Chapter 4

Boat-Based Population Surveys of Sea Otters in Prince William Sound

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INTRODUCTION

Sea otters (*Enhydra lutris*) in Alaska were 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 (Kenyon 1969). They were extirpated throughout much of their range, with only a few small remnant populations surviving. It is believed that the present sea otter population in Prince William Sound (PWS) is derived from one such remnant population that persisted in the southwestern portion of the Sound (Lensink 1962). Surveys conducted in the 1960s and 1970s documented the northeastward expansion of sea otters into unoccupied areas of PWS (Pitcher 1975). By the mid-1980s, 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 (EVOS), the size of the PWS sea otter population was unknown but was believed to number between 5000 and 10,000 individuals. During the first few days following the spill, it was uncertain in which direction the oil would move and what proportion of the sea otter population would be injured.

The number of sea otter carcasses recovered could only produce a minimal estimate of the damage to the PWS sea otter population. Carcass recovery rates were determined, and were used to calculate an estimate of total spill-related mortality (Doroff and DeGange 1993). Another method to determine extent of damage was comparison of pre- and postspill population estimates. This study reports the results of nine postspill sea otter population surveys conducted in PWS between June 1989 and July 1991, and discusses their implications for damage of the PWS sea otter population as a result of the spill. The objectives of this study were to: (1) test that differences in sea otter densities were not significantly different between pre- and postspill surveys in oiled and unoiled areas in PWS; (2) estimate the magnitude of any change between pre- and postspill sea otter population estimates in PWS; and (3) estimate postspill sea otter population size and monitor sea otter population trends in PWS.

METHODS

Study Area

In the southwest portion of PWS, the study area was bounded by a line extending from Cape Junken eastward to Montague Island (Fig. 4-1). 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 1 km^2 to more than 250 km^2. The shoreline is highly convoluted, with numerous fiords, passes, and bays. Water depths within the study area varied from less than 2 m to more than 870 m.

Sampling Units

The study area was divided into three survey strata: shoreline, coastal, and pelagic. The shoreline stratum was based on shoreline transects surveyed by Irons et al. (1988) during May to August of 1984 and 1985, and was defined as the 200-m-wide strip immediately adjacent to the coastline. Within the study area, Irons et al. (1988) defined 742 shoreline transects with a total area of 822.3 km^2. Shoreline transects were of varying size, ranging from groups of rocks or small islands with less than 1 km of coastline, to sections of the mainland with over 25 km of coastline. The mean transect length was 6.57 km, with a sampled area of 1.11 km^2. Transect end points 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 seabirds and sea otters simultaneously, so some of the sampling decisions in this survey were made primarily for seabird considerations. It was known that certain bird species occur in association with coastlines, while others occur farther from shore. Thus, waters outside the shoreline stratum were divided into sampling "blocks" based on a 5-minute latitude/longitude grid system. In an attempt to differentiate these blocks with respect to distance from shore, they were then stratified into two categories: coastal and pelagic. The coastal stratum consisted of those blocks located immediately adjacent to 1 km or more of shoreline, while the pelagic stratum consisted of those blocks adjacent to less than 1 km 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 4524 km^2 and 3637 km^2, respectively.

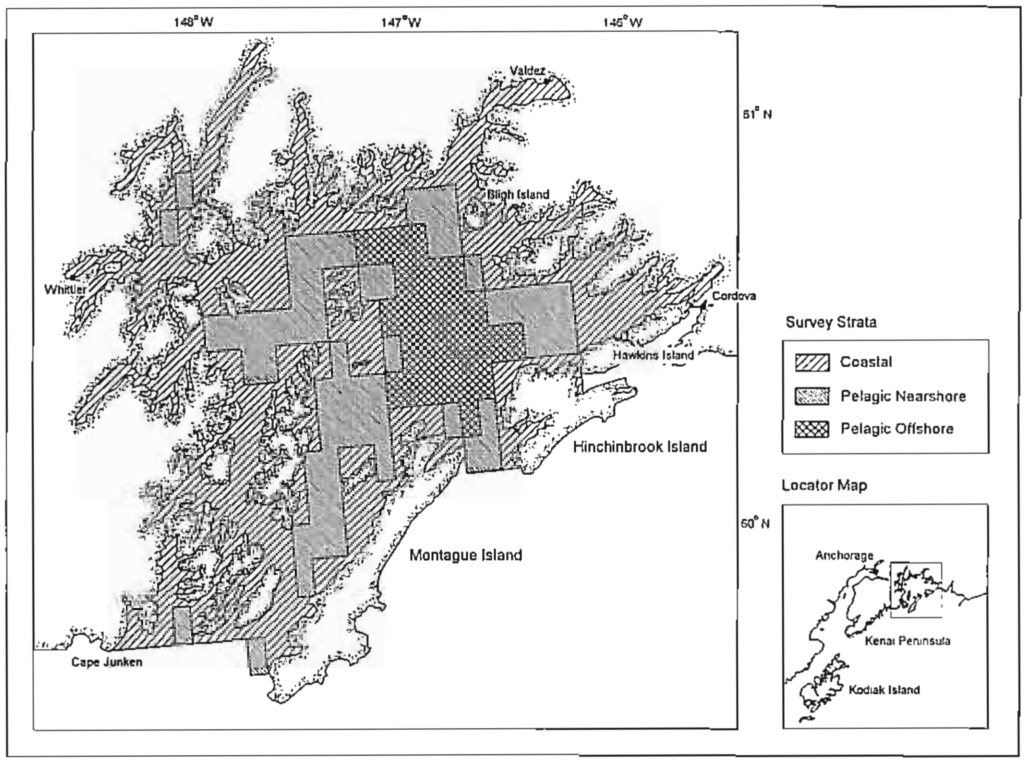

Figure 4-1. Prince William Sound study area, indicating survey strata. Shoreline stratum consisted of all shoreline located within the shaded areas.

Within each block, 200-m-wide strip transects were systematically placed along north–south meridians located 1 minute 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 a Natural Resource Damage Assessment Bird Study). For most blocks, these meridians resulted in the placement of two 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 intersect the coastline, transects were always paired and ran the entire 5-nautical-mile length of the block. An example of the three survey strata is presented in Figure 4-2.

After the first field season in June–August 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 PWS, sea otters have been observed to forage at mean depths of 7–28 m at various study sites (Garshelis 1983). Some pelagic blocks were located directly over shallow water, while others were located several kilometers distant. Assuming that sea otters occur in proximity to shallow water feeding areas, the pelagic stratum was poststratified into pelagic nearshore and pelagic offshore strata, based on distance from the 20-m bathymetric contour (contours in digital format for PWS were available in 20-m increments). The cutoff distance between the pelagic nearshore and pelagic offshore strata was 5 km from the 20-m contour. Under this new stratification, the pelagic nearshore strata had characteristics similar to the coastal strata (relatively close to shore or shallow water). However, these strata could not be pooled since the initial random samples were drawn separately from the coastal and pelagic strata.

Prespill Data

As stated earlier, the shoreline stratum in this study was based on a set of transects originally surveyed during May to August of 1984 and 1985 (Irons et al. 1988). Over the course of two field seasons, they surveyed virtually all the available shoreline transects within the PWS study area (708 out of the possible 742 transects). These data served as the prespill baseline for comparison with postspill surveys. It should be noted that changes in the PWS sea otter population

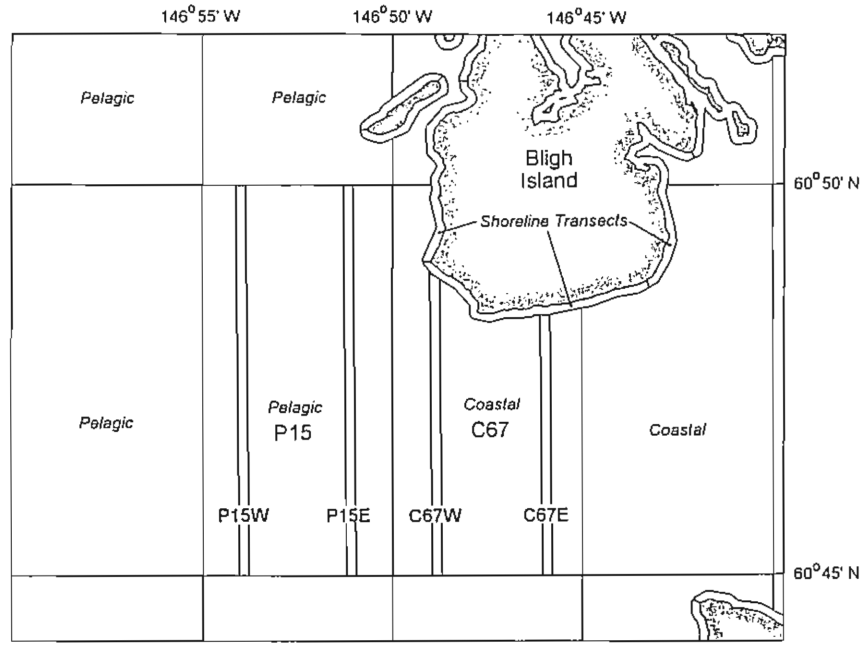

Figure 4-2. Area near Bligh Island in Prince William Sound, Alaska, illustrating shoreline, coastal, and pelagic survey strata used in this study. Coastal and pelagic transects are located along meridians 1' of longitude from eastern and western block boundaries.

between the Irons et al. (1988) survey and the time of the spill may have occurred. Waters beyond the shoreline stratum were not sampled during the prespill survey.

Field Methods

Sampling techniques in all postspill surveys duplicated those of the baseline study of Irons et al. (1988). Researchers used 8-m motor boats, with three crew members serving equally as operator and observers. Shoreline transects were surveyed from 100 m 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 100 m. The 100-m cutoff distance was visually estimated, with periodical calibration, using rangefinders or a float attached to a 100-m-long line. The 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 100 m. 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 were recorded on standardized data sheets.

To insure consistency between 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 end points based on geographic features. Surveys during the second and third years of the study used experienced personnel as boat team leaders and observers.

Survey Dates and Sample Sizes

Three replicates of the survey were conducted in June, July, and August 1989 to determine if a continued, ongoing effect of the spill was occurring. These replicates were repeated during June, July, and August 1990 for comparison with 1989, and to further examine variability within the 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 seabirds, minimizing the effect of certain species migrating 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.

Postspill surveys were initially conducted during summer 1989 as a simple random sample of approximately 25% of all shoreline transects and coastal and pelagic blocks. Due to logistic 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.

In order to complete surveys during March when daylight is a limiting factor and weather conditions are often less favorable, only a subset of the original set of shoreline transects and coastal and pelagic blocks was sampled. This subset consisted of approximately 14% of the shoreline transects and coastal blocks. The sample size of pelagic blocks (n=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.

On the advice of peer reviewers, an additional 25 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 western PWS. 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 Geographic Information System (GIS) coverage depicting the movement of oil over the surface of the water. Since sea otters are mobile animals, those inhabiting areas adjacent to the path of the oil could have encountered oil during their normal movement patterns. Given this assumption, coupled with an inherent uncertainty as to the exact geographical extent of the surface oiling, a buffer zone of 5 km was added to the oiled zone boundary to represent an area within which sea otters might have been affected by oil (Fig. 4-3). Shoreline transects and coastal and pelagic blocks with any area located within this buffer zone (i.e., within 5 km of surface oil) were classified as oiled.

Analytical Methods

Sea otter density and abundance estimates for each survey strata were calculated using ratio estimator techniques (Cochran 1977). The following notation will be used to define the estimators density and abundance within a stratum in which i refers to the i^{th} block within the stratum:

a_i=area of transects in the block,
A_i=area of the block (note: for shoreline stratum a_i=A_i),
A =total area of all blocks in the stratum,
n_i=number of sea otters observed in the block,
d_i=observed sea otter density in the block (=n_i/a_i),
B =number of blocks in the stratum, and
b =number of sampled blocks in the stratum.

The estimator of density for a stratum and its standard error (SE) are

$$\hat{D}=\frac{\sum_{i=1}^{b} A_i d_i}{\sum_{i=1}^{b}} \qquad (1)$$

$$\hat{Se}(\hat{D})=\frac{B}{A}\sqrt{\frac{\sum_{i=1}^{b} A_i^2 (d_i-\hat{D})^2}{b(b-1)}\,\frac{B-b}{B}} \qquad (2)$$

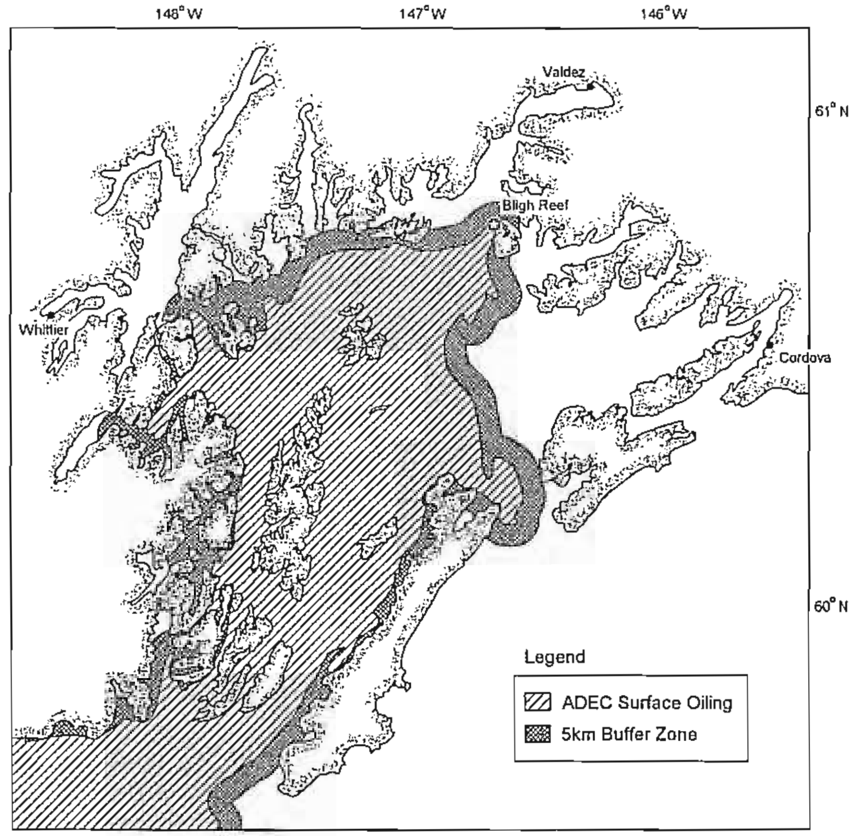

Figure 4-3. Extent of surface oiling in Prince William Sound, Alaska, following the *Exxon Valdez* oil spill. Data are from the Alaska Department of Environmental Conservation overflights. Sampling units located within 5 km of surface oiling were classified as oiled.

The finite population correction factor (B-b/B) was not used for the coastal and pelagic strata because the location of transects within a block were systematically placed. The estimator of abundance for a stratum and its standard error are

$$\hat{N}=A\hat{D} \tag{3}$$

$$\hat{Se}(\hat{N})=A\cdot\hat{Se}(\hat{D}) \tag{4}$$

Abundance estimates for the entire PWS study area were calculated by summing the estimates for each strata. For the summer 1989 and 1990 field seasons, density and abundance estimates were also calculated using the mean of the three sea otter counts per transect from the June, July, and August surveys of that year.

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

$$t=\frac{\hat{D}_2-\hat{D}_1}{\hat{V}(\hat{D}_2-\hat{D}_1)} \qquad (5)$$

where:

$\hat{D}_1$	-	prespill density estimate,
$\hat{D}_2$	-	postspill density estimate, and
$\hat{V}(\hat{D}_2-\hat{D}_1)$	-	variance of the difference between density estimates.

Degrees of freedom for this test were (n-1) for the smaller of the two sample sizes. The same test was used to compare sea otter density estimates in the coastal and nearshore pelagic strata between oiled and unoiled areas. A similar form of the t test was used to compare postspill abundance estimates of all survey strata combined. Effective degrees of freedom were calculated for each abundance estimate according to Satterthwaite's (1946) approximation as cited in Cochran (1977). Degrees of freedom for this test were (n-1) for the smaller of the two samples.

RESULTS

Survey Effort and Sea Otter Counts

During nine postspill surveys, a total of 2639 transects were sampled with 4791 sea otter sightings totaling 6469 individuals. The majority of sea otters counted (5975) were within the shoreline stratum (Table 4-1). Counts within the coastal and pelagic nearshore strata were lower and variable. With the exception of one sea otter sighted during July 1990, no otters were observed in the pelagic offshore stratum. Thus, density and abundance estimates are not presented for the pelagic offshore stratum.

Sea Otter Densities

Observed sea otter densities were highest in the shoreline stratum, followed by the coastal and pelagic nearshore strata (Table 4-2). Since the prespill 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.

Table 4-1. Sample sizes (b) and numbers of sea otters counted (n) 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. (— = no data)

	Oiled areas						Unoiled areas					
	Shoreline		Coastal		Pelagic nearshore		Shoreline		Coastal		Pelagic nearshore	
Survey Date	b	n	b	n	b	n	b	n	b	n	b	n
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 4-2. Estimated sea otter densities ($\hat{D}$) and associated standard errors ($\hat{S}e(\hat{D})$)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. (--- = no data)

	Oiled areas						Unoiled areas					
	Shoreline		Coastal		Pelagic nearshore		Shoreline		Coastal		Pelagic nearshore	
Survey date	$\hat{D}$	$\hat{S}e(\hat{D})$	$\hat{D}$	$\hat{S}e(\hat{D})$	$\hat{D}$	$\hat{S}e(\hat{D})$	$\hat{D}$	$\hat{S}e(\hat{D})$	$\hat{D}$	$\hat{S}e(\hat{D})$	$\hat{D}$	$\hat{S}e(\hat{D})$
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 4-3. Estimated abundance ($\hat{N}$) 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						All areas	
	Shoreline		Coastal		Nearshore pelagic		Shoreline		Coastal		Nearshore pelagic			
Survey date	$\hat{N}$	95%ci	$\hat{N}$	95%ci	$\hat{N}$	95%ci	$\hat{N}$	95%ci	$\hat{N}$	95%ci	$\hat{N}$	95%ci	$\hat{N}$	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	±382	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 4-4. 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		
	Shoreline	Coastal	Pelagic Nearshore	Shoreline	Coastal	Pelagic Nearshore
Survey date	percent	percent	percent	percent	percent	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.

In the unoiled area, shoreline sea otter density in summer 1989 was approximately 14% greater than prespill density (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 summer 1990 showed further declines in shoreline sea otter density in the oiled area to 54% below the prespill 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 prespill 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.

Within the coastal stratum, sea otter densities observed during postspill 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 4-3). In some instances, these strata accounted for over 50% of the total estimated population (Table 4-4). 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. 4-4). All survey strata were sampled in July and August 1989; June, July, and August 1990; and July 1991. Since July was the only month all strata were surveyed 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 fewer sea otters than the July 1989 estimate (2165 versus 2819). 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 (2165 versus 2149). Within the unoiled area, the July 1990 estimate was 1110 fewer sea otters than the July 1989 estimate (4312 versus 5422). Again, due primarily to the large variances, 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 (4312 versus 4360).

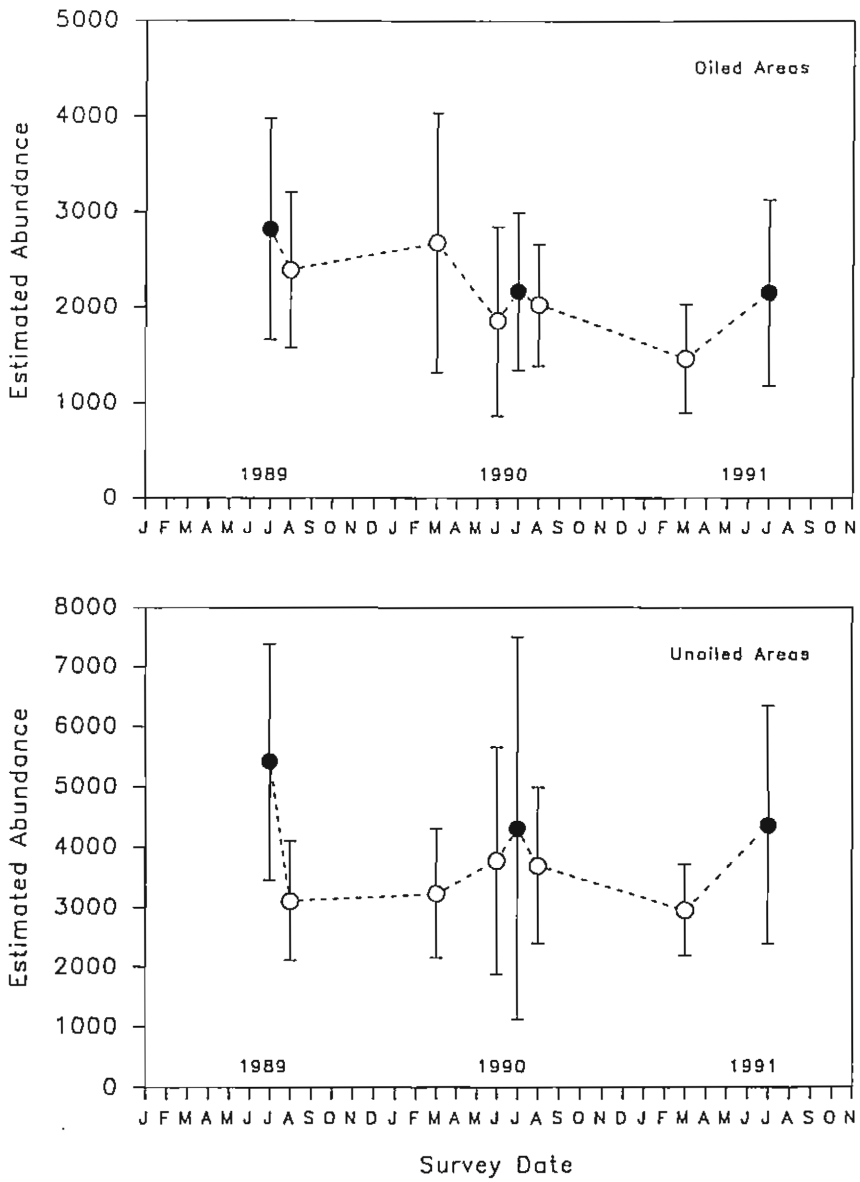

Figure 4-4. Estimated abundance of sea otters in oiled and unoiled areas of Prince William Sound, all survey strata combined. Error bars represent 97% confidence intervals. July estimates indicated for comparison by filled circles.

DISCUSSION

Based on comparisons of prespill 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 PWS sea otter population. This result is not surprising, given that over 400 sea otter carcasses had been retrieved from PWS prior to the first postspill 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 1993). Based on 424 carcasses recovered, an estimated 20% carcass recovery rate, and 89 otters that died in rehabilitation centers, Doroff and DeGange (1993) estimated an acute loss of 2209 sea otters from PWS 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 PWS. Was there a Sound-wide decline in the sea otter population between the summers of 1989 and 1990? Abundance estimates of all survey strata combined for July 1989 and July 1990 were not 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 with this survey design.

Other damage assessment studies suggested an ongoing effect of the oil spill on sea otters in PWS. The age-class structure of dying sea otters, based on carcasses recovered during the spill year (defined as 1989) and postspill (defined as 1990 and 1991) within the oiled area was significantly different from the prespill age-class structure (Monson 1993). Specifically, the proportion of "prime-age" animals (2 to 8 years old) in the spill year and postspill samples was higher than that observed prespill. 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 sea otter abundance in unoiled areas of PWS may be less obvious. Results of radiotelemetry 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 sea otters from other study groups (Monnett et al. 1990). Furthermore, following the release of these rehabilitated sea otters, other study groups of otters in eastern PWS (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 PWS, 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 prespill surveys and summer 1989 was due to a redistribution of otters among strata. If one assumes that the net loss of sea otters in the shoreline stratum in the oiled area was offset by an increase in the coastal or nearshore pelagic strata (as may have occurred in unoiled areas between the summers of 1989 and 1990), it would require the prespill 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 unoiled areas during the postspill surveys. Lacking prespill data for all but the shoreline stratum, there is no method to determine if this difference represents injury due to the spill, or merely a reflection of differences in habitat 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 sea 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 prespill density may have been.

Accepting that the decline in shoreline sea otter density between prespill 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 PWS sea otter population (Garrott et al. 1993). This exercise produced a loss estimate of approximately 2800 sea otters for PWS. This result is comparable to the estimate of 2209 sea otters lost based on carcass recovery rates (Doroff and DeGange 1993).

The long-term effects of the spill on sea otters in the western portion of PWS 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 PWS.

Continued monitoring of the PWS sea otter population will yield postspill 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 damage assessment studies was the quality of available prespill data (Spies 1993). Study design, methodology, and the amount of time between pre- and postspill 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 prespill 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 prespill 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.

In order to improve the precision of abundance estimates, modifications to the survey design are necessary. Keeping the shoreline stratum intact to allow for comparison with prespill 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 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 by 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. However, it may be necessary to continue sampling this area in consideration of some seabird species.

CONCLUSIONS

Shoreline sea otter densities in the unoiled area increased 14% between prespill 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 prespill density. Based on these and related data, a cooperative effort to quantify total injury to the PWS sea otter population estimated that approximately 2800 otters were initially killed by the spill (Garrott et al. 1993). 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 prespill shoreline sea otter density within the oiled area.

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REFERENCES

Alaska Department of Environmental Conservation (ADEC). 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* K. Bayha and J. Kormendy (eds.), 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. U.S. Fish & Wildlife Service Biological Report 90(12).

Cochran, W. G. 1977. Sampling techniques. John Wiley and Sons, Inc., New York, New York. 428 p.

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* K. Bayha and J. Kormendy (eds.), 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. U.S. Fish & Wildlife Service Biological Report 90(12).

Doroff, A. M., and A. R. DeGange. 1993. 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 Wildlife Service. Anchorage, Alaska.

Garrott, R. A., L. L. Eberhardt, and D. M. Burn. 1993. Mortality of sea otters in Prince William Sound following the *Exxon Valdez* oil spill. Marine Mammal Science 9:343–359.

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

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. Unpublished Report, U.S. Fish and Wildlife Service. Anchorage, Alaska. 31 p.

Kenyon, K. W. 1969. The sea otter in the eastern Pacific Ocean. North American Fauna 68. 352 p.

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

Monnett, C., and L. M. Rotterman. 1993. The efficacy of the T/V *Exxon Valdez* oil spill rehabilitation program and the possibility of disease introduction into recipient sea otter populations. Page 273, *in Exxon Valdez* oil spill symposium, 2–5 February 1993, Anchorage, Alaska. (Available, Oil Spill Public Information Center, 645 G Street, Anchorage, Alaska 99501.)

nett, 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* K. Bayha and J. Kormendy (eds.), 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. U.S. Fish & Wildlife Service Biological Report 90(12).

nson, D. H. 1993. 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 Wildlife Service. Anchorage, Alaska.

cher, K. W. 1975. Distribution of sea otters, Steller sea lions, and harbor seals in Prince William Sound, Alaska. Division of Game, Alaska Department of Fish and Game unpublished report. 76 p.

dman, 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). 126 p.

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

ies, R. B. 1993. So why can't science tell us more about the effects of the *Exxon Valdez* oil spill? Pages 1–5, *in Exxon Valdez* oil spill symposium, 2–5 February 1993, Anchorage, Alaska. (Available, Oil Spill Public Information Center, 645 G Street, Anchorage, Alaska 99501.)