A retrospective evaluation of *Exxon Valdez* oil spill Trustee Council sponsored sea otter studies

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An extensive and diverse array of studies were implemented concurrent with and for several years following the *Exxon Valdez* oil spill to determine the acute and chronic effects to sea otters. Additional studies were implemented 1996 to determine the status of sea otter populations relative to recovery and to determine what factors could be constraining recovery. The purpose of this paper is to 1) identify studies of sea otters that are required to effectively evaluate the acute, sub-acute and potential chronic effects of another spill of similar magnitude, 2) identify studies that will be useful in evaluating recovery from damages in the context of a restoration endpoint, and 3) provide a retrospective analysis of the utility of sea otter studies that were implemented after the 1989 spill. The first part of this paper will describe what activities relative to sea otters should take place prior to, during and following another spill similar to the *Exxon Valdez*. The second part will focus on what was done in 1989 and the years following related to sea otters.

Our ability to accurately and defensibly determine the effects of any perturbation on sea otter (or other) populations and subsequent recovery processes will be determined largely on the quantity and quality of data available to describe the affected, as well as an unaffected, or reference population immediately prior to the perturbation. Post spill data collection for the most part will consist of repeating pre spill data collection protocols. Attempts to describe spill effects in the absence of this baseline data for the affected (treatment) and unaffected (reference) populations can, and will be subjected to the valid criticism of an inadequate experimental design to assign cause to effect. Studies that are implemented to determine spill effects in the absence of baseline data will lead to uncertainty in the conclusions that will ultimately be drawn. Moreover, a lack of accurate and defensible baseline data on populations will preclude assigning meaningful restoration endpoints. Estimating the magnitude of acute mortality should be directly assessed by two independent methods; 1) subtracting post spill abundance estimates from pre spill estimates, and 2) summing the number of carcasses recovered and those not recovered. Estimating effects of sub-acute or chronic exposure or constraints to recovery are more difficult and require additional data collected under the experimental design described above. The primary objectives of some studies will be acute, or immediate mortality estimates (e.g. carcass marking and recovery), others will be used to estimate potential longer term effects (e.g. bioindicators, health measures), and some will useful in determining both acute and chronic effects (e.g. surveys of abundance, survival estimates).

Despite the extensive resources that were allocated to describing the effects of the *Exxon Valdez* spill, we were unable to defensibly quantify the magnitude of the spill effect, or unequivocally describe the status of affected sea otter populations relative to recovery. If a single lesson should be learned from the 1989 spill in Prince William Sound (PWS), it is that no amount of post spill study can replace the lack of accurate and precise pre spill data.

A. Pre spill data requirements

Sea otters provide a good case study of what can be done in preparation for a large scale perturbation such as an oil spill, largely because of the methods available to acquire accurate data on a variety of population and individual parameters. Sea otters, a coastal marine species, dive for relatively short periods, consume their benthic prey on the surface and are easily observed from shore. Capture, visual and remote sensing techniques are well developed and the relations of sea otters to the structure and function of coastal marine communities are reasonably well described. Additionally, life history variables contributing to population dynamics such as age specific fecundity and survival are measurable

Data needs in the following list are provided in a declining order of priority. For each data need, techniques are suggested to acquire the data. Priorities are based primarily on the value of the data, but secondarily include cost considerations. In conjunction with each of these specific recommendations, sampling protocols as well as plans for sample and data acquisition and management and quality control are critical and should be part of the spill preparation/response plan.

1) <u>Accurate estimates of geographic distribution, population size and status (rate of change)</u>.

Aerial surveys that estimate sea otter abundance and distribution were developed following the *Exxon Valdez* spill. The methodology should be implemented in and adjacent to areas of oil storage and transport at intervals to determine pre spill population abundance and trends in abundance. These surveys should be repeated as soon as possible following a spill, and at appropriate intervals through recovery. Without any additional pre spill data collection, these surveys could provide defensible mortality estimates, rates of recovery and restoration endpoints. However, these surveys alone would not provide information on causes of mortality or sub-acute effects, factors contributing to or limiting recovery, or ecosystem level effects of the spill.

2) <u>Age and sex specific measures of individual health.</u>

Systematic capture and marking of sea otters prior to a spill will provide baseline data on blood and serum chemistries, bioindicators of health and exposure to naturally occurring contaminants, morphometrics and sex and age composition in the population. Effective and efficient techniques to capture and permanently mark individual sea otters are available. *Exxon Valdez* studies of individual health are suggestive of spill induced changes as many as 10 years post spill. Interpretation of post spill data is compromised because we lack pre spill data for comparison. We are forced to compare these measures with values from one or more unoiled area which we assume to be comparable (but which we know vary in potentially important ways, e.g. habitat and sea otter density).

3) Age specific survival.

Collections of sea otter carcasses that died pre spill can be used to estimate pre spill age specific survival rates. This technique requires relatively large sample sizes that can be acquired efficiently prior to a spill. Combined with similar post spill collections, time varying population models can describe if, and the most likely ways how, survival changes following a spill.

4) Sea otter diet and prey populations.

Visual observations of foraging sea otters with high resolution telescopes provide data on foraging success rates, prey number, species and size, dive times and surface intervals. These data are useful for two purposes. First, they can be used to estimate the time an individual (and by inference, a population) allocates to foraging. This parameter has been used to determine population status relative to prey resources and was of value in defining injured population status and identifying potential constraints to recovery during the *Exxon Valdez* event. Secondly, this parameter can be used to assess if and how prey populations may have been affected by a spill.

Because sea otter prey can be easily determined by visual observations and most prey are sessile or of limited mobility, evaluations of the species composition, density and size distribution of many prey populations are practical. Declines in some sea otter prey (e.g. mussels and clams) were documented and attributed to the *Exxon Valdez* spill. Additionally, we have observed differences in the species, abundance and sizes of some sea otter prey between oiled and unoiled areas that have led to speculation regarding the status and potential constraints to recovery of affected sea otter populations. Without knowing how, or if prey populations differed among or within sites prior to the spill, or because of the spill, uncertainty prevails in interpretation of observed differences in prey populations between oiled and unoiled sites. Additionally, measures of benthic invertebrates would also fill a data need to evaluate community or "ecosystem" effects of the spill and endpoints for recovery of invertebrate populations.

5. Age/ sex specific fecundity, survival and home range sizes.

Survival of juvenile sea otters was significantly lower in oiled compared to unoiled areas in PWS. Because of the potential confounding area effect we could not unequivocally conclude this resulted from the oil spill. Pre-spill data on this parameter, which appears to be a sensitive indicator of population status, would allow determination of a likely spill effect as well as provide an important variable for modeling population recovery and defining restoration endpoints.

Despite increases in the western PWS sea otter population of about 800 animals between 1993 and 1998, we have failed to detect any increase in abundance in areas where oiling was heaviest and mortality greatest. Reproduction and food appears adequate to support growth, therefore mortality (or emigration) may be elevated. Direct measures of survival are obtained through telemetry and would also provide estimates of home range size. If the carrying capacity of the habitat was diminished due to the spill, home range sizes may be predicted to increase (as observed in river otters) and reflected in lower population density.

Standard telemetry tools are available and tested and can provide accurate and precise estimates of fecundity, survival, and home range sizes; however, such studies are relatively expensive.

B. At spill data requirements (prior to oiling)

Regardless of the extent, if any, of studies prior to the time of the spill, the additional studies identified below should be implemented with the following objectives; 1) augment acute loss estimates, and 2) provide description and estimates of sub-acute and chronic effects of oiling and aid in determining restoration endpoints. In addition, if pre spill studies were conducted they should be repeated at appropriate times and places to provide the necessary experimental rigor to defensibly ascribe effects to the spill (see post spill data requirements). Additionally, it may be possible to implement some aspects of the studies identified above in A.1-3, after oil has spilled, but prior to contact with sea otter populations. However, this would be a poor general strategy, as it may be impossible to acquire any pre spill data after a spill occurs.

1. Capture and marking of individuals to estimate survival and carcass recovery rates.

Marking of individuals potentially exposed to oil can provide estimates of survival and carcass recovery rates useful in determining overall effects and defining restoration endpoints. Marking should include both a permanent visual (or electronic) aspect, a telemetry component, as well as biological sample collections.

2. Surveys and marking of beach cast carcasses.

Surveys and collection of sea otters that died and were deposited on beaches prior to the spill will allow accurate determination of the proportion of carcasses eventually recovered during and after the spill that should be classified as spill related. The ages of these dead, pre spill animals can also be used in estimating pre spill survival rates (see A.2 above).

Other potential at spill activities may include the emergency pre-emptive capture of sea otters. It may be possible to actively capture and remove sea otters from the path of an encroaching spill. Although not a study to assess impacts or restoration, this activity may potentially reduce immediate spill effects. The potential for capture, holding and relocation effects should be considered. This activity has not been tested and may be applicable only under limited circumstances. However, given the relatively low proportion of animals that survived following rehabilitation and release and the high cost of rehabilitating oiled otters, this strategy should be considered, and may benefit from development and testing prior to implementation.

C. Post spill data requirements (post oiling)

1. Carcass collections and marking and release of carcasses.

The collections of carcasses post oiling can provide a reasonable estimate of total mortality. However, data to address several assumptions in this procedure require the marking and release of carcasses. A systematic process for selecting carcasses for marking, marking methods, and release should be designed a priori. Carcasses not selected for marking and release should be collected for necropsy and tissue sampling to evaluate causes of death and a potential dose/response curve. Some common sampling of all carcasses, both those marked and released and those selected for necropsy should occur.

2. Monitoring of age and sex specific measures of individual health.

Capture, marking, biological sampling and subsequent release of live sea otters during and following sub-acute exposure will provide a dose/response curve that will be valuable in assessing potential effects of exposure to oil.

3. Instrumenting and releasing captured oiled otters.

A study designed to estimate survival of sea otters with varying degrees of external oiling would improve our understanding of the degree of oiling an animal can endure without immediate mortality. Additional similar study of surviving sea otters, following acute mortality, would also allow us to look at the long term survival of sea otters subjected to sub-lethal or residual oiling, as there are data suggestive of long term pathologies in sea otters that survived *Exxon Valdez* rehabilitation that are similar to those that died of acute exposure. In addition, these surviving otters appear to have reduced long term survival compared to non oiled animals. Evidence from the *Exxon Valdez* spill indicate survival may be the demographic factor limiting recovery of PWS sea otter populations.

Although not designed to determine oiling effects or restoration, the rehabilitation of oiled otters is a response that can compromise studies of spill effects by eliminating access to potential study animals. A thorough discussion of the pros and cons of this response activity is outside the scope of this paper. However, from a strictly biological perspective, the success of the past rehabilitation in terms of the relatively low proportion of animals that survived following release and the potential for introduction of disease into the wild population require serious review before this option is undertaken. Effects of this activity should consider relations to other assessment and restoration objectives.

D. The ecosystem approach

While temperate coastal marine communities are complex, the complexities may be better understood in this system than many others. This relatively good understanding, plus the spatial constraints, and limited mobility of many member species could facilitate a level of "ecosystem" study of damage assessment and restoration that might not be possible for other communities. Nonetheless, an "ecosystem" approach will likely still depend on estimates of composition, densities, productivity and status of selected species that comprise the system. In addition this approach will require understanding how those species are influenced by environmental conditions, biological productivity, and ecological interactions. The "ecosystem approach" should not be viewed as an easier path to damage assessment and restoration. The data required to satisfy this approach will still need to be collected prior to the treatment. The data identified under pre pill data requirements (A.1-4) above should meet many of the basic requirements of an "ecosystem approach" at least from the perspective of the sea otters as an important component of the community.

In 1996 sea otters were included in the Nearshore Vertebrate Predator ecosystem study to assess the status of recovery of the nearshore community in PWS. That work is in progress, nearing completion and incorporates many of the study components identified in this review that would be useful in assessing sub acute oil exposure effects and identifying restoration endpoints.

E. Restoration endpoints and activities

From the information collected under sections A-C above, we would likely have a reasonable definition of a "restoration endpoint" for sea otters. That endpoint could consist of a return to pre spill density, distribution, and age/sex composition, projected from pre spill population data. Additional endpoints could include age/sex specific survival, home ranges, individual health measures, bio-indicators, and energy budgets equivalent to pre spill values (or adjusted for pre spill trends).

Direct restoration of sea otter populations may be affected by several direct actions. Nearshore habitats were altered by oiling and response activities that resulted in reduced nearshore clam habitats and clam populations. If the pre spill status of the habitat and infauna were known (or could be inferred from known effects), it may be possible to actively restore habitat and some prey populations. In addition, human related mortality through the subsistence harvest can contribute to delayed recovery, particularly where mortality is limiting the recovery rate. Restoration may be enhanced by redirecting that portion of the mortality caused by hunting to unaffected areas.

A retrospective analysis

A diverse array of studies were initiated in the 10 years following the *Exxon Valdez* spill, most of which are encompassed in some way in the studies identified in A-C above. These studies include surveys of abundance, productivity, mortality, estimates of age/sex specific fecundity and survival, age and sex composition, carcass movement and recovery rates, oil exposure and measures of individual health (including blood and serum chemistries, bioindicators, sperm viability and body condition), foraging success, descriptions of prey populations and contaminant levels, assigning causes of death and development of an aerial survey method. The fundamental problems arose not necessarily with the data, or how they were collected, but with the comparisons we were able to make and thereby the inferences we could draw. Pre spill data were available in only limited instances (mortality surveys, based on beach cast carcasses, shoreline skiff surveys). Thus imposing a study design requiring comparisons between affected and unaffected sites (without pre spill data) and the assumption that the sites varied in no ways other than the oiling (a recognized invalid assumption).

During the damage assessment phase sea otter studies were apparently selected based on two criteria; 1) a probability of contributing to documented damages, or 2) in response to potential public perceptions. Initial planning efforts at the time of the spill included the capture and marking of sea otters to estimate survival and carcass recovery rates (see B.1 and C.3 above). Although initially approved by the agency, this project was soon suspended, and never implemented, due to potential negative public perceptions. Most studies that were approved and implemented, were completed at least to some reasonable endpoint. The Nearshore Vertebrate Predator study is nearing completion in 2000.

Despite the shortcomings imposed by an inadequate study design, the results of several sea otter studies were instrumental in damage assessment and eventually defining restoration endpoints. Those include the following; listed by category as most useful, useful, and least valuable relative to describing spill effects or restoration endpoints. The categorizations are not meant to assign values outside the context of the *Exxon Valdez* spill. Several of the "less valuable" studies are now valuable contributions to the primary scientific literature and would be most valuable contributions to improved responses and restoration in future spills assuming that pre spill data are available. No ranking of value within category is intended.

Most Valuable

1. Carcass recovery. These studies provided an absolute minimum mortality estimate that was the foundation of at least 2 published total mortality estimates. The total mortality estimates provided a range of potential restoration endpoints and a second method independent of abundance surveys to estimate total mortality.

2. Carcass marking and release. This study provided our only estimate of the proportion of carcasses that were recovered, an essential component of a total loss estimate derived from the number of carcasses recovered. The recovery rate estimates could have been improved by increasing the sample size of marked and released carcasses and the geographic extent of the sampling.

3. Mortality surveys. This study provides good evidence of the value of pre treatment data, although data from a reference site may have increased the utility of the data. Beach cast sea

otters were counted and aged for 10 years prior to 1989, providing a distribution of the ages of dying animals before the spill. Similar work after the spill provides a distribution of ages of animals dying after the spill. These 2 data sets have been used to estimate post spill age specific survival rates and describe how they differ from pre spill rates. Direct measures of survival are possible through telemetry and avoid some assumptions required in this modeling method.

4. Sea otter necropsies. These studies proved valuable in assigning cause and time of death to recovered carcasses, an important aspect in estimating total mortality. Moreover, these studies contributed new information of the pathologies suffered by sea otters exposed to oil. The data acquired may have been improved by processing carcasses prior to freezing (e.g. lung and bile for hydrocarbon analysis). In the event of a very large number of carcasses to necropsy, it may be appropriate to sub sample.

5. Physiological and toxicological measures of oil exposure. These studies have allowed us to monitor the duration of injury, variation among individuals within a population, and return of affected populations to normal baseline conditions, based on comparisons to unaffected populations. These studies were compromised by the ability to measure exposure accurately but should be improved in future spills by improved techniques to quantify oiling.

Valuable

1. Skiff surveys of sea otter abundance. Sea otter surveys by skiff provide an index to abundance rather than an estimate of abundance. The index cannot be used to estimate the magnitude of change, but can detect trends in numbers over time. The use of the PWS skiff survey data to evaluate spill effects provides a good example of the effects of using data for a purpose it was not designed, in this case estimating spill mortality from trend data. Depending on the analysis, sea otter populations between 1984/85 and after the spill either declined by up to nearly 3,000 otters or increased by a small number. Nonetheless, these survey data do allow for evaluating trends in sea otter abundance in both oiled and unoiled areas, that can be used in defining restoration endpoints.

2. Hydrocarbon assays. Elevated concentrations of hydrocarbons were measured in sea otter tissues, but returned to normal within 1 year. Because vertebrates metabolize hydrocarbons, a bioindicator such as Cytochrome P4501A would have been valuable to look at in conjunction with tissue hydrocarbon values over time. Cytochrome P4501A assays were not implemented until 1996, and were observed to be elevated as recently as 1998.

3. Estimates of age/sex specific survival. Employing radio telemetry, these studies estimated survival and reproduction in sea otters from the spill area and from eastern PWS as well as reproduction and survival of rehabilitated and released sea otters. Although statistically significant differences were found in juvenile survival between areas, we could not exclude

potential area differences, independent of the spill, from contributing to the observed differential survival rates. Overall the telemetry studies were extremely costly and were compromised by limits of study design. Some of the telemetry data were utilized in the development of population recovery models.

Least Valuable (But only in the context of EVOS)

1. Intersection model of mortality. This study provided an estimate of exposure and mortality along the Kenai Peninsula. This work contributed little to provide defensible mortality estimates but did provide a tool that should be valuable to future oil spill risk assessments.

2. Foraging behavior and hydrocarbon levels of prey. This study described foraging attributes of sea otters in an oiled and unoiled area of PWS. It provided suggested mechanisms of transport of residual oil to sea otters through prey, particularly among juveniles, but did not contribute significantly to damage assessment.

3. Bioindicator of genotoxicity. Early studies on bioindicators examined sperm cells for evidence of genotoxic effects. Similar methods had been used successfully on other mammalian species but applicability to sea otters under field conditions was limited by our ability to collect high-quality semen samples from the otters, and by the number of adult males captured and sampled.

4. Design and testing of an aerial survey method for sea otters.
Pre spill skiff surveys of sea otter abundance are biased to the extent they do not account for detection of diving animals or avoidance behavior, and only sampled a 200m shoreline strip. A new method was designed and tested that reduced these biases. Because comparable pre spill data are not available, this work did not aid in damage assessment directly, but implementation and repeated surveys during recovery have aided in evaluating recovery.

5. Carcass drift study. Using radio telemetry and surrogate sea otter carcasses, this study attempted to describe patterns of sea otter carcass drift in PWS. Inferences to the spill were limited by study design, primarily uncontrolled space and time effects. A similar study implemented during a spill may be more useful.

6. Helicopter surveys of abundance. These surveys, initiated after the spill and conducted prior to, or concurrent with the spill, took place along the Kenai and Alaska Peninsulas and Kodiak Island. Post spill surveys were conducted in the fall of 1989. The results of the surveys provide our only recent estimates of abundance in some of these remote areas. These surveys identified non significant spill related declines in abundance; however, the precision of the estimates was low. Further, the survey method did not receive adequate research and development prior to implementation.

Conclusion

A diverse array of tools are available for evaluating effects of oil spills on sea otters, evidenced in work supported by the *Exxon Valdez* Trustee Council. Advances in population estimation, health assessments and bioindicators of oil exposure that resulted from the 1989 spill have increased the tools at our disposal. However, these tools cannot be skillfully or efficiently used if they are brought to bear only after the next tanker goes aground. Estimating acute mortality from oiling can be readily estimated by rigorous surveys of abundance and carcass mark recapture experiments. Estimation of population abundance, not an index, is required in advance of the event. Carcass mark recapture can be initiated at the spill, but requires advance planning.

Determining effects of sub acute initial oiling or continued exposure to residual oil is more difficult, but ample evidence demonstrates that effects extend beyond the acute mortality phase. Those effects include, but may not be limited to; delayed recovery rates, organ damage, higher rates of mortality, and increased levels of exposure to residual oil. Accurately estimating chronic damage or restoration endpoints will be made possible only if the appropriate pre spill studies have been completed.

Due to a lack of funds, throughout most of the spill area, as well as in most of the sea otter habitat in the north Pacific, we are little better prepared today for another *Exxon Valdez* than we were a decade ago. Because of the demonstrated susceptibility of this species to spilled oil it is important that we do not repeat past mistakes.

Following is a list of papers published after the *Exxon Valdez* that review or recommend sea otter study relative to oil spill planning and response.

Bayha, K. and J. Kormendy, Technical Coordinators. 1990. Sea otter symposium: Proceedings of a symposium to evaluate the response effort on behalf of sea otters after the T/V Exxon Valdez oil spill into Prince William Sound, Anchorage, Alaska, 17-19 April 1990. US Fish and Wildlife Service, Biological Report 90 (12). 485 pp.

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