Marine Mammals and the *Exxon Valdez*

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Chapter 5

An Intersection Model for Estimating Sea Otter Mortality along the Kenai Peninsula

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INTRODUCTION

One of the primary objectives of state and federal resource agencies following the *Exxon Valdez* oil spill (EVOS) was to estimate the mortality of marine birds and mammals. The recovery of 781 carcasses after the spill (Doroff et al. 1993) indicated extensive acute mortality of sea otters (*Enhydra lutris*). Causes of mortality included hypothermia resulting from oiled pelage and interstitial pulmonary emphysema, gastric erosion and hemorrhage, hepatic and renal lipidosis, and centrilobular hepatic necrosis (Lipscomb et al. 1993, Chapter 16). Estimating the magnitude of acute sea otter mortality resulting from the spill beyond the number of recovered carcasses was difficult because baseline population data on sea otters throughout the spill area did not exist. This was particularly true of otters along the Kenai Peninsula (Fig. 5-1).

Garrott et al. (1993) and Doroff et al. (1993), using different approaches, estimated the numbers of sea otters killed from acute exposure to oil from the EVOS. However, each approach had significant limitations. Garrott et al. (1993) compared the number of animals in Prince William Sound (PWS) before and after the spill. This method required accurate pre- and postspill population estimates for each affected area. Doroff et al. (1993) assumed that carcasses recovered during the spill represented a proportion of the total mortality. Their method required accurate estimates of the carcass recovery rate for each affected area.

Along the Kenai Peninsula, a comparison of pre- and postspill survey data did not detect a significant loss of sea otters and data on carcass recovery rates were not available. Therefore, we examined a third approach for estimating the loss of sea otters along the Kenai Peninsula based on their exposure to oil and the relation between exposure and sea otter mortality. We developed an intersection model to integrate parameters estimated from three distinct data sets that resulted from

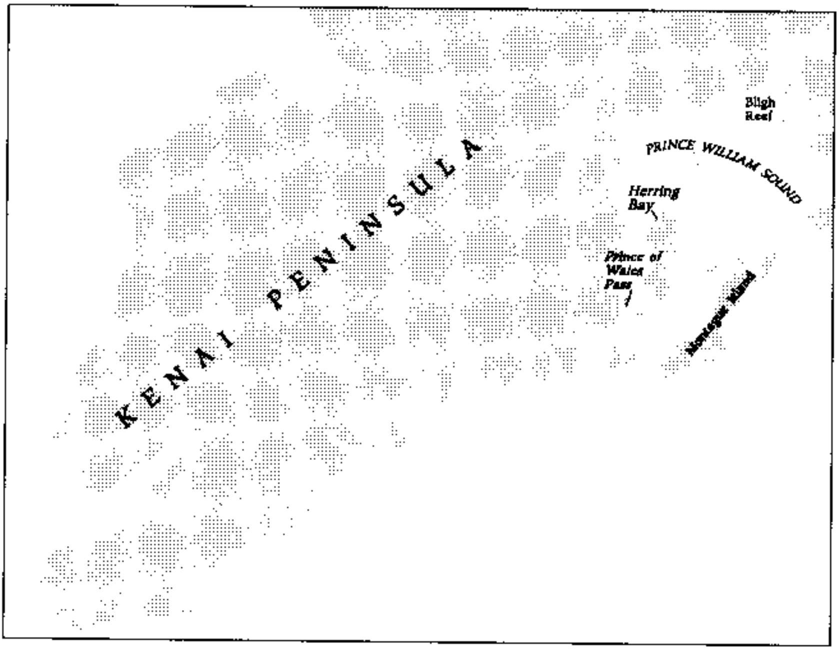


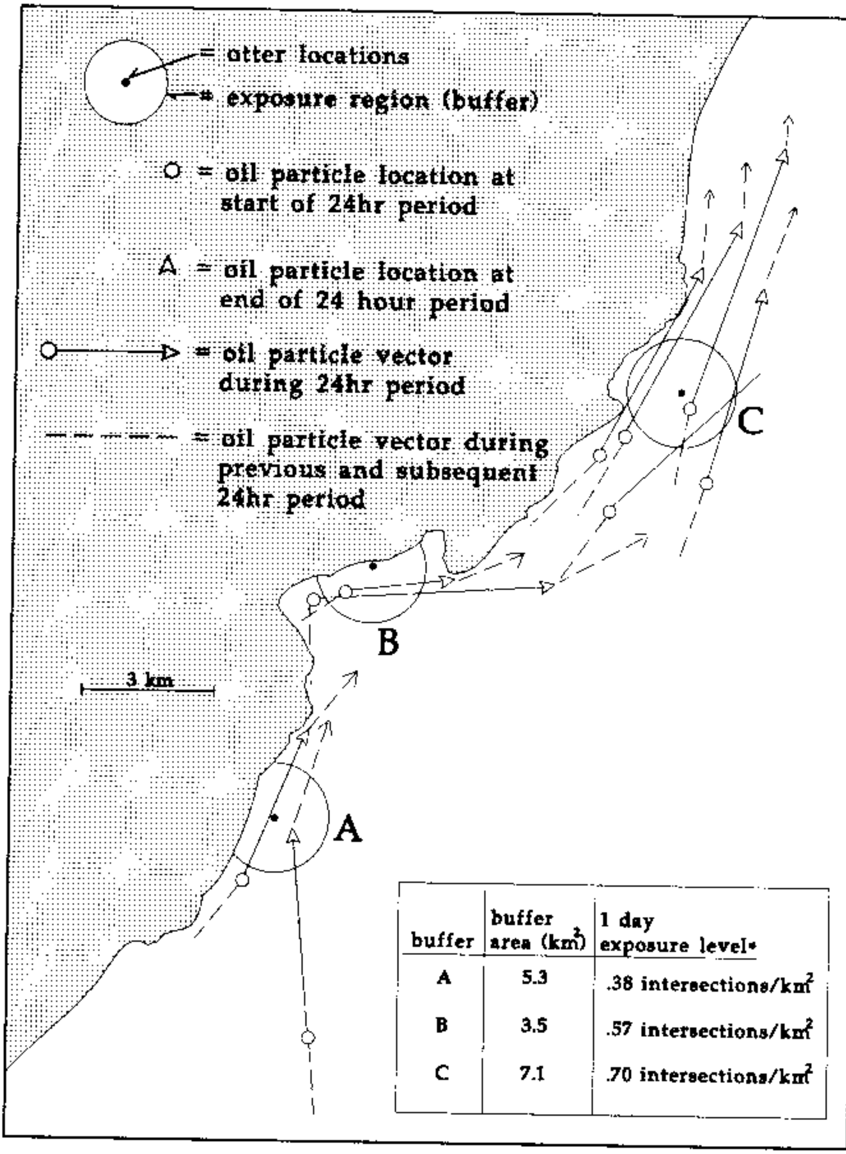
Figure 5-1. The survival of sea otters was estimated at two sites in Prince William Sound, Herring Bay and Prince of Wales Pass. Estimated survival rates were based on the recovery of carcasses and the survival of otters captured live and treated at rehabilitation facilities.

the EVOS: (1) the distribution, amount, and movements of spilled oil; (2) the distribution and abundance of sea otters along the Kenai Peninsula; and (3) the estimates of site-specific sea otter mortality relative to oil exposure from otters captured in PWS for rehabilitation and from collected carcasses. In this chapter, we describe the data sets and provide examples of how they can be used in the model to generate acute loss estimates. We also examine the assumptions required by the model and provide suggestions for improving and applying the model.

METHODS

Oil Movements

The On-Scene Spill Model (OSSM), a generalized computer model developed by the National Oceanic and Atmospheric Administration (Torgrimson 1984), was used to describe the distribution of oil particles as they traveled through PWS and along the Kenai and Alaska Peninsulas. The OSSM model output was iteratively



buffer	buffer area (km²)	1 day exposure level*
A	5.3	.38 intersections/km²
B	3.5	.57 intersections/km²
C	7.1	.70 intersections/km²

Figure 5-2. A hypothetical example of the calculation of intersection densities of three sea otter locations during one 24-hour period. Arrows indicate direction of oil particle movements.

adjusted based on the observed and computed distribution and movements of oil in a hindcast trajectory analysis (Galt et al. 1991). The hindcast trajectory analysis traced the movement of 10,000 particles of oil, each of which represented about 4169 liters, from their origin at Bligh Reef on 24 March through 23 May 1989 Depending on the thickness of the oil on the water, the sea surface covered by one particle (4169 liters) could range from 1.2 to 85 km^2. (Our model required only the assumption that the area represented by each particle was the same and that area remained constant over time. The validity and consequences of this assumption are discussed below.) We used the location of each modeled particle at 3-hour intervals to represent the distribution of oil over time along the Kenai Peninsula (Fig. 5-2). We defined a continuous path for each of the 10,000 oil particles by the vectors between the locations of each oil particle at 3-hour intervals. As oil evaporated, sank, or became beachcast, the number of oil particles decreased, but each remaining particle continued to represent the constant oil volume of 4169 liters.

Sea Otter Abundance and Distribution

The abundance and distribution of sea otters in nearshore and offshore habitat along the Kenai Peninsula at the time the oil passed through was estimated with data from a helicopter survey (DeGange et al. 1993). The survey combined a strip count of otters along the coastline and line transect counts running perpendicular to the shoreline out to the 50-fathom (approximately 100 m) depth contour. The location of each otter or group of otters was recorded on navigational charts (1:82,000). The counts were corrected for group size and visibility bias to estimate total population size (DeGange et al. 1993). Observed locations of otters at the time of the survey were used to estimate the distribution of the animals relative to exposure for our model.

Sea Otter Mortality

Data for relating exposure levels to oiling and subsequent mortality of otters were collected in two areas of PWS (Fig. 5-1). One area was Herring Bay (HB), (60°28'N, 147°45'W) on the north end of Knight Island, where heavy oiling persisted over time, all captured otters were oiled, and 22 oiled sea otter carcasses were recovered (Table 5-1). The second site included the northeast third of Prince of Wales Pass (PWP) including Iktua Bay (60°06'N, 148°00'W) between Evans and Bainbridge Islands. This area received less oil than Herring Bay and the oil passed through during a shorter period of time. Most captured otters were either lightly oiled or not oiled, and only one carcass was recovered.

During the first 3 weeks of April, attempts were made to capture all otters in these areas irrespective of the presence or degree of oiling (Bodkin and Weltz 1990), and to recover carcasses. Each otter was subjectively classified by one of

Table 5-1. Mortality rates of sea otters by degree of oiling in Herring Bay and Prince of Wales Pass, western Prince William Sound, and the Kenai Peninsula. Rates in Herring Bay and the Prince of Wales Pass include oiled carcasses collected between 1 and 15 April 1989 but do not include three carcasses with unknown oiling status. (H=heavy, M=moderate, L=light, N=none). Carcasses with undetermined oiling condition were not included.

	Degree of oiling				
	H	M	L	N	Total
Herring Bay					
Captured live (survived >35 days)	1	2	1	0	4
Captured live (survived ≤ 35 days)	4	2	1	0	7
Number of recovered carcasses	10	10	2	0	22
Total	15	14	4	0	33
Mortality rate ($\bar{x}$=0.88)	.93	.86	.75	nd	.88
Prince of Wales Pass					
Captured live (survived >35 days)	0	2	12	7	21
Captured live (survived ≤ 35 days)	0	1	7	3	11
Number of recovered carcasses	0	0	1	0	1
Total	0	3	20	10	33
Mortality rate ($\bar{x}$=0.36)	nd	.33	.40	.30	.36
Combined Mortality ($\bar{x}$=0.62) (both sites)	.93	.76	.46	.30	.62
All Western Prince William Sound					
Captured live	50	14	44	10	118
Percent of total	.42	.12	.37	.08	
Mortality rate	.76	.50	.31	.70	.58
Kenai Peninsula					
Captured live	3	19	70	32	124
Percent of total	.02	.15	.56	.26	
Mortality rate	.00	.11	.11	.12	0.1

us (JLB) into one of four categories based on the quantity of oil observed on its pelage at the time of capture. The categories were

no oiling—oil not visually or tactically evident on the pelage;
light oiling—oil not easily visible or detectable, or a small proportion (%) of the pelage showed visible oil;
moderate oiling—oiling visible on about 25–75% of the pelage; and
heavy oiling—oil visible on all or nearly all of the pelage.

A similar subjective classification was used for all animals brought to rehabilitation centers (Lipscomb et al. 1993). No quantitative means of assessing the degree of oiling were available and in the case of dead otters, postmortem oiling was possible.

While the capture of live animals was under way, the carcasses of dead otters were also collected. The date, location, and degree of oiling of each carcass were recorded. All carcasses collected were relatively fresh. With the exception of five nonoiled animals that were released after capture in Prince of Wales Pass, all captured otters were transported to rehabilitation centers where they were cleaned and held. We assume that the five nonoiled animals survived.

To estimate oiling and mortality rates for otters in each capture area, we used data from all captured live otters and from carcasses. The proportion of animals in each degree of oiling category was estimated by capture area (Table 5-1). Mortality rates were estimated by capture area and by category of oiling (Table 5-1). Pups born at the rehabilitation facilities, otters with an undetermined oiling status, and otters with obvious non-oil-related pathology (e.g., gunshot wounds) (Lipscomb et al. 1993) were excluded from the calculations of oiling and mortality rates. We assumed that sea otters that were able to survive more than 35 days in captivity did not die as an immediate result of the spill.

Oil Exposure

To estimate exposure (the amount and persistence of oil), an exposure region was defined for each otter or group of otters as a circle (area=7.1 km^2 with a 1.5-km radius) centered at the otter's observed location during the helicopter survey (Fig. 5-2). This radius represented the average distance sea otters moved between successive radio relocations recorded between 18 and 36 hours apart in California (Ralls et al. 1988). These data included movements of adult and subadult male and female sea otters (n=38).

Exposure to oil was estimated at each location of a Kenai Peninsula otter by summing the number of oil particles that were present in an exposure region during each 24-hour interval, summing over the time period of the spill, and dividing by the area of the exposure region (exposure regions were usually less than 7.1 km^2 because most otters were observed less than 1.5 km from a shoreline; Fig. 5-2, Table 5-2). For example, 10 particles intersecting one complete exposure region of 7.1 km^2 in 1 day would result in an exposure level of 1.4 intersections/km^2. The same exposure level would be obtained from one particle remaining inside that same exposure region for 10 days. (This method of estimating exposure weights quantity and persistence of oil in an area equally. Additional information on the effects of oil on otters and their response to exposure may suggest improved measures of exposure.) The proportion of otters observed at each location was used to estimate the proportion of the total Kenai Peninsula population with that location's level of

Table 5-2. Estimated exposure of discrete hypothetical sea otter exposure regions (3.0 km diameter) in western Prince William Sound and at 131 observed locations of otters along the Kenai Peninsula 24 March - 23 May 1989.

Exposure area	Number of exposure regions	Mean exposure[a]	SE	Max	Min
Herring Bay	10	226	18	316	158
Prince of Wales Pass	10	51	12	101	13
Kenai Peninsula	131	6	0.7	32	0.16

[a] Intersections/km^2.

exposure. The range of exposure levels in HB and PWP was estimated by calculating the exposure in intersections/km^2 for 10 randomly distributed exposure regions of 1.5-km radius in each of the two capture areas.

Examples of Model-Generated Loss Estimates

The mortality data from HB and PWP provide only two independent observations for estimating the relation between exposure and mortality. This sample size limited consideration to only the simplest functional forms for the relation. We used two different sets of assumptions about the functional form to derive two different relations between exposure and mortality. Because of the limited amount of data and problems with the type of data that could be obtained from rehabilitation centers (discussed below), neither of these relations is likely to be realistic, but we used these relations as examples to illustrate how the model can generate loss estimates.

Each exposure-mortality relation provided a separate estimate of the mortality rate associated with the estimated exposure level at each location where otters were observed from the helicopter along the Kenai Peninsula. The total number of otters estimated to have received one of the estimated exposure levels was multiplied by the mortality-rate estimate for that exposure level and these numbers were then summed to obtain an estimate of the total number of otters lost. A separate estimate of total loss was obtained with each of the examples of the mortality-exposure relation (Fig. 5-3).

In Example 1, we assumed the mortality-exposure relation could be approximated as a straight line through the mean mortality rates of otters in HB and PWP at the mean exposure levels for those locations (Table 5-3, Fig. 5-3). Symbolically, the relation is given by

$$Y_i = a + bX_i, \quad X_i \leq X_q$$
$$Y_i = 1.0, \quad X_i \geq X_q,$$

Table 5-3. Estimated or assumed mortality rates, proportions of otters in oiling categories, and calculated weighted mortality rates (Example 2) used in the mortality estimate examples. PWP=Prince of Wales Pass and HB=Herring Bay.

Example 1

Location	Mean exposure	Mean mortality rate
PWP	51	0.36
HB	226	0.88

Example 2

Oiling category	Estimated mortality rates (Y)	% of otters in each oil category at PWP (P_{pwp})	Mortality by oil category at PWP (Y P_{pwp})	% of otters in each oil category at HB (P_{hb})	Mortality by oil category at HB (Y P_{hb})
H	0.93	0.00	0.00	0.45	0.42
M	0.76	0.09	0.07	0.42	0.32
L	0.46	0.61	0.28	0.12	0.06
N	0.3	0.3	0.09	0	0
			Σ 0.44		Σ 0.80

where Y_i is the mortality rate at location i, X_i is the exposure level at location i (in intersections/km^2), and X_q is the exposure level that resulted in 100% mortality. We estimated the parameters a and b by fitting a straight line through the mean exposure and mortality values at HB and PWP. We estimated X_q by extrapolating the line to the point where mortality (Y) was equal to 1.0.

In Example 2, we used the survival of sea otters from HB and PWP by degree of oiling to approximate the exposure-mortality relation (Tables 5-1 and 5-3). The relation was calculated in two steps. First, we estimated the proportion of otters in each oiling category resulting from each level of exposure. We then multiplied these proportions by mortality rates estimated specifically for each oiling category

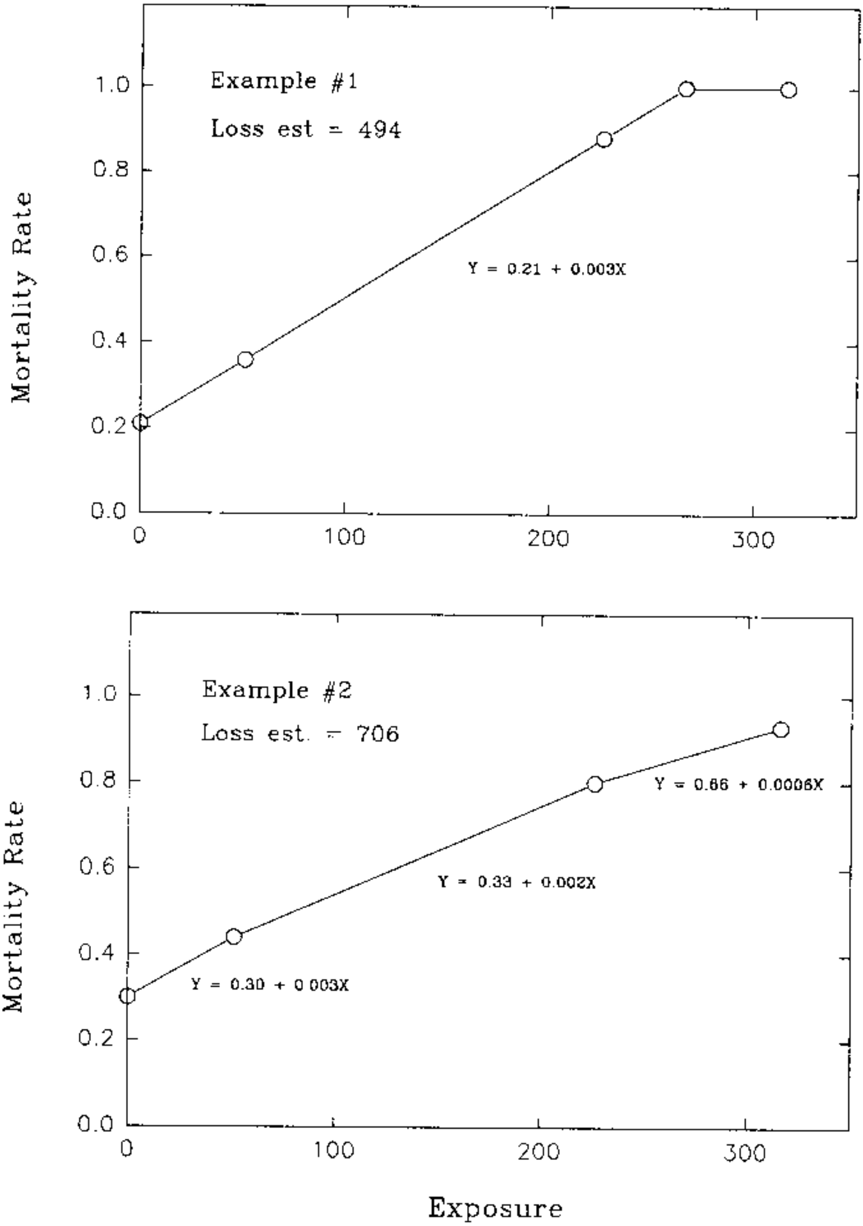


Figure 5-3. Two examples of the application of exposure-dependent mortality rates for the estimation of total acute sea otter mortality along the Kenai Peninsula. Exposure measures the number of oil particles that pass within 1.5 km of an observed otter location between 24 March and 23 May 1989.

and summed the products to obtain an overall mortality rate for each level of exposure. The first step is based on the assumption that the probability of an otter being in any particular degree of oiling category was a piecewise linear function of exposure. We assumed that: (1) none of the otters were oiled at locations without exposure, and (2) there was some exposure level above which all of the otters were heavily oiled. For locations with intermediate levels of exposure, we assumed that

$$P_{ij} = a_{j1} + b_{j1}X_i, \qquad 0 \le X_i \le x_{(PWP)}, \qquad j=1,\cdots,4$$

$$P_{ij} = a_{j2} + b_{j2}X_i, \qquad x_{(PWP)} \le X_i \le x_{(HB)}, \qquad j=1,\cdots,4$$

$$P_{ij} = a_{j3} + b_{j3}X_i, \qquad x_{(HB)} \le X_i \le X_H, \qquad j=1,\cdots,4,$$

where j indexes the oiling categories (1=none, 2=light, 3=moderate, 4=heavy), P_{ij} is the probability of an otter at location i (PWP or HB) being in category j, $x_{(PWP)}$ is the mean exposure level at PWP, $x_{(HB)}$ is the mean exposure level at HB, and X_H is the exposure level that resulted in all otters being heavily oiled. We estimated the parameters a_{jk} and b_{jk}, j=1, 4, k=1, 3, by fitting straight lines between the points $(0, P_{0,j})$, $(x_{(PWP)}, P_{(PWP),j})$, $(x_{(HB)}, P_{(HB),j})$, and $(X_H, P_{H,j})$, separately for each j=1, 4. $P_{(PWP),j}$ and $P_{(HB),j}$, j=1, 4 were estimated by the proportion of otters in category j from PWP and HB, respectively. By assumption, $P_{0,1}=1$; $P_{0,j}=0$, j=2, 4; $P_{H,j}=0$, j=1, 3; and $P_{H,4}=1$. We estimated X_H by extending the line through $(x_{(PWP)}, P_{(PWP),4})$ and $(x_{(HB)}, P_{(HB),4})$ to the point where $P_{i,4}=1$. In the second step, we estimated overall mortality rates as weighted sums specific for each oiling category; weights were equal to the probabilities for each of the oiling categories. Thus, the mortality functions had the form

$$Y_i = y_1P_{i1} + y_2P_{i2} + y_3P_{i3} + y_4P_{i4},$$

where y_j, j=1, 4, are the category-specific mortality rates. We estimated each of the y_j, j=1, 4, by the mortality rates for the respective categories in the combined HB and PWP data sets.

RESULTS

Oil Movements

The OSSM model indicated that oil first entered the waters along the Kenai Peninsula on about 30 March 1989. The quantity of oil leaving PWS and entering the Kenai Peninsula diminished through late April. According to Galt et al. (1991), about 25% of the spilled oil left PWS and traveled along the Kenai Peninsula. Local physiography and climatology resulted in incomplete coverage of oil on Kenai Peninsula beaches; the heaviest oiling occuring along prominent headlands.

Sea Otter Abundance and Distribution

A total of 351 groups totaling 1114 sea otters were detected from helicopters during surveys along coastal and offshore transects along the Kenai Peninsula during April 1989. Ninety-seven percent of the individual otter sightings were detected on the coastal transects. Based on these counts, DeGange et al. (1993) estimated a population size of 1275 sea otters (SE=26) in 778 km^2 of coastal habitat and 1055 sea otters (SE=215) in 3353 km^2 of offshore habitat. The estimated total number of sea otters on the Kenai Peninsula was 2330 (SE=217).

Sea Otter Oiling and Mortality

We captured or handled 43 live sea otters, 11 from HB and 32 from PWP, and recovered 23 carcasses, 22 from HB and 1 from PWP (Table 5-1). Rates of oiling, degree of oiling, and estimated mortality rates at HB and PWP, and comparisons between sea otters captured throughout western PWS and at the Kenai Peninsula are presented in Table 5-1. The proportion of heavily and moderately oiled sea otters captured in HB was 82%, whereas only 14% of the otters captured in PWP were in these categories. Twenty-two carcasses were recovered from HB (91% of which were heavily or moderately oiled) but only one carcass was recovered from PWP and it was lightly oiled. The mean mortality rates were 0.88 (29 of 33) at HB and 0.36 (12 of 33) at PWP. By the end of April 1993 only two live otters could be found in HB, at which time capture efforts were discontinued.

Oil Exposure

OSSM oil particles intersected 131 of the 351 sea otter exposure regions along the Kenai Peninsula on one or more days between 24 March and 23 May 1989 (Table 5-2). These 131 exposure regions represented an estimated 1211 of the estimated 2330 (52%) sea otters along the Kenai Peninsula. Potential exposure levels of this group averaged 6.1 intersections/km^2 (SE=0.75; range=0.17–32). Mean exposure levels at HB and PWP were 226 and 51 intersections/km^2, respectively (Table 5-2). Because 75% of the oil did not leave PWS and the oil that moved along the Kenai Peninsula tended to be offshore, we did not obtain the high levels of oil exposure at otter locations along the Kenai Peninsula that were measured in PWS. However, heavily and moderately oiled animals were captured along the Kenai Peninsula (Table 5-1).

Examples of Model-Generated Loss Estimates

Estimated mortality rates in Example 1 ranged from 0.21 at an exposure level of $X_i=0$ intersections/km^2 to 1.0 at exposure levels greater than or equal to $X_i=266$ intersections/km^2 (Fig. 5-3). At the Kenai Peninsula, estimated mortality rates attained a maximum value of 0.30 at the maximum estimated exposure of $X_i=32$ intersections/km^2. This example generated a total mortality estimate of 494 otters at the Kenai Peninsula.

In Example 2, estimated mortality rates ranged from 0.30 at $X_i=0$ to 0.93 at $X_i \geq X_H=316$ (Fig. 5-3). Although the mortality functions of Examples 1 and 2 crossed, estimated rates were higher in Example 2 than in Example 1 over the full range of the estimated exposure levels at the Kenai Peninsula. The maximum mortality rate estimated in Example 2 at the Kenai Peninsula was 0.39 at $X_i=32$. Example 2 generated a total mortality estimate of 706 otters along the Kenai Peninsula.

DISCUSSION

Several assumptions were required for the use of the data sets with the intersection model in addition to the assumptions of the model itself. The most important data assumptions were that: (1) the OSSM model accurately reflected the spatial and temporal distribution of spilled oil; (2) estimates of sea otter distribution and abundance from the helicopter survey were unbiased; (3) sea otter collection methods at the two capture sites were not selective; and (4) mortality rates of captured otters were not affected by the capture or the rehabilitation process.

Four key assumptions of the intersection model were (1) the relation between exposure to oil and mortality as measured by intersections/km^2 can be approximated by a piecewise linear function; (2) the relative exposure level measured in the region around each observed otter location reflected the relative exposure of those otters to oil; (3) the relation between exposure and mortality at the capture sites in PWS was the same as the relation at the Kenai Peninsula; and (4) the distribution and abundance of sea otters remained constant throughout the period of potential exposure.

Assumptions for Data

We did not have information to address all of the assumptions associated with estimates of oil and sea otter abundance and distribution. Bodkin and Weltz (1990) provided data that support the assumption of unbiased capture of live otters in HB and PWP. Most potential biases in carcass retrieval would result in fewer rather than more retrieved carcasses. This would have the potential effect of reducing mortality rates and, thereby, loss estimates. However, inclusion of oiled but non-spill-related carcasses would increase mortality rates and loss estimates. Because the carcasses collected in HB and PWP were fresh, it is most likely that mortality occurred at or near these areas and was, in fact, spill related.

Our estimates of mortality-exposure relations from the PWP and HB data required the assumption that rehabilitation did not affect survival rates. If this assumption was valid, we would expect little or no mortality among nonoiled otters. However, mortality rates of lightly oiled and nonoiled sea otters in PWS were 0.40 and 0.30, respectively, suggesting that the rehabilitation treatment had a negative effect on nonoiled and lightly oiled sea otters. Also, it may be reasonable to assume that all heavily and moderately oiled otters would die (Costa and Kooyman 1982) and that any survival among the animals in these oiling categories could be attributed to rehabilitation. Of the 86 heavily or moderately oiled sea otters captured in either PWS or the Kenai Peninsula (Table 5-1), 42 survived >35 days, resulting in a mortality rate of 0.55. This suggests that rehabilitation may have had a positive effect on the survival rate of heavily and moderately oiled sea otters. It would be a straightforward procedure to use our approach to generate loss estimates based on the assumption that there was no mortality of nonoiled or nonexposed otters, but without additional data, there is no basis for determining the magnitude of the corresponding adjustment required for the heavily and moderately oiled otters.

Assumptions for the Model

Our data indicated that mortality and the proportions of heavily oiled otters were increasing functions of exposure, but we were unable to evaluate the shape of these functions with the two data points available from HB and PWP. In order for our estimated relative exposure levels to have strictly corresponded to the actual relative exposure of otters to oil, the surface area represented by each OSSM oil particle would have to have been the same for all particles and would have had to remain constant over time. Also, sea otter movements and responses to potential exposure would have to have been the same for all otters. In fact, the surface area represented by an oil particle is likely to have changed with time. We did not have information to assess how sea otter behavior may have varied over the area affected by the spill. Failure to meet our assumption of similarity in the exposure-mortality function between PWS and the Kenai Peninsula may have biased the loss estimates to the extent that the exposure-mortality function varied over time. Potential changes may have resulted from cumulative effects of exposure to oil or changes in the quality (e.g., weathering) of spilled oil over time in addition to the effects of the change in surface area represented by each particle. The model also required the assumption that sea otters did not move in response to oil. We had no data to evaluate the validity or the effects of violating this assumption. During the capture of otters in PWS, we observed otters in apparently unoiled areas in close proximity to oiled areas; whether these observations were of avoidance or of good fortune is unknown.

Loss Estimates

Our examples provided loss estimates lower than the estimated loss of 868 sea otters provided by Doroff et al. (1993) and higher than the postspill difference of 183 sea otters provided by DeGange et al. (1993). Both of our examples resulted in loss estimates that were greater than the 167 carcasses recovered from the Kenai Peninsula. The mortality-exposure relationships used in our examples are unrealistic because they assigned nonzero mortality rates to nonoiled otters. However, reducing the mortality rate of nonoiled otters in the model would result in unrealistically low loss estimates. This suggests that mortality rates for lightly oiled otters are likely to have been greater than assumed in our examples.

CONCLUSIONS

The intersection approach seemed to provide an adequate estimate of relative exposure to oil for a case where suitable data on oil abundance and movement and on the abundance and distribution of sea otters were available. Our examples of loss estimates generated with the model demonstrated its sensitivity to the assumed relation between exposure to oil and mortality rates. The mean exposure values in HB and PWP were 38 to 8.5 times greater than those at the Kenai Peninsula (Table 5-2). Refinement of the model should include better definition of the exposure-mortality relation, particularly at low exposure levels. Mortality rates of otters subjected to rehabilitation should not be used to estimate this relation unless the effects of the interaction between rehabilitation and degree of oiling on mortality can be quantified. Further development of the model should also focus on obtaining an estimate of the precision of loss estimates. It is likely that bootstrap procedures (Efron 1982) will be required because of the complex nature of the loss estimator.

The need for a theoretical approach to estimate acute losses of sea otters arose because complete baseline data on sea otter abundance before the spill were lacking. This limited our ability to quantify the acute mortality of sea otters from the spill beyond the number of recovered carcasses. Direct estimates of losses from well designed pre- and postspill surveys would be preferable to those provided by models such as the intersection. Therefore, we recommend development and implementation of rigorous survey protocols in areas shared by sea otters and oil recovery, storage, and transportation. The most effective uses of the intersection model may be predictive modeling of the effects of future spills and quantifying exposure in a spill area.

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