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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 (Galt 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. Botkin 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 Weltz 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.*, Ames 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) Natoa-Pye Island, (5) Nuka/Tonsina Bay, (6)Windy/Rocky 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 $(1 - \text{mortality})$ 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

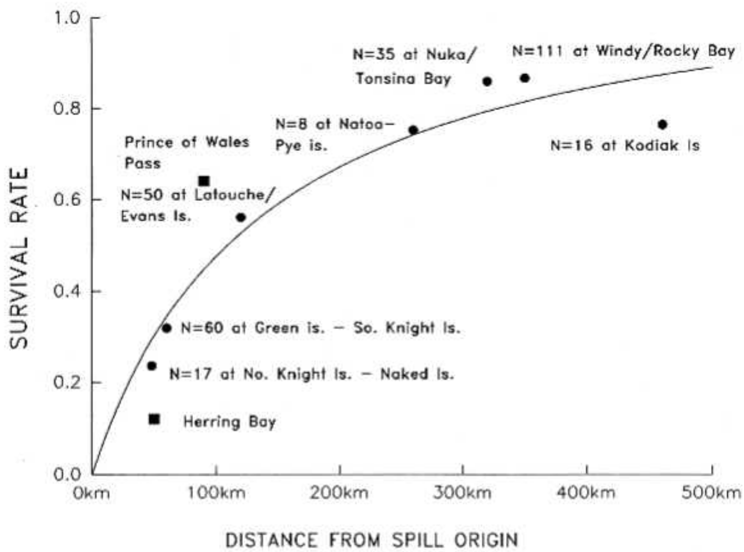

Figure 1. Crude survival rate as a function of distance from spill origin (at Bligh Reef) for 297 sea otters captured in rescue efforts during the *Exxon Valdez* oil spill. See text for explanation of plotted regression line. The two estimates represented by squares, for Prince of Wales Pass and Herring Bay, are from Botkin and Udevitz (in press, table 1). These two estimates were based on otters captured for rehabilitation, as well as carasses recovered in these locations, and were not included when fitting the regression line.

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 Weltz (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 nth 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

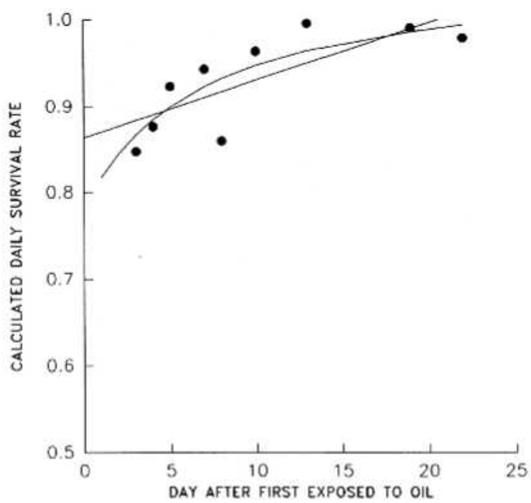

Figure 2. Calculated daily survival rates for 105 sea otters first exposed to oil on approximately day 5 of EVOS in western Prince William Sound and subsequently captured. See text for explanation of plotted regression lines.

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:

$$s = (1.023 \times d)/(1.288 + d)$$

($R^2 = 0.465$, $F = 11.4$, $P = 0.006$, 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,

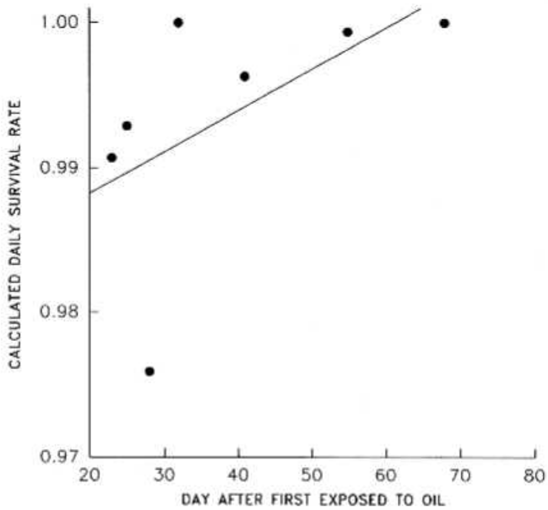

Figure 3. Calculated daily survival rates for 109 sea otters first exposed to oil on approximately day 18–20 of EVOS off the Kenai Peninsula and subsequently captured. Linear regression is not significant.

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 (1985), 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 CDFG census data for the affected area.