Exxon Valdez Oil Spill State/Federal
Natural Resource Damage Assessment
Final Report

Age Distributions of Sea Otters Found Dead in Prince William Sound, Alaska, Following the *Exxon Valdez* Oil Spill

Marine Mammal Study 6-15
Final Report

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Study History: Marine Mammal Study 6 (MM6), titled *Assessment of the Magnitude, Extent and Duration of Oil Spill Impacts on Sea Otter Populations in Alaska*, was initiated in 1989 as part of the Natural Resource Damage Assessment (NRDA). The study had a broad scope, involving more than 20 scientists over a three year period. Final results are presented in a series of 19 reports that address the various project components. Earlier versions of this report were included in NRDA Draft Preliminary Status Reports for MM6 (November 1990: "Section 5 - Post-spill sea otter mortality in Prince William Sound"; November 1991: "Section 5 - Age Distributions"). This report also includes data on sea otter carcasses recovered in 1993, which were collected as part of Restoration Project 93043 (Sea Otter Demographics).

Abstract: Age distributions of sea otters (*Enhydra lutris*) found dead on beaches in western Prince William Sound, Alaska, from 1976 to 1984, were compared to those of sea otters found dead from 1989 to 1993, following the *Exxon Valdez* oil spill. The age distribution of sea otters recovered in western Prince William Sound prior to the spill was bimodal and composed of primarily young and old animals. The ratio of "young" ($\leq$1 year old) to "prime-age" (2-8 years old) to "old" ($\geq$9 years old) sea otters was 44:17:39 (N=145). In contrast, the age distribution of otters recovered in western Prince William Sound during spill response efforts (1989) was 30:47:23 (N=379), and in 1990-1991 was 33:43:24 (N=66). The high proportion of prime-age otters recovered immediately following the spill indicates significant losses occurred within a segment of the population which normally experiences very low mortality. The high proportion of prime-age otters recovered in 1990-1991 may be evidence of a prolonged, spill-related effect on the western Prince William Sound sea otter population. The age distribution of sea otters collected in 1992-1993 was 37:17:46 (N=35) indicating that sea otter mortality in western Prince William Sound is returning to a normal, bimodal pattern.

Key Words: carcasses, *Enhydra lutris*, *Exxon Valdez*, mortality, oil spill, sea otter.

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INTRODUCTION

On March 24, 1989, the tanker vessel *Exxon Valdez* ran aground on Bligh Reef in Prince William Sound, Alaska, spilling 11 million gallons of Prudhoe Bay crude oil. Many sea otters in the path of the spill were killed. By September 1989, approximately 900 sea otter carcasses had been recovered (DeGange and Lensink 1990). Estimated total mortality due to the spill was approximately 3,900 otters (DeGange et al. 1994), with the loss in Prince William Sound estimated at 2,650 otters (Garrott et al. 1993). Effects on sea otter populations may not have been limited to acute mortalities. Pathologies associated with oil exposure in sea otters include emphysema, liver damage (Lipscomb et al. 1994), and altered hemotological and serum chemistry values (Rebar et al. 1994, Rebar et al. 1995). Sea otters surviving sublethal exposure to oil could have experienced similar pathologies but to a lesser degree. Consequently, exposed otters may be more susceptible to natural stressors, resulting in reduced reproductive success or increased mortality (McCahon and Pascoe 1990, Khan 1990).

Sea otters may be subject to continued exposure to oil persisting in the environment, either directly or through contaminated prey. Following the spill, an estimated 40-45% of the oil (4.3 to 4.9 million gallons) beached in western Prince William Sound (Wolfe et al. 1993a). Approximately 5-8% of the beached oil was removed by cleaning crews in the following summers, but most was removed by wave action which intermittently moved oil back into the water column, particularly during the winters of 1989-90 and 1990-91 (Wolfe et al. 1993a). However, beached oil did undergo relatively rapid biodegradation, and except for a few isolated beaches in protected bays, most remaining oil residues were deemed non-toxic by the summer of 1991 (Wolfe et al. 1993b, Boehm et al. 1993). Mussels from heavily oiled areas contained high levels of petroleum hydrocarbons in 1989 (Babcock et al. 1993b). Although clam samples contained only background levels of hydrocarbons by 1991 (Doroff and Bodkin 1994), mussel beds still showed evidence of low level contamination in 1992 (Babcock et al. 1993a).

Due to the patchiness of oil contamination (Galt et al. 1991) and the mobility of sea otters, exposure of individual otters to oil was undoubtedly highly variable. However, there are no practical means to measure the exposure levels of individual otters in the wild. Alternatively, we can look at the population level to indirectly assess chronic effects of oil exposure. Indirect methods of describing sea otter mortality may be useful in assessing effects on the surviving sea otter population.

Information from recovered carcasses, including the age distribution of dying animals, may be used to describe trends and patterns in population mortality (Bodkin and Jameson 1991, Caughley 1966). The proportion of "prime-age" animals dying is an important parameter, as survivorship of this age-class has the greatest influence on the dynamics of many mammalian populations (Eberhardt 1985). Age-specific mortality functions for long-lived, large mammals typically follow a fairly consistent bimodal pattern (Emlen 1970). High juvenile mortality rates decrease rapidly to a minimum at some point prior to sexual maturity. Mortality through the prime reproductive years remains low but may slowly increase with age, with an accelerated increase near senescence. This pattern is evident from empirical data collected from a variety of mammals (Caughley 1966, Siler 1979, Eberhardt 1985, Garrott and Taylor 1990, Barlow and Boveng 1991). The dominant mortality peak (young or old age class) varies, depending on the species and ecological conditions affecting the population.

Wild sea otters attain ages of 15 to 20 years (Riedman and Estes 1990) with adult female maturation at 3 to 5 years (Kenyon 1969, Garshelis et al. 1984, Bodkin et al. 1993, Jameson and Johnson 1993). Pup mortality to age 1 is high with a peak occurring soon after parturition (Schneider 1973, Garshelis 1983, Siniff and Ralls 1991, Jameson and Johnson 1993) and again after weaning (Rotterman and Monnett 1991). Adult survival is much higher, with annual rates typically 80 to 90% (Siniff and Ralls 1991, USFWS unpublished data). Current age-specific mortality data are inadequate to produce a complete mortality curve for any discrete sea otter population. However, young and old otters predominate in carcasses collections at Amchitka Island, Alaska (Kenyon 1969, USFWS unpublished data) and in Prince William Sound, Alaska (Johnson 1987). This suggests the pattern described by Emlen (1970) accurately describes natural sea otter mortality patterns.

OBJECTIVE

We compared age distributions of sea otters found dead in Prince William Sound from 1989 through 1993, following the spill, with the age distribution of sea otters recovered by Johnson (1987) in Prince William Sound prior to the spill. The objective was to test the hypothesis that the proportion of "prime-age" otters in carcass collections from western Prince William Sound did not change from pre- to post-spill years.

METHODS

Study Area

From 1976 to 1984, systematic beach surveys for sea otter carcasses were conducted by the U.S. Fish and Wildlife Service (Johnson 1987) at Green Island in western Prince William Sound, in south-central Alaska (Fig. 1). From 1990 to 1993, similar surveys were conducted at Green Island by U.S. Fish and Wildlife personnel. In 1989, systematic beach surveys were not conducted, but carcasses were collected throughout western Prince William Sound between March and September during spill response efforts. In 1990 to 1993, in addition to systematic beach surveys, carcasses were collected opportunistically from spill-affected areas of western Prince William Sound (Fig. 1). The major islands from which carcasses were collected after the spill included Green Island, and portions of Montague, Knight, Naked, and Perry Islands and numerous smaller islands in western Prince William Sound.

Beach Surveys

Surveys were conducted in April or May soon after snow melt, and prior to the regrowth of beach grasses which can conceal carcass remains. Beaches were walked by two observers, one searching the strand line (area of debris deposition from the previous winter's storms) while another searched the upper intertidal zone. Data recorded for each recovery included the date of carcass collection, location, relative position on the beach, relative condition (i.e., extent to which carcass was scavenged or decomposed), sex and an age estimate based on tooth wear. The skull and baculum were collected when present, and a tooth (preferentially a pre-molar, if available) removed for age analysis (Garshelis 1984).

Only carcasses determined to have been deposited during the previous winter or that spring (i.e., recent deposits) are included in the 1990-93 post-spill age distributions. A carcass was identified as a recent deposit if hide and/or cartilage were present on the skeletal remains, and the bones were not sun-bleached and dried out. Generally, bones of recently deposited carcasses were still articulated, and located above the previous year's layer of dead vegetation on the strand line or below the strand line in the intertidal zone. Old, weathered and bleached remains, or remains buried in the previous year's vegetation, were considered to have been deposited prior to the previous winter and excluded from post-spill comparisons. Carcasses collected in 1989 were judged to be either pre- or post-spill deaths, based on condition at the time of recovery (DeGange and Lensink 1990).

Age determinations were made by Matson's Laboratory (Box 308, Milltown, MT 59851). Several longitudinal sections of the tooth were decalcified for cementum annuli readings (Garshelis 1984, Pietz et al. 1988). Estimates were made assuming the dark annulus is laid down in winter.

Data Analysis

Sea otter age distributions were collapsed into three age-classes for statistical comparison based on sea otter life history and an assessment of Johnson's (1987) pre-spill age distributions. Classes included "juveniles" ($\leq$1 yr), "prime-age" (2-8 yrs) and "old" ($\geq$9 yrs). Data were categorized into two pre-spill components: 1976-84, and 1989-pre-spill; and five post-spill components: 1989-post-spill, 1990, 1991, 1992 and 1993. Logistic regression analysis was used to determine trends in pre- and post-spill prime-age mortality. T-tests were used to test for differences between the proportion of prime-age otters collected in each post-spill component and the mean pre-spill proportion of prime-age otters. The variance associated with the mean pre-spill proportion, using years as replicates, was used as a basis for t-test comparisons. Differences between pre- and post-spill age distributions were tested using the G-test with a 3 X 2 contingency table. Differences were considered significant at $\alpha \leq 0.05$.

RESULTS

Search Effort

Approximately 54 km of beach were searched in the Green Island area during the systematic beach surveys conducted from 1990 to 1993. In addition, approximately 1,100 and 380 km of beach were searched in 1990 and 1991, respectively, by multi-agency crews monitoring spill cleanup efforts. Monitoring of beaches in 1992 and 1993 was greatly reduced, and few carcasses were recovered other than in the Green Island area. In 1989, the search effort was undoubtedly large. However, no estimate of coverage is available as numerous public and private groups examined and/or cleaned many kilometers of coast again and again. In addition, an unknown number of carcasses were recovered offshore within the oil-slick during early spill response efforts.

Age Distributions

Prime-age sea otters composed 17% of those collected pre-spill by Johnson (1987) at Green Island (Table 1, Fig. 2). This age distribution was essentially identical (G-test, P = 0.99) to the age distribution of dead otters collected in 1989 after the spill, but judged to have died prior to the spill (1989-pre-spill; Fig. 3), and thus the 1976-84 and 1989-pre-spill samples were combined for comparisons with post-spill data. Though the proportion prime-age recovered each pre-spill year varied, no significant trend was evident (logistic regression, P = 0.84, Fig. 4). Prime-age otters composed 47% of those judged to have died in 1989 after the spill (Fig. 5), and 34% of those found dead from 1990 to 1993. The spill-year and 1990-1993 distributions were both significantly different from the pre-spill distribution (G-test, P < 0.001 and P = 0.004 respectively), and they were also significantly different from each other (G-test, P = 0.03).

However, the proportion of prime-age otters decreased in the years following the spill (Table 1; logistic regression, P = 0.002, Fig. 4). Prime-age animals composed 47% of the 1989-post-spill sample, which was significantly higher than the pre-spill mean of 17% (t-test, P = 0.04). The 1990 sample included 40% prime-age which, although relatively high, was not significantly different (t-test, P = 0.10) from the pre-spill mean. The 1991 sample included 50% prime-age, which was again significantly higher that the pre-spill mean (t-test, P < 0.03). The proportions of prime-age recovered in 1992 and 1993 were 22% and 12% respectively; neither value differed significantly from the pre-spill mean.

Based on the initial examination of proportion prime-age in the post-spill samples, the 1990 to 1993 data were pooled into two groups: 1990-1991, and 1992-1993. The distribution from 1990-1991 (Fig. 6) was significantly different than the pre-spill distribution (G-test, P = < 0.001), but was similar to the 1989-post-spill distribution (G-test, P = 0.7). The 1992-1993 distribution, which included 17% prime-age (Fig. 7), was similar to the pre-spill age distribution (G-test, P = 0.89), and was significantly different than the 1989-post-spill and the 1990-1991 distributions (G-test, P = 0.001 and P = 0.02, respectively).

DISCUSSION

Although an effort was made to quantify search effort (measured as km of beach searched), this was difficult given lack of information about extent or repetition of post-spill beach monitoring. Pre-spill data demonstrated large annual variability in the number of carcasses collected, during a period of assumed relatively constant otter abundance. For these reasons, we do not attempt to interpret the absolute number of otter carcasses recovered in any given year as an indicator of total mortality.

Due to the extent and variability in the degree of oil coverage and the number of sea otters living in western Prince William Sound at the time of the spill, it is highly probable that some sea otters survived varying degrees of sublethal acute exposure to oil. In addition, oil stranded on beaches continued to move back into the water column through at least the winter of 1989-1990, and to a lesser extent through the winter of 1990-1991 (Wolfe et al.

1993a). This provided an opportunity for sea otters living near heavily impacted beaches to have continued direct contact with oil residues. Sea otters were also at risk of consuming contaminated mussels, at least through the summer of 1991 and into 1992 (Babcock et al. 1993a).

Boat-based population surveys indicated an initial decline in sea otter numbers following the spill, and no subsequent increase in population size in the spill area through 1991 (Burn 1994). However, these surveys were not sensitive to small changes in abundance and do not provide definitive evidence that the population was not starting to recover. Other evidence suggests effects of oil on the western Prince William Sound otter population may have persisted for at least one year. Rotterman and Monnett (1991) found low weanling survival in western Prince William Sound, one year after the spill. It is, however, difficult to link this one year of low recruitment to the spill due to a lack of pre-spill recruitment data from this population.

The age distributions of sea otters recovered dead in western Prince William Sound are valuable because of available pre-spill data (Johnson 1987). Pre-spill age distributions revealed relatively few losses occur in the prime-age sea otter population in any given year. In contrast, the age distribution of otters found dead in western Prince William Sound during the spill reveals significant losses to the prime-age component of the population, which is not surprising given the extensive oil contamination of the shoreline and the vulnerability of sea otters to oiling (Costa and Kooyman 1982, Siniff et al. 1982). However, the age distribution of otters recovered as carcasses in 1990 and 1991 indicates relatively high prime-age mortality persisted for at least two years following the spill.

We do not have direct evidence that the apparent increased prime-age mortality in 1990 and 1991 was a result of oil exposure. However, considering the large volume of spilled oil, the number of otters at risk, and the possible pathways of exposure, it seems reasonable to assume that the spill was related to altered patterns of mortality in subsequent years. A cause and effect relationship is supported by results of post-spill sea otter surveys (Burn 1994), and the sea otter weanling survival study (Rotterman and Monnett 1991). The 1992 and 1993 age-class distributions, however, suggest that factors influencing prime-age mortality have begun to normalize. This finding was supported by an increase in sea otter weanling survival in western Prince William Sound during the winter of 1992-1993 (USFWS unpublished data), and also by the diminished amounts and toxicity of oil residues in Prince William Sound by 1992 (Wolfe et al. 1993a,b, Boehm et al. 1993).

In making pre- to post-spill comparisons, several assumptions are made: 1) ages of sea otters were assigned correctly or without bias, 2) the probability of carcass recovery was equal for all dying sea otters, regardless of age, and 3) the spill did not significantly alter the age distribution of the surviving sea otter population in affected areas. The accuracy of age estimation using tooth annuli has not been evaluated thoroughly for sea otters. However, all teeth were prepared and scored by a single, highly experienced individual, eliminating variation due to protocol or reader differences. Studies to assess the accuracy of age estimations using teeth from known-age otters are ongoing. Though some degree of inaccuracy is probable, at present no bias in aging tooth annuli is evident. Thus, assumption 1 is likely met.

If a bias exists in the age distribution data, it may be due to under-representation of age class 0 and 1 otters (assumption 2). The carcass of a young animal likely has a lower probability of recovery than the carcass of an adult due to small size and increased possibility of being completely scavenged. However, such a bias should have affected the pre-spill, spill and post-spill age distributions equally, and comparisons across years would still be valid.

A stable age distribution is assumed when making the pre- to post-spill comparisons (assumption 3). This implies that all sea otters, regardless of age, were equally susceptible to death from oil and that the effect of the spill on the western Prince William Sound population was a reduction in total numbers without a significant alteration of the age distribution of surviving otters. Alternatively, if younger and older otters were more susceptible to oil-related mortality in 1989, the post-spill age distribution might have been altered from pre-spill. However, based on field observations during the weeks following the spill (Bodkin and Udevitz 1994) and the 1989-post-spill age distribution, there is no evidence to suggest lower mortality of prime-age otters in 1989, after the spill. Further, the 1990 and 1991 age distributions do not show a relative lack of older animals, which might have been expected if they had died at a high rate in 1989.

In general, changes in age structure seem to affect whether the young or old age-class dominates in the age distribution of recovered carcasses rather than affecting the proportion of prime-age. Sea otter populations at Amchitka Island, Alaska, went from a growing population, through a population decline, and subsequent increase and stabilization (Estes 1990). However, relatively few prime-age adults were found dead during these periods of change (Kenyon 1969, USFWS unpublished data) suggesting that although a population may oscillate and the age-structure may change, prime-age mortality remains relatively low. Thus, the increased proportion of prime-age animals recovered in Prince William Sound post-spill remains significant.

CONCLUSIONS

The high proportion of prime-age sea otters recovered as carcasses on western Prince William Sound beaches in 1990 and 1991 suggests losses due to the spill were not restricted to 1989, but continued through 1991. This finding is evidence of a population-level spill effect on sea otters which would depress the population's ability to recover from the spill. The lower proportion of prime-age sea otters recovered in 1992 and 1993 indicates sea otter mortality patterns in western Prince William Sound are returning to normal pre-spill patterns.

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Table 1. Age-class distributions of sea otters found dead in western Prince William Sound, Alaska, before and after the 1989 *Exxon Valdez* oil spill.

	Age (years)					
	0-1		2-8		>8	
Time period	n	(%)	n	(%)	n	(%)
Pre-spill '76-84	64	(44)	24	(17)	57	(39)
Pre-spill '89[a]	24	(44)	9	(17)	21	(39)
Post-spill '89[b]	115	(30)	179	(47)	85	(23)
Post-spill '90[c]	17	(33)	21	(40)	14	(27)
Post-spill '91[c]	5	(36)	7	(50)	2	(14)
Post-spill '92[c]	8	(42)	4	(21)	7	(37)
Post-spill '93[c, d]	5	(31)	2	(13)	9	(56)

[a] Data from otter carcasses collected post-spill in western Prince William Sound, judged to have died pre-spill.

[b] Data from otter carcasses collected post-spill in western Prince William Sound, judged to have died post spill. Does not include otters which were captured live and died in captivity.

[c] Data from combined systematic and opportunistic carcass collections in western Prince William Sound.

[d] Data collected as part of Restoration Project 93043.

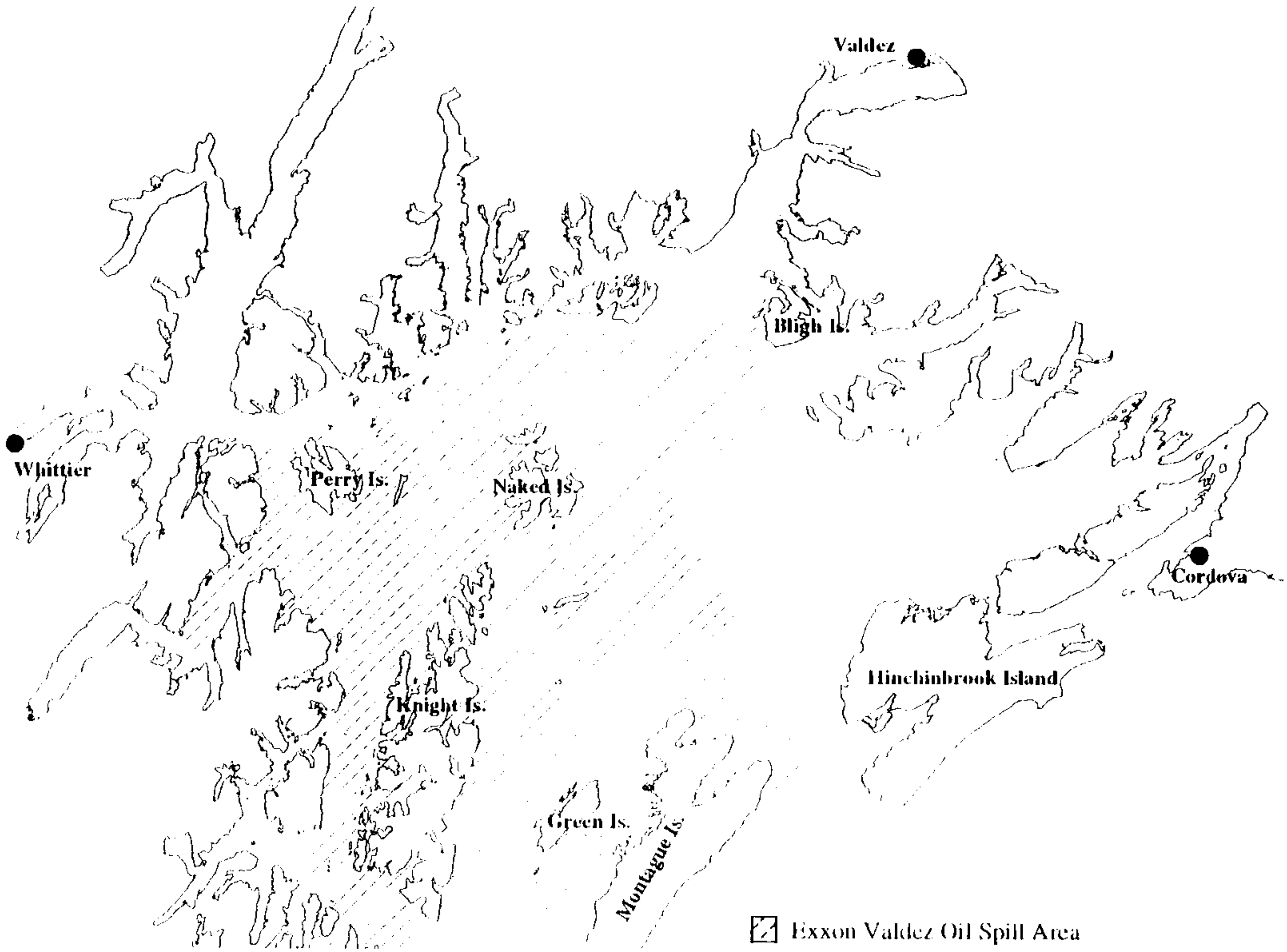

Figure 1. Areas searched for the collection of sea otter carcasses in Prince William Sound, Alaska. Shaded area indicates the oiled area of western Prince William Sound.

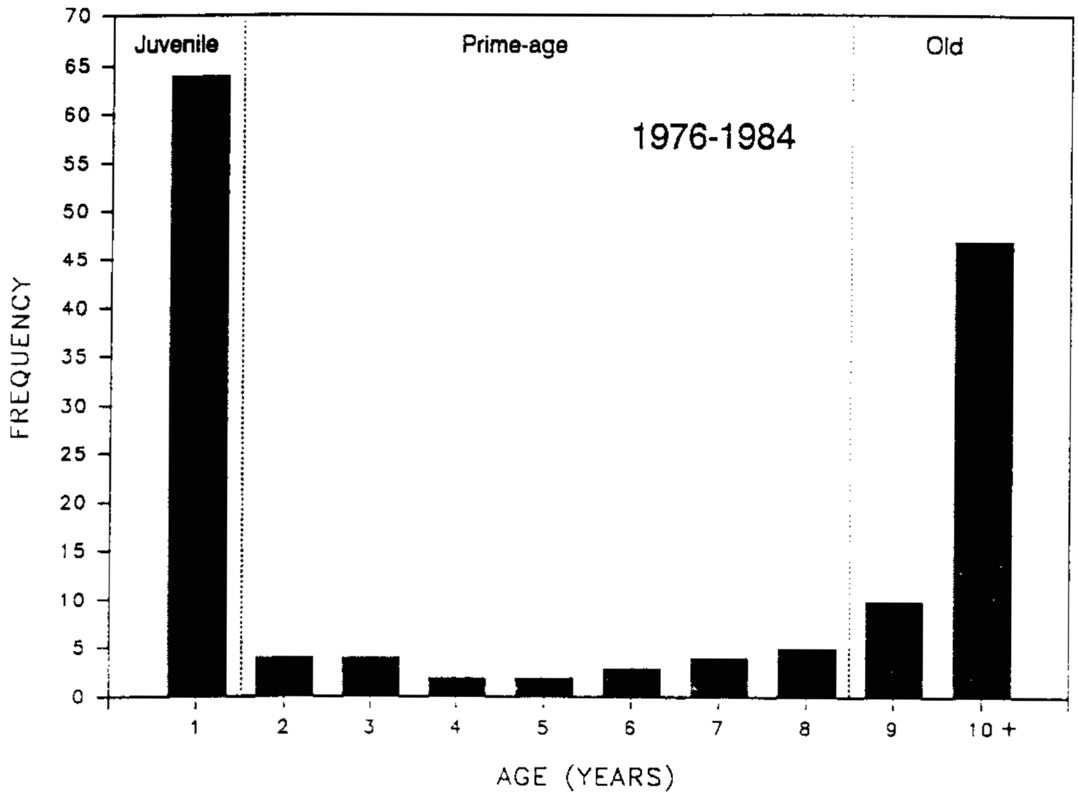

Figure 2. Age distribution of sea otters found dead in western Prince William Sound from 1976-1984.

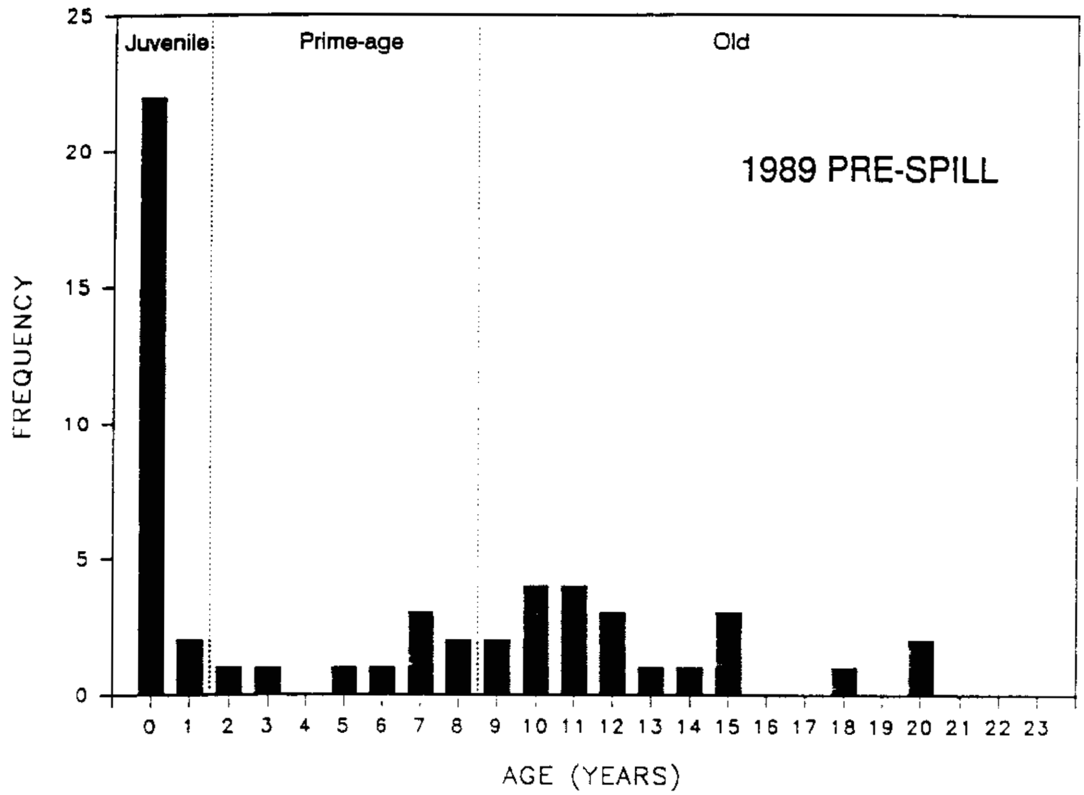

Figure 3. Age distribution of sea otters found dead in 1989, judged to have died prior to the spill.

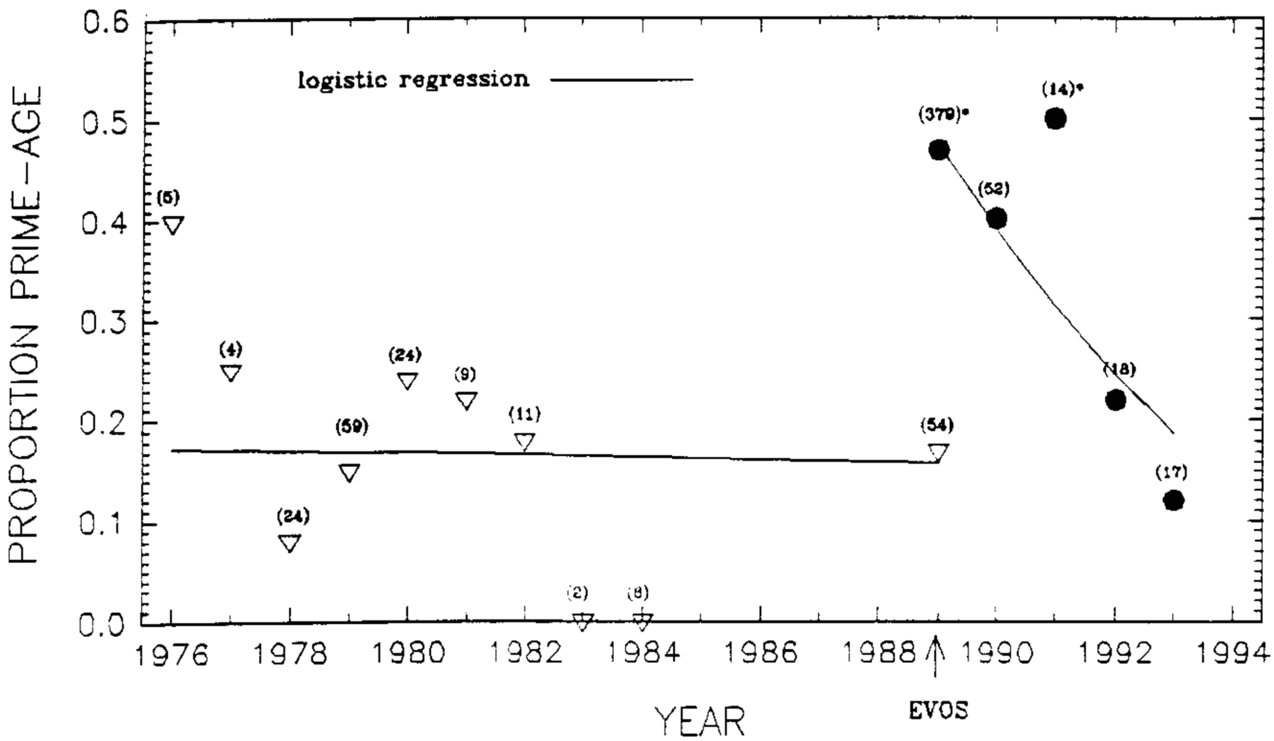

Figure 4. Logistic regression on observed proportion of prime-age sea otters found dead on beaches in Prince William Sound prior to and following the *Exxon Valdez* oil spill. The sample size for each year is in parentheses above the symbol.

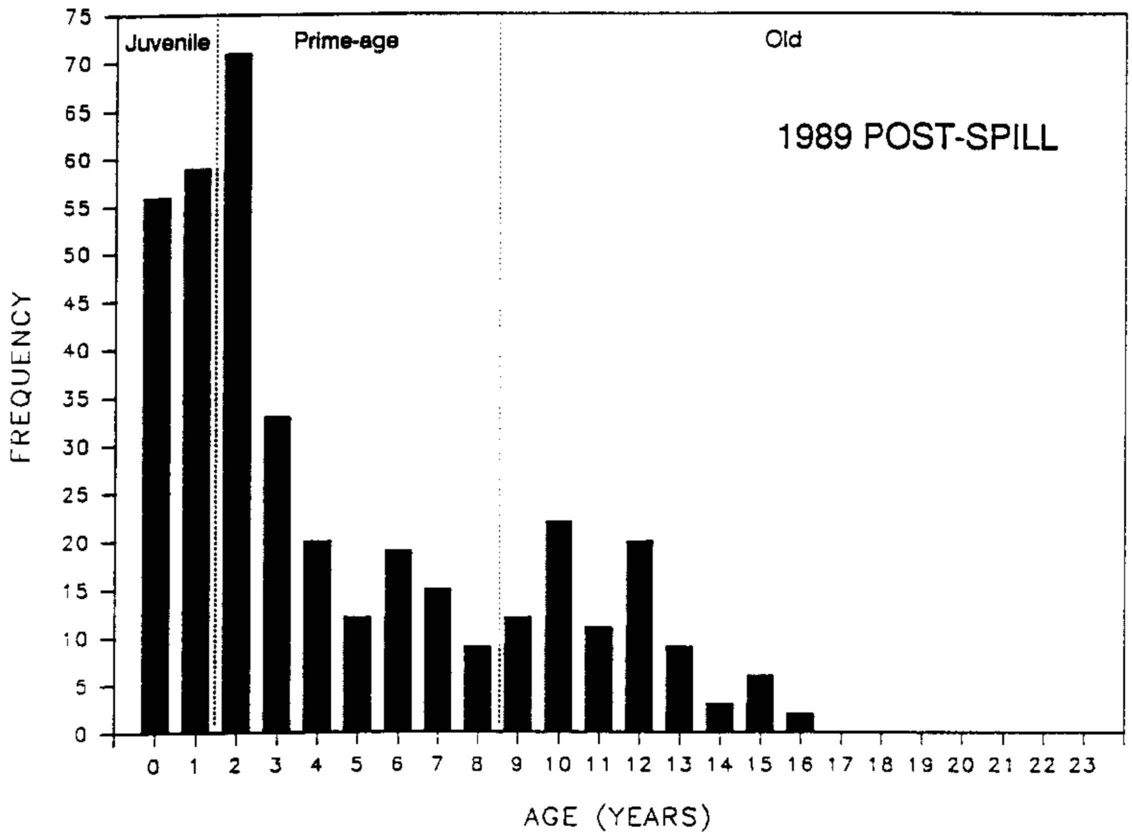

Figure 5. Age distribution of sea otters found dead in 1989, judged to have died following the *Exxon Valdez* oil spill.

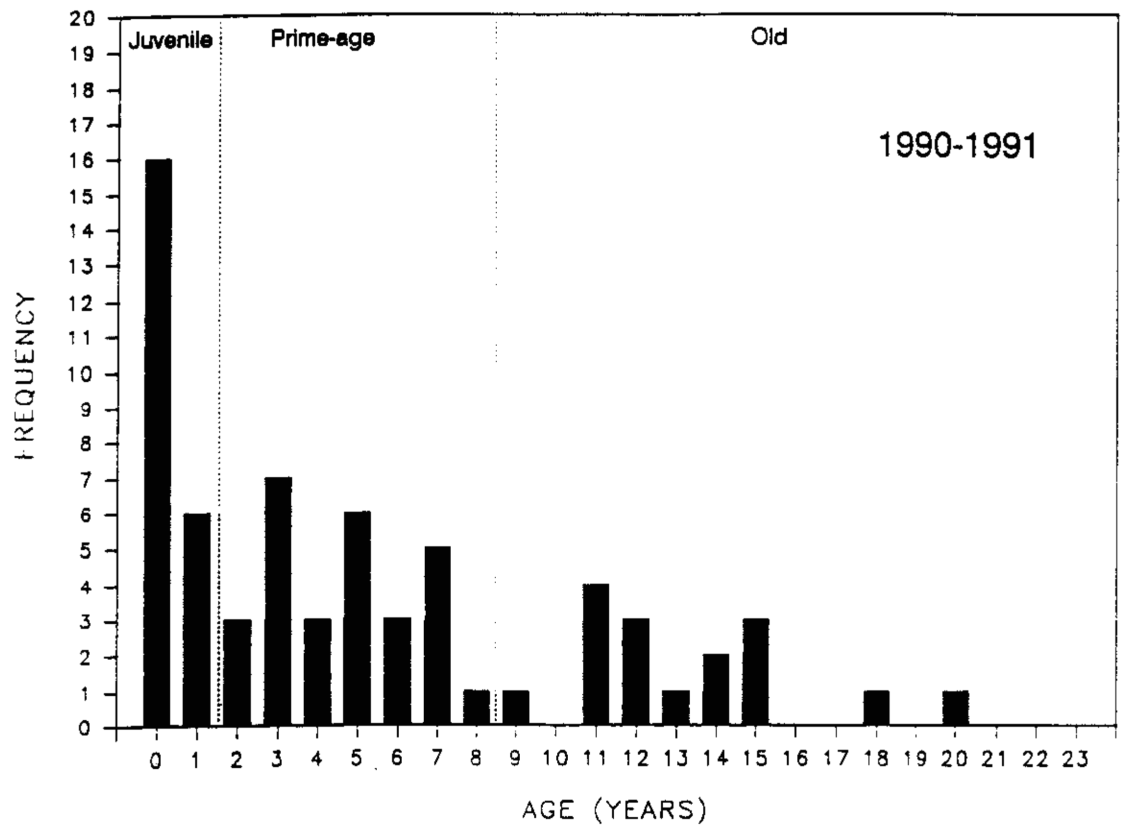

Figure 6. Age distribution of sea otters found dead in western Prince William Sound in 1990 and 1991.

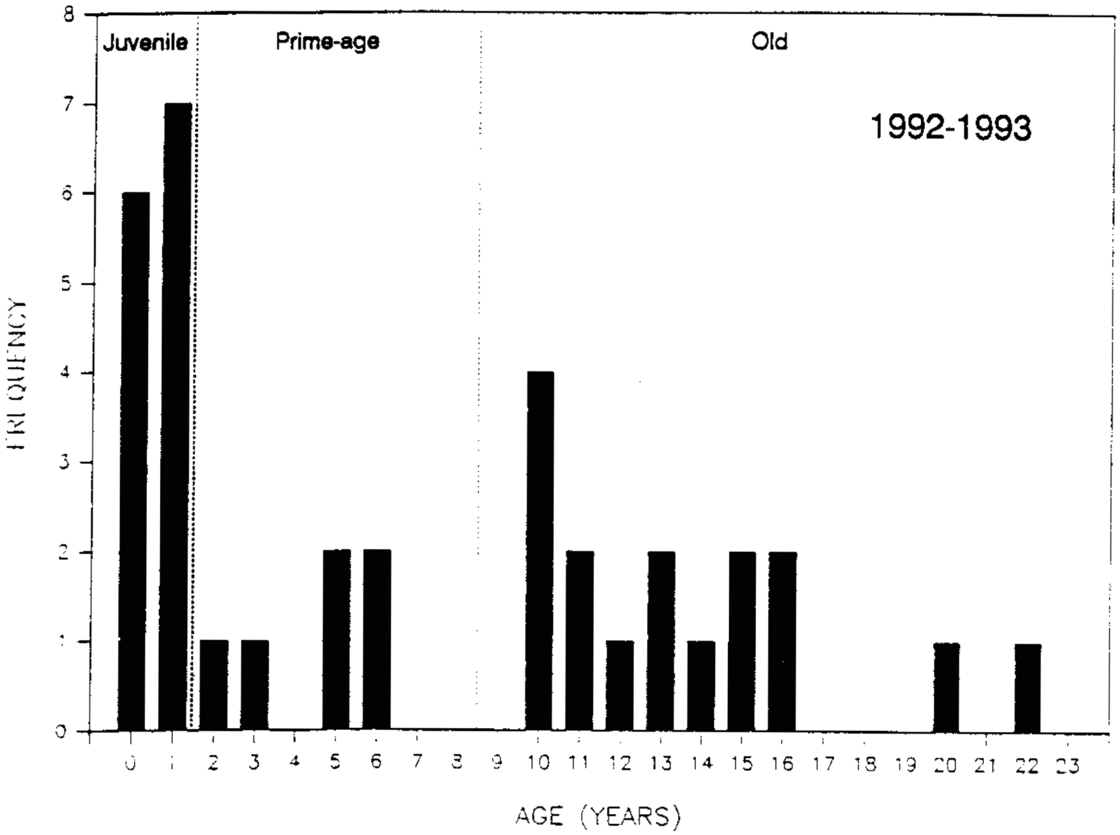

Figure 7. Age distribution of sea otters found dead in western Prince William Sound in 1992 and 1993.