POTENTIAL IMPACT OF OIL SPILLS ON CALIFORNIA SEA OTTERS: IMPLICATIONS OF THE EXXON VALDEZ SPILL IN ALASKA

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ABSTRACT

Based on the survival of sea otters held at rehabilitation centers during the 1989 Exxon Valdez oil spill in Alaska, we built two models of otter mortality. One was based on the relationship between mortality and distance from spill origin, the other was based on the relationship between mortality and time from the spill origin. These models are simplistic and are meant as first steps in arriving at realistic risk estimates and in providing a conceptual framework for relating oil spills and sea otter mortality. Using the distance model, we simulated the impact of an Exxon Valdez event occurring at different locations along the California coast. A spill at the Monterey Peninsula had the greatest impact, exposing 90% of the California sea otter population to oil and killing at least 50% of the individuals. The time model was used to predict the mortality of otters exposed to oil of various ages and for various periods of time. It suggested that efforts to rehabilitate otters should be discontinued 20–30 d after a spill.

The limitations of the data available from the Exxon Valdez spill emphasize the importance of being prepared to conduct appropriate research during the next oil spill in sea otter habitat.

Key words: Enhydra lutris, sea otter, oil spill, survival rate, model.

The California sea otter (Enhydra lutris) population was listed as threatened under the Endangered Species Act in 1977, primarily due to the risk of oil spills in its geographically constricted range (USFWS 1977). Prior to 1989 the only information on the vulnerability of sea otters to oil came from limited experiments with captive otters (Costa and Kooyman 1982, Siniff et al. 1982) and anecdotal
reports of sea otters killed by an oil spill in the former U.S.S.R. (Barabash-Nikiforov 1947).

Assessment of the potential impact of oil spills on the southern sea otter population requires estimates of the probability that oil will contaminate areas inhabited by otters and the probability that otters in contaminated areas will die. Although several computer models have been constructed to simulate the dynamics of oil spills (e.g., Smith et al. 1982) and used to estimate the probability that oil will contact sea otters along the California coast (Ford and Bonnell 1986), data to estimate the probability that an otter in a contaminated area will die are lacking.

In March 1989 the oil tanker Exxon Valdez ran aground and released 11 million gallons of oil into Prince William Sound, Alaska, an area inhabited by sea otters. The Exxon Valdez oil spill (EVOS) provided an opportunity to acquire many of the data needed for assessing the impact of oil on sea otter populations. Unfortunately, however, data collected prior to and during the spill did not directly measure sea otter mortality due to the oil spill (Estes 1992, Garrott et al. 1993). Counts of sea otters in Prince William Sound were conducted in 1984–1985 (Irons et al. 1988) and in 1989, 1990, 1991, and 1993 (USFWS, Anchorage, AK) using similar methods. However, the only survey conducted before the spill was the 1984–1985 work and, because the otter population had changed since that date, pre-spill information was essentially lacking. Nevertheless, several estimates of mortality have been made. These estimates have wide confidence limits, ranging from 500 to 5,000 with a loss estimate of 2,650 (Garrott et al. 1993) to 1,904–11,157 with a loss estimate of 3,905 (DeGange et al. 1994).

In a massive effort to capture and rehabilitate oiled otters, over 400 sea otters from Prince William Sound, Kodiak Island, and the Kenai Peninsula were captured between March and August 1989. In general, the capture effort was directed at rescuing obviously distressed animals, but some of the effort was preemptive. Detailed records of the fate of captured animals were maintained and, after considering all the available EVOS data sets with the help of USFWS personnel, we concluded that these data on captive otters could provide some insight into the mortality rates of the entire population during the spill. Data from the rehabilitation centers indicate that otters were less likely to become heavily oiled as a function of time and distance from the spill origin. As oil spread from the origin of the EVOS, it weathered, evaporated, and degraded (Gait and Payton 1990). Thus, distance and time from the origin of the spill until an otter was captured were correlated with average degree of oiling. Boktin and Udevitz (in press) found a relationship between distance from the spill site, degree of oiling, and survival for two areas where they were able to account for most of the otters present when the oil arrived.

In this paper we build two simple models of otter mortality during EVOS. One is based on the relationship between mortality and distance from spill origin, the other is based on the relationship between mortality and time from spill origin. The first model is combined with a simple model of oil spill dynamics constructed by Ford (1985) and recent information on the distribution of sea
otters in California, to arrive at estimates of the potential mortality were an
EVOS-sized spill to occur in California. These models are simplistic and are
meant only as first steps in arriving at realistic risk estimates; we anticipate that
their greatest utility is in providing a conceptual framework for thinking about
oil spills and sea otter mortality, and in providing a departure point for discussion
of future research and management needs.

The Models

Data Base

The data used to construct the models came from the Natural Resource
Damage Assessment data base maintained by USFWS Alaska Fish and Wildlife
Research Center. As alluded to previously, this data base was NOT compiled
with the intent of making mortality estimates and, as such, is fraught with bias
and inconsistency. The quality of the data base obviously influences the reliability
of our results. At this point let us simply describe the data base and assumptions
that were necessary to use it in the models. We will touch on some of the
problems with the necessary assumptions in this section and will discuss them
in further detail after the models are presented.

Information on otters captured in rehabilitation and mitigation efforts during
and immediately after the spill was compiled in the Natural Resource Damage
Assessment relational data base. Included in this data base were the date and
location that each otter was captured and the date and nature of its final
disposition; captured individuals for which any of this information was missing,
or whose recorded capture location could not be found on a navigational chart,
were excluded from our analysis. Capture efforts did not begin until 30 March
1989, six days after the Exxon Valdez ran aground and at least four days after
oil reached the islands of western Prince William Sound. Thus, animals that
died in the first four days were not included in the data base and did not
contribute to our estimates.

Several assumptions were necessary to use the data base for our purposes.
The first assumption was that the captured animals represented a random and
unbiased sample of the otters in the areas contaminated by oil. This may be
unrealistic, as the capture effort was undertaken to mitigate the effects of the
spill, not to estimate spill-caused mortality, and there was no attempt to obtain
an unbiased sample of animals. In fact, efforts early in the spill were directed
at rescuing the most heavily oiled and obviously debilitated animals, while later
in the spill preemptive efforts were directed at capturing as many animals as
possible regardless of their condition. Additionally, dip-nets were the primary
means of capture in Prince William Sound, while tangle-nets were used later
on, especially along the Kenai Peninsula (Bodkin and Welz 1990, Britton et
al. 1990). Variations in manpower, weather, and local sea conditions may also
have introduced biases into the capture effort. Unfortunately, while it is clear
that the captured animals are not an unbiased sample, information that would
allow the biases to be quantified is not available.
The second assumption is that animals did not change their general location during the course of the spill; hence, individuals had been resident in the area where they were captured since the beginning of the spill. This assumption may be reasonable because most otters are relatively sedentary over the short term (Siniff and Ralls 1988), although they occasionally make long-distance movements (Monnett 1988). There is anecdotal evidence that capture operations and the spill itself caused some long-distance movements. While such movements may have influenced observed survival rates, it is not clear that they introduce a definite bias into local survival rates.

The third assumption is that there is a direct relationship between an individual otter’s exposure to oil prior to capture and its survival in captivity; i.e., that animals that died in captivity would have died if left in the wild, and that those that survived in captivity would have survived in the wild. Thus, we assume that, on average, the rehabilitation effort had no effect on survivorship. Estes (1992) discusses the controversy over the efficacy of the rehabilitation program. Unfortunately, it is not clear whether the rehabilitation program increased otter survival (e.g., Van Blaricom 1990), decreased otter survival (e.g., Arnes 1990), or, as we assume here, had no net effect on survival.

A Model of Sea Otter Mortality in Relation to Distance from Spill Origin

Capture efforts during EVOS did not occur in random locations but tended to concentrate in seven relatively discrete areas: (1) North Knight Island-Naked Island, (2) Green Island-South Knight Island, (3) Latouche-Evans Island, (4) Natou-Pye Island, (5) Nuka/Tonsina Bay, (6) Windy/Rockey Bay, and (7) Kodiak Island. We grouped animals captured in each area together and estimated the mortality rate for that area by dividing the number of captured animals that died in captivity by the total number of animals captured in that area. We then plotted survival (1 - mortality) against the distance that each area was from the spill origin at Bligh Reef for each of the seven areas (Fig. 1). Survival was regressed against distance, testing three simple models—a linear model \( s = ad + b \), a logarithmic transformation \( \log(s) = a \log(d) + b \), and a reciprocal transformation \( 1/s = a(1/d) + b \), where \( s \) = survival, \( d \) = distance, and \( a \) and \( b \) are constants. Of these, the reciprocal transformation was the best fit to the data as measured by least squares, yielding:

\[
1/s = 137.97/d + 0.88
\]

\((R^2 = 0.97, F = 192.0, P < 0.0001)\). This equation can be rearranged to yield:

\[
s = (1.13 \times d)/(156.6 + d)
\]

which is plotted in Figure 1. This form of equation is intuitively appealing because it is found in models of dynamic systems throughout many fields of biology (models of enzyme kinetics and functional responses of predators to prey abundance among others). In this form the constant 1.13 is the asymptotic value of the dependent variable (survival), and the constant 156.6 is the value
of the independent variable at which the dependent value is one half of its asymptotic value, i.e., the distance from the spill origin at which sea otter survival would be one half of 1.13, or approximately 50%. This formulation also forces the relationship through the origin, implying that survival at the point of origin of the spill is 0.

A Model of Sea Otter Survival in Relation to Time from Spill Origin

The distance that oil moves from the spill origin depends on the time it has had to move, and it is to be expected that the relationship between sea otter survival and time from spill origin would parallel the relationship between survival and distance from spill origin. Indeed, Bodkin and Welz (1990) document that the survival of otters captured during the EVOS increased as time went by, presumably because the oil was diluted and weathered over time. In modeling this relationship, we assumed that each day of the spill was associated with a particular daily survival rate for the otters exposed to oil on that day. We calculated the probability of an otter surviving a given time interval as the product of the daily survival rates. The survival of captive individuals was then
a function of how old the spill was when it reached the area where an individual was captured and how many days each individual was exposed to the oil before it was captured.

Using the description of oil movement in Galt and Payton (1990), we determined the day that each captured animal was likely to have been first exposed to oil on the basis of its capture location. Individuals were then grouped into "cohorts" of animals that did not contact oil until day E of the spill and then were exposed for L days. Thus, the difference between the capture date (C) and the date of exposure (i.e., $C - E$) was the number of days an individual was at risk of contacting oil (L). This measure assumes that animals were exposed continuously from the time of first exposure until capture and, thus, represents the longest possible exposure time.

We then constructed a "life-table", assuming the total number of animals captured in a particular area was the population and calculating daily survival rates based on how these cohorts survived in captivity. There were two areas with large enough sample sizes for this analysis to be performed. One of these was the western part of Prince William Sound (the areas surrounding Eleanor Island, Green Island, Knight Island, and Evans Island) which, according to Galt and Payton (1990), was first exposed to oil on days 4–6 of the EVOS and from which the majority of the animals were captured during approximately days 10–28 of the spill. The other was the western Kenai Peninsula, where animals were first exposed to oil on approximately days 18–20 of the spill and were captured between approximately days 40 and 110.

Animals captured from each area were subdivided by day of capture, grouping animals where necessary to provide sample sizes of at least eight animals per group. None of the groups from the western Prince William Sound encompassed a capture period of more than five days, and none of those from the Kenai Peninsula were longer than 10 d. Captured animals that could not be fit into a group were excluded from the analysis, resulting in total sample sizes of 105 and 109 otters for western Prince William Sound and the Kenai Peninsula, respectively. When there was more than one day between successive capture days, the daily rate between capture days was assumed to be constant and was estimated by taking the $n$th root of the crude rate for the interval, where $n$ = number of days between capture days (Heisey and Fuller 1985).

Figures 2 and 3 plot the calculated daily survival rates against the day after first exposure. The fitted curves use the reciprocal transformations described above, with the day of first exposure serving as the independent variable and daily survival rate as the dependent variable. For the Prince William Sound data, $R^2 = 0.48$, $F = 7.352$, $P = 0.030$. For the Kenai Peninsula data, $R^2 = 0.27$, $F = 13.33$, $P = 0.070$, indicating that the daily survival rate had leveled off about 20 d after the spill occurred. The mean and standard error of the calculated daily survival rates for the Kenai Peninsula were 0.9936 ± 0.0086, which is not significantly different from 1.0 ($P = 0.27$). If otter survival was still influenced by oil 20 d after the spill, it was not detectable in our sample.

To arrive at a general relationship between age of oil and daily survival rate of otters during EVOS, data from Prince William Sound were combined with
Figure 2. Calculated daily survival rates for 105 sea otters first exposed to oil on approximately day 5 of EVOS in western Prince William Sound and subsequently captured. See text for explanation of plotted regression lines.

those of the Kenai Peninsula, and day of first exposure was translated to indicate the absolute age of oil on the day animals were first exposed. For example, the daily survival rate of 0.8764 calculated for otters in the western Prince William Sound 4 d after the first day of oil exposure applies to oil $4 + 5 = 9$ d old, and the rate of 0.9970 for 25 d after first exposure off the Kenai peninsula applies to oil $25 + 20 = 45$ d old. Figure 4 plots daily survival rate against age of oil for the entire data set. Daily survival rates were then regressed against age of oil, and the three simple models used earlier (linear, logarithmic transformation, and reciprocal transformation) were tested. The reciprocal model again provided the best fit, the rearranged equation being:

$$s = \frac{(1.023 \times d)}{(1.288 + d)}$$

($R^2 = 0.465, F = 11.4, P = 0.006$, plotted in Fig. 4). This analysis implies that the daily survival rate for otters exposed to oil rises quickly with the age of the oil, being 50% at 1.288 d of age, and that oil does not cause direct mortality after approximately 20 d of age.

**Estimating the Mortality Risks Associated with Oil Spills in California**

Above are two simple deterministic models of sea otter mortality during EVOS. The obvious next question was, “What are the implications of these models for California?” Assuming for the moment that mechanisms of otter mortality due to oil would be the same in California as they were in Alaska,
the models can be applied to California if the area or time course of an EVOS-sized oil spill in California can be estimated. While there are a large number of detailed stochastic simulation models of oil spill dynamics along the California coast, we know of no simple deterministic models which could be easily linked to our time-dependent model of sea otter mortality during EVOS. Ford (1983), however, constructed a simple deterministic model of the length of coast affected by a given-sized oil spill, that could be easily coupled to our distance-based model of sea otter mortality. He analyzed the relationship between the area affected by a spill, the amount of oil spilled, and several environmental variables for 39 nearshore oil spills, and arrived at the following equation to predict the length of coast impacted by a spill:

$$\log(COAST) = -0.8357 + 0.4525 \log(VOL) + 0.0128(LAT)$$

where $COAST = $ length of coastline affected in km, $VOL = $ volume of the spill in barrels, and $LAT = $ the latitude of the spill origin in degrees. The standard deviation of the log of length of coast affected was 0.384.

Predicting the effect of an EVOS-sized spill on the California sea otter population thus became a three-step process. First, the length of coast likely to be affected by an 11-million-gallon spill in California is estimated with Ford's model. Second, the number of otters likely to be affected by such a spill is estimated using recent USFWS and CDPG census data for the affected area.
Lastly, the distance-based model of mortality derived above from the EVOS is applied to the affected population to estimate the number of animals killed.

Ford’s model predicts that an 11-million-gallon spill off central California \((\text{LAT} = 37^\circ)\) would affect 140 km of coast (95% confidence intervals: 24–820 km). It predicts that the 11 million gallons spilled at Prince William Sound \((\text{LAT} = 60^\circ\) degrees) should have affected 276 km (95% confidence intervals: 47–1,616 km). The exact length of coast affected by EVOS is not known, but oil was found as far away as Chirikof Island, approximately 660 km from the spill’s origin (Galt and Payton 1990). This is greater than the mean length predicted by Ford’s model and, in fact, is almost exactly 1 standard deviation longer (668 km) than the predicted mean. We realize that the distance traveled by a spill would vary, depending on conditions; however, to mimic what happened in Alaska, we modeled spills that affected one standard deviation above the predicted length for California, that is, 339 km. This length of coast is about three-quarters of the current range of the California sea otter. We also modeled a spill affecting the predicted length of coast for California, 140 km.

We based the sea otter distribution along the California coast on the spring 1992 census conducted by USFWS and CDFG (total count = 2,101). In their census activities these agencies use a one-dimensional ordinate system traced over the 3-fathom depth contour along the coast to record each animal’s position; we used this one-dimensional ordinate system to represent distance; that is, we distributed the otters along this "3-fathom line" according to the census data.
and assumed that spills spread along this line from their point of origin. Although an oil spill in California might move in any direction, we modeled the simplest case by assuming that spills spread with the prevailing winds and current from north to south. We built a simulation model that introduced spills at successive points along the 5-fathom line, each spill spread south, killing contacted animals in the proportions predicted by the EVOS distance-based model. Figure 5 shows the number of animals that would die as a result of a spill originating at each point along the 5-fathom line and spreading southward for 339 km. It indicates that the greatest mortality would occur from a spill originating at Point Pinos at the tip of the Monterey Peninsula, which would kill 1,041 otters, or 49.5% of the population. Figure 6 details the distribution of mortality for such a spill.

We then used the same procedure to introduce a spill affecting 140 km of coast (the value predicted by the Ford model), also originating at Point Pinos (Table 1). Note that the predicted mortality from a spill affecting more than 339 km of coast would be the same as for the spill affecting 339 km. This is because the southern boundary of the sea otter range in California is about 340 km south of the Monterey Peninsula.

**DISCUSSION**

*Reliability of the Models*

We have constructed two models of sea otter mortality as a function of oil exposure based on the survival of sea otters captured during the EVOS, and
based our assessment of the potential risk of an EVOS-sized spill to the California population on one of them. Formal validation of these models is impossible. However, to help judge how reliable these models may be, we can consider how their predictions might be affected by violations of the major assumptions made in building them.

The major assumption in the models is that the mortality of sea otters captured during EVOS truly represents mortality due to oil exposure in the wild population. That is, we assume that capturing and cleaning otters did not affect their survival. Opinions on the benefits of the rehabilitation program vary substantially, with some maintaining that the program improved otter survival (e.g., Van Blaricom 1990) and others arguing that capture efforts actually increased overall mortality (e.g., Ames 1990). If rehabilitation efforts did increase otter survival, then our models overestimate the survival of unincaptured otters.

We assumed that the fates of the captured otters were a random and unbiased sample of the fates of otters in the spill zone. This assumption seems very unlikely to be valid. We know that the majority of the early capture efforts were directed at obviously distressed animals, so there would have been a tendency to capture animals that were more likely to die if left in the field. However, many otters died in the first three to four days of the spill and were, thus, no longer available to be included in the sample that went to the rehabilitation centers. The absence of these individuals from the sample would lead to an overestimate of survival, tending to counteract the underestimate resulting from targeting distressed individuals for capture. It is certain that, as the oil aged,
Table 1. Summary of predicted effect of an 11-million-gallon oil spill occurring near the tip of the Monterey Peninsula, according to the simple model of mortality as a function of distance from spill origin. Based on Ford's (1986) relationship between spill volume and length of coast affected, the relationship between distance from spill origin and otter mortality observed in EVOS as described in text, and the Spring 1992 census of the southern sea otter population.

<table>
<thead>
<tr>
<th>Length of coast affected by spill:</th>
<th>140 km</th>
<th>339 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentile of expected distribution:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>of length affected:</td>
<td>50</td>
<td>84</td>
</tr>
<tr>
<td>Number of otters in spill zone:</td>
<td>1,172</td>
<td>1,883</td>
</tr>
<tr>
<td>(Percent of total population):</td>
<td>(56%)</td>
<td>(80%)</td>
</tr>
<tr>
<td>Number of otters killed:</td>
<td>778</td>
<td>1,041</td>
</tr>
<tr>
<td>(Percent of total population):</td>
<td>(38%)</td>
<td>(50%)</td>
</tr>
<tr>
<td>Percent of otters in the spill zone that are killed:</td>
<td>66</td>
<td>55</td>
</tr>
</tbody>
</table>

...fewer animals encountered it in a manner that resulted in total body coverage. Less coverage would result in greater survival, since it has been shown that otters can clean themselves of oil to some degree (Siniff et al. 1982, Costa and Kooyman 1982).

Furthermore, capture and transport are stressful experiences for wild otters and can result in capture myopathy and death even in unsedated individuals (USFWS 1992). The most common cause of death among the otters captured in the EVOS was "shock characterized by hypothermia, lethargy, and often hemorrhagic diarrhea" (Rebar et al. 1993). Lightly oiled otters were as likely to die from this cause as heavily oiled otters, leading Rebar et al. (1993) to suggest that capture and captivity were more important than oil exposure as causes of mortality. If so, animals captured some time after the spill began may have had higher mortality rates than those left in the wild. Thus, the overall bias in the survival rates of the captive animals may have been towards lower mortality in the rehabilitation centers compared to those in the wild shortly after the spill, but towards higher mortality in these centers compared to those in the wild later in the spill. If this is true, the shape of the survival curve of animals in the wild would tend to be more rectangular (that is, rise more steeply, but level out earlier) than that calculated for the captured animals. But overall, these biases would tend to cancel and the overall mortality observed in the captured animals may indeed be indicative of overall mortality in the wild.

The results of extrapolating our calculated survival rates back to the immediate post-spill period before capture efforts began are obviously highly dependent on the form of the model chosen. The reciprocal model is intuitively appealing and easy to apply, and the small sample sizes available do not justify fitting models of more than two parameters. However, this model is undoubtedly an oversimplification that could potentially lead to errors in estimates of the survival rates immediately after the spill. Furthermore, the analysis assumes that daily survival rates are independent of the number of days exposed. If, as might be the case, exposure on one day reduces an otter's chance of survival on the next, the
probability of an otter surviving continuous exposure during the first few days of a spill would be even smaller than the model predicts.

We also assumed that otters remained in one location during the spill. Since both models depend on survival calculated for specific areas, violations of this assumption affect the reliability of the estimates. It is likely that both the oil itself and the associated human activity, including capture efforts, increased otter movements during the four-month period considered in the analyses. If large numbers of otters successfully avoided contact with oil by moving away from oil or human activity, then our survival estimates based on the geographic proximity of otters and oil underestimate the survival of oiled otters.

We must also consider differences in physical habitat between Alaska and California. The multitude of islands, arms, sheltered bays, and tide-influenced shallows of Prince William Sound are in sharp contrast to the open coast, high surf, and narrow zone of shallow water along central California. If otters escaped contact with oil in Alaska, it would be much more difficult for them to do so in California, whether by chance or avoidance behavior. Thus, survival in California would be poorer. Finally, our models address only the immediate effects of oil on sea otter population dynamics. Long-term effects of oil on sea otter habitat may have additional impacts on the health and survival of sea otter populations exposed to oil.

Implications for Sea Otters in California

Despite the caveats outlined above, we believe the models are useful as long as their resolution, purpose, and shortcomings are kept in mind. Because different oil spills can move various distances in a given time period, the time-based model would seem to be more general than the distance-based model. It approximates the chance that an otter will survive a day of exposure to oil of a given age. It can be used to calculate the expected survival of animals exposed to oil at different times, and for different time intervals, during a spill and could be linked with explicit models of oil-spill movement (Smith et al. 1982) to arrive at more realistic predictions of sea otter mortality as a result of oil spills. The exact parameter estimates we made are only a starting point for such analyses, and attempts to link this model with models of spill dynamics should include sensitivity analyses exploring the effects of wide variation around these estimates.

The fact that a simple relationship between mortality and exposure emerged from the EVOS data is more important than our exact parameter estimates. The reciprocal model of survival in relation to time of exposure is a theoretically sound, and now empirically supported, framework that can be used to improve estimates of the risk oil spills pose to the California sea otter population.

The distance-based model gave us some idea of the effect that a spill the size of the EVOS might have in California. The length of coast affected by the EVOS fell well within the range predicted by Ford's (1983) simple model of oil spill dynamics, providing some support for the validity of that model. A similar prediction for California indicated that the entire range of the southern sea otter could easily be affected by a spill the size of the EVOS.
The distance-based model also allowed us to make the first empirically based analysis of the risk of a spill in relation to the location of its origin along the California coast. The worst location for a spill was off the tip of the Monterey Peninsula. Our simulation of an EVOS at this location resulted in the death of nearly 50% of the California sea otter population. Because survival rates based on the otters captured in Alaska are likely to be overestimates and because sea otters in California are less likely to be able to avoid exposure to oil, we regard this estimate as a best-case scenario for such a spill.

The models in this paper may not accurately represent mortality and time/distance relationships, but their general form seems reasonable: that is, sea otter mortality decreases with time and distance from the spill. This relationship has implications for future otter rehabilitation efforts in California which will be undertaken in the event of an oil spill, in spite of the debatable benefits of the EVOS rehabilitation program (Estes 1992). Regardless of one’s beliefs regarding the value of attempting to capture and clean oiled otters immediately after an oil spill, our models imply that such rescue efforts will not be beneficial to otters at some time and distance from a spill. This time and distance will vary among spills, depending on the type of oil, the rate at which it weathered, and the rate at which it travels. However, our time-based model suggests that rehabilitation efforts should be discontinued 20–30 d after the spill.

Finally, the shortcomings of the EVOS data we used emphasize the importance of designing and implementing appropriate research plans for the next oil spill that occurs in sea otter habitat. These objectives should include unbiased observations of sea otter behavior in contaminated areas and the data required for unbiased estimates of the proportion of otters killed in contaminated areas. Garrott et al. 1993 make useful suggestions regarding the design of such a research program, particularly pre-spill surveys, estimation of carcass recovery rates, and the use of radio telemetry to follow the fates of oiled carcasses and live otters in areas affected by the spill. We would like to reiterate the need for such a design to be already in place by the time the next oil spill occurs in sea otter habitat.

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