1989 and July 1991, and discusses their implications for injury of the Prince William Sound sea otter population as a result of the spill.

OBJECTIVES

1. Test that differences in sea otter densities are not significantly different between pre- and post-spill surveys in oiled and unoiled areas in Prince William Sound.

2. Estimate the magnitude of any change between pre- and post-spill sea otter population estimates in Prince William Sound.

3. Monitor post-spill sea otter population trends in Prince William Sound.

METHODS

Study Area

The study area consisted of the waters of Prince William Sound, Alaska (Fig. 1). In the southwest portion of the Sound, the study area was bounded by a line extending from Cape Junken eastward to Montague Island. Proceeding eastward, the northern shores of Montague, Hinchinbrook, and Hawkins Islands defined the southernmost extent of the study area.

Prince William Sound contains numerous islands ranging in size from less than $1km^2$ to more than $250km^2$. The shoreline is highly convoluted, with numerous fiords, passes, and bays. Water depths within the study area varied from less that 1 fathom (2m) to more than 475 fathoms (870m).

Sampling Units

The study area was divided into 3 strata: shoreline, coastal, and pelagic (Fig. 2). The shoreline stratum was based on shoreline transects surveyed by Irons et al. (1988) during the summers of 1984 and 1985, and was defined as the 200m-wide strip immediately adjacent to the coastline. Within the study area, Irons et al. (1988) defined 742 shoreline transects with a total area of $822.3km^2$. Shoreline transects were of varying lengths, ranging from groups of rocks or small islands with less than 1km of coastline, to sections of the mainland with over 25km of coastline. The mean transect length was 6.57km; the mean sampled area was $1.11km^2$. Transect endpoints were often located at geographic features such as points of land or other landmarks to facilitate orientation in the field.

This survey was designed to count both marine birds and mammals, and some of the sampling decisions in this survey were made primarily for marine bird considerations. Certain bird species were known to occur in association with coastlines, while others occur further from shore. Thus, waters outside the shoreline stratum were divided into sampling "blocks" based on a 5-minute latitude/longitude grid system. To differentiate these blocks with respect to distance from shore, blocks were stratified into 2 categories: coastal and pelagic. The coastal stratum was comprised of those blocks located immediately adjacent to 1km or more of shoreline, and the pelagic stratum was comprised of those blocks adjacent to less than 1km of shoreline. Where the grid intersected the coastline in such a way as to create an unmanageably small block, adjacent grid cells were pooled together into a longer or wider block. This classification scheme resulted in the creation of 207 coastal and 86 pelagic blocks, with total areas of $4,524km^2$ and $3,637km^2$, respectively.

Within each block, 200m-wide strip transects were systematically placed along north-south meridians located 1' of longitude from the eastern and western block boundaries. The choice of these meridians was made to facilitate simultaneous aerial and boat-based sampling (aerial sampling was a component of NRDA Bird Study 2). For most blocks, these meridians resulted in the placement of 2 transects identified by the block designation followed with an 'E' or 'W' to indicate if the transect was on the east or west side of the block. In some coastal blocks, one of the appropriate meridians may have fallen on land, thus only one transect was placed within the block. For those blocks that consisted of pooled grid cells as described above, a third transect was placed within the block if the appropriate meridian occurred over water. These additional transects were designated with an 'E2' or 'W2' subscript. Due to their intersection with the coastline, coastal transects ranged from hundreds of meters in length to the full 5 nautical mile length of the block. Since pelagic blocks by definition did not significantly intersect the coastline, transects were always paired and ran the entire 5 nautical mile length of the block. The choice of such long transect lengths was also made in consideration of simultaneous aerial and boat-based sampling. Due to logistical constraints, these simultaneous counts were never implemented in the field.

Pre-spill Data

As stated earlier, the shoreline stratum in this study was based on a set of transects originally surveyed for sea otters and birds during the summers of 1984 and 1985 (Irons et al. 1988). Over the course of 2 field seasons (Irons et al. 1988) surveyed virtually all of the available shoreline transects within the Prince William Sound study area (708 of the possible 742 transects). These data served as the pre-spill baseline for comparison with post-spill surveys. Waters beyond the shoreline stratum were not sampled during the pre-spill survey.

Field Methodology

General survey techniques in all post-spill surveys duplicated those of the baseline study of Irons et al. (1988). Watercraft used in this survey were 25' Boston Whalers, with 3 crew members serving equally as operator and observers. Shoreline transects were surveyed from 100m offshore at a cruising speed of 5-10 knots. One observer scanned the water from the vessel up to and including the shoreline, while another observer scanned the water from the vessel seaward an additional 100m. Coastal and pelagic transects were surveyed at a slightly faster cruising speed of 10-15 knots, with two observers, one on each side of the boat, scanning the water from the trackline of the boat outward 100m. In addition, the watercraft operator assisted with observations of animals directly ahead of the vessel. While the vessel was in motion, all marine mammals and birds sighted within transect boundaries were recorded on standardized data sheets.

To insure consistency among years, an observer handbook was written after the first field season to familiarize new field personnel with the survey design and field methods. A transect guide was also developed to help field personnel locate transect endpoints based on geographic features. Surveys during the second and third years of the study used experienced personnel as boat team leaders, and the return of experienced observers was also high.

Survey Dates and Sample Sizes

Three replicates of the survey were conducted in June, July, and August of 1989 to determine if a continued, ongoing effect of the oil spill was occurring. These replicates were repeated during June, July, and August of 1990 for comparison with 1989 results, and to further examine variability within the summer field season. Due to reduced funding levels, a single survey was conducted in July 1991 to allow for comparisons with July 1989 and July 1990 results. July was considered the preferred month to survey for summer seabird populations, minimizing the effect of migration of certain species into or out of the study area. Surveys were conducted in March 1990 and 1991 primarily to collect information on wintering seabird distribution and abundance. Allowing for inclement weather and mechanical failure, approximately 3 weeks were needed to complete each replicate of the survey.

Post-spill surveys were initially conducted during the summer of 1989 as a simple random sample of approximately 25% of all shoreline transects and coastal and pelagic blocks. Due to logistical constraints, only the shoreline stratum was sampled during June 1989. All three strata were sampled in July and August 1989, and on each of the following surveys. Once the initial random sample of transects and blocks was chosen, each successive survey replicated the same sampling units to allow for comparison over time.

To complete surveys during March when daylight is a limiting factor and weather conditions are often less optimal, only a subset of the original set of shoreline transects and coastal and pelagic blocks was sampled. This subset was comprised of approximately 14% of the shoreline transects and coastal blocks. The sample size of pelagic blocks (25) was not reduced during the March surveys. The magnitude of this reduction was based on an estimated time available for the survey of approximately 10 complete sampling days.

Twenty-five shoreline transects were added to the sample beginning with the fifth survey in June 1990, increasing the proportion sampled from 25% to 29%. These additional transects were randomly selected from the area in western Prince William Sound that was surveyed by Irons et al. (1988) in 1984. The transects were added to increase sample size in the portion of the spill area for which there was recent (e.g. 1984) pre-spill data on marine bird and mammal abundance. Sample sizes of the coastal and pelagic strata were not increased.

Oiling Classification

Classification of sampling units as oiled or unoiled was based on Alaska Department of Environmental Conservation overflight data collected at the time of the spill (ADEC 1989). Aerial observations were used to create a GIS coverage depicting the movement of oil over the surface of the water. Since sea otters are highly mobile animals, otters inhabiting areas adjacent to the path of the oil could have encountered the slick during their normal movement patterns. Given the mobility of sea otters, and uncertainty as to the exact geographical extent of the surface oiling, a buffer zone of 5km was added to the oiled zone boundary to represent an area within which otters might have been affected by oil (Fig. 3). Shoreline transects, and coastal and pelagic blocks with any area located within this buffer zone (i.e. within 5km of surface oil) were classified as oiled.

Analytical Methods

After the first 3 surveys conducted in the summer of 1989, it was recognized that the pelagic stratum was not homogeneous with respect to sea otter distribution. Sea otters are benthic feeders that forage primarily in shallow subtidal areas (Riedman and Estes 1990). In Prince William Sound, otters have been observed to forage at mean depths of 7m to 28m at various study sites (Garshelis 1983). Some pelagic blocks were located directly over shallow water, while others were located several kilometers distant. The pelagic stratum was therefore post-stratified into pelagic nearshore and pelagic offshore strata, based on distance from the 20m bathymetric contour (contours in digital format for Prince William Sound were available in 20m increments). The cutoff distance between the pelagic nearshore and pelagic offshore strata was 5km from the 20m contour. The resulting areas of the pelagic nearshore and pelagic offshore strata were 2,450km^2 and 1,187km^2, respectively. Under this new stratification, the pelagic nearshore strata had characteristics similar to the coastal strata (relatively close to shore and/or shallow water). However, these strata could not be pooled since the initial random samples were drawn separately from the coastal and pelagic strata.

Sea otter density and abundance estimates for each survey strata were calculated using ratio estimator techniques (Cochran 1977).

Shoreline sea otter densities were calculated as a ratio:

$$R=\frac{\Sigma y_i}{\Sigma x_i} \qquad [1]$$

where: R = shoreline sea otter density
y_i = number of sea otters within shoreline transect *i*
x_i = area of shoreline transect *i* in km^2

Standard error of this ratio was calculated as:

$$s(R)=\frac{1}{\bar{x}}\sqrt{\frac{\Sigma(y_i-Rx_i)^2}{n(n-1)}\frac{N-n}{N}} \qquad [2]$$

where: $s(R)$ = standard error of R
N = total number of shoreline transects
n = number of sampled shoreline transects

The ratio estimate of shoreline sea otter population was:

$$\hat{Y}_R=RX \qquad [3]$$

where: $\hat{Y}_R$ = ratio estimate of shoreline sea otter population
X = total area of all shoreline transects in km^2

The standard error of this estimate was calculated as:

$$s(\hat{Y}_R)=s(R)X \qquad [4]$$

where: $s(\hat{Y}_R)$ = standard error of the ratio estimate $\hat{Y}_R$

Sea otter densities were calculated within each coastal, pelagic nearshore, and pelagic offshore block as:

$$r_i=\frac{\Sigma y_t}{\Sigma x_t} \qquad [5]$$

where: r_i = sea otter density for survey block *i*
y_t = number of sea otters within transect(s) for survey block *i*
x_t = area of transect(s) sampled within survey block *i* in km^2

Otter densities were calculated for the coastal, pelagic nearshore, and pelagic offshore strata as:

$$R=\frac{\Sigma x_i r_i}{\Sigma x_i} \quad [6]$$

where: R = sea otter density in coastal/pelagic strata

x_i = total area of sampled survey block i in km^2

The effect of this equation is to weight the individual survey block densities by the area of the block (similar to a weighted mean statistic).

The standard error of this ratio was calculated as:

$$s(R)=\frac{1}{\bar{x}_i}\sqrt{\frac{\Sigma(r_i x_i - R x_i)^2}{n(n-1)}} \quad [7]$$

where: s(R) = standard error of R

n = number of sampled coastal/pelagic blocks

Estimates of coastal, pelagic nearshore, and pelagic offshore sea otter population size were calculated as:

$$\hat{Y}_R=RX \quad [8]$$

where: $\hat{Y}_R$ = ratio estimate of coastal/pelagic sea otter population

X = total area of all coastal/pelagic habitat in km^2

Standard error of the estimated coastal/pelagic population size was calculated as:

$$s(\hat{Y}_R)=s(R)X \quad [9]$$

where: $s(\hat{Y}_R)$ = standard error of estimate $\hat{Y}_R$

Abundance estimates for the entire Prince William Sound study area were calculated by summing the estimates and associated variances for each strata. For the summer of 1989 and 1990 field seasons, density and abundance estimates were also calculated using the mean otter count per transect from the June, July, and August surveys of that year.

Comparisons between pre- and post-spill shoreline sea otter density estimates were made with a t-test of the form:

$$t = \frac{R_2 - R_1}{V(R_2 - R_1)} \quad [10]$$

where: R_1 = pre-spill density estimate
R_2 = post-spill density estimate
$V(R_2-R_1)$ = variance of the difference between density estimates

Degrees of freedom for this test were (n-1) for the smaller of the two sample sizes. A similar t-test was used to compare sea otter density estimates in the coastal and nearshore pelagic strata between oiled and unoiled areas.

Comparisons between post-spill sea otter abundance estimates (all strata combined) were made with a t-test of the form:

$$t = \frac{\hat{Y}_2 - \hat{Y}_1}{V(\hat{Y}_2 - \hat{Y}_1)} \quad [11]$$

where: $\hat{Y}_1$ = abundance estimate at time 1
$\hat{Y}_2$ = abundance estimate at time 2
$V(\hat{Y}_2-\hat{Y}_1)$ = variance of the difference between abundance estimates

Effective degrees of freedom were calculated for each abundance estimate according to Satterthwaite's approximation (Satterthwaite 1946) as cited in Cochran (1977). Degrees of freedom for the t-test were (n-1) for the smaller of the two samples.

RESULTS

Survey Effort and Sea Otter Counts

Over the course of 9 post-spill surveys, we sampled a total of 2,639 transects. The complete database contains over 78,000 records of seabird and marine mammal sightings. Of these, 4,791 were sea otter sightings, totalling 6,469 individuals.

The majority of sea otters counted were observed within the shoreline stratum Table 1). Counts within the coastal and pelagic nearshore strata were much lower and more variable. With the exception of one sea otter sighted during the July 1990 survey, no otters were observed in the pelagic offshore stratum. For this reason, density and abundance estimates for the pelagic offshore stratum were exluded from the analysis.

Sea Otter Densities

As expected based on the numbers of sea otters counted, observed sea otter densities were highest in the shoreline stratum, followed by the coastal and pelagic nearshore strata (Table 2).

Since the pre-spill surveys of Irons et al. (1988) were conducted over the course of a longer field season (May - August), mean summer shoreline density values were used for comparison. In the unoiled area, summer 1989 shoreline sea otter density was 14% higher than pre-spill density. This difference was not statistically significant ($t=0.941$, $df=68$, $p=0.35$). In the oiled area, shoreline sea otter density declined approximately 35% during the same interval ($t=-4.622$, $df=117$, $P<0.001$). Surveys conducted in the summer of 1990 showed further declines in shoreline sea otter density in the oiled area to 54% below the pre-spill value. Shoreline otter density in unoiled areas also declined during the same period between 1989 and 1990. Mean summer 1990 density in the unoiled area was 28% lower than the pre-spill density ($t=-2.779$, $df=77$, $p=0.007$). Shoreline sea otter density within both oiled and unoiled areas did not appear to have changed between 1990 and 1991. With the exception of the July 1990 survey, shoreline otter densities in the oiled area were consistently lower than those in the unoiled areas of Prince William Sound.

Within the coastal stratum, sea otter densities observed during post-spill surveys in June, July, and August were consistently higher in the unoiled area. The difference was significant at the $p<0.05$ level for all but the July 1990 survey. Density estimates in the pelagic nearshore stratum were not significantly different between oiled and unoiled areas.

Sea Otter Abundance

Although sea otter densities were lower in coastal and nearshore pelagic strata than in the shoreline stratum, given their large total areas, these strata contained a considerable number of otters (Table 3). In some instances, these strata accounted for over 50% of the total estimated population (Table 4). The proportion of otters within each of the three survey strata varied from survey to survey. In some instances, changes in density within one stratum were offset by changes in other strata. For this reason, monitoring the sea otter population over the course of this study can best be done by comparisons between abundance estimates of all survey strata combined
(Fig. 4). Since July was the only month we surveyed all strata in all years, comparisons between these data points were used to assess population trends following the spill.

Within the oiled area, the July 1990 estimate was 654 less otters than the July 1989 estimate (2,165 vs. 2,819). Given their large variances, the estimates were not significantly different ($t= -0.9$, $df=124$, $p=0.37$). The July 1991 abundance estimate for the oiled area was virtually identical to the July 1990 estimate (2,165 vs. 2,149). Within the unoiled area, the July 1990 estimate was 1,110 fewer otters than the July 1989 estimate (4,312 vs. 5,422).

These estimates were not significantly different ($t= -0.58$, $df=34$, $p=0.57$). Similar to the oiled area, the July 1990 and 1991 estimates were almost identical (4,312 vs. 4,360).

DISCUSSION

Based on comparisons of pre-spill and summer 1989 survey data, the 35% decline in shoreline sea otter density within the oiled area suggested a significant first-year effect of the oil spill on the Prince William Sound sea otter population. This result is not surprising, given that over 400 sea otter carcasses had been retrieved from Prince William Sound prior to the first post-spill survey in June 1989 (DeGange and Lensink 1990). Other studies suggested that the number of carcasses recovered may have represented only 20% of the total mortality (Doroff and DeGange ms). Based on 424 carcasses recovered, an estimated 20% carcass recovery rate, and 89 otters that died in rehabilitation centers, Doroff and DeGange (ms) estimated an acute loss of 2,209 sea otters from Prince William Sound due to the spill.

Further declines in shoreline sea otter density within the oiled area between 1989 and 1990 suggested a continuing oil effect. However, this decline was mirrored by a decline in shoreline sea otter density within unoiled areas of the Sound. Was there a Sound-wide decline in the sea otter population between the summers of 1989 and 1990? Comparison of abundance estimates of all survey strata combined for July 1989 and July 1990 were not statistically significantly different in either the oiled or unoiled areas. Due to the large variance of the abundance estimates, changes in the sea otter abundance, if real, would have had to be very large to be detected as significant with this survey design.

Other damage assessment studies suggested an ongoing effect of the oil spill on sea otters in Prince William Sound. The age-class structure of dying sea otters, based on carcasses recovered during the spill year (defined as 1989) and post-spill (defined as 1990 and 1991) within the oiled area was significantly different from the pre-spill age-class structure (Monson ms). Specifically, the proportion of "prime-age" animals (2-8 years old) in the spill year and post-spill samples was higher than that observed pre-spill. This result suggested that some abnormal mortality had occurred within the oiled area beyond the first year of the spill.

Reasons for a possible decline in the sea otter abundance in the unoiled areas of the Sound may be less obvious. Results of radio-telemetry studies conducted to monitor the fate of sea otters released back into the wild from the rehabilitation centers indicated that these individuals exhibited relatively low survivorship when compared to radio-implanted otters from other study groups (Monnett et al. 1990). Furthermore, following the release of these rehabilitated otters, other study groups of otters in eastern Prince William Sound (an unoiled area) that had been radio-implanted prior to the spill also exhibited reduced survivorship (Monnett and Rotterman 1993). Monnett and Rotterman (1993) have suggested that the release of rehabilitated otters deleteriously affected sea otters in eastern Prince William

Sound, perhaps through the introduction of disease, resulting in unusually high mortality in the wild sea otter population.

The variability in the proportion of sea otters within the shoreline stratum among surveys adds an element of uncertainty to the use of shoreline density values as an index of the population. However, it seems unlikely that the 35% decline in shoreline sea otter density in the oiled area between the pre-spill surveys and the summer of 1989 was due to a redistribution of otters among strata. If one were to assume that the net loss of otters in the shoreline stratum in the oiled area was offset by an increase in the coastal and/or nearshore pelagic strata (as may have been the case in the unoiled areas between the summers of 1989 and 1990), it would require the pre-spill abundance of these strata to have been almost zero.

Sea otter density within the coastal stratum of the oiled area was significantly lower than in the unoiled areas during the post-spill surveys. Lacking pre-spill data for all but the shoreline stratum, there is no way to determine if this difference represents injury due to the spill, or merely a reflection of differences in habitat and/or population status between the two areas. However, if sea otter densities within the coastal stratum were homogeneous throughout the Sound prior to the spill, this difference between oiled and unoiled coastal strata would represent the loss of a considerable number of otters from the oiled coastal stratum. Alternatively, this difference could also have been the result of a shift in otter distribution. Continued monitoring of the sea otter population within the coastal stratum of the oiled area may eventually provide an indication of what the pre-spill density may have been.

Accepting that the decline in shoreline sea otter density between pre-spill and mean summer 1989 estimates represented a significant oil effect, results of studies on sighting probability, carcass recovery rates, and the age structure of the recovered carcasses were combined with these survey data to calculate an estimate of the initial first-year injury to the Prince William Sound sea otter population (Garrott et al. 1993). This exercise produced a loss estimate of approximately 2,800 sea otters for Prince William Sound. This result is comparable to the estimate of 2,209 otters lost based on carcass recovery rates (Doroff and DeGange ms).

All estimates of sea otter density and abundance presented in this report are uncorrected for the fraction of otters that may have been missed by the observers. A pilot study of sea otter sightability conducted concurrently with the August 1990 survey (Udevitz et al. ms.), found that as few as 70% of the otters in surveyed shoreline transects were detected by boat-based observers. However, the sample size was small (n=22) and the authors cautioned against a broad application of their results. I have therefore not adjusted the estimates of otter density and abundance for undetected otters. All estimates presented in this report should therefore be considered conservative.

The long-term effects of the spill on sea otters in the western portion of Prince William Sound are unknown. Two key factors that will influence potential long-term effects on sea otters are the impact of the spill on the populations of sea otter prey items (primarily mussels and clams), and continued exposure of sea otters to hydrocarbons through their prey. Either of these factors could have a profound impact on the recovery of the sea otter population in the oiled area of the Sound.

Continued monitoring of the Prince William Sound sea otter population will yield post-spill population trends, but due to the uncertainty involved with using shoreline sea otter abundance as an index of the population, the issue of recovery may be difficult to address. A common limitation of many of the NRDA studies was the quality of available pre-spill data (Spies 1993). Study design, methodology, and the amount of time between pre- and post-spill data points are all potential sources of uncertainty. While it was a relatively easy matter in this study to replicate the sampling methodology of the shoreline stratum of Irons et al. (1988) there is no way to compensate for lack of pre-spill data in other strata. While sea otter density within the shoreline stratum may not be an ideal index of the total population, it is the only statistic available for comparison with a pre-spill value. An increase in shoreline sea otter density within the oiled area accompanied by proportional increases in the coastal and nearshore pelagic strata may indicate a real increase in the population rather than redistribution, and may be the best means of gauging recovery of the population.

To improve the precision of abundance estimates, modifications to the survey design are necessary. Keeping the shoreline stratum intact to allow for comparison with pre-spill data, I suggest a redesign of the coastal and pelagic strata with a more biologically meaningful basis. For sea otters, proximity to shallow water feeding areas should be a useful criterion. Use of a geographic information system (GIS) with bathymetric data layers would aid in this objective. Sampling units (blocks) within these areas should be smaller than those of the current design, and have their transects placed parallel to one another, oriented perpendicular to the general direction of the coastline. The current survey design samples a relatively small proportion (approximately 2%) of the total area of the coastal and pelagic strata. An increase in the sample sizes in these strata would likely reduce the variance of the estimates. This could be accomplished by extending the survey window beyond the present 3-week period, or adding additional survey vessels. Based on the results from the pelagic offshore stratum, it would seem that this area of the Sound would not need to be sampled for sea otters.

CONCLUSIONS

Shoreline sea otter densities in the unoiled area increased 14% between pre-spill surveys conducted in 1984-1985 and 1989, while densities in the oiled area declined 35%. The mean summer 1989 density estimate in the oiled area was significantly lower than pre-spill density. Based on these and related data, a cooperative effort to quantify total injury to the Prince William Sound sea otter population estimated that approximately 2,800 otters were initially killed by the spill. Shoreline sea otter densities from additional surveys conducted in

June, July, and August 1990 suggested a decline between 1989 and 1990 in both oiled and unoiled areas of the Sound. However, abundance estimates of all survey strata combined for these areas were not significantly different between July 1989, 1990, and 1991. As a measure of recovery, the population trend of all strata combined should be considered along with future comparisons with pre-spill shoreline sea otter density within the oiled area.

LITERATURE CITED

Alaska Department of Environmental Conservation. 1989. *Exxon Valdez* oil spill: cumulative oiling on water through June 20, 1989. ARC/INFO Data Files.

Batten, B. T. 1990. Press interest in sea otters affected by the T/V *Exxon Valdez* oil spill: a star is born. Pages 32-40 In Sea Otter Symposium: Proceedings of a symposium to evaluate the response effort on behalf of sea otters after the T/V *Exxon Valdez* oil spill into Prince William Sound. Anchorage, Alaska, 17-19 April 1990. K. Bayha and J. Kormendy, eds. U.S. Fish & Wildlife Service Biological Report 90(12).

Cochran, W. G. 1977. Sampling Techniques. John Wiley and Sons, Inc., New York, N.Y. 428pp.

DeGange, A. R., and C. J. Lensink. 1990. Distribution, age, and sex composition of sea otter carcasses recovered during the response to the T/V *Exxon Valdez* oil spill. Pages 124-129 In Sea Otter Symposium: Proceedings of a symposium to evaluate the response effort on behalf of sea otters after the T/V *Exxon Valdez* oil spill into Prince William Sound. Anchorage, Alaska, 17-19 April 1990. K. Bayha and J. Kormendy, eds. U.S. Fish & Wildlife Service Biological Report 90(12).

Doroff, A. M., and A. R. DeGange. ms. Experiments to determine drift patterns and rates of recovery of sea otter carcasses following the *Exxon Valdez* oil spill. Marine Mammal Study No. 6. Final Report. U.S. Fish and Wildife Service. Anchorage, Alaska.

Garrott, R. A., L. L. Eberhardt, and D. M. Burn. 1993. Some impacts of *T/V Exxon Valdez* oil spill on the Prince William Sound sea otter population. Marine Mammal Science. 9(4):343-359.

Garshelis, D. L. 1983. Ecology of sea otters in Prince William Sound, Alaska. Ph.D. thesis, University of Minnesota, Minneapolis, MN. 321pp.

Irons, D. B., D. R. Nysewander, and J.L. Trapp. 1988. Prince William Sound sea otter distribution in relation to population growth and habitat type. U.S. Fish and Wildlife Service. Anchorage, Alaska. Unpubl. report. 31pp.

Lensink, C. J. 1962. The history and status of sea otters in Alaska. Ph.D. thesis, Purdue University, Lafayette, IN. 186pp.

Monnett, C., L. M. Rotterman, C. Stack, and D. Monson. 1990. Postrelease monitoring of radio-instrumented sea otters in Prince William Sound. Pages 400-409 In Sea Otter Symposium: Proceedings of a symposium to evaluate the response effort on behalf of sea otters after the T/V Exxon Valdez oil spill into Prince William Sound. Anchorage, Alaska, 17-19 April 1990. K. Bayha and J. Kormendy, eds. U.S. Fish & Wildlife Service Biological Report 90(12).

Monnett, C., and L. M. Rotterman. 1993. The efficacy of the T/V *Exxon Valdez* oil spill rehabilitation program and the possibility of diseas introduction into recipient sea otter populations. Paper presented at the *Exxon Valdez* Oil Spill Symposium. Anchorage, Alaska, February 2-5, 1993.

Monson, D. H. ms. Age distributions of sea otters dying in Prince William Sound, Alaska, following the *Exxon Valdez* oil spill. Marine Mammal Study No. 6. Final Report. U.S. Fish and Wildife Service. Anchorage, Alaska.

Pitcher, K. W. 1975. Distribution of sea otters, Steller sea lions, and harbor seals in Prince William Sound, Alaska. Division of Game, Alaska Dept. of Fish and Game. 76pp.

Riedman, M. L., and J. A. Estes. 1990. The sea otter (*Enhydra lutris*): behavior, ecology, and natural history. U.S. Fish and Wildlife Service, Biological Report 90(14). 126pp.

Rotterman, L. M., and T. Simon-Jackson. 1988. Sea Otter (*Enhydra lutris*). In Selected Marine Mammals of Alaska: Species Accounts with Research and Management Recommendations. J. W. Lentfer, editor. Marine Mammal Commission, Washington, D. C.

Spies, R. B. 1993. So why can't science tell us more about the effects of the *Exxon Valdez* oil spill? Paper presented at the *Exxon Valdez* Oil Spill Symposium. Anchorage, Alaska, February 2-5, 1993.

Satterthwaite, F. E. 1946. An approximate distribution of estimates of variance components. Biometrics 2:110-114.

Udevitz, M. S., J. L. Bodkin, and D. P. Costa. ms. Sea otter detectability in boat-based surveys of Prince William Sound, Alaska. Marine Mammal Study No. 6. Final Report. U.S. Fish and Wildife Service. Anchorage, Alaska.

Table 1. Sample sizes and numbers of sea otters counted in oiled and unoiled areas of Prince William Sound, Alaska before and after the *Exxon Valdez* oil spill. Pre-spill values are from Irons et al. (1988) data. Sample size in the shoreline stratum is the number of shoreline transects surveyed; in the coastal and pelagic nearshore strata, sample size is the number of blocks surveyed.

	Oiled Areas						Unoiled Areas					
	Shoreline		Coastal		Pelagic Nearshore		Shoreline		Coastal		Pelagic Nearshore	
Survey Date	Sample Size	Otter Count	Sample Size	Otter Count	Sample Size	Otter Count	Sample Size	Otter Count	Sample Size	Otter Count	Sample Size	Otter Count
1984-1985	423	2191					285	1666				
1989												
June	115	400					68	445				
July	118	414	21	12	15	19	69	460	25	59	3	2
August	118	464	21	6	15	13	69	425	25	20	3	3
Summer[a]	118	430	21	9	15	16	69	445	25	40	3	3
1990												
March	61	173	15	16	15	5	38	216	14	14	3	9
June	133	219	20	10	14	15	78	305	24	44	3	0
July	134	384	21	12	15	7	78	253	25	61	3	1
August	134	411	21	8	15	7	78	388	25	38	3	4
Summer[a]	134	339	21	10	15	10	78	315	25	48	3	2
1991												
March	61	123	15	6	15	3	38	195	14	16	3	5
July	134	406	21	12	15	6	78	294	24	55	3	6

[a] Summer value calculated using the mean of transect counts from the June, July, and August surveys of that year.

Table 2. Estimated sea otter densities (d) and associated standard errors (s.e.) in oiled and unoiled areas of Prince William Sound, Alaska before and after the *Exxon Valdez* oil spill. Pre-spill values are from Irons et al. (1988) data. Density values are in units of otters/km^2.

	Oiled Areas						Unoiled Areas					
	Shoreline		Coastal		Pelagic Nearshore		Shoreline		Coastal		Pelagic Nearshore	
Survey Date	d	s.e.	d	s.e.	d	s.e.	d	s.e.	d	s.e.	d	s.e.
1984-1985	5.25	0.12					4.53	0.19				
1989												
June	3.29	0.42					5.22	0.77				
July	3.30	0.42	0.27	0.10	0.34	0.25	5.31	0.83	1.67	0.48	0.18	0.09
August	3.70	0.54	0.12	0.08	0.23	0.14	4.90	0.84	0.56	0.19	0.27	0.15
Summer[a]	3.43	0.38	0.20	0.06	0.29	0.17	5.14	0.61	1.13	0.30	0.22	0.09
1990												
March	2.60	0.23	0.53	0.27	0.09	0.03	4.35	0.75	0.61	0.22	0.80	0.41
June	1.58	0.39	0.23	0.16	0.29	0.13	3.16	0.67	1.29	0.47	0.00	0.00
July	2.76	0.47	0.26	0.11	0.13	0.11	2.62	0.38	1.65	0.82	0.09	0.09
August	2.95	0.49	0.19	0.08	0.13	0.07	4.02	0.58	1.01	0.31	0.36	0.09
Summer[a]	2.43	0.41	0.23	0.09	0.17	0.06	3.26	0.41	1.29	0.37	0.15	0.03
1991												
March	1.85	0.19	0.21	0.10	0.05	0.04	3.94	0.67	0.62	0.14	0.45	0.09
July	2.91	0.34	0.26	0.18	0.11	0.08	3.04	0.48	1.50	0.50	0.54	0.15

[a] Summer value calculated using the mean of transect counts from the June, July, and August surveys of that year.

Table 3. Estimated abundance (N) and associated 95% confidence intervals (95%ci) of sea otters in oiled, unoiled and all areas of Prince William Sound, Alaska before and after the *Exxon Valdez* oil spill. Pre-spill values are from Irons et al. (1988) data.

	Oiled Areas			Unoiled Areas			
Survey Date	Shoreline N 95%ci	Coastal N 95%ci	Nearshore Pelagic N 95%ci	Shoreline N 95%ci	Coastal N 95%ci	Nearshore Pelagic N 95%ci	All Areas N 95%ci
1984-1985	2285 ±128			1754 ±143			
1989							
June	1430 ±362			2020 ±586			
July	1438 ±360	694 ±500	688 ±982	2053 ±631	3293 ±1857	76 ±74	8240 ±2280
August	1611 ±460	304 ±382	474 ±554	1897 ±635	1098 ±749	113 ±128	5497 ±1283
Summer[a]	1492 ±320	499 ±316	581 ±682	1988 ±465	2239 ±1147	95 ±74	6894 ±1485
1990							
March	1130 ±199	1361 ±1338	182 ±135	1685 ±566	1203 ±844	340 ±340	5901 ±1731
June	690 ±331	577 ±779	585 ±520	1221 ±511	2548 ±1815	0	5621 ±2131
July	1200 ±397	650 ±562	262 ±442	1013 ±291	3261 ±3178	38 ±74	6424 ±3297
August	1284 ±419	482 ±384	255 ±293	1554 ±439	1991 ±1208	151 ±74	5717 ±1438
Summer[a]	1059 ±348	578 ±433	354 ±242	1263 ±315	2546 ±1449	63 ±25	5881 ±1602
1991							
March	804 ±161	539 ±524	109 ±154	1524 ±510	1234 ±557	189 ±74	4399 ±948
July	1268 ±287	664 ±880	217 ±308	1177 ±362	2956 ±1932	227 ±128	6509 ±2198

[a] Summer value calculated using the mean of transect counts from the June, July, and August surveys of that year.

Table 4. Distribution of sea otters in survey strata based on estimated abundances in oiled and unoiled areas of Prince William Sound, Alaska during surveys conducted following the *Exxon Valdez* oil spill.

	Oiled Areas			Unoiled Areas		
Survey Date	Shoreline percent	Coastal percent	Pelagic Nearshore percent	Shoreline percent	Coastal percent	Pelagic Nearshore percent
1989						
July	51.0	24.6	24.4	37.9	60.7	1.4
August	67.5	12.7	19.8	61.0	35.3	3.7
Summer[a]	58.0	19.4	22.6	46.0	51.8	2.2
1990						
March	42.3	50.9	6.8	52.2	37.3	10.5
June	37.3	31.2	31.5	32.4	67.6	0.0
July	56.8	30.8	12.4	23.5	75.6	0.9
August	63.5	23.9	12.6	42.0	53.9	4.1
Summer[a]	53.2	29.0	17.8	32.6	65.6	1.6
1991						
March	55.4	37.1	7.5	51.7	41.9	6.4
July	59.0	30.9	10.1	27.0	67.8	5.2

[a] Summer value calculated using the mean of transect counts from the June, July, and August surveys of that year.

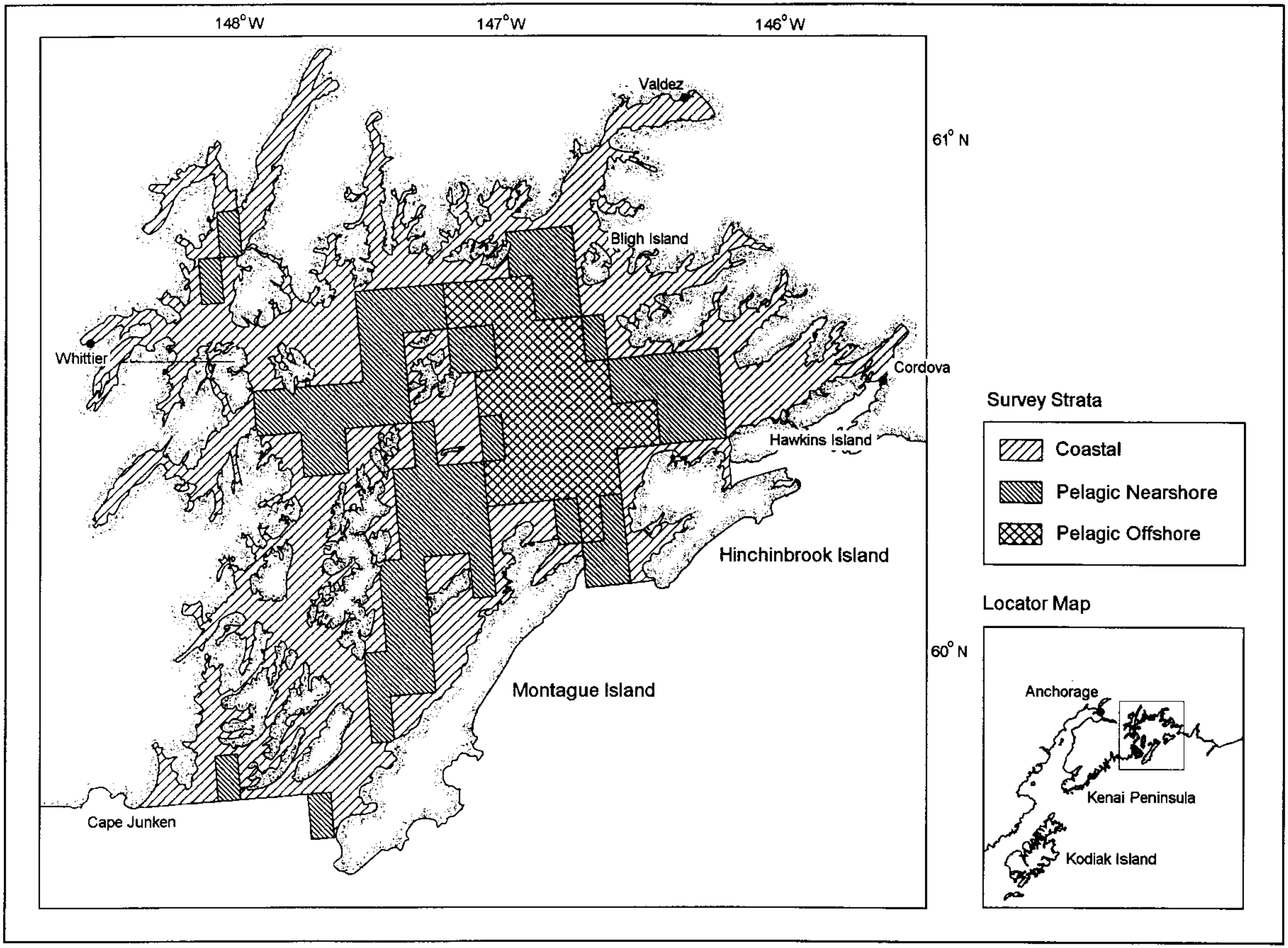

Figure 1. Prince William Sound study area, indicating survey strata. Shoreline stratum consisted of all shoreline located within the shaded areas.

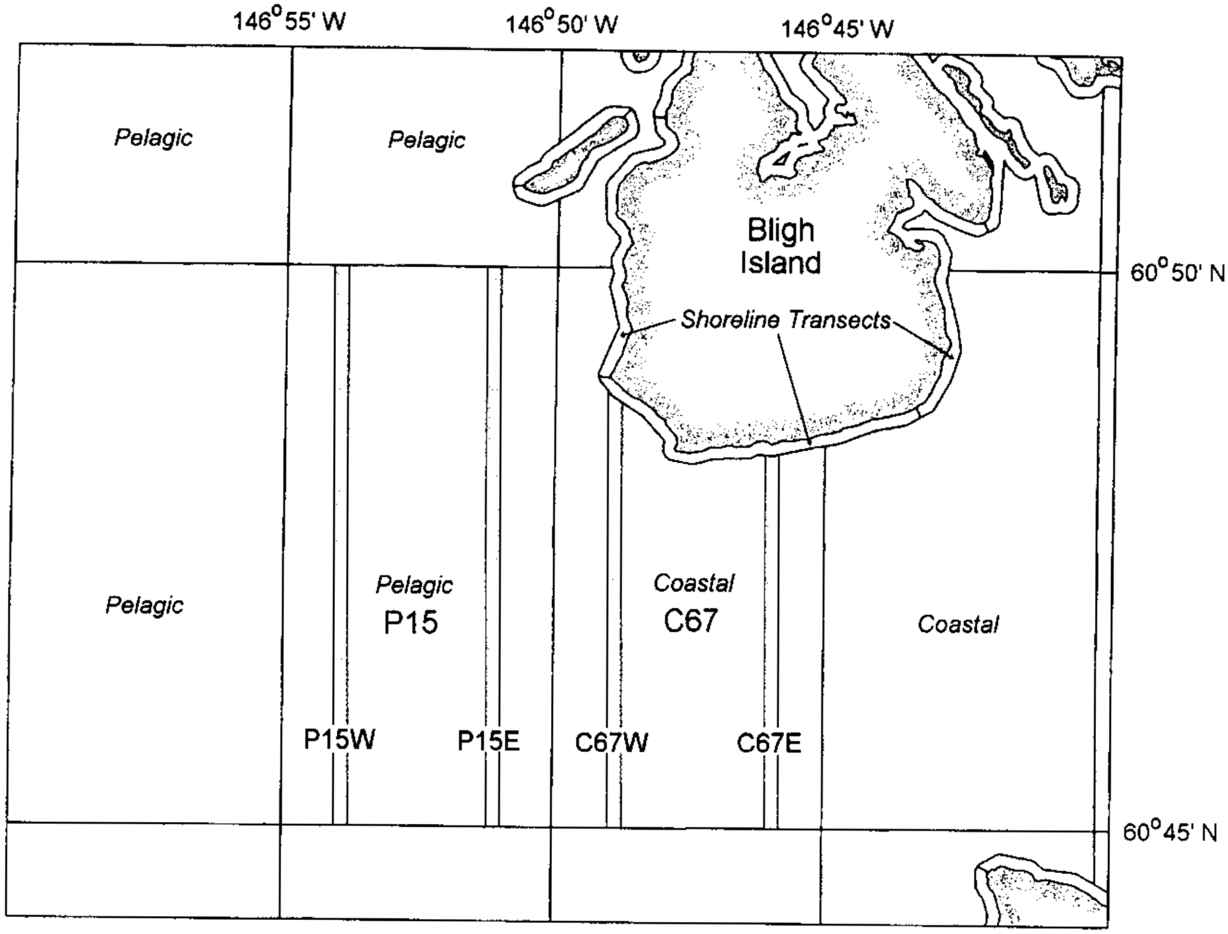

Figure 2. Area near Bligh Island in Prince William Sound, Alaska illustrating shoreline, coastal, and pelagic survey strata as used in this study. Coastal and pelagic transects are located along meridians 1 minute of longitude from eastern and western block boundaries.

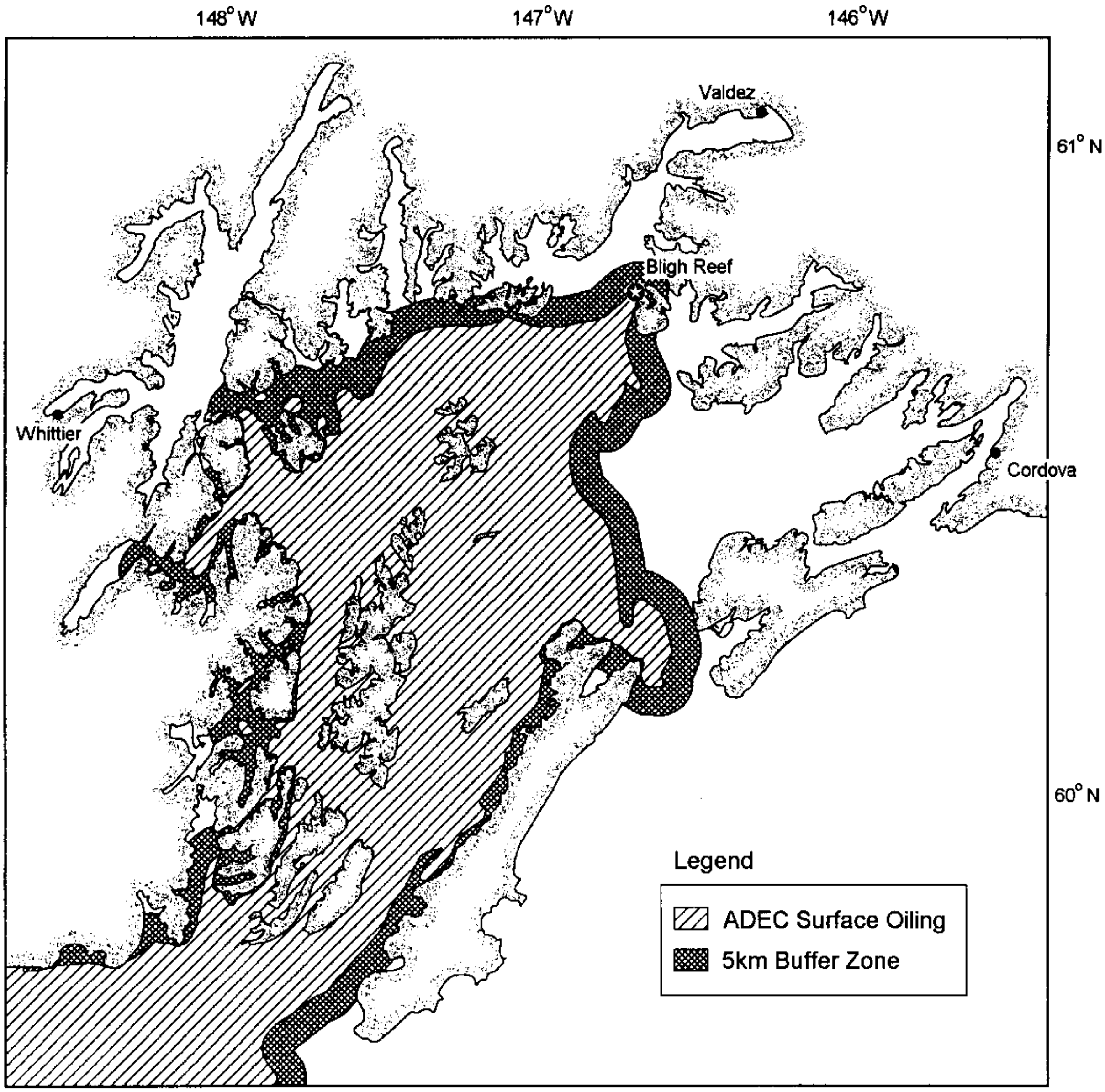

Figure 3. Extent of surface oiling in Prince William Sound, Alaska following the *Exxon Valdez* oil spill. Data are from Alaska Department of Environmental Conservation overflights. Sampling units located within 5km of surface oiling are classified as oiled.

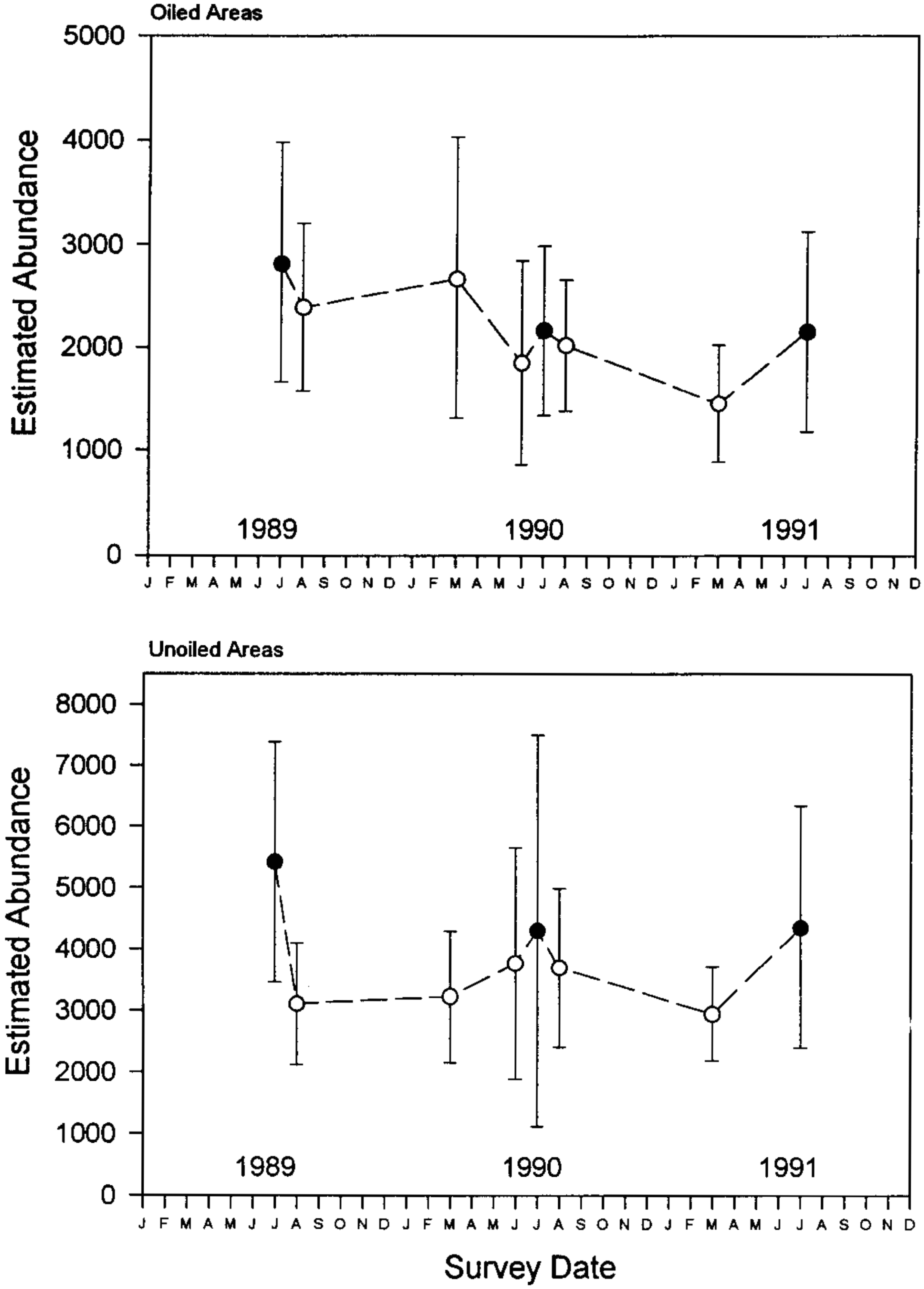

Figure 4. Estimated abundance of sea otters in oiled and unoiled areas of Prince William Sound, all survey strata combined. Error bars represent 95% confidence intervals. July estimates indicated for comparison by filled circles.