Marine Mammals and the *Exxon Valdez*

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Chapter 3

An Overview of Sea Otter Studies

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INTRODUCTION

The *Exxon Valdez* oil spill (EVOS) on 24 March 1989 threatened extensive areas of prime sea otter (*Enhydra lutris*) habitat along the coasts of south-central Alaska. The spill occurred in northeastern Prince William Sound (PWS), and oil moved rapidly south and west through PWS into the Gulf of Alaska. Much of the coastline of western PWS was heavily oiled, and the slick eventually spread as far southwest as Kodiak Island and the Alaska Peninsula (Galt and Payton 1990; Morris and Loughlin, Chapter 1). All coastal waters affected by the spill were inhabited by sea otters.

Concern for the survival of sea otters following the oil spill was immediate and well founded. Sea otters are particularly vulnerable to oil contamination because they rely on pelage rather than blubber for insulation, and oiling drastically reduces the insulative value of the fur (Costa and Kooyman 1982; Siniff et al. 1982; Geraci and Williams 1990). Within days of the spill, recovery of oiled live otters and carcasses began. During the several months following the spill, sea otters became symbolic of the mortality associated with the spilled oil, and of the hope for rescue and recovery of injured wildlife (Batten 1990).

An extensive sea otter rescue and rehabilitation effort was mounted in the weeks and months following the spill. Handling and treatment of the captive sea otters posed an enormous and difficult challenge, given the large number of otters held at the facilities and minimal prior experience in caring for oiled sea otters. Rehabilitation of sea otters was a separate effort from the postspill studies designed to evaluate injury to the otter populations and is not addressed in this chapter only as it relates to evaluation of damage assessment studies. Detailed information on the rehabilitation effort is presented in Bayha and Kormendy (1990) and Williams and Davis (1990).

Sea otters retained a high profile in the Natural Resource Damage Assessment (NRDA) studies largely because the initial injury to the sea otter population was readily demonstrable, but also because of concerns about long-term damages. The scope of the postspill studies to assess oil-related damages to sea otters was extensive: From 1989 through 1993, more than $3,000,000 was spent, and more than 20 scientists were involved in a comprehensive research program. The studies were predominantly directed at sea otter populations in PWS.

Damages to sea otters generally can be classified as either acute, defined as spill-related deaths occurring during the spill, or chronic, defined as longer term lethal or sublethal oil-related injuries. Studies of acute damages focused on estimating the total initial loss of sea otters. Characterization of the pathologies associated with exposure to oil was a secondary goal of studies of acute effects. Chronic or longer term damages may have resulted from sublethal initial exposure or continued exposure to hydrocarbons persisting in the environment. Studies of chronic effects included evaluating abundance and distribution, survival and reproduction rates, foraging behavior, and pathological, physiological, and toxicological changes in the years following the spill.

The objective of this chapter is to review the studies conducted on sea otters in response to the EVOS and to synthesize the major findings of those studies relative to injury to the sea otter population associated with exposure to oil. We also provide recommendations for research to improve our understanding of the effects of future oil spills on sea otter populations.

STUDIES OF ACUTE INJURY TO SEA OTTERS

Acute losses to the sea otter population were reflected in the carcasses collected in the spring and summer following the spill. Four hundred ninety-three sea otter carcasses were collected from PWS, 181 from the Kenai Peninsula, and 197 from the Kodiak Island/Alaska Peninsula area, with a total recovery of 871 carcasses. In addition, 123 sea otters died at the rehabilitation centers, bringing the total number of carcasses accumulated in the 6 months following the spill to 994 (Doroff et al. 1993; DeGange and Lensink 1990). Undoubtedly, some additional number of sea otters were exposed to oil and subsequently died but were not recovered during the clean-up efforts. Studies of carcass recovery efforts have shown relatively low recovery rates (Wendell et al. 1986; Piatt et al. 1990; Ford et al. 1991).

Quantifying the total number of sea otter deaths related to the oil spill was of extreme importance for the U.S. Fish and Wildlife Service (USFWS) and U.S. Department of Justice in light of pending litigation against Exxon Corporation and the potential monetary value associated with each sea otter mortality. Consequently, several approaches were taken to enumerate the total acute loss of sea otters; these are described below.

Surveys of Sea Otter Abundance and Distribution

One approach to enumeration of the total sea otter loss was comparison of pre- and postspill estimates of otter abundance. At the time of the spill, knowledge of sea otter abundance along the Kenai and Alaska Peninsulas or in the area of Kodiak Island was limited. Helicopter surveys were implemented in April 1989, concurrent with or prior to the arrival of oil in these areas (DeGange et al. 1994), to obtain "prespill" estimates of sea otter abundance and distribution. These surveys were repeated in the fall of 1989, providing "post-spill" counts for comparison with the prespill data.

In PWS, a boat-based survey of sea otters had been conducted in 1984-1985 (Irons et al. 1988), providing a relatively recent prespill count for comparison. A boat-based survey was also conducted in PWS in the summer of 1989 to estimate postspill sea otter abundance and distribution (Burn, Chapter 4); the survey was repeated in the spring and summer of 1990, 1991, and 1993. Pre- and postspill survey methods were similar, except that the entire shoreline of PWS was surveyed prespill, whereas only a portion (approximately 25% or less) of the coastline in PWS was surveyed postspill (Burn, Chapter 4).

The helicopter surveys did not detect acute losses for the Kenai Peninsula, Kodiak Island, and Alaska Peninsula areas (DeGange et al. 1994). Although declines in estimated abundance of sea otters were seen between the pre- and postspill helicopter surveys in all three regions, none of the decreases was statistically significant. Additionally, no changes were observed in the distribution of sea otters among heavily, lightly, and nonoiled areas within each region (DeGange et al. 1994).

Burn (Chapter 4) analyzed the data collected in the boat surveys and found a 35% decline (793 fewer otters) in abundance of sea otters in oiled areas of PWS in 1989, and a 13% increase (234 more otters) in abundance in nonoiled areas. Garrott et al. (1993), who used the analysis of these data outlined by Burn (Chapter 4) and adjusted the counts for population growth and detectability of sea otters (Udevitz et al. 1994), estimated that 2800 sea otters died acutely in PWS following the oil spill. However, differences in the areas where the pre- and postspill surveys were conducted complicated analysis and interpretation of the data. In a separate analysis of the boat-survey data set, D. Garshelis (Minnesota Department of Natural Resources, personal communication) concluded that sea otters were at least as abundant in western PWS after the spill as in the mid-1980s. He recognized, based on recovery of carcasses, that significant mortality of otters had occurred after the spill. To explain these observations, Garshelis speculated that the otter population in western PWS may have increased in abundance between 1984-1985 and 1989.

Evaluation of the Probability of Carcass Recovery

A second approach to quantifying acute losses involved estimating the probability of recovery of sea otter carcasses. This was accomplished by a trial release of 25 marked sea otter carcasses that had been recovered by clean-up crews, and then releasing them back into the water in the vicinity of northern Kodiak Island in May and June 1989 (DeGange et al. in press; Doroff and DeGange 1994). Clean-up efforts were ongoing in the area. Five of these carcasses were relocated and returned to the collection center, for a recovery rate of 20%.

Due to constraints existing in 1989 associated with the overall effort to collect carcasses, the sample size used in this study was small and several factors limit the validity of extrapolating to sea otter carcasses collected throughout the spill zone. Nevertheless, this effort provided the only quantitative estimate of the probability of recovery of sea otter carcasses following the oil spill (DeGange et al. in press; Doroff and DeGange 1994). Applying the recovery probability of 20% to the overall spill area, the number of sea otters estimated to have died acutely following the oil spill is 4028 (3905 plus 123 dead at rehabilitation centers).

Intersection Model for Estimation of Total Acute Mortality

Development of an analytical model to estimate sea otter mortality based on oil exposure levels was the third approach to quantifying total acute losses (Bodkin and Udevitz, Chapter 5). The Kenai Peninsula sea otter population was modeled because data were most recent and complete for that area. The model integrated oil abundance and movements, sea otter distribution and abundance, and estimates of mortality associated with exposure to varying amounts of oil (including data from rehabilitated sea otters). Simulations indicated potential exposure to some degree of oiling of approximately half (1200 of 2330) of the sea otters along the Kenai Peninsula. By assigning exposure-specific mortality rates to those sea otters exposed to oil, acute mortality can be estimated. However, accurate estimates of total Kenai Peninsula mortality were not possible because of an apparent nonlinear relation between the amount of oil otters encountered and the survival of those otters following the rehabilitation process. Given current limitations of the data, the intersection model may prove to be of greater application in risk assessment than for estimation of the total spill-related mortality.

Necropsies of Sea Otter Carcasses

Necropsies of sea otter carcasses were performed to maximize our understanding of pathological mechanisms contributing to death following oil exposure and to estimate the proportion of deaths that could be classified as oil related (Lipscomb et al., Chapter 16). During the necropsy procedures, tissues were collected for hydrocarbon assays (Ballachey and Mulcahy 1994a; Mulcahy and

Ballachey, Chapter 18) and reproductive studies (Bodkin et al. 1993), and morphometric data were collected to complement other studies.

Pathologic and histopathologic changes of the lung, liver, and kidney associated with oil exposure were observed in many of the sea otter carcasses (Lipscomb et al. 1993, Chapter 16). For 71% of the carcasses, death of the otter was judged to be oil related. In only 1% of the cases was the cause of death clearly due to causes other than the oil spill. These findings substantiate the conclusion that most deaths of sea otters recovered as carcasses in the spring and summer of 1989 were oil related rather than incidental mortalities.

Hydrocarbon Assays

Elevated but variable levels of hydrocarbons were found in tissues of heavily oiled sea otters from PWS that died soon after the spill, as compared to control samples from southeastern Alaska (Mulcahy and Ballachey, Chapter 18). As time and distance from the spill increased, hydrocarbon concentrations in the tissues tended to decrease. Hydrocarbon levels in sea otter tissues had seemingly returned to normal levels by the summer of 1990 (USFWS, unpublished data).

Summary of Acute Injury to Sea Otters

Considerable effort was put into the determination of acute losses of sea otters related to the oil spill. However, because of prespill data limitations and a lack of or limitations on studies implemented immediately after the spill, a reliable and defensible estimate of the total number of sea otters that died because of the oil spill cannot be generated. A synthesis of available information leads us to conclude that the total acute loss was in the range of several thousand sea otters.

STUDIES OF CHRONIC INJURY TO SEA OTTERS

Chronic or long-term damages may have limited recovery of sea otters in oiled areas. Several mechanisms for long-term injury can be postulated: (1) sublethal initial exposure to oil causing pathological damage to the otters; (2) continued exposure to hydrocarbons persisting in the environment, either directly or through ingestion of contaminated prey; and (3) altered availability of sea otter prey as a result of the spill.

A variety of approaches, as described below, were taken to evaluate chronic injury to sea otter populations. The design for many of these studies was based on comparisons of sea otters in eastern PWS, a region considered a "control" area because it was not directly affected by the spilled oil, with sea otters in western PWS, much of which was directly contaminated with oil. Differences in population demography and habitat between eastern and western PWS, however, provide difficulties when making comparisons between areas. As in studies of acute losses, efforts to quantify chronic damage suffered from a lack of baseline data and from unavoidable delays in implementation of postspill studies.

Patterns of Mortality

Beach-cast sea otter carcasses were routinely collected in western PWS for approximately 10 years prior to the spill and ages of the otters at the time of death estimated (Johnson 1987). Mortality of sea otters during this period occurred mostly in very young (2 years of age) and older (8 years of age) animals. Only 15% of the carcasses recovered during the prespill period were prime-aged otters (2 to 8 years of age). Similar natural mortality patterns have been described in other sea otter populations (Bodkin and Jameson 1991; Kenyon 1969). From 1989 to 1993, beach-cast sea otter carcasses were collected in western PWS providing comparable postspill data on ages at death.

As expected, given the catastrophic nature of the spill, the sea otter carcasses recovered in 1989 included a much higher proportion of prime-aged sea otters. However, this pattern persisted in 1990 and 1991 (Monson 1994). This shift from a low prespill incidence to a relatively high postspill incidence of prime-aged animals suggests prolonged spill-related mortality. The proportion of prime-aged sea otters recovered from beaches in 1992 decreased relative to the previous years, and by 1993 was similar to prespill values, indicating that perhaps the population is returning to a prespill pattern of mortality. Sample sizes from 1992 and 1993 were relatively small, however, and compared to collections in 1990 and 1991, included fewer carcasses collected from the most heavily oiled areas of PWS.

Survival and Reproduction Rates

Telemetry studies were used by C. Monnett and L. Rotterman (1984-1991) and by the USFWS (1992-1993) to evaluate survival and reproductive rates of sea otters in PWS. Three segments of the population were studied: (1) juvenile sea otters in their first year of life; (2) adult female sea otters; and (3) sea otters released from rehabilitation centers.

Survival of juvenile sea otters (normally born in the spring) through their first winter was measured as an index of population status. Differences were observed in the overwinter survival rate of juvenile sea otters in eastern and western PWS in 1990-1991 (Rotterman and Monnett 1991) and again in 1992-1993 (USFWS, unpublished data). Both studies demonstrated lower survival for pups inhabiting western areas of PWS, relative to the eastern areas. However, the survival rates for both eastern and western areas were lower in 1990-1991 relative to 1992-1993. The influence of the oil spill on survival in subsequent years, relative to factors such as habitat quality, overall population status, and severity of weather conditions in the different years is difficult to ascertain.

Adult female sea otters were monitored from late 1989 to the summer of 1991 (Monnett and Rotterman 1992a). The survival rate of adult female sea otters was not observably diminished by oil exposure (Monnett and Rotterman 1992a). Reproduction of the adult females did not differ: similar pupping rates were observed in eastern and western PWS in 1991 and 1992 (Monnett and Rotterman 1992a). This observation was supported by similar ratios of independent to dependent sea otters counted in surveys in eastern and western PWS in 1991 (Bodkin and Udevitz 1991).

Sea otters released from the rehabilitation centers in the summer of 1989 and monitored until the summer of 1991 exhibited relatively low survival and reproduction rates (Monnett et al. 1990; Monnett and Rotterman 1992b). Interpretation of these results is complicated by the inability to differentiate effects of oil exposure, treatment, prolonged captivity, and translocation (animals were not released in the areas where they had originally been captured) on the sea otters. Although rehabilitated sea otters may not be representative of the larger sea otter population, the relatively low reproduction and survival rates indicate potential long-term damages may result from oil exposure, rehabilitation, or translocation.

Boat-based Surveys of Sea Otters in Prince William Sound

The boat-based surveys conducted in 1989 were repeated in 1990, 1991, and 1993. In addition, a pilot study to evaluate detectability of sea otters in boat surveys was conducted (Udevitz et al. 1994) in conjunction with the summer 1990 boat survey. Counts of sea otters in PWS in 1990 and 1991 were slightly lower but not significantly different from the 1989 counts (Burn, Chapter 4), suggesting that recovery of the population was not occurring. Preliminary analysis of the 1993 data, however, suggests a slight (but, again, not significant) increase in numbers of sea otters inhabiting oiled areas relative to numbers obtained in 1990 and 1991.

Foraging Behavior and Hydrocarbon Levels of Prey

Prey selection and foraging success of sea otters at two oiled sites and one nonoiled site in western PWS were examined in the summer of 1991 (Doroff and Bodkin, Chapter 11). Clams, a common prey item, were collected from subtidal areas at each site for hydrocarbon analyses. Prey selection and foraging success were similar among areas, and hydrocarbon levels in clams were generally low and similar among areas.

Intertidal mussels were reported to retain relatively high levels of hydrocarbon following oiling (Babcock et al. 1993). Mussels contributed about 20% of the total prey items recovered at each site (Doroff and Bodkin, Chapter 11), providing an avenue of continued oil exposure for otters. Sea otters consuming relatively large quantities of mussels may be subjected to higher exposure rates of hydrocarbons.

Physiological and Toxicological Measures of Oil Exposure

Blood analyses

Blood sampled from live sea otters in PWS in 1989 to 1992 was submitted for hematologic and serum chemistry analyses (Rotterman and Monnett, unpublished data; Rebar et al. 1994; Lipscomb et al., Chapter 16; USFWS, unpublished data). Several differences in blood parameters were noted between eastern and western PWS, but in most cases the biological significance of the differences was difficult to ascertain. Elevated levels of serum transaminases measured in the samples collected in western PWS in 1992 (USFWS, unpublished data) were consistent with liver damage but cannot be linked to oil exposure without histopathological examination of tissue samples. Unfortunately, little information is available on pathologies observed in sea otters in the years subsequent to 1989 because fresh carcasses suitable for necropsy are rarely recovered.

Bioindicators of genotoxicity

Methods for detection of genotoxic damage at the cellular or DNA level (McBee and Bickham 1990; Ballachey et al. 1986; Evenson 1986) were applied to evaluate chronic oil-related injury to sea otters. Cells used in this component of the studies included blood lymphocytes, sperm, and testicular cells from adult male sea otters in eastern and western PWS. The cell samples were analyzed by flow cytometry, a technique that allows rapid measurement of large numbers of cells per sample (Melamed at al. 1979). For all three cell types, DNA was the object of the flow cytometry measurements (Ballachey 1994).

No differences in DNA characteristics were noted in sperm or testicular samples from sea otters living in eastern PWS versus western PWS, suggesting that oil exposure did not adversely affect male germ cells. For blood lymphocytes, mean values did not differ but variance of the sample values was higher for otters from oiled versus nonoiled areas, suggesting chemical exposure and genotoxic damage to a proportion of the western otters (Ballachey 1994). Because exposure of individual otters to oil was not known, linking this observation to oil exposure is difficult.

Hydrocarbon residues in tissue samples

Prior to studies conducted in response to the *Exxon Valdez* spill, little was known about hydrocarbon residues in mammalian tissues. Since the oil spill, approximately 500 sea otter tissue samples (primarily liver, blood, and fat) from both oil-exposed and nonexposed animals have been analyzed for levels of aliphatic and aromatic hydrocarbons (Ballachey and Mulcahy 1994a,b; Mulcahy and Ballachey, Chapter 18). This effort has generated a large and unique data base and provides a basis for comparison in future studies on contamination of tissues by hydrocarbons. Analyses of the data suggest that sea otters sampled after 1989 did not have elevated levels of hydrocarbons (USFWS, unpublished data).

Summary of Chronic Injuries to Sea Otters

By late 1991, three findings indicated that chronic damages were limiting recovery of the sea otter population in PWS: patterns of mortality were abnormal when compared to prespill data (Monson 1994), surveys showed no increase in abundance (Burn, Chapter 4), and juvenile survival was low in oiled areas of western PWS (Rotterman and Monnett 1991). These results generated concern about the status of the population and were the impetus for continued research. However, continuing studies of mortality patterns, abundance, and survival rates indicate that by 1993 chronic damages may be subsiding and recovery of the sea otter population may be under way.

Possible mechanisms for prolonged oil-related injury to sea otters were substantiated by several studies. Pathologies of the liver and kidney were observed in oiled sea otters recovered dead (Lipscomb et al., Chapter 16), and it seems reasonable to assume that similar pathological changes may have occurred in sea otters that were exposed to oil and survived. Residual oil persisted in intertidal (Roberts et al. 1993) and subtidal (O'Clair et al. 1993) areas of PWS, providing the potential for continued direct exposure of sea otters to oil and possible ingestion through grooming. In addition, particularly high concentrations of oil were found in mussel beds 2 and 3 years after the spill (Babcock et al. 1993). Because mussels are common prey for sea otters, particularly juveniles, the contaminated mussel beds may have been a source of continued indirect exposure to oil.

CONTINUING POSTSPILL STUDIES OF SEA OTTERS

Studies after 1992 focused on restoration of injured populations rather than on further damage assessment. The primary direction of restoration efforts for sea otters has been to monitor the PWS population for evidence of recovery. As with many other species injured by the oil spill, little if anything can be done to speed the recovery. Habitat protection through establishment of marine sanctuaries or parks may have merit, depending on developing patterns of use in affected areas (e.g., increased recreation, logging). Subsistence take by native hunters, as allowed under the Marine Mammal Protection Act, is apparently increasing throughout Alaska. With the cooperation of native hunters, harvests could be managed to afford additional protection and an opportunity for increasing the rate of recovery for sea otters.

Studies in 1993-1994 include further development of aerial survey methods that should result in more accurate and precise estimates of sea otter abundance and distribution, continued evaluation of patterns of mortality through recovery of beach-cast carcasses in PWS, and modeling of the PWS sea otter population as a tool to predict recovery. We anticipate some level of population monitoring, including abundance estimates, mortality monitoring, and possibly evaluation of physiological parameters, will continue for the next several years.

CONCLUSIONS

Oil spilled from the T/V *Exxon Valdez* caused a significant proportion of the exposed sea otter population to die within several months of the spill. The total acute loss probably numbered several thousand otters; however, due to a lack of prespill data on population abundance and distribution and inability to implement appropriate studies immediately following the oil spill, a precise estimate cannot be made.

Studies of long-term effects of the spill indicate that the sea otter population in PWS suffered from chronic effects of oil exposure, at least through 1991. Data collected in 1992 and preliminary results from 1993 suggest a decline in chronic effects, which may lead to recovery. Monitoring continues to provide additional information regarding the status of recovery of the sea otter population.

In retrospect, the studies on sea otters (and most of the postspill studies) were driven largely by the impending litigation against the Exxon Corporation. Political and scientific considerations influenced the direction of the research. Strong emphasis was placed on estimating acute mortality and documenting continuing damages. These tasks were rendered from difficult to impossible by a lack of prespill data and a lack of contingency plans for research, along with the failure to implement appropriate studies in a timely manner.

Our experience at describing the effects of the EVOS on the PWS sea otter population has provided an opportunity to consider how the damage assessment process may provide improved results in future similar events. It is critical to have studies designed and equipment ready in advance of an oil spill. Standardized protocols for the collection of carcasses and biological specimens should be established. Accurate and precise estimates of abundance should be obtained at regular intervals in areas of petroleum recovery, storage, or transportation, and repeated following a spill. A rigorous study to estimate the probability of recovering a carcass, using telemetry and ratio estimators, should be implemented at the time of the spill. Survival and reproduction of exposed animals should be estimated by marking animals prior to and during the spill and following those individuals over time by telemetry. Marked individuals should provide evaluation of exposure-dependent effects on survival, reproduction, and behavior.

Although there are many uncertainties in describing the effects of this oil spill on sea otter populations, there is incontrovertible evidence that the population suffered a major perturbation. We will likely never know the full effect of this spill on PWS sea otters. A long-term commitment to monitoring change in the affected sea otter population through the recovery process may provide our final insight into the effects of the EVOS on sea otters.

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