APPENDIX C

USING INFORMATION ABOUT THE IMPACT OF THE EXXON VALDEZ OIL SPILL ON SEA OTTERS IN SOUTH-CENTRAL ALASKA TO ASSESS THE RISK OF OIL SPILLS TO THE THREATENED SOUTHERN SEA OTTER POPULATION

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ABSTRACT

The work described herein uses information about the effects on sea otters of the Exxon Valdez oil spill in Prince William Sound, Alaska to enhance assessment of the risks of oil spills to the threatened southern sea otter population in California. Previous models of oil spills and otter populations are described briefly. Data on sea otters captured during rescue operations in Prince William sound are used to build a simple model of otter mortality as a function of distance from spill origin. The model allows assessment of the relative risk of an 11 million gallon spill occurring at different locations along the California coast, and identifies the tip of the Monterey Peninsula as the point of origin of a spill that would have the greatest effect on the population. Such a spill would expose 90% of the population to oil and result in a minimum range-wide mortality of 50%. The data is further analyzed in a life-table to arrive at estimates of the daily mortality rates of otters exposed to oil. These survival rates may be used to predict the mortality of otters exposed to oil at different times and for different lengths of time during an oil spill. It is hoped that these rates can be linked with explicit models of oil spill dynamics to construct mechanistic models of the potential impact of oil on the southern sea otter population. Limitations of the analyses are discussed, and direction for further research suggested.

Purpose.

The introduction to this report is brief. It is assumed that persons interested in this analysis are already familiar with the history of sea otter management in California and Alaska, and are familiar with the work of the various government agencies and universities involved in sea otter research, particularly those studies aimed at assessing the impact of the Exxon Valdez oil spill (EVOS) on the sea otter population of Prince William Sound and the Kenai Peninsula. The purpose of the present work is to use data about the impact of EVOS to improve understanding of the risk of oil spills to the southern sea otter population.

Previous work.

In the fifteen years since the Endangered Species Act provided the impetus for assessing the potential impacts of oil on the southern sea otter population, such assessments have revolved around three central questions: 1) what is the chance of oil contaminating the environment inhabited by sea otters?, 2) how does oil behave in the environment?, and 3) how do otters react to oil? Complete risk assessment must address all of these questions and link the answers in a realistic fashion. As it is impossible to study the effects of oil on a sea otter population experimentally, assessment of the risks of a spill to the southern population have been based on analysis of computer models constructed to simulate the dynamics of both oil spills and the sea otter population.

The principal model of oil spill dynamics is the OSRAM of USGS (Smith et al 1982), which models oil movement in detail but provides only a "yes or no" answer in regards to spills contacting specific geographic targets. Ford and Bonnell (1986) used this model to assess the risks of oil contacting sea otters in California. The majority of their analysis focused on predicting the probability of oil spills occurring and contaminating sea otter range; sea otter mortality in relationship to oil contamination was incorporated in only a general, delphic, fashion.

Bodkin and Udevitz (1991) linked a detailed oil spill movement model with known geographic distribution of sea otters along the Kenai Peninsula, and were able to estimate differences in potential exposure to otters during EVOS. Currently their model does not include specific relationships between exposure and mortality.

Brody (1988) developed a model of the dynamics of the California sea otter population that emphasized demographic detail but lacked any empirically-based incorporation of the effect of oil. The boundaries of any spill were static, and the probability of an individual otter dying within a spill zone was modeled as a function of 3 parameters describing the mortality associated with oiling, the ability of an animal to find local refuge within a spill zone, and the probability of an animal surviving a spill by leaving the spill zone entirely. While this seemed theoretically sound, there were no data with which to estimate these parameters; thus they were incorporated into the model as purely delphic parameters, where the user must speculate as to what the values of these parameters might be.

In reviewing previous work, it is obvious that, of the 3 questions mentioned earlier, the third one, "how do otters behave in oil?" is the one for which the answer is least developed. Data on behavior of individual otters inside a spill zone would obviously be very useful for estimating the effect of oil on a population. Though Bodkin and Weltz (1990) give anecdotal descriptions of the behavior of animals observed in oil during capture efforts, quantitative data was impossible to collect during the EVOS. The best estimates of potential oil spill mortality will come when we can relate oil exposure and sea otter mortality in a mechanistic fashion. Describing such a relationship, based on information from EVOS, is the focus of this report.

General approach.

To be able to model the effects of oil spills on a sea otter population in a mechanistic fashion, we would like to have a "dose-response" curve that gives sea otter survival as a function of oil exposure. Oil exposure might be measured by something like gallons of oil in the home range or decreased insulating ability of fur. There are ongoing efforts at elucidating what the relationship between exposure and mortality might be (Mulcahy and Ballachey 1991, Rebar 1991), but at present there is not enough data to describe the relationship in sufficient detail to include in a model. Until we can put oil exposure "on the x axis", then, we must be satisfied with using parameters which we assume to parallel oil exposure as predictors of mortality. The most obvious of these parameters are time and distance from the spill origin. In general, as time elapses after the spill, oil weathers, aromatics evaporate, hydrocarbons degrade. With increasing distance from the spill origin, oil is diluted, stabilizes, and settles out of the habitat. Local weather events, currents, and mechanical properties of oil will, influence how well time and/or distance might reflect actual exposure of otters to oil after a given spill.

At this point we should consider how information from the Alaskan population might be applicable to otters in California. Perhaps the most obvious differences between Alaska and California that would pertain to an oil spill are in habitat physiognomy. 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 in central California. The geography of Prince William Sound provided refugia of oil-free habitat within the spill zone that would certainly be much rarer during a similar-sized spill in California. It is also likely that oil would move faster and probably weather faster in California. Thus the relationships between time, distance, and oil exposure after a spill will be different. It is unlikely, however, that there are any major differences in the mechanistic, physiologic relationship between individual animals' exposure to oil and mortality between the 2 populations. A given-sized spill will affect otters differently in Alaska than in California, but the difference is better thought of as a difference in the interaction of habitat and oil, not of otters and oil. This may seem a minor point, but it gives a conceptual framework around which we can apply information from Alaska to California. Again, the purpose here is not to build another model of oil spill dynamics, but to provide a more realistic link between such models and otter mortality, to concentrate on the third question raised in the introduction.

Data.

Since EVOS there has been monumental effort directed at quantifying the effect of the spill on the southcentral Alaskan sea otter population. Prior to the analysis described herein, a general survey of data that were and were not available was conducted by USFWS personnel (Table 1). Counts of local populations that would have allowed comparison of pre- and post-spill population sizes and direct calculation of spill-related mortality were not available. As mentioned earlier, information on the behavior of individual animals exposed to oil during EVOS would have been extremely useful, but, for various reasons, was not collected.

Maps of degree of oil-contamination of beaches were available, as were maps of locations of recovered carcasses. Attempts to correlate the degree of local contamination to number of carcasses recovered were stymied by an inability to relate number of local carcasses to local mortality rate (i.e., no information on pre-spill population size) and uncertainties about carcass movement and recovery rates. While there have been some estimates of carcass recovery rates (DeGange et al, in preparation, Wendell et al 1986), the applicability of these estimates to actual mortality rates is not well established. In attempt to acutely mitigate the effects of EVOS, over 400 sea otters from Prince William Sound, Kodiak Island, and the Kenai Peninsula, were captured between March and August 1989. Much of the capture effort was directed at rescuing obviously stressed animals, but some of the effort was preemptive. Detailed records of the fate of captured animals were available, and, after considering the information above, it appeared that mortality rates of captured animals would provide the best insight into actual field mortality rates. The analysis in this report, then, focuses on the survival rates of these captured otters. This information was available in the N.R.D.A. relational data base (as it existed on 15 May 1992) maintained at the U.S.F.W.S. Research Center in Anchorage. Aspects of this data base that were relevant for the following analyses included the date and location of capture and the final disposition and date of disposition of each captured animal. Animals for which any of this information was missing, or whose recorded location was not able to be located on a navigational chart, were excluded from analysis. A listing of the raw data extracted from the N.R.D.A. data base is appended.

The major assumption made about these data is that there is a direct relationship between the ability of an animal to survive after capture and the impact suffered from exposure to oil prior to capture; that those animals that died after capture or needed to be euthanized would have died from exposure to oil (though not necessarily on the day they were captured) and those that survived captivity would have survived in the wild. To be sure, there is much debate about this relationship, with some arguing that capture increased overall mortality (e.g. Ames 1990) and others believing in the efficacy of rehabilitation (e.g. VanBlaricom 1990). Perhaps in retrospect we can hope that any true rehabilitation was exactly balanced by the stresses of capture and captivity.

A second assumption is that animals did not change their general location during the course of the spill; that animals captured at a particular location had been resident there since the beginning of the spill. There is anecdotal evidence that capture operations, and the spill itself, did indeed cause some long range movements of animals, but there is no explicit information available on such movements. While such movements may have indeed influenced observed survival rates, it is not clear that they introduce a definite bias to lovsl survival rates.

A simple model of oil spill mortality based on distance.

Gait and Payton (1990) describe how the character of EVOS changed with time. With the idea that acute and sub-acute toxicity from oil will decrease with distance from the spill origin, the effect of distance from EVOS origin on survival was investigated. Most of the capture effort occurred in 7 general locations; fates of individual animals captured in each general location were tallied to give an average survival rate for that location. Results are plotted in Figure 1. It must be remembered that capture operations did not begin until 30 March 1989, 6 days after the Exxon Valdez ran aground, and at least 4 days after oil reached the islands of western Prince William Sound where capture operations started. Animals that died in the 4 days before capture operations began, when the oil was undoubtedly most toxic, were not available for capture and thus would not be included in the calculations of local survival rates. Overall mortality was almost certainly greater than the mortality of captured animals would indicate. For this reason, survival rates calculated from the fates of captured animals must be considered as maximums. A linear regression of these local survival rates on distance from the spill origin was significant (R^2=0.73, F=17.5, p=0.009), but as the plot suggested a curvilinear relationship, log and reciprocal transforms were performed and tested. The best fit was the reciprocal transformation (R^2=0.97, F=192.0, p=0.0001), which yielded:

$$1/s = 0.88 + 137.97/d$$

where *s* and *d* are survival and distance from spill origin, respectively. This equation can be rearranged to give a "Michaelis - Menton" equation:

$$s = (1.13 \times d) / (156.6 + d)$$

which is illustrated in Figure 1. Equations of this form have been used to describe many relationships in biology (for instance population growth, enzyme kinetics, and response of predators to prey abundance...), and are attractive because the parameter estimates represent easily understandable quantities: the parameter in the numerator (1.13) represents the asymptotic value of the dependent variable (survival), and the parameter in the denominator (156.6) represents the value of the independent variable (distance) at which the dependent variable is at 1/2 of its maximum value. Note that this formulation forces the relationship between distance and mortality through the origin, that is, there is no survival, at the point of origin of the spill. This may in part compensate for the overestimate of survival that might result from measuring survival rates more than 4 days after the spill began.

Application of simple distance-based model to California.

We now have a simple relationship between distance from spill and otter mortality, and are in a position to see what the implications of the empirical relationship from Prince William Sound are for the southern sea otter population. To do this, we need an idea of how a similarly sized spill would affect the California coast. Ford (1985), studied the relationship between spill size, location, wind speed, wave height, water temperature and the length of coast affected by 39 near-shore oil spills. He found that the best predictor of the length of coastline impacted by a spill was given by:

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

where *COAST* = length of coastline affected in kilometers, *VOL* = volume of spill in barrels, and *LAT* = latitude of the spill origin in degrees; the standard deviation of the log of length of coast affected was 0.384. Given this relationship, an 11 million gallon (349,206 bbl) spill in Prince William Sound (latitude = 60 degrees) would be expected to impact 276 km of coast; +/- 1 standard deviation would bracket the estimate between 114 and 668 km. To determine the length of coast actually affected by EVOS invites discussion as to how exactly that might be measured, but all would agree that it was much more than the 275 km predicted by Ford's regression equation. Gait and Payton (1990) describe oil from EVOS being found on the shore at Chirokof Island, approximately 660 km from Bligh Reef. This is about 1 standard deviation above the expected length of coast affected, falling on the 84th percentile of expected length of coast affected.

According to Ford's (1985) relationship, a spill of 11 million gallons occurring off of central California (latitude = 37 degrees) would be expected to affect 140 km of coast. An 11 million gallon spill affecting a length of coast 1 standard deviation above the expected length would affect 334 km of coast, or about three quarters of the current range of the southern sea otter. The ninety-fifth percentile of the length of coast affected is 597 km, a distance longer than the current sea otter range.

Assuming that an oil spill will spread with the prevailing winds and current from north to south along the California coast, the numbers of otters that would be killed by a spill the size of the EVOS can be predicted by a simple deterministic simulation model that applies the relationship between distance and survival indicated in Figure 1 to the distribution of sea otters along the coast. In this model the spill moves down the coast from the point of origin and kills otters in the proportion predicted. For example, at 10 km from the point of origin, (1.135x10)/(156.6+10) = 6.8% of the animals at that location will survive the spill, while at 50 km from the point of origin (1.135x50)/(156.6+50) = 27.5% of the animals at that location will survive the spill.

In this model, the 5-fathom line ordinate system developed by USFWS and CDFG in their census activities is used to represent distance, and the most recent census data available (spring 1992, total count = 2101) is used to represent otter distribution. To determine the relative risks to the southern sea otter population of a spill the size of EVOS occurring at given points along the coast, spills affecting 334 km of coast were introduced successively every 5 km along the 5–fathom line, and the numbers of animals that would be killed by spills at each successive location totaled. Results are depicted in Figure 2, which may be interpreted as a graphic representation of the risk to the population as a function of the point of origin of an 11 million gallon spill.

The model predicts that the most damage would be done by a spill introduced near the tip of the Monterey Peninsula (5-fathom line ordinate 386), killing 1041 of the 2101 otters that were counted, or 49.5% of the population. The model was then run introducing spills affecting 140 and 597 kilometers of coast to reflect the probability distribution determined by Ford's (1985) analysis. These predictions are summarized in Table 2. Note that predicted mortality from spills affecting 343 and 597 kilometers of coast are the same. This is because the southern boundary of sea otter range in California is approximately 340 km south of the Monterey Peninsula, so oil spreading more than 340 km would kill very few additional otters.

The pattern of mortality predicted from a spill introduced near the tip of the Monterey Peninsula and affecting 334 km of coast is shown graphically in Figure 3. Note that this analysis implies that the spill originates on the 5-fathom line, and thus affects otters at distance 0 km from the origin. This would be possible if the spill resulted from a disabled tanker drifting into shallow water, but if the spill is presumed to result from an offshore source the distances used in the model would have to be adjusted accordingly.

A model of survival based on time of exposure.

The above distance-based model is independent of time. Time and distance from spill origin are intimately related, and in fact the processes that determine how far a spill will spread, such as wind and current, and how toxic or persistent a quantity of oil will be, such as dilution and evaporation, are all time-driven. The distance-based model was constructed first because distance was much easier to measure in retrospect, but to construct more useful mechanistic models of the relationship between oil spills and otters it will be necessary to model mortality as a function of time of exposure and age of the spill. Existing models of oil spill dynamics (e.g.the USGS OSRAM (Smith et al 1982)) iterate on a time basis, and integration of a model of sea otter mortality in relation to oil exposure into such a model will be facilitated if mortality is in some fashion driven by the age of oil.

Bodkjn and Weltz (1990) note that the ultimate survival of otters captured during and immediately after EVOS increased with elapsed time from the spill origin. Presumably this resulted in large part from a decrease in the toxicity of oil over time. If indeed this is the case we might think of each day of the spill being associated with a particular daily survival rate for otters exposed to oil on that day, and that the daily survival rate increases with time. The probability of an animal surviving a given time interval would then be given by the product of the daily rates, and the overall survival of animals will be a function of not only how old the spill is, but also how many days the animal is exposed to oil. For instance, an animal first exposed on the second day of the spill would have less chance of surviving the spill than one first exposed on the 10th day of the spill, and an animal exposed on days 10 through 12 would have a better chance of survival than one exposed on days 10 through 20.

To see if such a relationship is borne out in the data, it was assumed that captured animals were resident at their capture locations throughout the duration of the spill, and were first exposed to oil on the day that oil moved into the capture location. Using the description of oil movement in Gait and Payton (1990), the day that each captured animal was likely to have been first exposed to oil was determined on the basis of its capture location. Animals could then be grouped into "cohorts" of animals that were first exposed to oil on day *E* of the spill and exposed for *L* days, where $L = C - E$ and *C* is the day the animal was captured. Note that this assumes that animals were exposed continuously from the time of first exposure until capture. Analysis of variance of the effect of length of time exposed *(L)* and day first exposed *(E)* on survival, weighted by the number of animals, conducted with the SAS General Linear Model procedure (SAS 1982) showed significant effects of both *E* and *L*:

Source	MSE	F	P<F
E	12.97	47.4	0.001
L	1.84	6.7	0.011
ExL	0.98	3.6	0.062

and subsequent regression gave significantly positive estimates for the effects of *E* and *L* (0.021 and 0.007, respectively, $p<0.0001$ for each), suggesting that observed survival actually increased with the length of time an animal was exposed to oil.

This result implies that animals captured later in the spill and after longer periods of exposure had already survived the worst effects of oiling -- many of the animals that were not to survive the spill had died prior to the commencement of capture operations, and were then not available for capture. That this was indeed the case was alluded to earlier, in the discussion of the distance-based model of survival. The fact that many animals may have died prior to being available for capture does not, however, affect calculations of daily mortality rates for the period of time during which capture operations were occurring, as long as the assumption that the effect of oil on an animal's survival is not affected by capture holds. Thus a "life-table" type of analysis, where the population considered was the total number of animals captured during the spill, was conducted for 2 areas where sample sizes were large enough to do such an analysis. One area was the Eleanor Island - Green Island - Knight Island - Evans Island area of western Prince William Sound, which, according to Gait and Payton (1990), was first exposed to oil on days 4-6 of EVOS and from which the majority of captured animals were captured between about days 10 and 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 about days 40 and 110 of the spill.

Animals captured from these areas were subdivided by day of capture, grouping animals where necessary to provide sample sizes of at least 8 animals per group. None of these capture day groups encompassed more than a 5 day period of capture days for the western Prince William Sound animals or a 10 day period for the Kenai animals. Captured animals that could not be fit into a group were excluded from analysis, so that total sample sizes for western Price William Sound and the Kenai Peninsula were 105 and 109 animals respectively. The data thus organized is presented graphically in Figures 4 and 6. Tables 3 and 4 outline the calculations that this manipulation allows. Where there was more than 1 day between successive capture days the daily rate between capture dates was assumed to be constant and 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). As expected, the daily survival rates are greater for the Kenai Peninsula, as otters here were exposed to "older" oil.

Figure 5 plots the daily survival rates against the day after first exposure to oil for otters in western Prince William Sound. Daily survival rate increases with time, indicating again that mortality decreases with the age of oil. Regression lines of daily survival against time after first exposure are shown for linear regression and the Michaelis-Menton (reciprocal) regression. Again, the non-linear model provides a better fit on the basis of sum of squares, although the difference is not dramatic (R^2=0.43, F=6.419, p=0.0445 for the linear model vs. R^2=0.48, F=7.352, p=0.0350 for the non-linear model). Note that there is little difference between linear and non-linear models in predicted mortality over the range of times for which data was collected, but that the 2 models have drastically different implications for the mortality in the days immediately after a spill.

Figure 7 plots the daily survival rates against the day after first exposure on the Kenai Peninsula. While the plot does indicate an upwards trend, the regression is only marginally significant (R^2=0.27, F=13.33, p=0.07), indicating that the daily survival rate 20 days after the spill has leveled off. The mean and standard error of the calculated daily rates for the time period in Figure 7 is 0.9936 +/- 0.0086, which is not significantly lower than 1.0 (p=0.27). Either the daily survival rate is in fact still influenced by oil 20 days after the spill, but to a degree not detectable in our small sample, and/or the mortality observed at this point is in fact capture-related.

This uncertainty notwithstanding, having made the above calculations we can combine data from both areas to arrive at a general relationship between exposure of an animal to oil of a given age and mortality. To do this we translate the x-axis so that it represents the day after the spill started rather than the time after first exposure. For instance, the daily survival rate of 0.8764 calculated in the western Prince William Sound otters 4 days after exposure applies to oil 4+5 = 9 days old. Similarly, the daily survival rate of 0.9970 calculated for 25 days after exposure off the Kenai Peninsula applies to oil 25+20 = 45 days old. Combining data from the 2 areas, then, gives the plot in Figure 8. Finally, reciprocal and log-transformed regression analysis were performed on the combined data. Again, the reciprocal transformation fit slightly better (R^2=0.465, F=11.43, p=0.006) than the logarithmic transformation (R^2 = 0.416, F=9.58, p=0.010). The Michaelis-Menton representation of the reciprocal equation is:

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

Standard errors of the parameter estimates are 1.023 +/- 0.014 and 1.288 +/- 0.267 (Figure 9). Caution is necessary when using regression equations to extrapolate outside the range of original data, but the implications of the above relationship for sea otter mortality in the first few days of a spill cannot be ignored. Animals exposed on day 1 of a spill have only a 45% (95% confidence interval = 35% - 59%) chance of survival; animals exposed continuously from day 1 through day 3 have only a 20% (95% confidence interval = 11% - 38%) chance of survival.

Reliability of the models.

In examining information on survival of sea otters captured during EVOS we have constructed 2 models of sea otter mortality as a function of oil exposure. Formal validation of these models is impossible because of obvious constraints on experimentation and data collection. Speculating on what the effects of violations of the major assumptions used in building the models would be on model predictions can serve as a measure of how reliable the models might be.

The most important assumption in the models is that observed mortality of captured sea otters represents actual field mortality due to oil exposure. If capturing animals did in fact lead to significant rehabilitation, field survival estimates are biased high. It should be remembered, however, that the majority of capture effort early in the spill was directed at obviously stressed animals, and that there was undoubtedly a bias toward capturing animals that were more likely to die if left in the field. In a more general sense, effects of acute mitigation, i.e., oil clean-up, are not taken into account.

The fact that there was undoubtedly a large amount of mortality before mitigation efforts even began is discussed earlier in this report. While this tends to overestimate survival as a function of distance from spill origin, the life-table approach to estimating daily survival rates escapes this problem by estimating daily rates during the time that capture operations were occurring. Again, however, since early capture efforts were not at all random, the calculated daily rates might underestimate actual survival rates. The extrapolation of survival rates to the immediate post spill period (i.e., days before capture operations began) is obviously highly dependent on the form of model chosen. The "Michaelis—Menton" model is intuitively appealing and easy to apply, and the small sample sizes involved do not justify fitting models of more than 2 parameters, but it is undoubtedly an oversimplification that could potentially lead to large errors in estimates of the survival rates immediately after a spill. Furthermore, the analysis assumes that daily survival rates are independent of the number of days exposed. If, as might very well be the case, exposure on a previous day reduces an animal's chance of survival if exposed on the next day, the probability of surviving continuous exposure during the first few days of a spill would be even smaller than the model predicts.

The second major assumption used in constructing the models is that animals did not change location during the spill. Since both models depend on survival calculated for specific areas, violations in this assumption affect the reliability of-the estimates. It is very likely that both the oil itself, and the associated human activity, including, obviously, capture operations, increased otter movements during the 4 month period considered in the analyses. If otters actively avoided oil and human activity successfully, survival estimates based strictly on the geographic proximity of otters and oil are biased high. This point becomes more important when the differences in habitat between California and Alaska are considered; the relative lack of local refugia and the linearity of the coast in California would make both chance and purposeful avoidance of oil more difficult there, and thus decrease local survival.

Finally, both models address only the acute and subacute effects of oil on sea otter population dynamics. Evidence of chronic effects of oil on the habitat is accumulating, and those effects might ultimately prove to be just as important as immediate mortality in regards to the long-term health and survival of sea otter populations exposed to oil.

Conclusion.

Despite the caveats outlined in the preceding discussion, the models presented herein can go far towards answering the question posed in the introduction, "how do otters react to oil?" An inability to formally validate the models does not render them useless as long as the resolution and purpose of the models are kept in mind. The very fact that recognizable patterns present themselves in the face of such uncertainty about the data collection is reassuring.

The distance-based model gives us an idea of the magnitude of the effect that a spill the size of EVOS might have on the southern sea otter population. The amount of coast affected by EVOS fell well within the range predicted by Ford's (1985) simple model of oil spill dynamics, providing some support for the reliability of that model, and indicates that the entire range of the southern sea otter could very easily be affected by a spill the size of EVOS. A population-wide survival rate of 50% should be considered a best-case scenario should such a spill occur. The distance-based model also allows, for the first time, an empirically based analysis of the risk of a spill in relation to the location of origin.

The time-based model describes the chance of an otter surviving 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 thus can be combined with explicit models of spill movement to arrive at more realistic predictions of mortality. The exact parameter estimates are only a starting point for making such predictions, and any linking of this model with spill dynamic models must include sensitivity analyses that explore the effect of liberal variation around these estimates. Perhaps more important than the parameter estimates themselves is the fact that a simple relationship between mortality and exposure precipitated. The Michaelis-Menton formulation is a theoretically sound, and now empirically supported, framework within which to further refine estimates of the effect of oil on sea otters.

Finally, these analyses indicate what future work will most increase our understanding of the relationship between otters and oil. On the theoretical side, it is time to link detailed models of oil spill dynamics with models of sea otter population dynamics. On the empirical side, we must be prepared with research objectives for the next oil spill in sea otter habitat, and these objectives must include making unbiased observations of otter behavior and mortality in oil.

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Table 1. Summary of available types of data about the impact of EVOS on the southcentral Alaskan sea otter population. Compiled by U.S.F.W.S. personnel in May 1992.

Available data.

1. Boat survey data (1984/85) of sea otter population in Prince William Sound.
2. Boat survey data (1989, post-spill) of Prince William Sound sea otter population.
3. Helicopter surveys (1989, post—spill) of Kenai Peninsula, Kodiak Island, and Alaska Peninsula populations.
4. HAZ-MAT model -- video of oil movement in 3 hour increments.
5. Map of beaches contaminated by oil in categories of heavy, medium, light, and no contact.
6. Number of otters captured by area and their fates.
7. Number of beached carcasses recovered, by area.
8. Bodkin and Udevitz's INTERCEPT model.
9. Estimates of mortality rates of otters occupying 2 areas of known level of oil exposure.
10. Estimates of carcass recovery rates from California and Kodiak Island.

No data available.

1. Abundance of otters by specific area prior to exposure to oil.
2. Behavior of otters exposed to oil.
3. Movement of otters during period of exposure to oil.
4. Change in actual mortality rates of otters relative to age of oil (i.e., time since spillage) at time of contamination.
5. Percent of total mortality of oiled otters in the field represented by number of beached caráasses found.
6. Movement of otter carcasses from point of oil contamination or death to site of collection.

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. "Michaelis-Menton " regression line is plotted.

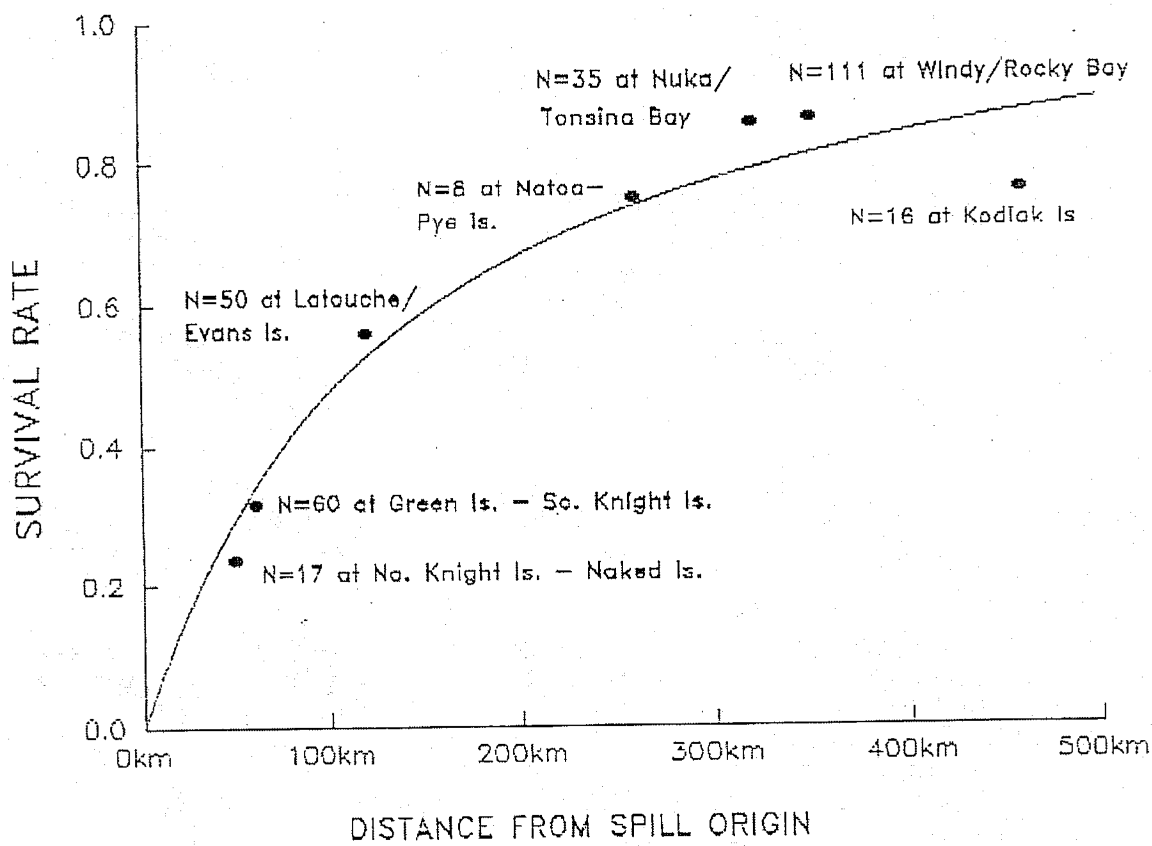


Figure 2. Relative risk of an 11 million gallon oil spill affecting 140 kilometers of coast as a function of location along the 5-fathom line. Y-axis is the predicted number of deaths, assuming a range-wide population of 2101 animals.

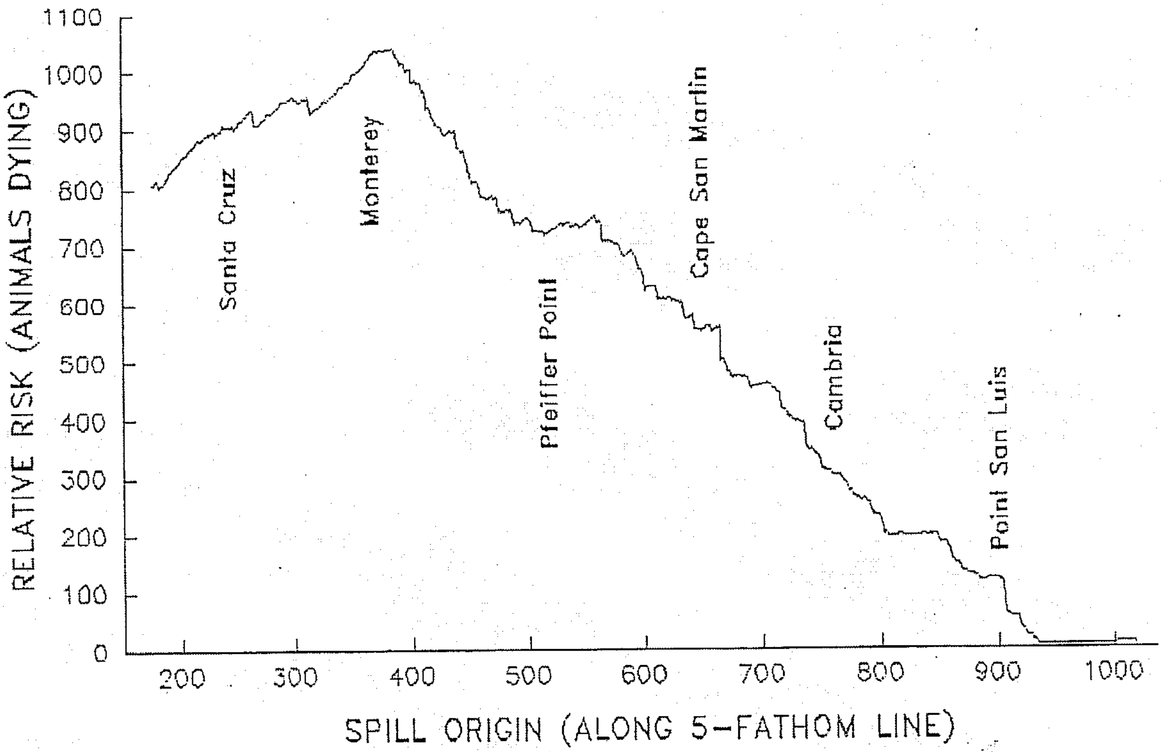


Table 2. Summary of predicted effect of an 11 million gallon oil spill occurring near the tip of the Monterey Peninsula, according to the simple model of mortality as a function of distance from spill origin. Based on Ford's (1985) relationship between spill volume and length of coast affected, the relationship 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.

Length of coast affected by spill:	140km	334km	597km
Percentile of expected distribution of length affected:	50	84	95
Number of otters in spill zone:	1172	1883	1883
(Per cent of total population):	(56)	(90)	(90)
Number of otters killed:	778	1041	1041
(Per cent of total population):	(38)	(50)	(50)
Percent of otters in the spill zone that are killed:	66	55	55

Figure 3. Graphic representation of the distribution of sea otters along the California coast, and the proportion that would be killed by a 11 million gallon oil spill affecting 343 kilometers of coastline from Pt. Pinos south. Each bar represents the population in a 10 kilometer section of coast.

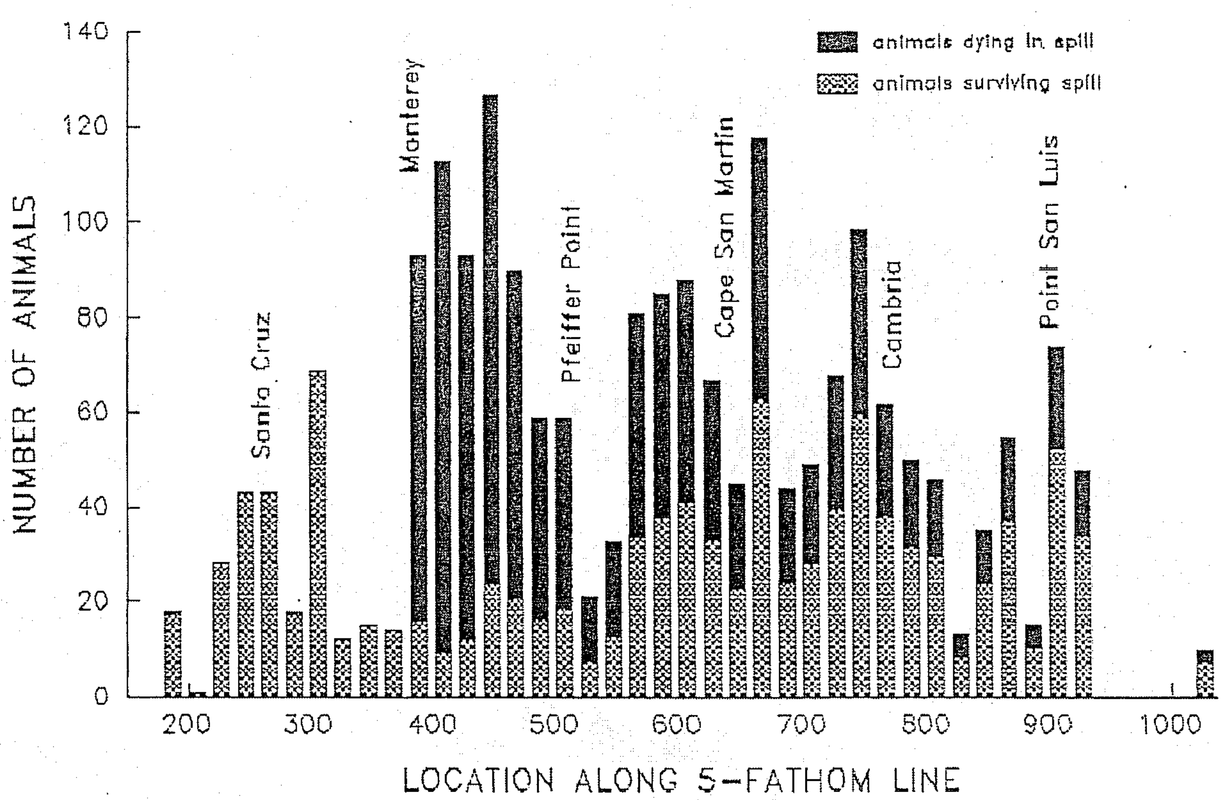


Figure 4. "Survivorship curve" for 105 sea otters first exposed to oil on approximately day 5 of EVOS in western Prince William Sound and subsequently captured.

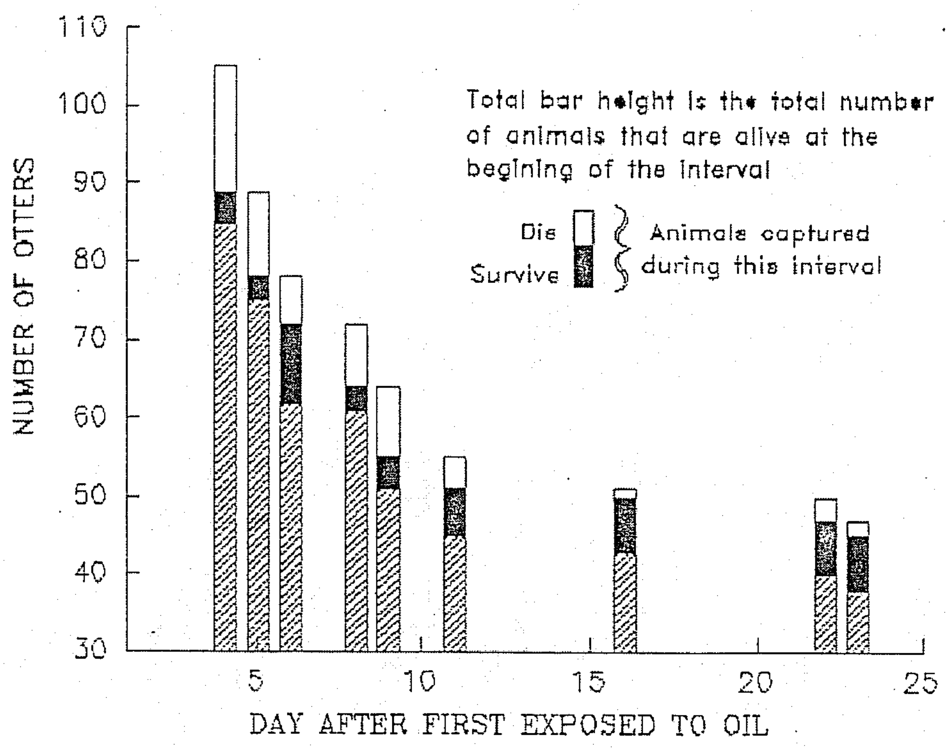


Table 3. Calculations used in estimating daily survival rates for 105 captured sea otters that were first exposed to oil on approximately day 5 of EVOS in western Prince William Sound.

x	N_x	N_{x+1}	i	d_x (c_x)	$s_{i,x}$	s_x	X
4	105	89	1	16 (20)	.8476	.8476	4
5	89	78	1	11 (14)	.8764	.8764	5
6	78	72	1	6 (10)	.9231	.9231	6
8	72	64	2	8 (11)	.8889	.9428	7
9	64	55	1	9 (13)	.8594	.8594	9
11	55	51	2	4 (10)	.9273	.9630	10
16	51	50	5	1 (8)	.9804	.9951	13
22	50	47	6	3 (10)	.9400	.9900	19
23	47	45	1	2 (9)	.9575	.9785	23

COLUMN DEFINITIONS:

x Number of days exposed to oil.
N_x Number of animals alive on day x.
N_{x+1} Number of animals alive on day x+1.
i Number of days in interval between successive capture dates.
c_x Number of animals captured on day x.
d_x Number of animals captured on day x that will die.
$s_{i,x}$ Survival rate for interval i, beginning on day x.
s_x Daily survival rate in interval i ($s_i^{1/i}$).
X Day at which s_x applies (midpoint of interval i).

Figure 5. 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 regression lines.

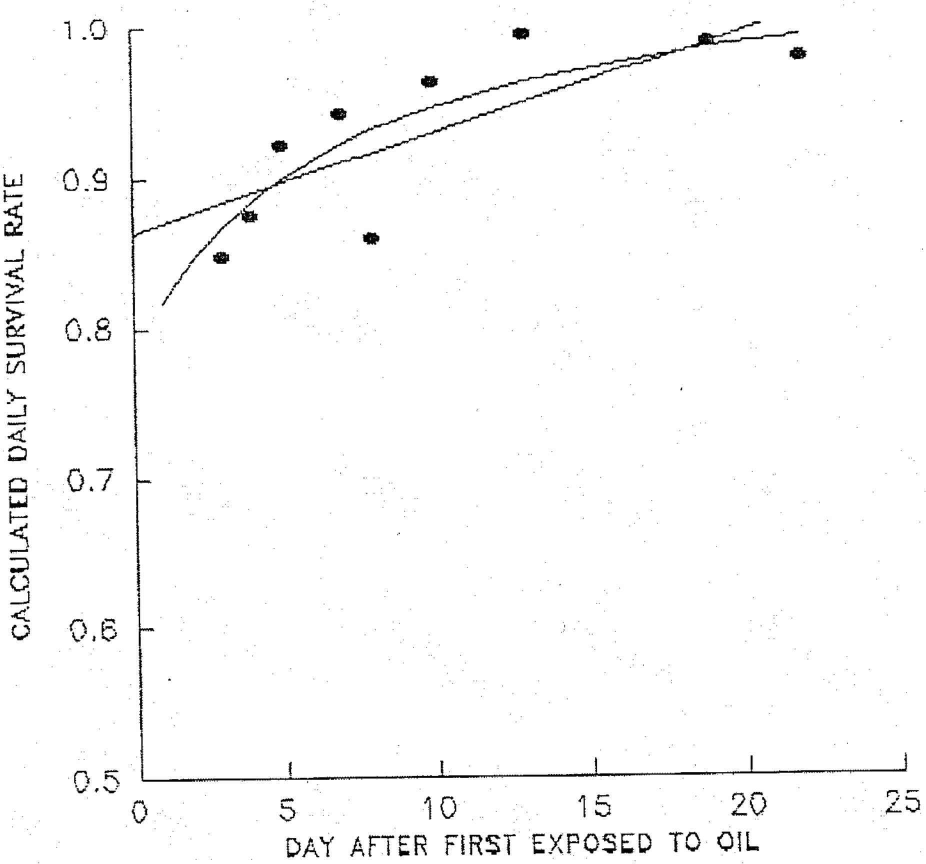


Figure 6. "Survivorship curve" for 109 sea otters first exposed to oil on approximately day 18-20 of EVOS off the Kenai Peninsula and subsequently captured.

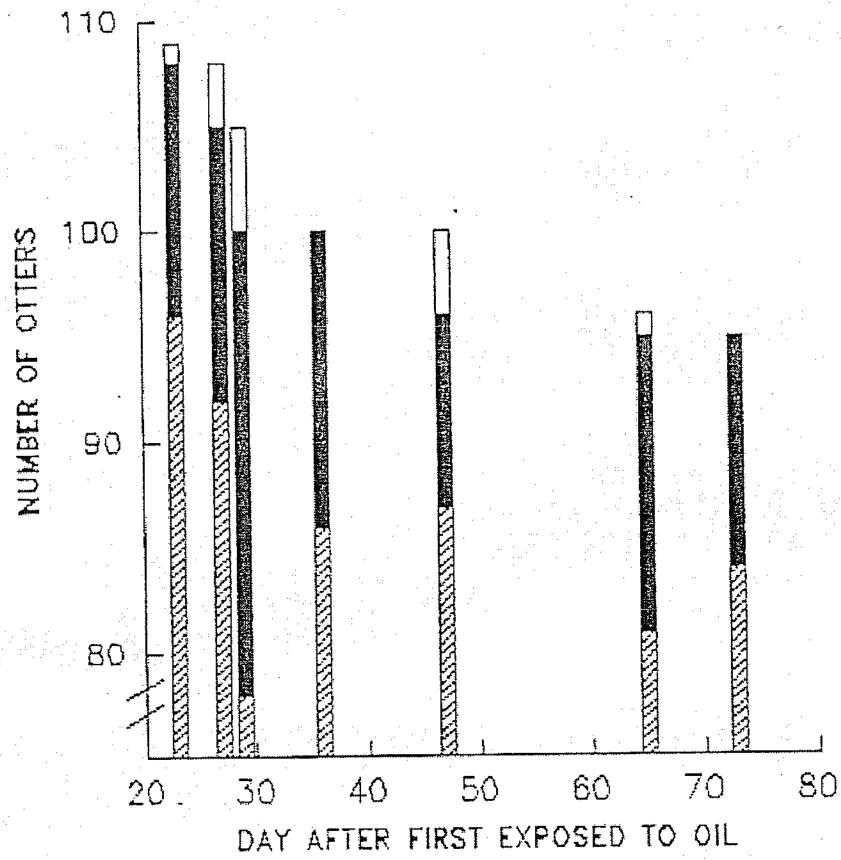


Table 4. Calculations used in estimating daily survival rates for 109 captured sea otters that were first exposed to oil on approximately day 20 of EVOS on Kenai Peninsula.

x	N_x	N_{x+1}	i	d_x (c_x)	$s_{i,x}$	s_x	X
23	109	108	1	1 (13)	.9907	.9907	23
27	108	105	4	3 (16)	.9722	.9929	25
29	105	100	2	5 (27)	.9523	.9759	28
35	100	100	6	0 (14)	1.0	1.0	32
46	100	96	11	4 (13)	.9600	.9963	41
64	96	95	18	1 (15)	.9895	.9994	55
73	95	95	9	0 (11)	1.0	1.0	68

COLUMN DEFINITIONS:

- x Number of days exposed to oil.
- N_x Number of animals alive on day x.
- N_{x+1} Number of animals alive on day x+1.
- i Number of days in interval between successive capture dates.
- c_x Number of animals captured on day x.
- d_x Number of animals captured on day x that will die.
- $s_{i,x}$ Survival rate for interval i, beginning on day x.
- s_x Daily survival rate in interval i ($s_i^{1/i}$).
- X Day at which s_x applies (midpoint of interval i).

Figure 7. 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.

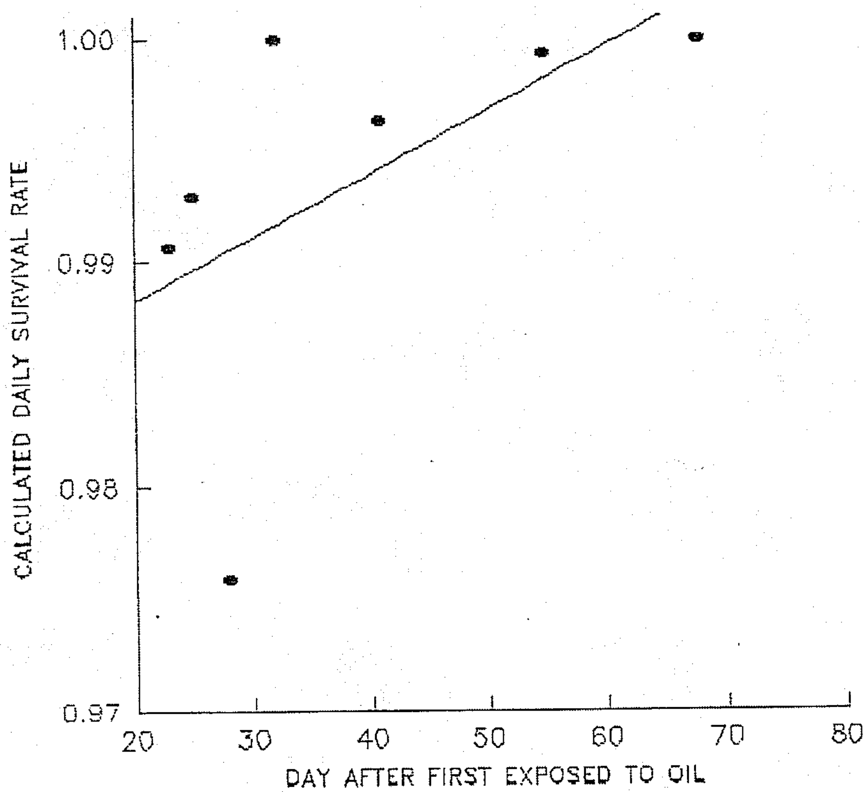


Figure 8. Calculated daily survival rates for 214 sea otters captured in rescue efforts after EVOS as a function of the age of the oil they were exposed to. Solid regression line is the "Michaelis Menton" relationship, dashed line is the log transformation.

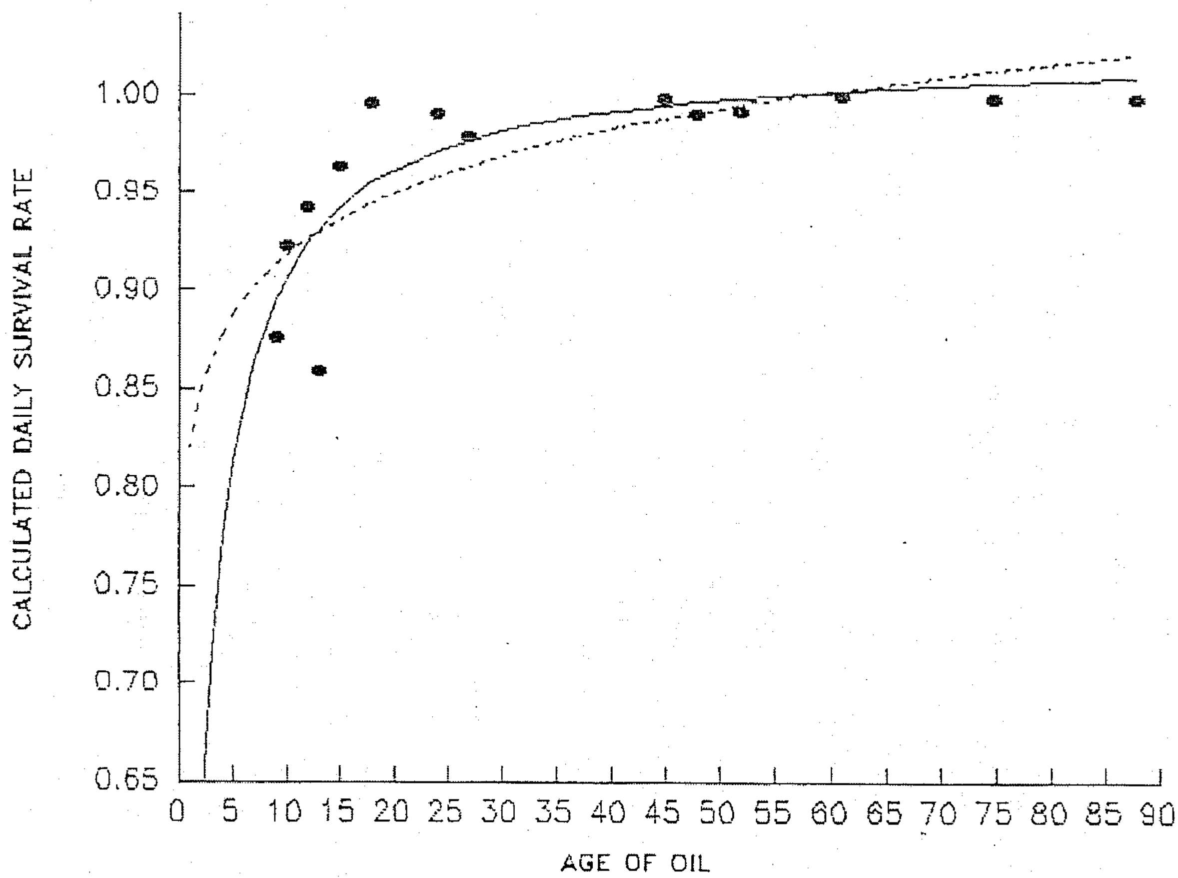
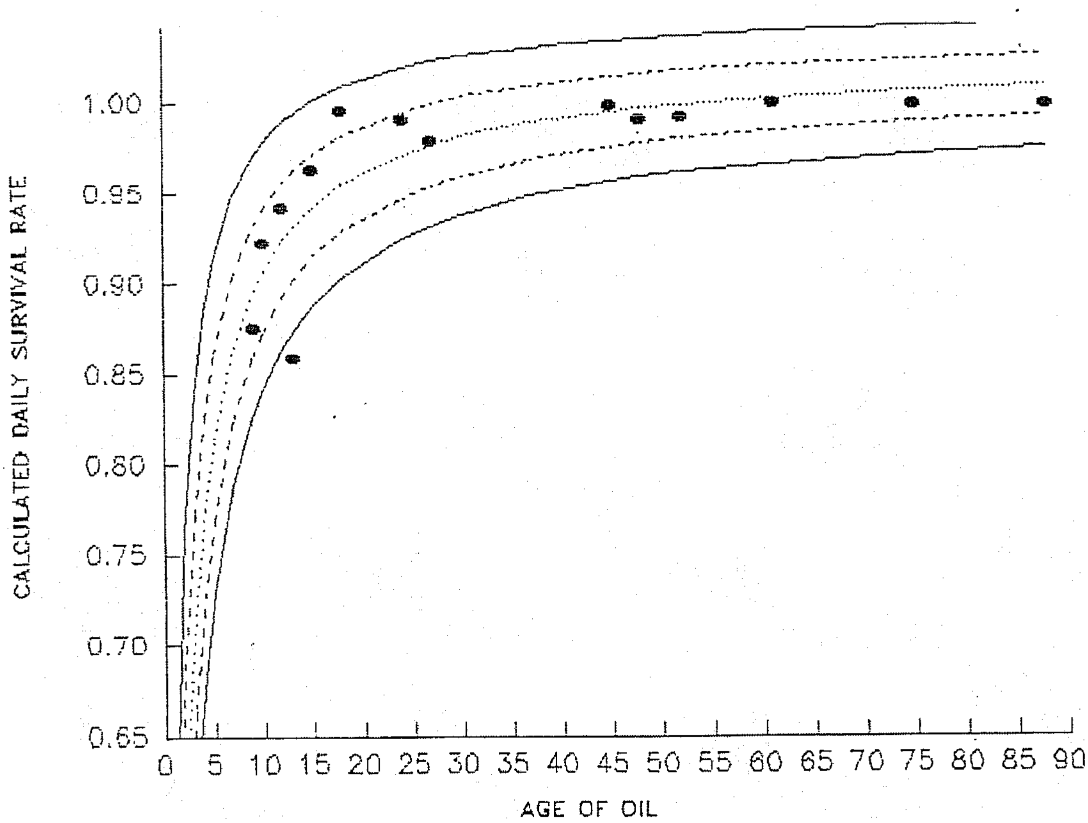


Figure 9. "Michaelis-Menton" regression relationship for daily survival rates of 214 sea otters captured in rescue efforts after EVOS as a function of the age of the oil they were exposed to. Dotted line is median estimate, dashed lines are +/- 1 standard error, solid lines are +/- 2 standard errors.



APPENDIX

Listing of raw data from N.R.D.A. relational data base of sea otters captured in rescue operations after EVOS, used in the analysis of mortality due to the oil spill.

KEY:

Oil = Light, Medium, Heavy, or None ... amount of oil on pelt at capture.

Fate = Died, Euthanized; R,V,X,H,Z ... survived.

Serial Number	Sex	Date of Capture			Location of Capture	Oil	Fate	Age
VZ-126	F	04	15	89	2 Mi N. Horseshoe Bay Latouche	M	Z	ADT
VZ-013	M	04	01	89	APPLEGATE	H	D	JUV
VZ-012		04	01	89	APPLEGATE	H	D	.
VZ-003	U	03	31	89	Applegate Rocks	H	D	.
VZ-015	M	04	01	89	Applegate Rocks	H	D	.
VZ-005	F	03	31	89	Applegate Rocks	H	Z	.
VZ-004	F	03	31	89	Applegate Rocks	H	Z	.
VZ-016	M	04	01	89	Applegate Rocks	H	D	.
VZ-014		04	01	89	Applegate Rocks	H	D	.
VZ-007	F	03	31	89	APPLEGTE	H	D	.
VZ-148	M	04	29	89	Bainbridge Is	L	R	ADT
VZ-075	F	04	06	89	Bay of Isles, Knight Is.	L	D	JUV
VZ-122	M	04	13	89	Bay of Isles KNIGHT I	N	R	ADT
VZ-091	F	04	08	89	BAY OF ISLES Knight Is.	L	Z	.
VZ-152	M	04	29	89	Berger Bay	H	R	ADT
SW-020	F	05	05	89	BOOT LEG BAY	U	H	.
SW-016	M	05	04	89	Bootleg Bay	M	X	.
SW-014	M	05	04	89	Bootleg Bay	M	X	.
SW-024	F	05	05	89	BOOTLEG BAY	U	H	.
SW-013	F	05	04	89	Bootleg Bay	M	H	.
SW-017	F	05	04	89	Bootleg Bay	L	R	.
SW-015	F	05	04	89	Bootleg Bay	L	R	.
SW-172	M	07	23	89	Chignik	N	Z	PUP
VZ -123	M	04	15	89	Chiswell Natoa Is	L	R	ADT
VZ-111	F	04	09	89	CRAB BAY	H	D	ADT
VZ-140	M	04	20	89	CRAB BAY, Evans Is	L	R	ADT
VZ-137	M	04	20	89	CRAB BAY, Evans Is	L	R	.
VZ-141	F	04	20	89	CRAB BAY, Evans Is	L	D	ADT
VZ-138	M	04	20	89	CRAB BAY, Evans Is	L	R	ADT
VZ-139	M	04	20	89	CRAB BAY, Evans Is	L	R	ADT
VZ-006	F	03	31	89	Elinore Island	H	D	.
VZ-143	F	04	22	89	Elrington I., Elrington Pass	M	R	JUV
VZ-100	F	04	08	89	EVANS IS, Sawmill Bay	M	D	ADT
VZ-120	F	04	13	89	Ewan Bay, Delenia Is	L	R	ADT
VZ-047	F	04	04	89	FLEMING	L	D	JUV
VZ-046	M	04	04	89	FLEMING	L	R	ADT
VZ-048	M	04	04	89	FLEMING	L	R	ADT
VZ-045	F	04	04	89	FLEMING	M	D	ADT
VZ-044	F	04	02	89	Fleming Island	L	Z	PUP
VZ-049	F	04	04	89	Fleming OR Evans Is.	M	D	ADT
VZ-050	F	04	04	89	Fleming OR Evans Is.	L	D	ADT
SW-102	F	05	10	89	From Homer, Flat Island Off En	N	Z	PUP

SW-163	F	07	05	89	Frount Pt. (Tonsina Bay)	N	E	.
VZ-057	F	04	05	89	Gibbon Anchorage	U	E	ADT
SW-103	F	05	20	89	Granite Passage	L	D	.
VZ-023	F	04	01	89	GREEN IS	H	Z	ADT
VZ-035	M	04	02	89	GREEN IS	H	E	JUV
VZ-043	F	04	03	89	GREEN IS	M	D	JUV
VZ-010		04	01	89	GREEN IS	H	D	.
VZ-024	M	04	01	89	GREEN IS	H	D	ADT
VZ-032	F	04	02	89	GREEN IS	H	R	ADT
VZ-036	F	04	02	89	GREEN IS	H	Z	ADT
VZ-008	M	03	31	89	GREEN IS	H	D	.
VZ-033	U	04	02	89	GREEN IS	U	D	.
VZ-011	F	04	01	89	GREEN IS	L	D	JUV
VZ-019	F	04	01	89	GREEN IS	H	D	AGD
VZ-029	M	04	02	89	GREEN IS	H	R	ADT
VZ-026	F	04	01	89	GREEN IS	H	Z	ADT
VZ-034	M	04	02	89	GREEN IS	H	D	ADT
VZ-041	F	04	03	89	GREEN IS	H	D	ADT
VZ-018	F	04	01	89	GREEN IS	H	D	ADT
VZ-030	M	04	01	89	GREEN IS	H	R	ADT
VZ-028		04	01	89	GREEN IS	H	D	ADT
VZ-022	U	04	01	89	GREEN IS	H	D	.
VZ-017	U	04	01	89	GREEN IS	H	D	ADT
VZ-020	U	04	01	89	GREEN IS	H	D	.
VZ-021	F	04	01	89	GREEN IS	H	D	ADT
VZ-027	F	04	01	89	GREEN IS	H	Z	JUV
VZ-031	F	04	02	89	GREEN IS	H	D	ADT
VZ-038	F	04	02	89	GREEN IS	H	D	ADT
VZ-009		04	01	89	GREEN. IS	H	D	.
VZ-025		04	02	89	GREEN IS	H	D	.
VZ-131	F	04	17	89	GREEN IS, Gibbon Anch	L	X	ADT
VZ-040	F	04	03	89	GREEN IS, Gibbon Anch	H	D	ADT
VZ-132	F	04	17	89	GREEN IS, Outside Gibbon Anch	H	Z	ADT
VZ-042	F	04	03	89	Green Island, Gibbon Anch	H	D	ADT
SW-160	M	06	25	89	Hardover Pt.	N	D	.
VZ-146	M	04	27	89	Hardover Pt Nuka I.	L	R	JUV
VZ-071	F	04	05	89	Herring Bay	U	D	ADT
VZ-064	F	04	05	89	Rerring Bay	H	D	ADT
VZ-Q70	F	04	05	89	Herring Bay	H	E	ADT
VZ-063	F	04	05	89	Herring Bay	H	D	ADT
VZ-072	F	04	05	89	Herring Bay, Knight Is	M	Z	ADT
VZ-068	F	04	05	89	Herring Bay, Knight I.s	H	R	ADT
VZ-073	F	04	05	89	Herring Bay, Knight Is.	L	E	ADT
VZ-069	F	04	05	89	Herring Bay, Knight Is.	M	D	ADT
VZ-112	F	04	09	89	Herring Bay, Knight Is.	H	E	ADT
VZ-066	F	04	05	89	Herring Bay, Knight Is.	M	D	ADT
VZ-062	M	04	05	89	Hogan Bay, Knight Is.	L	R	ADT
VZ-055	M	04	04	89	Hogan Bay, Knight Island	L	D	ADT
VZ-054	F	04	04	89	Hogan Bay, Knight Island	H	D	JUV
VZ-056	M	04	04	89	Hogan Bay, Knight Island	L	D	ADT
VZ-092	M	04	07	89	HorshoeBay Latouche Is	H	R	ADT
VZ-037	F	04	02	89	Iktua Bay	L	D	JUV

VZ-058	F	04	05	89	Iktua Bay	U	D	ADT
VZ-119	M	04	13	89	IKTUA Bay, Evans Is	L	R	ADT
VZ-106	F	04	09	89	IKTUA Bay, Evans is	L	D	ADT
VZ-114	F	04	10	89	IKTUA Bay, Evans Is	L	X	ADT
VZ-118	F	04	13	89	IKTUA Bay, Evans Is	L	D	ADT
VZ-116	M	04	10	89	IKTUA Bay, Evans Is	L	Z	ADT
VZ-104	M	04	09	89	IKTUA Bay, Evans Is	L	R	ADT
VZ-115	F	04	10	89	IKTUA Bay, Evans Is	L	Z	ADT
VZ-105	F	04	09	89	Iktua Bay Evans Is	N	R	ADT
VZ-121	M	04	13	89	Ingot Is, PWS	N	D	.
SW-158	F	06	23	89	Island #1, Rocky Bay	L	R	.
SW-124	F	05	31	89	Island #1, Rocky Bay	L	R	.
VZ-002	M	03	31	89	KNIGHT I	H	D	.
VZ-128	F	04	17	89	KNIGHT I, Herring Bay	L	R	ADT
VZ-135	F	04	19	89	KNIGHT I, Marsha Bay	H	D	ADT
VZ-129	F	04	17	89	KNIGHT I, SE Herring Bay	M	R	ADT
VZ-076	F	04	06	89	KNIGHT I, South end	U	E	ADT
VZ-082	F	04	06	89	KNIGHT I, SW	L	Z	.
VZ-094	F	04	07	89	Knight Is.	H	D	ADT
SW-174	M	07	26	89	Kodiak (Larson Bay)	N	E	JUV.
SW-138	M	06	14	89	Kodiak, Foul Bay	U	E	.
SW-137	F	06	14	89	Kodiak, Foul Bay	L	H	.
SW-131	F	06	10	89	Kodiak, Larson Bay	N	Z	PUP
SW-149	F	06	19	89	Kodiak, Ouzinkie	N	E	.
SW-177	F	08	21	89	Kodiak, Ouzinkie	N	Z	PUP
SW-176	M	07	31	89	KODIAK, Sumner Strait	N	Z	PUP
SW-114	M	05	24	89	Kodiak, Uyak Bay	N	H	.
SW-116	F	05	24	89	Kupreanoff Straight	L	R	.
SW-120	F	05	25	89	Kupreanoff Straights	L	E	.
SW-115	F	05	24	89	Kupreanoff Straights	L	E	.
SW-119	F	05	25	89	Kupreanoff Straights	L	H	.
SW-113	F	05	23	89	Kupreanoff Straights	L	H	.
SW-122	M	05	25	89	Kupreanoff Straights	L	H	.
SW-123	F	05	25	89	Kupreanoff Straights	L	H	.
SW-112	F	05	23	89	Kupreanoff Straights	L	H	.
SW-121	F	05	25	89	Kupreanoff Straights	L	H	.
VZ-124	M	04	16	89	LATOUCHE	L	R	ADT
VZ-125	F	04	15	89	LATOUCHE Is, Horseshoe Bay	L	R	ADT
VZ-108	M	04	09	89	LATOUCHE Is, Nontgomery	L	R	ADT
VZ-117	M	04	11	89	LATOUCHE Is, SW	L	Z	ADT
VZ-097	F	04	07	89	Latouche Is.	L	R	ADT
VZ-156	F	05	29	89	Little Bay, Knight Is	N	D	ADT
SW-164	F	07	05	89	Long Island (Tonsina Bay)	L	R	.
SW-162	F	07	05	89	Long Island (Tonsina Bay)	L	R	.
SW-161	F	07	05	89	Long Island (Tonsina Bay)	L	R	.
VZ-107	F	04	09	89	Main Bay Kenai Pen;	L	D	ADT
VZ-052	M	04	04	89	Mummy Bay	M	R	ADT
VZ-053	F	04	04	89	Mummy Bay	H	D	ADT
VZ-051	F	04	04	89	Mummy Bay	H	Z	JUV
VZ-081	M	04	06	89	N. Chenega Bay	L	E	ADT
VZ-039	M	04	03	89	N.W. tip Green Island	M	D	ADT
VZP154	F	05	03	89	N A	N	D	PUP

VZP142	F	04	22	89	N A	N	D	PUP
VZ-134	M	04	18	89	NATOA IS	M	D	ADT
VZ-130	M	04	17	89	NATOA IS	M	R	ADT
VZ-133	M	04	18	89	NATOA IS	L	R	ADT
VZ-144	M	04	22	89	New Chenega Hbr	L	R	ADT.
SW-167	F	07	06	89	NUKA BAY	L	R	.
SW-105	F	05	20	89	Nuka bay	U	E	.
SW-109	F	05	21	89	Nuka Bay, East Arm	U	E	.
SW-165	F	07	06	89	NUKA BAY, East Arm	U	H	.
SW-166	F	07	06	89	NUKA BAY, East Arm	N	H	.
VZ-127	F	04	16	89	NW SQUIRE I	H	R	ADT
SW-173	M	07	25	89	Oizinkie, Kodiak	N	Z	PUP
VZ-136	M	04	19	89	ORCA INL	U	D	AGD
VZ-083	M	04	06	89	PERRY IS, N	U	D	PUP
SW-153	M	06	21	89	Picnic Bay	L	H	.
SW-045	F	05	07	89	Picnic Harbor	N	R	ADT
VZ-147	F	04	27	89	Port GRAHAM	N	D	PUP
VZ-086	F	04	07	89	Powder Pt. NW Latouche Is.	U	R	ADT
VZ-102	F	04	08	89	Pr Wales	L	D	.
VZ-085	F	04	07	89	Pr Wales Evans Is.	M	D	ADT
VZ-087	M	04	07	89	Pr Wales Evans Is.	U	D	JUV
VZ-101	M	04	08	89	Prince Wales	L	X	JUV
VZ-088	F	04	07	89	PRINCE Wales Is.	U	D	ADT
VZ-096	F	04	08	89	Prince Wales Pass	L	R	ADT
VZ-103	M	04	08	89	Prince Wales Evans Is.	L	D	ADT
SW-175	F	07	28	89	PYE ISLAND	N	Z	PUP
SW-152	M	06	20	89	Rock entrance of Rocky River	L	H	.
SW-067	F	05	11	89	Rocky Bay	L	D	.
SW-061	F	05	11	89	Rocky Bay	M	X	ADT
SW-076	F	05	11	89	Rocky Bay	M	D	.
SW-039	F	05	07	89	Rocky Bay	L	R	ADT
SW-028	F	05	05	89	ROCKY BAY	L	H	.
SW-155	F	06	21	89	Rocky Bay	M	R	.
SW-159	F	06	23	89	Rocky Bay	U	R	.
SW-070	M	05	11	89	Rocky Bay	U	R	.
SW-026	F	05	05	89	ROCKY BAY	U	H	.
SW-027	F	05	05	89	ROCKY BAY	L	H	.
SW-093	F	05	18	89	Rocky Bay	L	H	.
SW-037	F	05	07	89	ROCKY BAY	U	H	.
SW-036	F	05	07	89	ROCKY BAY	U	H	.
SW-107	M	05	21	89	Rocky Bay	U	E	.
SW-068	F	05	11	89	Rocky Bay	L	R	.
SW-156	M	06	22	89	Rocky Bay	L	H	.
SW-101	F	05	19	89	Rocky Bay	U	H	.
SW-080	F	05	11	89	Rocky Bay	M	H	.
SW-062	F	05	11	89	Rocky Bay	L	H	.
SW-154	M	06	21	89	Rocky Bay	N	H	.
SW-079	F	05	11	89	Rocky Bay	L	H	.
SW-096	M	05	18	89	Rocky Bay	L	H	.
SW-069	F	05	11	89	Rocky Bay	M	H	.
SW-029	F	05	05	89	ROCKY BAY	M	H	.
SW-104	M	05	20	89	Rocky Bay	L	D	.

SW-100	F	05	19	89	Rocky Bay	U	H	.
SW-097	F	05	18	89	Rocky Bay	L	H	.
SW-094	M	05	18	89	Rocky Bay	L	H	.
SW-099	M	05	18	89	Rocky Bay	L	H	.
SW-091	F	05	18	89	Rocky Bay	L	H	.
SW-095	M	05	18	89	Rocky Bay	L	H	.
SW-063	F	05	11	89	Rocky Bay	U	H	.
SW-098	F	05	18	89	Rocky Bay	M	H	.
SW-150	F	06	19	89	Rocky Bay Island #1	L	H	.
SW-126	M	06	05	89	Rocky Bay, Island #1	L	H	.
SW-135	M	06	13	89	Rocky Bay, Island #1	L	D	.
SW-125	F	06	05	89	Rocky Bay, Island #1	L	D	.
SW-134	F	06	13	89	Rocky Bay, Island #1	L	H	.
SW-128	F	06	06	89	Rocky Bay, Island #14	L	R	.
SW-127	F	06	05	89	Rocky Bay, Island #3	L	D	.
SW-130	M	06	06	89	Rocky Bay, Island #4	L	H	.
SW-129	F	06	06	89	Rocky Bay, Island #4	L	H	.
SW-092	F	05	18	89	Rocky Bay	L	H	.
SW-157	F	06	23	89	Rocky River	L	R	.
VZ-090	M	04	08	89	Sawmill Bay Latouche Is.	L	R	ADT
SW-117	F	05	25	89	Seal Island	N	H .	.
SW-118	M	05	25	89	Seal Island	N	H	.
VZ-099	M	04	08	89	Shelter Bay, Knight Is.	L	D	ADT
SW-008	F	05	02	89	SKAXUNDS	L	D	.
VZ-001	M	03	30	89	SMITH IS	H	D	.
VZ-077	F	04	06	89	Snug Hbr, Knight Is.	H	D	ADT
VZ-079	F	04	06	89	Snug Hbr, Knight Is.	L	D	ADT
VZ-109	M	04	09	89	Snug Hbr KNIGHT I	M	D	ADT
VZ-110		04	09	89	Snug Hbr KNIGHT I	H	E	.
SW-057	F	05	11	89	South Bay Natoa Island	M	H	.
SW-110	F	05	22	89	Spiridon Bay, Kodiak I	U	H	.
SW-044	M	05	07	89	TAYLOR BAY	L	H	.
SW-043	F	05	07	89	TAYLOR BAY	L	H	.
SW-041	F	05	07	89	Tonsina Bay	U	R	ADT
SW-042	M	05	07	89	TONSINA BAY	L	H	.
SW-034	F	05	05	89	Tonsina Bay	L	R	ADT
SW-032	F	05	05	89	TONSINA BAY	U	H	.
VZ-145	F	04	27	89	TONSINA BAY	L	R	JUV
VZ-150	F	04	29	89	TONSINA Bay	L	R	ADT
SW-001	F	05	01	89	TONSINA BAY	N	D	.
SW-170	M	07	17	89	Tonsina Bay	N	E	.
SW-004	F	05	01	89	Tonsina Bay	N	Z	PUP
SW-009	F	05	03	89	TONSINA BAY	L	H	.
SW-003	F	05	01	89	TONSINA BAY	N	H	.
VZ-153	F	04	29	89	Tonsina Bay	L	R	ADT
SW-010	F	05	03	89	TONSINA BAY	L	H	.
SW-031	F	05	05	89	TONSINA BAY	L	H	.
SW-005	F	05	01	89	TONSINA BAY	L	H	.
VZ-151	F	04	29	89	Tonsina Bay	L	R	ADT
SW-002	F	05	01	89	TONSINA BAY	N	R	.
SW-030	M	05	05	89	Tonsina Bay	L	X	ADT
SW-007	F	05	01	89	TONSINA BAY	L	H	.

SW-011	F	05	03	89	TONSINA BAY	L	H	.
SW-169	M	07	08	89	Tonsina Bay	L	H	.
SW-168	F	07	08	89	Tonsina Bay	N	H	.
VZ-149	F	04	29	89	Tonsina Bay	M	X	ADT
SW-006	F	05	01	89	Tonsina Bay	L	H	.
SW-025	M	05	05	89	WINDY BAY	U	H	.
SW-050	F	05	10	89	Windy Bay	L	D	.
SW-089	F	05	17	89	Windy Bay	L	R	.
SW-171	M	07	22	89	WINDY BAY	L	R	.
SW-147	F	06	17	89	Windy Bay	U	H	.
SW-059	F	05	11	89	Windy Bay	U	R	ADT
SW-077	F	05	11	89	Windy Bay	M	E	.
SW-048	F	05	10	89	Windy Bay	L	E	.
SW-047	F	05	10	89	Windy Bay	U	R	ADT
SW-049	F	05	10	89	Windy Bay	L	D	.
SW-018	M	05	05	89	WINDY BAY	N	H	.
SW-065	M	05	11	89	Windy Bay	H	R	ADT
SW-055	F	05	10	89	Windy Bay	M	X	ADT
SW-142	F	06	17	89	Windy Bay	N	R	.
SW-082	F	05	11	89	Windy Bay	M	R	.
SW-040	F	05	07	89	Windy Bay	L	R	ADT
SW-143	F	06	17	89	Windy Bay	N	R	.
SW-012	F	05	03	89	WINDY BAY	L	H	.
SW-035	F	05	05	89	Windy Bay	L	R	ADT
SW-019	F	05	05	89	WINDY BAY	U	H	.
SW-084	F	05	11	89	Windy Bay	L	R	ADT
SW-023	F	05	05	89	WINDY BAY	U	H	.
SW-051	F	05	10	89	Windy Bay	L	H	.
SW-021	F	05	05	89	WINDY BAY	U	D	.
SW-146	F	06	17	89	Windy Bay	L	R	.
SW-075	F	05	11	89	Windy Bay	L	D	.
SW-145	F	06	17	89	Windy Bay	U	R	.
SW-033	F	05	05	89	Windy Bay	N	R	ADT
SW-052	F	05	10	89	Windy Bay	L	H	.
SW-085	F	05	17	89	Windy Bay	N	H	.
SW-087	F	05	17	89	Windy Bay	L	H	.
SW-139	F	06	17	89	Windy Bay	U	H	.
SW-081	F	05	11	89	Windy Bay	L	H	.
SW-058	F	05	11	89	Windy Bay	L	H	.
SW-108	M	05	21	89	Windy Bay	U	H	.
SW-064	F	05	11	89	Windy Bay	U	H	.
SW-060	F	05	11	89	Windy Bay	L	H	.
SW-141	F	06	17	89	Windy Bay	L	H	.
SW-083	M	05	11	89	Windy Bay	U	H	.
SW-148	F	06	17	89	Windy Bay	N	Z	PUP
SW-086	F	05	17	89	Windy Bay	L	H	.
SW-151	M	06	20	89	Windy Bay	L	H	.
SW-144	F	06	17	89	Windy Bay	N	H	.
SW-053	F	05	10	89	Windy Bay	L	H	.
SW-140	F	06	17	89	Windy Bay	U	H	.
SW-056	F	05	10	89	Windy Bay	M	H	.
SW-071	F	05	11	89	Windy Bay	L	H	.

SW-072	F	05	11	89	Windy Bay	L	H	.
SW-106	M	05	21	89	Windy Bay	N	Z	PUP
SW-074	F	05	11	89	Windy Bay	H	H	.
SW-088	F	05	17	89	Windy Bay	L	H	.
SW-022	F	05	05	89	WINDY BAY	U	H	.
SW-066	F	05	11	89	Windy Bay	U	H	.
SW-038	M	05	07	89	WINDY BAY	M	H	.
SW-078	M	05	11	89	Windy Bay	L	D	.
SW-073	F	05	11	89	Windy Bay	U	H	.
SW-054	F	05	10	89	Windy Bay	M	H	.
SW-133	F	06	13	89	Windy Bay, Kelp Bed 0	N	Z	PUP
SW-136	F	06	13	89	Windy Bay, Kelp Bed 0	L	H	.
SW-132	F	06	13	89	Windy Bay, Kelp Bed 0	L	H	.
SW-090	F	05	17	89	Wooded Island, Kodiak	L	H	.

Appendix D: Population Status of the Southern Sea Otter

Population Status of the California Sea Otter*

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Biological Resources Division
U.S. Geological Survey

4 November 1998

*White Paper prepared for the Ventura Field Office, U.S. Fish and Wildlife Service

INTRODUCTION

The geographical range of the sea otter (*Enhydra lutris*) extends across the North Pacific Ocean from about the central Pacific coast of Baja California, Mexico, to northern Japan. Prior to the Pacific maritime fur trade, which began with the discovery of Alaska and the Aleutian Islands by the Bering Expedition in the mid-1700's, high density sea otter populations probably occurred more or less continuously throughout this region, but the species was systematically hunted to the brink of extinction by the end of the 19th century. Sea otters were afforded protection from further take in 1911, at which time about a dozen remnant colonies survived. One of these remnant colonies occurred near Bixby Creek along the then remote Big Sur coastline.

With protection, the surviving colonies began to recover. While early records of recovery are necessarily sparse, the population in central California clearly has increased at a slower rate than all or most others (Estes 1990). For instance, a naturally reestablished population at Attu Island (in the western Aleutian archipelago) and populations reestablished through reintroductions in Washington State, Vancouver Island, and southeast Alaska, all increased at 17-20% yr^{-1}, which is about the theoretical maximum rate of population growth for the species. Other populations in Alaska and Asia seem to have recovered at about the same rate. The California sea otter population, in contrast, has recovered at about 4 to 6% yr^{-1} at best.

While records of initial population size and early growth are spotty because of a lack of information prior to World War II and varying survey methods thereafter, the data are sufficient to demonstrate that growth rate of the California sea otter population was always slow, even early in this century. Nonetheless, both the range and population size marched steadily upward until about the mid-1970s, at which time numbers began to decline. As information from field studies accumulated, it became evident that California sea otters were being lost to incidental entanglement in a coastal set-net fishery and there was increasing concern that this was the cause of the decline. Loss estimates to the fishery made by the California Department of Fish and Game added credence to that possibility (Wendell *et al.*, unpubl. CDF&G report). The State of California instituted a limited emergency closure of the set net fishery in 1982, followed by a range-wide 15 fathom closure in 1985, and the number of animals counted during annual surveys began to increase shortly thereafter (Riedman and Estes 1990, Estes 1990). A standardized survey method also was developed and put into use in 1982. Briefly, the new survey procedures involved counting animals twice annually (early autumn and late spring) from shore in accessible stretches of coastline, and from a fixed-wing aircraft in the remaining areas. The data from 1982 onward thus are not confounded by methodological change and have been used to assess population trends over the past 16 years. In addition to total population size, the number of dependent pups are noted in each survey. These data, in conjunction with findings from several more in-depth studies (Jameson and Johnson 1993, Riedman *et al.* 1994) are sufficient to assess female reproductive rates and changes in reproductive success of the California sea otter population through time.

During this same period, information has been obtained on sea otter mortality from beach-cast carcasses in a salvage program that has been variously organized and managed over the years by CDF&G, FWS, and BRD. As is the case with surveys of the living population, the methods and level of effort have varied through the years. Perhaps the most significant methodological change occurred in 1992 when necropsies of fresh otter carcasses were undertaken by trained veterinary pathologists from the National Wildlife Health Center in Madison, Wisconsin. This effort identified infectious disease as the ultimate cause of death in about 40 percent of the beach-cast carcasses for California--a significant finding because it helped explain the relatively low growth rate of the California sea otter population.

This White Paper was written at the request of the Ventura Field Office of the Fish and Wildlife Service following the movement of about 100 otters in spring of 1998 into the area near Government Point south of Point Conception. The redistribution was problematic because it created a management dilemma for the Fish and Wildlife Service. Government Point is in the "no-otter zone" established by Public Law 99-625, and the Service therefore is legally obligated to remove these animals. However, removal of so many otters might also have a detrimental effect on the parent population, listed as Threatened under the Endangered Species Act. Thus, compliance with one law would result in violation of the other. Our intent here is to provide Fish and Wildlife Service with an overview of the biological information needed to formulate a response plan. Specifically, we will 1) summarize the most recent data on distribution and abundance of the California sea otter population, from which we will assess current population status; 2) summarize data on numbers of beach-cast carcasses and cause of death in these animals; 3) discuss possible reasons for a recent change in population trends; 4) discuss the likely consequences of strict compliance with Public Law 99-625; and 5) identify future information needs. We will not analyze the data in detail, but rather identify what, in our judgement, are the high points and most relevant conclusions.

TRENDS IN POPULATION ABUNDANCE AND DISTRIBUTION

Information on the distribution and abundance of sea otters in California prior to 1990 is summarized by Riedman and Estes (1990). Although both range and numbers have increased during the 20th century, these variables are not well correlated. In particular, whereas population abundance has experienced several periods of decline, distribution evidently has not retracted during these periods.

Range delineation is somewhat arbitrary because individuals frequently wander well beyond the distributional limits of most of the population. Nonetheless, the geographic range of the California sea otter has expanded greatly since 1938, at which time most individuals occurred in the area between Bixby Creek in the north to Pfeiffer

Point in the south. As the population increased over subsequent decades, range expansion to the south was consistently more rapid than it was to the north. By the late 1980s, the California sea otter's range had increased to include the area between about Point Año Nuevo at the north and Point Sal at the south. Although the number of otters continued to increase through the mid 1990s, range expansion to the south slowed and to the north it essentially ceased during this period. By 1995, sea otters were commonly seen as far south as Point Arguello and in 1998 a substantial number of otters dispersed into the "no-otter zone" south of Point Conception.

Population abundance of the California sea otter has steadily increased through the twentieth century, except for two periods. By 1976 the population contained an estimated 1,789 individuals, but then declined to 1,443 by 1979 and to 1,372 by 1984. Standardized range-wide counts, undertaken in the spring and fall of each year, were initiated in 1982. The spring surveys have traditionally been used to assess population status since they are both consistently higher than the fall surveys in any given year and less variable among years. The number of animals counted during spring surveys remained essentially constant until 1985, increasing steadily thereafter until the mid-1990s (Fig. 1A & 1B). However, since 1996, the total number of animals counted in the spring surveys has progressively declined. This trend is evident in both the yearly counts (Fig. 1A) and in the same data plotted as 3-year running averages (Fig. 1B). Running averages were used to eliminate year-to-year vagaries in any given count, thus emphasizing overall trends. Trends in the spring counts thus indicate that the California sea otter population recently has declined. The fall counts show a similar pattern (Figs. 1C & 1D).

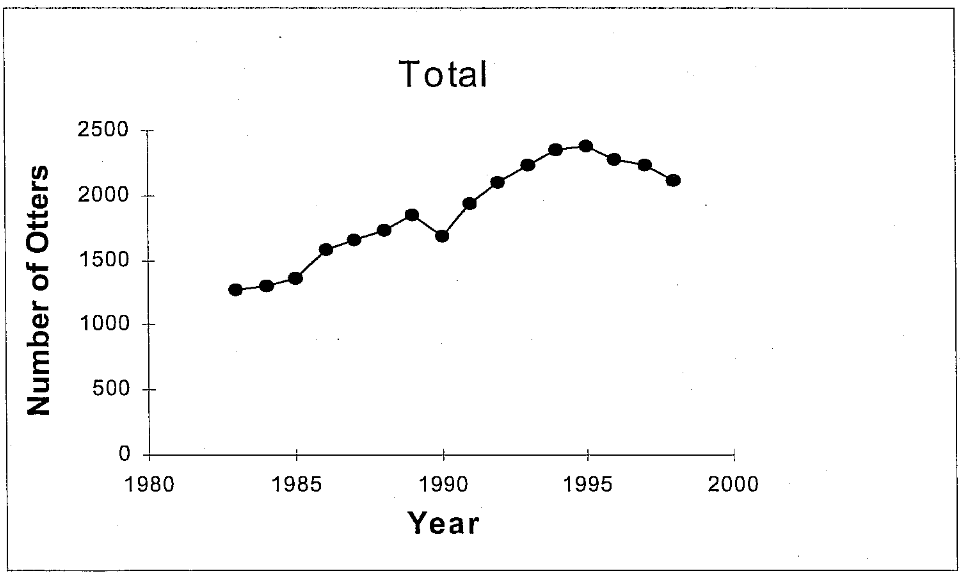

Figure 1A. The total number of sea otters counted from 1982 through 1998 during spring surveys.

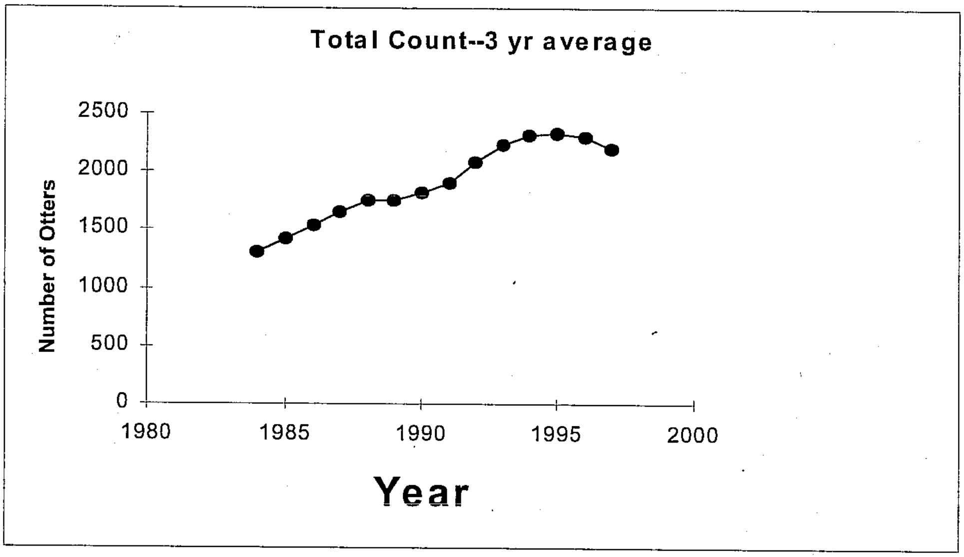

Figure 1B. Total number of sea otters counted during the spring surveys, plotted as 3-year running averages.

TRENDS IN MORTALITY

Our assessment of sea otter mortality in California is based on information obtained from beach-cast carcasses. Two measures are available: 1) the number of carcasses retrieved and 2) the cause of death in fresh carcasses. The number of carcasses recovered through time shows an overall pattern that is roughly consistent with population growth (Fig. 2). However, relative mortality patterns (measured by dividing the number of carcasses retrieved in a given year by the number of otters counted in the spring survey of that same year) indicate several departures from a time-constant relationship (Fig. 3). These data suggest further that mortality was roughly constant at about 5% yr^{-1} during the period of population increase (i.e., from about 1985 through 1994) but increased somewhat during periods of decline (i.e., the early 1980s and from 1995-1998). In sum, the available information suggests that the size of the California sea otter population has declined and mortality has increased over the past several years.

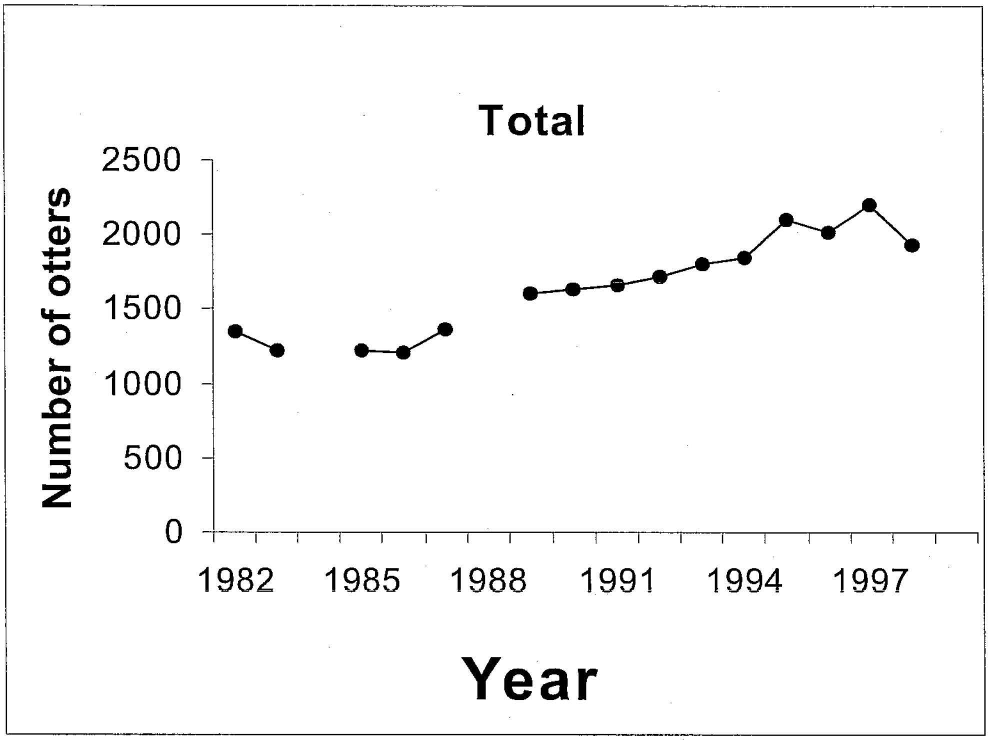

Figure 1C. Total number of sea otters counted from 1982 through 1997 in autumn surveys. Autumn surveys were not conducted in 1984 or 1988.

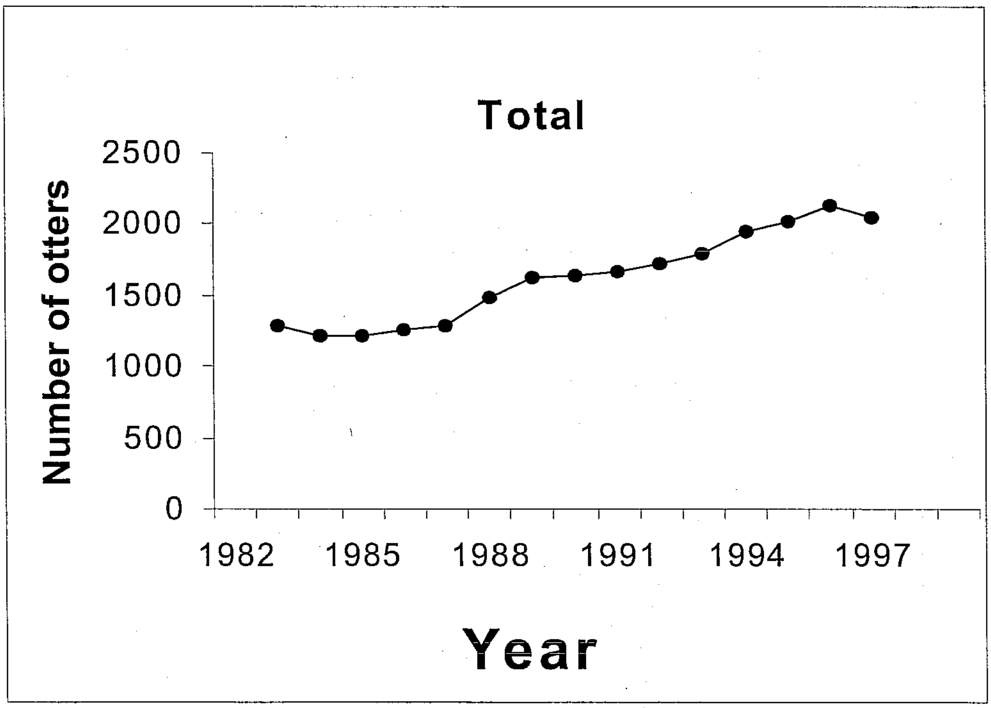

Figure 1D. Total number of sea otters counted in autumn surveys, plotted as 3-year running averages. No autumn surveys were conducted in 1984 and 1988; therefore years 1983-85 and 1987-89 are represented as 2-year averages.

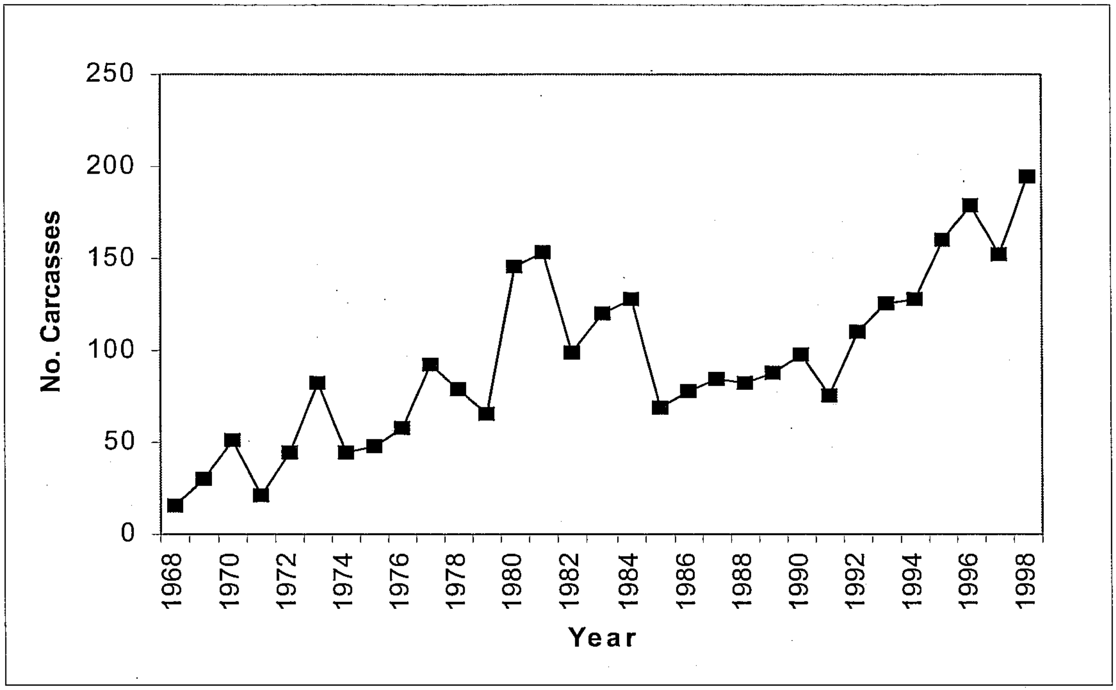

Figure 2. The number of beach-cast sea otter carcasses recovered by year from 1968 through 1998. Note that since 1998 is not yet over, the value was estimated by adding the number retrieved through September 1998 (172) to the most recent 10-year average number of carcasses recovered from October through December (22.9), for a total of 194.9.

Two explanations for increased mortality and reduced population abundance in the California sea otter have been suggested—infectious disease and incidental losses in coastal fishing gear. Because thorough necropsies have been done on fresh carcasses since 1992, it is possible to make a preliminary evaluation of the disease hypothesis. Inasmuch as the elevated mortality rate and declining abundance did not begin until about 1995, the incidence of infectious disease- induced mortality also should have increased concurrently if this were responsible for recent trend changes in the population. No changes in the rate of infectious disease are evident since 1992 (Fig. 4).

Nonetheless, two conclusions can be drawn about the influence of infectious disease on California sea otter populations. First, infectious disease must be an important factor in causing the slow growth rate, given that disease is responsible for roughly half of the deaths of animals obtained in the salvage program. Since the reproductive rate of California sea otters is comparable to that of other populations that are growing more rapidly, it follows that growth rate of the California population would be much higher in the absence of disease. The magnitude of this potential gain is unknown although it probably could be determined through population modeling. Second, the collective data suggest that the incidence of infectious disease may have been high throughout this century. The California sea otter population has never increased at more than about 5 % yr^{-1}, thus implying that mortality rate has not changed appreciably during the period of recovery. We also know that disease rate was high in the early 1990s, a time when the population was increasing at about 5 percent yr^{-1}. Therefore, if the rate of infectious disease has increased in recent years, some other source of mortality must have declined concurrently. Although such changes are conceivable, there is no reason to believe that they have occurred.

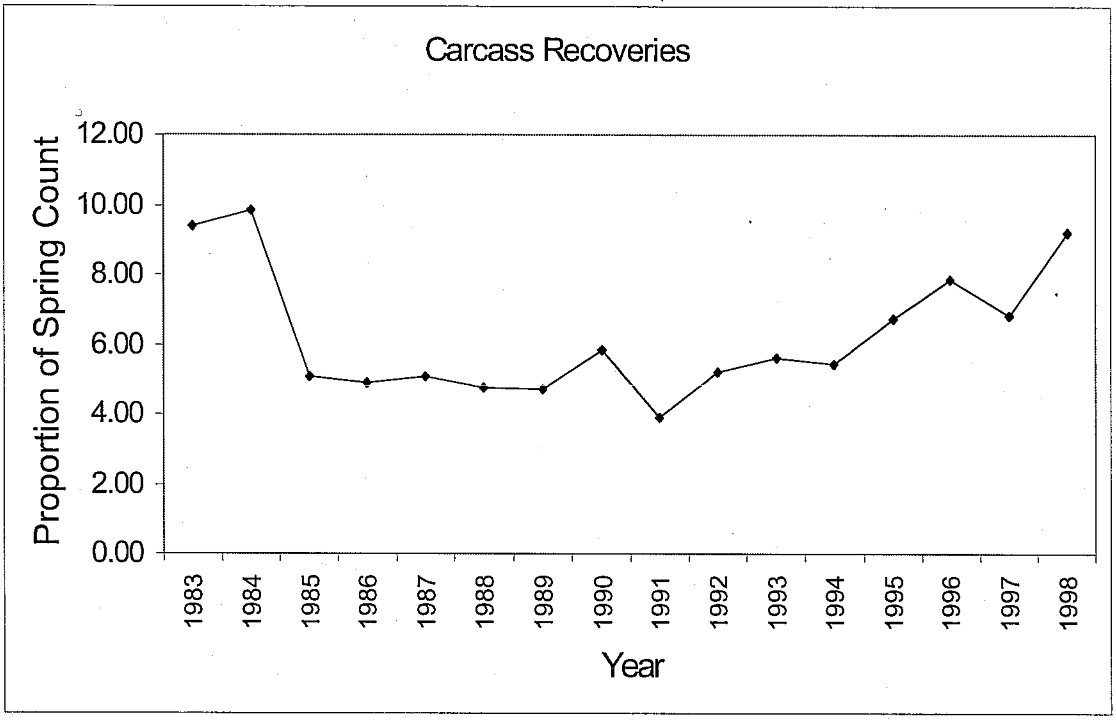

Figure 3. The relative number of sea otter carcasses retrieved by year. Proportions were determined by dividing the number of carcasses recovered by the number of otters counted in the spring surveys (x100).

While coastal pot fisheries are known to have intensified in recent years, and there are unconfirmed reports of otters having been killed by swimming into these pots for either their bait or targeted catch, we do not yet have sufficient information to evaluate this potential source of mortality. There is also a renewed concern about the incidental loss of sea otters in gill and trammel nets. The National Marine Fisheries has estimated the sea otter losses in central California have increased from near zero in 1995 to almost 50 individuals in 1998 (Karin Forney, NMFS, unpubl. data). Losses of this magnitude would significantly impact sea otter population trends.

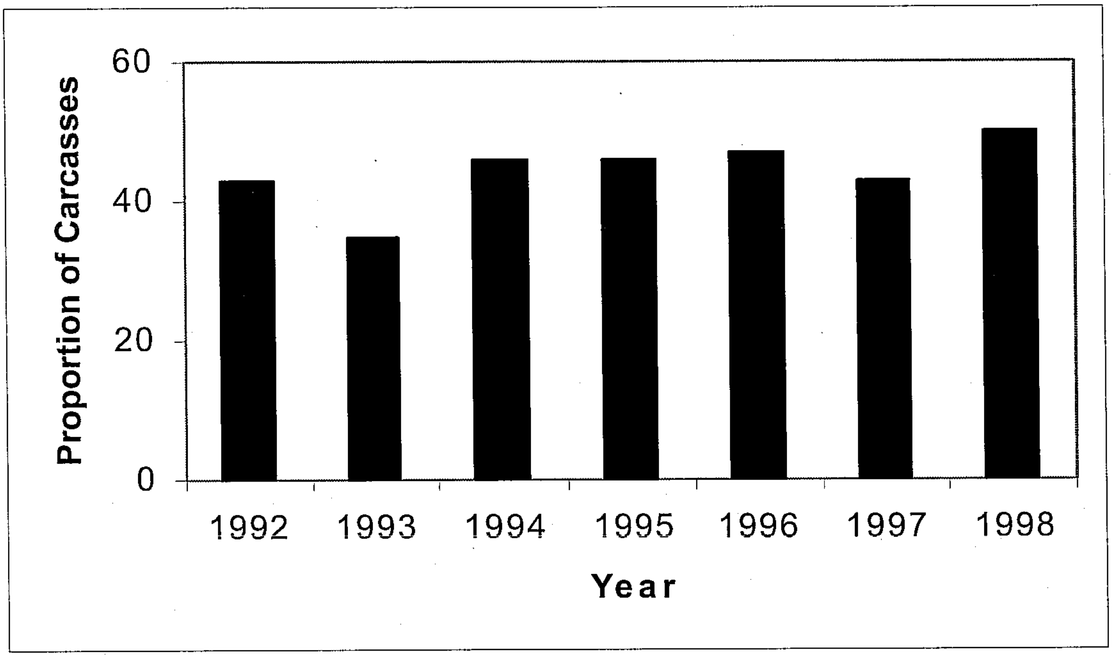

Figure 4. Proportion of sea otter carcasses necropsied at the National Wildlife Health Center that died of infectious or parasitic disease by year from 1992-1998. Two hundred and seventy one carcasses were examined, ranging from 65 in 1995 to 14 in both 1997 and 1998 (through July). These data should be treated as preliminary as diagnostic information on the most recent cases continues to be developed.

TRENDS IN REPRODUCTIVE SUCCESS

Reproduction has been studied in several sea otter populations (including California) by tagging known-age individuals and chronicling birth rate and pup survival rate from follow-up observations of the tagged animals. While the season of births and the probability of pup survival from birth to weaning vary by female age and population status, age-specific birth rates are virtually constant in all populations that have been studied. Several such studies, all completed prior to 1995, have been done on California sea otters (Siniff and Ralls 1989, Jameson and Johnson 1993, Riedman *et al.* 1994). There is no evidence for depressed reproduction from any of these studies.

A measure of reproductive success is also provided by the annual survey data, through the dependent pup counts. The pup to independent ratio varies considerably among years (Fig. 5). However, there is no obvious relationship between these measures and population trends.

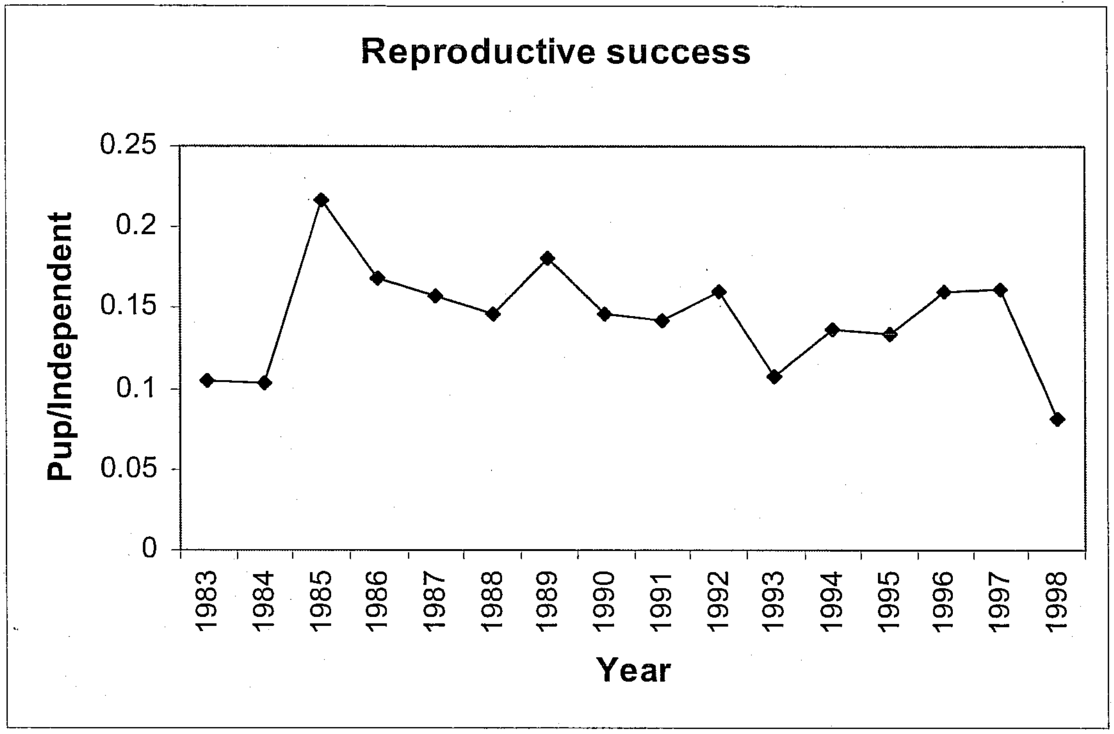

Figure 5. The ratio of dependent pups to independent sea otters as determined from the spring surveys done from 1983 through 1998.

Sea otters reproduce throughout the year and females typically come into estrous immediately after losing a pup (either from weaning or premature death). The low pup/independent ratios seen in the early 1980s probably were a lingering effect of the strong El Niño event that occurred in 1982-83. Intense winter storms caused an abnormally large number of females to lose their dependent pups, thus apparently resetting the annual birthing pattern for several more years. The same effect seems to have occurred in 1998. Even so, there is no indication of reproductive failure associated with the onset of the recent population decline.

ASSESSMENT OF CURRENT POPULATION STATUS

After at least 10 years of uninterrupted population growth, the California sea otter now appears to be in modest decline. There are three possible demographic explanations for the decline. One is that some of the otters have moved elsewhere. It is highly unlikely that the missing animals have moved to some other coastal area because the entire region is under almost constant surveillance by boaters and coastal observers. The distribution of otters may also have shifted offshore, thus decreasing the probability of an individual being observed during a survey. There is no evidence that distributional shifts of this nature occur in sea otters, nor have we noted any such change in the location of individuals during the surveys. We thus regard this possibility as unlikely, but worthy of further investigation. Another possibility is that the population has declined because of depressed reproduction. Again, the evidence both from past studies and the currently available data does not support this explanation. A third possibility is increased mortality. We regard this latter possibility as the most likely cause of the decline.

Mortality is difficult to study in wildlife populations. The only record of mortality patterns available for the California sea otter in recent years is the number and character of beached carcasses. At best, these materials provide a crude indicator of overall mortality because an unknown proportion of dead otters is recovered and it is uncertain that individuals found dead on the beach are representative of deaths in the population as a whole. While the number of carcasses recovered has increased in rough accordance with the population decline, there are no evident changes in cause of death in the freshly stranded animals. Since infectious disease has been shown to be the cause of death in almost half of the beached carcasses, any significant change in the incidence of this mortality source would be expected to appear as an increase in the proportion of diseased individuals among those that are necropsied. This pattern is not seen (Fig. 4) and thus we think it unlikely that an increase in infectious disease is responsible for the population decline. There are other possibilities, one of which is increased incidental take in fishing gear. In view of the recent growth of coastal pot fisheries, reports of otters being caught and killed in these pots, and high likelihood that incidental losses in fishing gear were responsible for an earlier population decline, the possibility of growing entanglement losses warrants further attention. Recent estimates of sharply increased sea otter losses in gill and trammel nets adds to this concern and the complexity of the issue.

Despite reasonably strong evidence for a recent population decline, the range of the California sea otter has continued to expand southward, thus resulting in about 100 individuals moving into the "no otter zone" south of Point Conception during late winter/spring of 1998. This situation raises the question of how compliance with Public Law 99-625 would affect the welfare of the California sea otter population. The easiest scenario to evaluate is that of removing these animals without placing them elsewhere. Inasmuch as the California sea otter population is in decline, such removals without replacement most likely would be additive to current losses, thus causing the population to decline even more rapidly. The potential consequences of removal with replacement are less certain, although several predictions are possible either from first principles of ecology or past experience. Relocations of these animals, either within the existing range north of Point Conception or outside the existing range, can be expected to cause the deaths of some of the relocated individuals. In addition, many of the relocated individuals almost certainly would return to the locations from which they were captured. There is also concern over how the relocated animals would interact with resident otters. The fact that these animals dispersed from the existing range makes it likely that their forced return would compromise the system in some manner, the two most likely mechanisms being via resource competition with the residents and disruption of the residents' social systems. Both processes would likely be detrimental to the residents. On the other hand, it is difficult to see how the residents might benefit from the intruders. In sum, regardless of exactly what is done with animals taken from the "no otter zone," removal of these animals would be detrimental to the California sea otter population. This issue may now seem moot because only a single sea otter was sighted south of Pt. Conception during the most recent (October) survey of the area. However, this is likely a seasonal pattern, and large numbers of otters should be expected to return the area south of Pt. Conception in late winter or spring of 1999.

There is little doubt that the California sea otter population would be best served by elimination of the "no-otter zone." This now appears essential for natural range expansion, and thus recovery, of the California sea otter. Disturbances to animals in this area will be detrimental to the population.

INFORMATION NEEDS

Conservation and management issues surrounding the California sea otter are complex and thus there are diverse needs for further information. Three specific problems require special attention. One is the issue of incidental losses of sea otters to fisheries. Further work is needed to assess whether such losses are of sufficient magnitude to be causing the population to decline. A second need is for basic information on sea otter demography and behavior. We have argued that reproductive failure is not responsible for the recent population decline, but in fact there have been virtually no data gathered since 1995 to assess that possibility. The same can be said of redistribution and mortality. A focused research program based on tagging and radio telemetry is needed to answer these questions. In view of the fact that a study of this kind was conducted during a time when the California sea otter population was growing (Siniff and Ralls 1989), similar information from the present would provide an illuminating contrast that would help clarify the reason for the current decline. A third need is to better understand the role of infectious disease in the population biology of California sea otters. Continued monitoring and detailed necropsies of fresh carcasses should receive high priority. The present policy of conducting detailed necropsies on every fourth otter is limiting our understanding of the decline but greatly reducing the power of the data to detect change. Although a reduced effort was justifiable while the population was still growing, it is no longer so now that the population is in decline. Further information on the history of disease and the ecology of the various parasites and disease organisms would also be of great value to understanding the status and trends of the California sea otter population.

Appendix E: Comments Submitted on Draft Revised Southern Sea Otter Recovery Plan Dated January 2000

In January 2000, we released the Draft Revised Recovery Plan for the Southern Sea Otter for public comment. During the comment period, we received 91 letters from Federal, State, and local agencies, nongovernmental organizations, business associations, and other members of the public. All letters of comment on the draft recovery plan are kept on file in the Ventura Fish and Wildlife Office, 2493 Portola Rd., Suite B, Ventura, California 93003. The following is a breakdown of the numbers of letters received from various affiliations:

Federal agencies–6
State agencies–3
local governments–1
nonprofit environmental/conservation organizations–9
commercial fishing and aquaculture associations–5
recreational groups–1
academia/professional–1
individual citizens–65

Many comments re-occurred in letters. The vast majority of responses came from individual citizens and expressed concern for the southern sea otter and support for research and recovery actions. Several comments either provided new or additional information for inclusion in the recovery plan or were editorial in nature. Those comments were incorporated into the final revised plan. Comments that were not incorporated into the recovery plan are summarized below along with our response.

Summary of Comments and our Responses

Comment 1. One commenter stated that the recovery plan should explain why the population should be viewed as endangered at a level where both the numbers and range would be greater than when the population was listed as threatened in 1977.

Response. This recovery plan incorporates current conservation biology principles. The initial listing and status classification did not have the benefit of such current thinking. Rather, the original classification of threatened was based on the presumed risk of extinction.

Comment 2. One commenter stated that it would be useful to note in the recovery plan revision why the type of population viability analysis described on page 25 of the draft revision was not or could not be done in the process of formulating the original recovery plan.

Response. Inclusion of such a discussion does not serve the purposes of the plan; *i.e.*, to identify the recovery criteria and tasks. Such an analysis was not completed in the 1982 recovery plan because that plan did not address the conditions under which the southern sea otter should be considered for reclassification as endangered.

Comment 3. One commenter stated that the table included as Appendix A does not, but should, provide estimates of the amount of range occupied by sea otters from 1982 to the present.

Response. The initial recovery plan provided estimates of the amount of range occupied by the sea otter as well as the population count. Later, as the sea otter population began to grow again subsequent to the restriction of gill and trammel nets, it became more difficult to identify the actual range occupied by the sea otters, and furthermore, it was difficult to find consensus amongst biologists as to what actually constituted the limits of the occupied range. Some suggested that range should be defined as all habitat in which sea otters occurred, including extra-limital sightings; others suggested it should be defined as the range in which females with pups were found. Pronounced seasonal movements of male otter groups further clouded this issue. Therefore, we decided that, to avoid confusion, it was best to present the table with only the population count data.

Comment 4. One commenter stated that pup counts are not important and recommended that recovery and delisting decisions use data for independent otters only. The commenter further stated that if pups are to be included, we need to provide a clearer rationale for using the spring counts.

Response. We and the Recovery Team believe that pup counts are important, and the recovery criteria will be based on spring counts. Pup counts provide an index of annual productivity, which is important when assessing the status of the population and evaluating other indicators of population health. The recovery plan does explain that spring counts have been established as the standard for assessing trend and population size because the conditions are more favorable for counting sea otters (*i.e.*, bull kelp is not present). During the fall counts, bull kelp is present and makes counting sea otters more difficult.

Comment 5. One commenter suggested including other human activities besides oil activities and commercial fishing, such as kelp harvest, use of personal water craft, other recreational uses (*e.g.*, kayaking, diving), impacts of contaminants, etc.

Response. Recovery plans identify those threats known to cause the species to be at risk of extinction including those identified at the time the species was listed and any additional threats subsequently identified. These other suggested activities were not included in the recovery tasks because they are not known to be threats contributing to the species' risk of extinction. If at any time in the future new threats are identified, the recovery plan can be updated to include these threats and management actions necessary to secure the protection and conservation of the sea otter.

Comment 6. One commenter recommended that we use a different factor for calculating the size at which the southern sea otter population should be considered endangered; *i.e.*, the threshold should be 1,550, not 1,850.

Response. The best available information regarding the threshold for endangered status for the southern sea otter was identified as that presented in the paper by Ralls *et al.*

(1983). In this paper, the authors considered the life history characteristics of the sea otter and determined that the correction factor of 27 percent is appropriate for the southern sea otters. Therefore, we did not change the threshold value.

Comment 7. One commenter asserted that the statement that sea otter populations in various geographic locations exhibit a wide range of growth rates and are thought to differ in life history parameters contradicts the Alaska sea otter stock assessments, which assumes a single high growth rate when assessing the stocks in Alaska.

Response. The statement within the draft revised recovery plan was a general statement comparing all sea otter populations and is supported by available literature. In Alaska, the sea otter population growth rate has ranged between 17 and 21 percent, while in California the southern sea otter population growth rate has ranged between 5 and 7 percent.

Comment 8. One commenter was concerned that the implication of recommending a 5-year study is that until the data from such a study are acquired, no management action will be taken. Given the continued decline of the population, the precautionary principle urges action that benefits the population in the absence of knowledge.

Response. We do not intend that no action will be taken until studies are completed and data analyzed. The responsible agency will take action using the best available information, subject to the availability of funds.

Comment 9. One commenter objected to what was believed to be the numerical objective for recovery as 8,400 sea otters along the California coast. It was further stated that there was no explanation for that number.

Response. This recovery plan, as well as the 1982 original plan and all subsequent drafts, recognizes our responsibility for managing sea otters not only under the Endangered Species Act, but also the Marine Mammal Protection Act. The recovery plan clearly recognizes that once the recovery objectives are achieved pursuant to the Endangered Species Act, we still have obligations under the Marine Mammal Protection Act. Those obligations are to restore the sea otter population to its optimum sustainable population level. Past efforts at determining marine mammal optimum sustainable population levels have identified the lower bound to be roughly 50-60 percent of the habitat's current carrying capacity. For the southern sea otter this lower bound is approximately 8,400 animals for the entire California coast, based on estimated historic population levels. A marine mammal population below its optimum sustainable population level is considered depleted. A conservation plan will need to be developed detailing methods for restoring the population to its optimum level.

Comment 10. One commenter believed that the recovery plan should reference the "seminal works" on sea otters.

Response. The original recovery plan recognizes much of the early literature on sea otters. The original plan is still available for anyone interested in obtaining these references. In developing this plan, we and the Recovery Team chose predominantly to cite current peer-reviewed literature. This recovery plan does direct readers to contact us or other agencies for additional information, if desired.

Comment 11. One commenter recommended that the recovery plan should provide alternatives and an evaluation of the risks, and that there should be public hearings.

Response. Recovery plans are developed for species at risk of extinction; the plans should identify the threats to a species, recommend tasks by which the threats can be removed, and state the criteria by which the species is no longer considered to be at risk of extinction and in need of protective measures under the Endangered Species Act. The plan is a "road map" to recovery. There may be other means to get to recovery, other means by which the threats are eliminated. The recovery plan does not preclude other efforts to eliminate the risks; those could be pursued. Under most circumstances, only as specific tasks are implemented is the NEPA process invoked. During this process, alternatives are identified and evaluated, public meetings are held, and comments are evaluated before actions are implemented

Comment 12. One commenter recommended that we revise the five criteria that are evaluated in any proposed rule or final rule to add or remove a species from the Federal list of threatened or endangered species pursuant to the Endangered Species Act.

Response. Section 4(a)(1) of the Act and regulations (50 CFR part 424) issued to implement the listing provisions of the Act identify the factors that must be evaluated to determine the classification of a species. The five criteria that are analyzed in all Federal rulemakings are: 1) The Present or Threatened Destruction, Modification, or Curtailment of Its Habitat or Range; 2) Overutilization for Commercial, Recreational, Scientific, or Educational Purposes; 3) Disease or Predation; 4) The Inadequacy of Existing Regulatory mechanisms; and 5) Other Natural or Manmade Factors Affecting its Continued Existence. These factors cover all possible threats and we do not believe they should be changed.

Comment 13. One commenter recommended that we or the U.S. Geological Survey should write and publish a comprehensive summary of information obtained since 1990.

Response. Although a comprehensive summary of information is not available and resources are not available for such an effort at this time, new information is published. Information is continually being updated and reviewed through a variety of reference sources; however, there is inadequate funding to compile all information into a single document at this time.

Comment 14. One commenter believed that the recovery plan greatly overstates the threat and effects of oil spills and stated that there is no discussion of oil spills that have affected California sea otters.

Response. There have been several events along the California coast that could easily have resulted in a large oil spill within the range of the southern sea otter. For example, in 1982, the Sealift Pacific lost steerage and nearly grounded along the Big Sur Coast. The vessel was able to stop its movement toward the shore by dragging its anchor. In 1992, an onshore pipeline broke and oil spilled into Avila Bay. Four oiled sea otters were removed from that area. We acknowledge that to date there has been no large oil spill in the range of the southern sea otter that has caused a high level of mortality. However, the *Exxon Valdez* oil spill event clearly demonstrates that a large-scale oil spill can occur, and that if one occurs within the range of sea otters, it will be capable of causing substantial mortality of sea otters and habitat degradation. We and many other agencies and organizations are concerned about the threat of oil spills and their effects on the California coastal environment. Because of the threat of oil spills, the U.S. Coast Guard and the Monterey Bay National Marine Sanctuary established an interagency team to develop a proposal to reduce oil spill risk from vessel traffic. A plan was developed and subsequently approved by the International Maritime Organization that manages international vessel routing.

Comment 15. One commenter recommended that we develop a sea otter containment program in collaboration with fishermen, who would provide matching funds to ensure ongoing capture capability.

Response. This comment is best addressed relative to our current effort toward developing a supplemental environmental impact statement on the translocation program. Because of the current status of the southern sea otter population and the changed circumstances surrounding the original translocation program, we are currently developing a supplemental environmental impact statement on the translocation program. As part of this effort, we have solicited public input through the scoping process and will be evaluating public comments and program alternatives. This recommendation, if it was submitted during the scoping process, can be evaluated for consideration.

Comment 16. One commenter recommended that habitat protection should have a high priority (regardless of listing status), and that an assessment of negative impacts (loss of kelp beds and shellfish larvae) on the coastal habitat from projects such as municipal sewer outfalls, silt, and pesticides in runoff and water intake and discharge from power plants be done. Areas or projects where negative impacts are occurring should be corrected or mitigated.

Response. The recovery plan does identify habitat issues known, or suspected, to threaten the southern sea otter (*e.g.*, contamination and disease). The recovery plan identifies the need to determine the causes of the problems and identify management actions that eliminate or reduce the threat. As new information becomes available identifying causes of habitat degradation, research and management efforts can be recommended to restore the coastal ecosystem.

Comment 17. A few commenters questioned how cessation of the "otter-free-management zone" would promote recovery of the southern sea otter.

Response. The translocation of southern sea otters to San Nicolas Island has been less successful than originally hoped for as a means of establishing a second, self-sustaining population of southern sea otters. Furthermore, the value of the colony, as originally envisioned, was to repopulate the mainland population if decimated by an oil spill, or some other event, by translocating small numbers of animals from San Nicolas Island. Experience has demonstrated that this goal may not be achievable given the tendency of translocated sea otters to disperse. The mainland population is still threatened because of its small population size and limited distribution. Recovery can best be achieved by having a larger number of southern sea otters distributed over a larger area. Since 1998, southern sea otters from the central coast seasonally have moved south of Point Conception into the management (otter-free) zone. Containment of these animals (*i.e.*, their capture and relocation back into the mainland population), in perpetuity, does not enhance recovery and, if moving large numbers of animals, is likely to adversely affect the mainland population, by disrupting social dynamics, increasing competition, etc. The natural movement of sea otters into a larger area would be better for the sea otter.

Comment 18. One commenter asked how, if the minimal viable population for sea otter is approximately 1,850 animals, we could have published a nonessential designation for moving 150 sea otters to San Nicolas Island when the fall survey for 1987 was 1,367 animals (that is, 483 animals fewer than 1,850 animals).

Response. It is important to note that the original target of 150 animals was the total number of animals that could be moved to San Nicolas Island over the term of the permit. This total number of animals was not permitted to be moved in a single year. However, the number of animals in the population at the time of the translocation was below the minimal viable population figure. This figure (1,850 or fewer) has been provided as an index as to when the southern sea otter population status should be considered endangered pursuant to the Act. The determination of the listing status of a species pursuant to the Act is different than the determination whether an experimental population under section 4(d) of the Act is essential or nonessential. The essential/nonessential determination has relevance only with respect to section 7 of the Act. If we had believed at the time of initiating the translocation that all 150 sea otters would be lost shortly after the translocation, the translocation would not likely have proceeded at that time or as designed.

Comment 19. One commenter recommended that we should study risks to sea otters south of Point Conception, impacts to other resources such as abalone, impacts to sea otters from offshore oil, sewage, nuclear power plant operations, etc., and economic impacts and potential impacts on other life-forms by foraging sea otters.

Response. We are currently undertaking a supplemental environmental impact statement on the translocation program. This effort will re-evaluate the threats and impacts addressed in the original environmental impact statement for the translocation of sea otters. This document should satisfy the recommendations stated above. There is no environmental impact process for evaluating the threats to southern sea otters in their current range. However, the recovery plan does identify a need for the further evaluation of threats, the determination of their sources, and the development of reasonable and prudent measures to minimize them.

Comment 20. Several commenters recommended the improvement of survey methods.

Response. We recognize that the current survey methodology does not count every sea otter. The survey is designed and intended to provide a standardized method for counting southern sea otters, and thus to provide an index for assessing population trends. We do believe that it is important to evaluate periodically whether the best methodology is being used. However, we believe that changing survey protocol at this time would confound efforts to assess and to understand the status of the southern sea otter population because data collected under a different protocol would not be comparable with the data already collected for previous years.

Comment 21. One commenter stated that the recovery objective of 8,400 sea otters for the entire California coast is excessive and requested that the number be changed to the lower number of 5,400 as in the 1991 draft plan.

Response. The figure 8,400 is the estimated recovery goal for achieving the optimum sustainable population level under the Marine Mammal Protection Act. The Marine Mammal Protection Act states that the goal for managing marine mammals should be to obtain an optimum sustainable population keeping in mind the carrying capacity of the habitat. An optimum sustainable population for the southern sea otter is likely a level equal to 50 to 80 percent of its current carrying capacity. The lower bound of the optimum sustainable population is approximately 8,400 animals for the entire California coast, based on estimated historic population levels.

Comment 22. One commenter suggested that the recovery plan should include language to allow the concept of zonal management in order to protect "the balance of our marine resources."

Response. It is important to note that recovery plans do not allow or authorize any activity. A recovery plan is a guidance document that identifies recovery criteria and our recommended actions for restoring the species to a status that it no longer needs the protective provisions of the Endangered Species Act. Regarding zonal management, the Southern Sea Otter Recovery Team believes that the primary action for promoting the recovery of the southern sea otter at this time should be the cessation of the management zone, and that without such a change in management, the likelihood of recovery is significantly lessened. We are taking this recommendation and other information under consideration and evaluating several alternative courses of action, including the continuation of zonal management, through the National Environmental Policy Act process.

Comment 23. Several commenters recommended that an "implementation team" be created, so that after the recovery plan is approved, recovery tasks can be set in motion.

Response. Although the formulation of an implementation team is not necessary to activate recovery actions, such a team can be useful as an advisory body regarding recovery efforts and can effectively serve to facilitate collaborative efforts. We will consider this recommendation and how it can best be implemented.

Comment 24. Numerous commenters stated the importance of declaring the San Nicolas

Island translocation a failure and ending zonal management. Reasons noted were: 1) risk to sea otters associated with capture and relocation; 2) undue stress placed on sea otters living in the area to which sea otters would be translocated; 3) exacerbating food limitations and habitat degradation; and 4) disrupting existing social structure.

Response. We are currently developing a supplemental environmental impact statement to reevaluate the southern sea otter translocation plan as described in the final Environmental Impact Statement for Translocation of Southern Sea Otters, Appendix B, May 1987. Through this process, we will consider the current program, modifications to the program, and termination of the program. The supplemental environmental impact statement will update information, assess the impacts of proposed alternatives, provide for public participation, and ultimately identify an alternative that will reduce the southern sea otter's vulnerability to extinction.

In response to comments received on the January 2000 draft revised plan, we asked the Recovery Team to complete a trend analysis to determine the population size that would be robust enough for us to detect trends in abundance reliably prior to the population declining to endangered status. In April 2002, we submitted this analysis for peer review by Alan Hastings (UC Davis), Marcel Holyoak (UC Davis), John R. Sauer (USGS-Patuxent Wildlife Research Center), and Dan Goodman (Montana State University). Their comments are summarized below:

Comment 1. Several reviewers questioned whether the use of a 5 percent rate of decline was appropriate considering that the rate of decline observed in the Alaska population was 16 percent or more.

Response. If one assumed a 16 percent rate of decline, with the same trial scenario as used originally (*e.g.*, CV = 0.1, alpha = 0.1, etc.), it would take 5 years to get a high likelihood of detecting a decline, during which time the population would drop by 58 percent. Therefore, the buffer above 1,850 would be 2,590 animals for a threshold of 4,440 animals (1,850 + 2,590). The Recovery Team finds using the higher rate of decline unreasonable for the California population because it has never been observed in California, and prefers to use the maximum rate of decline observed in the population since monitoring was initiated.

Comment 2. Several reviewers recommended conducting simulation trials to look at the robustness of the listing criteria (including trend analysis) and the 3-year running average index.

Response. Although this exercise would be valuable, it would take a programmer/analyst several months at a minimum to complete the work, at a cost of about $15,000. The Recovery Team recommended, and we agreed, that we should not delay completing the final revised recovery plan in order to complete this analysis. Rather, we should make final the current version of the recovery plan and then undertake the analysis and incorporate the results as part of the next status review in 5 years.

Comment 3. Several reviewers noted that using the 3-year running average is conservative when considering delisting, but it is not conservative when considering uplisting (*i.e.*, going from threatened to endangered).

Response. Most of the Recovery Team preferred to trigger uplisting to endangered if the population falls below 1,850 in a single year. However, the Fish and Wildlife Service has determined that it is appropriate to use the 3-year running average when considering uplisting. Because population counts have fluctuated from one year to the next, we believe it is prudent to use the 3-year running average to characterize population size during a given year. For example, if we used a single year count as the criterion to initiate reclassification to endangered when the population count is at or below 1,850, then during the course of developing and proposing a reclassification, if a subsequent count were above 1,850, we would have to terminate that proposal effort (thus making inefficient use of limited staff time). Using the 3-year running average is both consistent with how we assess population size and should provide assurance that the population is adequately characterized if we propose uplisting or delisting. (See also the response to Comment 2 above.)

Comment 4. Two reviewers commented that changes between years could be extreme and that linear trends may be less of a worry than nonlinear trends.

Response. The Recovery Team did not support this consideration, as increases and decreases in abundance of the California sea otter population since the 1970s have been approximately linear, with decreases in the late 1970s and early 1980s (likely due to density-independent mortality related to fishery interactions), increases from the mid-1980s to the mid-1990s, and then decreases from the mid-1990s to 2000.

Comment 5. One reviewer recommended that we verify that the coefficient of variation (cv) of the index counts are relatively constant and approximately 0.1.

Response. The cv (of 0.1) was estimated by deviations from the best fit to trends in the population count data. This method of estimating the cv is a very reasonable one; the only other way would be to replicate counts in a given year, which would be extremely expensive in terms of time and money.

Comment 6. One reviewer questioned why we did not use Lande's 5,000 figure when determining the criteria for when the southern sea otter should be considered endangered.

Response. Basically, Lande's calculation was for a time scale on the order of thousands of years. The Recovery Team thought that a time scale of decades to a century was more appropriate for management purposes; hence the 500 number was used

Comment 7. One reviewer raised a point that the 10 years required to detect a trend of less than 5 percent per year does not allow time for us to react and attempt mitigation.

Response. This point is valid. A simulation analysis would allow an evaluation of the probability of detecting a given decline in a given number of years. (See the response to Comment 2, above.) Furthermore, the simulation analysis needs to take into account the time it takes to propose and make final a reclassification ruling. The results of the analysis should be incorporated as part of the next status review in 5 years.