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

Population Dynamics of Brown Bears after the *Exxon Valdez* Oil Spill

Terrestrial Mammal Study Number 4
Final Report

Richard A. Sellers
Sterling D. Miller[1]

Alaska Department of Fish and Game
Division of Wildlife Conservation
P.O. Box 37
King Salmon, Alaska 99613

[1]Present address: National Wildlife Federation, Northern Rockies Office, 240 North Higgins, Missoula, MT 59802, USA.

August 1999

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

Population Dynamics of Brown Bears after the *Exxon Valdez* Oil Spill

Terrestrial Mammal Study Number 4
Final Report

Richard A. Sellers
Sterling D. Miller[1]

Alaska Department of Fish and Game
Division of Wildlife Conservation
P.O. Box 37
King Salmon, Alaska 99613

[1] Present address: National Wildlife Federation, Northern Rockies Office, 240 North Higgins, Missoula, MT 59802, USA.

August 1999

Population Dynamics of Brown Bears after the *Exxon Valdez* Oil Spill

Terrestrial Mammal Study Number 4
Final Report

Study History: Terrestrial Mammal Study Number 4 was initiated in the 1989 work plan as Assessment of *Exxon Valdez* Oil Spill on Brown Bear Populations on the Alaska Peninsula and continued through 1991. The paper comprising the body of this report was presented at the 11th International Conference on Bear Research and Management during April 1998 in Gatlinburg, Tennessee, and is pending publication in the journal Ursus.

Abstract: We estimated survival and reproductive rates of brown bears (*Ursus arctos*) on the coast of Katmai National Park, Alaska, during 1989-95 to assess effects of the 1989 *Exxon Valdez* oil spill. Fifteen percent of fecal samples ($n = 27$) from brown bears captured in 1989 contained hydrocarbons indicative of exposure to crude oil. Females captured in 1989 and 1990 were divided into 2 groups: 12 with multiannual relocations that included oiled coastline, and 21 that used unoiled areas. Survival rates during 1989-91 were not different ($P > 0.90$) between females from oiled versus unoiled areas. Based on the assumption that the availability and toxicity of oil was negligible by 1992, we also compared survival rates of both groups during 1989-91 with 1992-95 and observed no difference ($P > 0.40$). Recruitment rates during 1989-95 were not different ($P = 0.12$) between females from oiled and unoiled areas. Finite growth rates for the 2 groups suggested both were stable ($\lambda = 1.003$ and 1.014, respectively, for bears using oiled and unoiled areas).

Key Words: Alaska, brown bear, *Exxon Valdez* oil spill, Katmai National Park, population dynamics, reproduction, survival, *Ursus arctos.*

Project Data: *Description of data* - Radio telemetry data, reproductive and survival data, chemical analysis of fecal samples, standard measurements, blood and hair samples from captured brown bears. *Format* - FoxPro and Excel files. *Custodian* - Richard A. Sellers, ADF&G, P.O. Box 37, King Salmon, AK 99613. *Availability* - upon written request.

Citation:

Sellers, R.A., and S.D. Miller. 1998. Population dynamics of brown bears after the *Exxon Valdez* oil spill, *Exxon Valdez* Oil Spill State/Federal Natural Resource Damage Assessment Final Report (Terrestrial Mammal Study Number 4), Alaska Department of Fish and Game, Division of Wildlife Conservation, King Salmon, Alaska.

TABLE OF CONTENTS

INTRODUCTION

Brown bears and other carnivores may be exposed to crude oil following an oil spill. Exposure may occur from directly consuming oil on contaminated carcasses of sea birds or marine mammals that washed ashore, by grooming their own oil-contaminated fur, or indirectly by eating organisms that assimilated hydrocarbons from the marine environment (Geraci and Williams 1990, Neff 1990, Bowman 1995, Babcock and Short 1996, Andres 1997). An experimental study of the effects of crude oil on 3 captive polar bears (*Ursus maritimus*) showed that oil ingested from grooming treated fur caused erythropoietic dysfunction and renal abnormalities resulting in the deaths of 2 bears and sickness in the third (Oritsland et al. 1981). Physiologic symptoms in these bears peaked 5 to 6 weeks after exposure to oil. The third bear received therapy and fully recovered 5 months after initial exposure. In a controlled study of captive mink (*Mustela vison*) exposed to weathered crude oil similar to that which may have been ingested by brown bears in this study, White et al. (1992) did not detect effects on the reproductive parameters they measured in groups fed contaminated food for 7 or 120 days. They were unable to evaluate long-term effects. River otters (*Lutra canadensis*) in oiled areas of Prince William Sound (PWS) showed higher levels of blood haptoglobin and lower body weights in 1990 and 1991 than did river otters from unoiled areas. However, by 1992 no differences in haptoglobin or body weights occurred in otters from the 2 areas (Duffy et al. 1994a).

The *T/V Exxon Valdez* ran aground in PWS on 24 March 1989 spilling 42 million L of crude oil covering 1,750 km of shoreline (Wolfe et al. 1994). We selected the central portion of the Katmai coast on the Alaska Peninsula to assess the effects of this oil spill based on previous observations of brown bears feeding in the intertidal zone, the known high density of bears, the relative ease of capturing and observing bears compared with working in heavily forested areas closer to the spill site, and the importance of Katmai National Park as a brown bear sanctuary.

We hypothesized that survival of adult females and recruitment for a sample of bears with multi-year relocations that included oiled beaches (treatment group) would be lower immediately after the spill (1989-91) than for a sample of bears inhabiting unoiled coastal areas (control group). Brown bears are long-lived animals with low mortality and reproductive rates (Bunnell and Tait 1980, 1985), so we also looked for longer term effects. We hypothesized that if oil contamination of the ecosystem had delayed or amplified effects, survival rates and recruitment for the treatment group would be lower several years after the spill (1992-95) compared to the control group for the same period. We hypothesized that the survival rate of the control group would not differ between time periods.

Animal handling procedures followed the animal welfare policy of the Division of Wildlife Conservation, Alaska Department of Fish and Game.

STUDY AREA

Brown bears were captured on the central portion of the Shelikof Strait coast of Katmai National Park (58° 04' - 58° 10'N, 153° 40 - 154° 35'W), approximately 500 km southwest of the spill site. The study area, from Swikshak Bay to Amalik Bay, contained 482 km of shoreline.

Oil from the *Exxon Valdez* spill reached the study area between 26 April and 2 May 1989, over 1 month after the accident. By this time, most of the crude oil had weathered to an oil-water emulsion ("mousse"). Ocean currents, local wind patterns, and the configuration of the coast caused sporadic oiling of shorelines within the study area. Only about 2% of the spilled oil reached the Alaska Peninsula (Galt et al. 1991). Shoreline surveys during summer 1989 classified approximately 14%, 5%, and 0.5% of the coast line within the study area as being very lightly, lightly, and moderately oiled, respectively (*Exxon Valdez* Oil Spill Damage Assessment Geoprocessing Group 1991). Although shoreline oiling classification was somewhat subjective, the low percent of moderately and heavily oiled coast in the study area contrasts with the level of oil deposition within the western portion of Prince William Sound. Cleanup of oil began in early May and continued through 15 September 1989. After the 1989 cleanup, shoreline oiling within the study area in autumn 1989 was estimated at 3.2% very light, 1.6% light, 0.8% moderate, and 0.3% heavy. Cleanup efforts resumed during summer 1990. Because of the relatively light extent of oil contamination, clean-up crews generally spent only 1-2 days on most stretches of oiled coastline. Some moderately oiled shores required longer clean-up efforts, but these were generally confined to areas only a few hundred meters long. Bears may have been temporarily displaced by clean-up crews, and in 1 case a bear was killed when it was perceived to be a threat to workers, but we have no evidence that clean-up efforts affected survival and reproductive rates of bears in the treatment group.

Climate is subarctic maritime typified by cool, wet summers and relatively mild winters. Elevations used by brown bears ranged from intertidal to 1,000 m. Important vegetative communities included intertidal sedge flats (*Carex* spp.), alder (*Alnus crispa*) thickets, grass (*Calamagrostis canadensis*) forb meadows, and alpine tundra. Griggs (1936) and Cahalane (1959) gave more detailed descriptions of coastal vegetation. Brown bears opportunistically fed on a wide variety of foods, including Pacific salmon (*Oncorhynchus* spp.), intertidal invertebrates (e.g. clams), and a variety of vegetation (foliage, tubers, and berries).

METHODS

We captured bears by darting them from a helicopter (Taylor et al. 1989) in May and early June 1989 and in mid-May 1990 (Sellers et al. 1993). We attached radiocollars (Telonics, Mesa, Arizona) to adult females. We used canvas spacers in collars applied to subadult females and some males to ensure that collars dropped off before becoming too tight (Hellren et al. 1988). We tagged additional males with small (<100 g) transmitters glued to the hair of the mid-dorsal hump to serve as temporary marks for a capture-mark-resight population density estimate (Sellers et al. 1993, Miller et al. 1997). We examined captured bears for external evidence of oil, took blood samples, extracted a premolar tooth for aging, and applied lip tattoos and ear tags. We took fecal samples directly from the rectums of bears captured in 1989 and analyzed them at Texas A&M University, Geochemical and Environmental Research Group, College Station, Texas using gas chromatography for aliphatic hydrocarbons and mass spectroscopy for aromatic hydrocarbons.

We located bears marked with radio collars approximately twice each week from June to November 1989 and twice monthly during April-November thereafter. Radiocollars had motion sensors which indicated when mortalities occurred and aided in determining the cause of death. We plotted all locations on 1:63,360 scale topographic maps or recorded geographic positioning system (GPS) coordinates. We entered data into a geographic information system (GIS) (ArcInfo, Environmental Systems Research Institute, Inc., Redlands, California) and plotted all points for each bear on maps showing shoreline oiling classifications from summer 1989, autumn 1989, and spring 1990 surveys (Alaska Department of Natural Resources, Land Records Information Section, Anchorage, Alaska).

We assigned adult females captured in 1989 and 1990 into a treatment group (potentially exposed to oil) or control group based on all locations during 1989-95. If any of the locations fell within 1 km of an oiled shoreline, that bear was included in the treatment group. Radiocollared bears that were always located >1 km from the nearest oil contamination we assigned to the control group.

Because of the extreme complexity of brown bear feeding and habitat use, we did not attempt to quantify habitat attributes. The interspersion of oiled and unoiled shoreline within the study area and the large seasonal movements of brown bears reduced the likelihood that differences in habitat quality would affect reproduction or survival rates of bears classified as being from oiled versus unoiled areas. Indeed, there was considerable overlap of home ranges, other than along oiled shorelines, between bears assigned to each group. Other potentially confounding factors such as density and population structure were discounted because both groups were subsets of the same coastal brown bear population.

We used the Kaplan-Meier procedure (Pollock et al. 1989) to estimate survival rates of radiocollared bears. Cubs and yearlings accompanying radiocollared females were assumed to have died if they were never again present when their mothers were resighted. We used the log-rank chi-squared test (Pollock et al. 1989) to test for differences in survival rates between groups of bears using oiled and unoiled areas. We also tested for differences in survival between 1989-91 and 1992-95 because we assumed that availability and toxicity of residual oil was negligible by spring 1992 (Payne and McNabb 1984, Frost et al. 1994, Bowman et al. 1995).

We estimated recruitment rates from the cumulative number of offspring that radiocollared females successfully raised to ≥2 years of age divided by the total number of adult female bear-years between 1989 and 1995 (Craighead et al. 1995). We used log-linear analysis with covariates and a Z statistic to test the hypothesis that productivity of bears using oiled areas was lower than for bears using unoiled areas.

We used age-specific survival and reproductive rates of females in Lotka models (Eberhardt 1985, Eberhardt et al. 1994) to calculate the finite rate of population growth (λ) for the 2 groups of bears. We used annual survival rates during 1989-91 when effects of oil would have been most evident. Average production of cubs for each group was the total number of cubs observed in spring at den emergence divided by the total number of bear-years for radiocollared females ≥5 years old observed during 1989-95. This longer period was needed because of the low reproduction rates of brown bears. We also estimated cub and yearling survival rates during 1989-95 to achieve adequate sample sizes.

RESULTS

We captured 36 bears (24 females and 12 males) during 31 May-13 June 1989 and collared 20 females with standard radiocollars plus 3 females and 7 males with breakaway collars. During 19 -22 May 1990, we captured 20 females and 23 males and collared 14 females (including 2 recaptured bears whose radios had stopped transmitting) with regular radiocollars, 6 females and 8 males with breakaway collars, and 14 males with temporary glue-on radios. Other bears killed 1 female and 1 male while still sedated in 1989 and 1990, respectively.

None of the 79 bears handled in 1989 and 1990 had visible evidence of external oil contamination. Four of 27 fecal samples (15%) collected from bears captured in 1989 contained hydrocarbons that were indicative of exposure to crude oil. All 4 of these bears were captured within 1 km of oiled beaches. Of these 4 bears, 1 female shed her collar prematurely around 11 July 1989 and no further information was collected; a male lost his drop-off collar, as designed, in September 1990; female 136 died in an apparent snow slide in early spring 1993; and 1 female lived through 1995.

The level of exposure to oil deposited along the coast may have been reduced because many bears remained at higher elevations during May 1989 when most oiled carcasses were available. Radiocollared female brown bears in the Katmai study area denned at an average elevation of 412 meters ($n = 105$, range 148-888 meters; Sellers, unpublished data). Only 6% of radio locations prior to May 15 ($n = 99$) for females captured in 1989 and 1990 and monitored during 1989-95, were below 100 meters; 19% of relocations prior to 31 May were below 100 meters. We started capturing bears on 31 May 1989, and we found no remaining oiled carcasses of birds or marine mammals with residual soft tissue on the beaches where we worked.

We suspect oil ingestion may have contributed to or caused the death of 2 unmarked yearlings with female 136. This female had 2 yearlings when captured on 13 June 1989. The yearlings remained together near the capture site while we marked their mother, so we believe that reunion of both yearlings with the mother was highly likely. We located female 136 on 23 June, but we could not verify whether both yearlings were with her. We observed her on 27 June with only 1 yearling. On 30 June, she was standing beside a dead yearling on an open sedge meadow. We recovered the carcass later that day and performed a necropsy that showed no sign of trauma or other gross evidence of abnormalities. Subsequent analysis of bile detected naphthalene and phenanthrene concentrations of 160 and 18 ppm, respectively, suggesting that oil ingestion may have caused or at least contributed to this yearling's death. It is possible that the disappearance of female 136's other yearling had a similar cause.

Survival Rates

We assigned 12 adult female brown bears captured in 1989 and 1990 to the treatment group because their multi-year relocations ($\bar{x}$ = 74 locations/bear, SE = 9.6) included oiled shorelines. The control group consisted of 21 females that did not use oiled areas ($\bar{x}$ = 56 locations/bear, SE = 6.0). The number of locations per bear in each group was not different ($P > 0.10$).

No radiocollared bears died in 1989. During 1989-91, the survival rate of radiocollared females from both oiled and unoiled areas was 0.96 ($P > 0.9$). Survival rates during 1992-95 were not different between groups (0.92 for bears using oiled areas and 0.90 for bears using unoiled areas, $P > 0.45$). Although not significant ($P > 0.4$), the apparent drop in survival rates for both groups from 1989-91 to 1992-95 may be due to aging of radiocollared bears in the samples rather than a delayed response to oil contamination.

Because all radiotags used on males were designed to be temporary, we did not accumulate enough relocations to partition males into those using oiled or unoiled areas. No mortality occurred to 5 males followed for 31 bear-months in 1989. One male tagged in 1990 apparently was killed by another bear between 7 and 14 days after capture, but 7 other males survived for 89 bear-months before contact was lost.

There were no differences in survival during 1989-95 for cubs or yearlings of radiocollared females using oiled and unoiled areas. Survival was 0.36 for cubs (n = 26) of females using oiled areas and 0.37 for cubs (n = 37) of females using unoiled areas ($\chi^2 = 0.03$, 1 df, $P > 0.8$). Survival was 0.46 for yearlings of females using oiled areas (n = 13) and 0.77 for yearlings of females using unoiled areas (n = 13; $\chi^2 = 2.354$, 1 df, $P > 0.1$). The power of this analysis to detect differences in survival rates of yearlings suffers from small sample sizes. The lower survival rate of yearlings in oiled areas, although not statistically significant, can be attributed to one event - the lost of a 3-cub-litter in 1995. Because this litter was lost 6 years after the oil spill and the same mother successfully raised a litter during 1989 and 1990, we suspect the loss of this litter may not have been due to exposure to oil.

Reproductive Rates

Adult (≥5 years old) females from oiled areas raised 0.20 2.5-year-old offspring per bear-year (11 young in 56 adult female bear-years during 1989-95) compared with 0.30 2.5-year-old cubs per bear-year in unoiled areas (24 young in 79 adult female bear-years). There was no apparent reduction of recruitment in oiled areas (1-sided test; $Z = 1.1978$, $P = 0.12$).

Population Growth Rate

Estimates of population growth rate (λ) for the 2 groups based on (1) survival rates of independent females during 1989-91, (2) cub production, and (3) cub and yearling survival rates from 1989-95 were 1.003 for bears in oiled areas and 1.014 for bears in unoiled areas. Both values suggest relative population stability.

DISCUSSION

The risks of damage from oil spills depend on a number of factors, including the amount and timing of oil contamination, the toxicity of the oil, absorption into or effects on the food chain, the level of exposure by the population of interest, and the speed of cleanup. Adverse effects from this oil spill on the brown bear population along the coast of Katmai National Park were mitigated by several factors. By the time the crude oil reached the study area, it had weathered over a 5-week period into a less-toxic mousse (Galt et al. 1991). Only a fraction (<2%) of the oil spilled from the *Exxon Valdez* traveled the 500 km to the study area; local conditions resulted in only intermittent, relatively light oiling of shorelines within the study areas. Oil arrived on the coast early in the spring prior to peak bear use of coastal habitats in June.

Given the circumstances of this spill and the likelihood that some bears included in the treatment group did not actually contact oil, comparisons of vital rates between the treatment and control groups represents a subtle test of the potential harm oil contamination could cause to a brown bear population. Small sample sizes available for estimating survival and reproductive rates for oiled versus unoiled comparisons also reduced the power to detect possible biological effects of exposure to oil. Bowman et al. (1995) estimated that a sample of 150 radiotagged bald eagles (*Haliaeetus leucocephalus*) would be needed for each the oiled and unoiled group to achieve power of 0.80 to detect a 10% difference in survival rates. As in the present study, that sample size was impractical. However, we believe that the likelihood of making a Type II error in falsely accepting the null hypothesis was slight based on near identical estimates between groups for (1) survival of adult females and cubs, (2) total recruitment, and (3) population growth rates.

Evidence from other studies has demonstrated the potential toxicology of crude oil to polar bears (Oritsland et al. 1981) and river otters (Duffy et al. 1994*b*). Some brown bears did contact oil, as evidenced by hydrocarbons in 15% of fecal samples and sightings of oilstained bears along the Katmai coast (E. Brunner, Anchorage, Alaska, personal communication, 1989). One dead yearling had high levels of hydrocarbons in its bile; however the ratio of phenanthrenes to naphthalenes (0.11) was lower than generally found in bile samples from other mammalian casualties of the *Exxon Valdez* spill. Bile samples from oiled harbor seals from Prince William Sound exhibited considerable variation in the concentrations of these hydrocarbons (Frost et al.1994). Other possible explanations for the low phenanthrenes to naphthalenes ratio include postmortem effects or that the source of the oil was not from the *Exxon Valdez*. Despite the documented exposure of some bears to crude oil and the presence of hydrocarbons in bile one dead yearling, we did not detect demographic effects in this study. Long-term survival rates during 1989-95 for both groups of adult females in the study area were similar to other unhunted populations in Alaska (Sellers and Aumiller 1994, J. Keay United States Geological Survey, Anchorage, Alaska, personal communication, 1998).

Reproduction rates of both groups in Katmai were low primarily because of high cub mortality; we attributed this to the exceptionally high bear density (550 bears/1,000 km^2; Miller et. al. 1997) and a high proportion of adult males (Sellers et al. 1993) in a population that probably was near carrying capacity. Another protected, naturally regulated population at Denali National Park also had high cub mortality (J. Keay United States Geological Survey, Anchorage, Alaska, personal communication, 1998).

We cannot rule out the possibility of delayed effects to the brown bear population after 1995; however, several studies of vertebrates in PWS, where the amount and toxicity of oil from the Exxon Valdez spill were more severe than along the Katmai coast, documented diminished effects by the early 1990s (Duffy et al. 1994*a*, Frost et al. 1994, Bowman et al. 1995, Andres 1997). Similarly, polynuclear aromatic hydrocarbon concentrations in mussels and intertidal sediments from the Gulf of Alaska were below detection limits by 1991 (Babcock and Short 1996). We collected razor clams (*Siliqua patula*), a common bear food along the Katmai coast, in April 1990 from Kashvik Bay, just south of the study area. The shoreline of this bay was classified as oiled in summer (83.5% very light and 2.8% medium) and autumn (0.5% light and 3.3% medium) 1989. Clams did not contain elevated levels of hydrocarbon contaminants (U. Varanasi, National Oceanic and Atmospheric Administration, Northwest Fisheries Center, Seattle, Washington, unpubl. data). Given these findings and the lack of any significant differences in survival or reproduction rates, we conclude that there were no chronic effects of the oil spill on Katmai brown bears.

MANAGEMENT IMPLICATIONS

Ideally the experimental design of a study to evaluate the effects of any environmental catastrophe would include before and after measurements of habitat quality and vital rates for the population in question. Unfortunately, it is usually difficult to get funding for such base line studies even in areas slated for future development. We believe that data on population density (Miller et al. 1997) and estimates of survival and reproductive rates from this study can provide a base of information in advance of potential oil drilling or expanded shipping through Shelikof Strait adjacent to Katmai National Park.

Bears along the coast of Katmai National Park have been protected since 1930 and, until the Exxon Valdez oil spill, lived in a pristine environment with little human disturbance. The Lotka model suggested near stability for the population and is consistent with Bunnell and Tait's (1980) theory of population dynamics for a naturally regulated population of brown bear at carrying capacity, and as such this population offers vast possibilities for future research.

ACKNOWLEDGEMENTS

This study was funded by the *Exxon Valdez* Trustee Council, the National Park Service, and the Alaska Department of Fish and Game. Field assistance was provided by T. Boudreau, J. Faro, C. Gardner, D. Johnson, D. McAllister, M. McNay, R. Smith, L. VanDaele (Alaska Department of Fish and Game), J. Meldrum, R. Squib, R. Potts, S. Mills, B. Holms (National Park Service) and T. Smith (United States Geological Survey) and G. Wilker (Fish and Wildlife Service). E. Becker assisted with statistical analysis and J.W. Testa provided the model to calculate the finite rate of population growth. We thank T. Smith and R. Potts for comments on earlier drafts.

LITERATURE CITED

Andres, B.A. 1997. The *Exxon Valdez* oil spill disrupted the breeding of black oystercatchers. Journal of Wildlife Management 61:1322-1328.

Babcock, M.B., and J.W. Short. 1996. Prespill and postspill concentrations of hydrocarbons in sediments and mussels at intertidal sites within Prince William Sound and the Gulf of Alaska. *Exxon Valdez* Oil Spill State/Federal Natural Resource Damage Assessment Final Report (Coastal Habitat Study Number 1B), National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Auke Bay Laboratory, Juneau, Alaska, USA.

Bowman, T.D., P.F. Schempf, and J.A. Bernatowicz. 1995. Bald eagle survival and population dynamics in Alaska after the *Exxon Valdez* oil spill. Journal of Wildlife Management 59:317-324.

Bunnell, F.L., and D.E.N. Tait. 1980. Bears in models and reality--implications to management. International Conference on Bear Research and Management 4:15-23.

_____, and _____. 1985. Mortality rates of North American bears. Arctic 38:316-323.

Cahalane, V.H. 1959. A biological survey of Katmai National Monument. Smithsonian Institute Publication 4376. Wahington D.C., USA.

Craighead, J.J., J.S. Summer, and J.A. Mitchell. 1995. The grizzly bears of Yellowstone: their ecology in the Yellowstone ecosystem, 1959 –1992. Island Press, Washington D.C., USA.

Duffy, L.K., R.T. Bowyer, J.W. Testa, and J.B. Faro. 1994*a*. Evidence for recovery of body mass and haptoglobin values of river otters following the Exxon Valdez oil spill. Journal of Wildlife Diseases 30:421-425.

_____, _____, _____, and _____,. 1994*b*. Chronic effects of the *Exxon Valdez* oil spill on blood and enzyme chemistry of river otters. Environmental Toxicology and Chemistry 13:643-647.

Eberhardt, L. L. 1985. Assessing the dynamics of wild populations. Journal of Wildlife Management 49:997-1012.

_______, B.M. Blanchard, and R.R. Knight. 1994. Population trend of the Yellowstone grizzly bear population as estimated from reproductive and survival rates. Canadian Journal of Zoology 72:360-363.

Exxon Valdez Oil Spill Damage Assessment Geoprocessing Group. 1991. *Exxon Valdez* Oil Spill Technical Service 3. GIS Map and Statistical Analysis Oil Spill Public Information Center, Anchorage, Alaska, USA.

Frost, K.J., C. Manen, and T.L. Wade. 1994. Petroleum hydrocarbons in tissue of harbor seals from Prince William Sound and the Gulf of Alaska. Pages 331-358 *in* Marine Mammals and the *Exxon Valdez*. Academic Press, San Diego, California, USA.

Galt, J.A., W.J. Lehr, and D.L. Payton. 1991. Fate and transport of the *Exxon Valdez* oil spill. Environmental Science Technology 25:202-209.

Geraci, J.R., and T.D. Williams. 1990. Physiologic and toxic effects on sea otters. Pages 211-221 *in* J.R. Geraci and D.J. St.Aubin, editors. Sea mammals and oil: Confronting risk. Academic Press, San Diego, California, USA.

Griggs, R. F. 1936. The vegetation of the Katmai district. Ecology 17 (3).

Hellgren, E.C., D.D. Carney, N.P. Garner, and M.R. Vaughn. 1988. Use of breakaway cotton spacers on radio-collars. Wildlife Society Bulletin 16: 216-218.

Miller, S.D., G.C. White, R.A. Sellers, H.V. Reynolds, J.W. Schoen, K.Titus, V.G. Barnes, R.B. Smith, R.R. Nelson, W.B. Ballard, and C.C. Schwartz. 1997. Brown and black bear density estimation in Alaska using radiotelemetry and replicate mark-resight techniques. Wildlife Monograph 133.

Neff, J.M. 1990. Composition and fate of petroleum spills. Pages 1-33 *in* J.R. Geraci and D.J. St.Aubin, editors. Sea mammals and oil: Confronting risk. Academic Press, San Dieago, California, USA.

Oritsland, N.A., F.R. Engelhardt, F.A. Juck, R.J. Jurst, and P.D. Watts. 1981. Effects of crude oil on polar bears. Northern Affairs Program, Environmental Studies No. 24. Ottawa, Ontario, Canada.

Payne, J.R., and G.D. McNabb. 1984. Weathering of petroleum in the marine environment. MTS Journal 18(3): 1-20.

Pollock, K.H., S.R. Witerstein, and C.M. Bunck. 1989. Survival analysis in telemetry studies: the staggered entry design. Journal of Wildlife Management 53:7-15.

Sellers, R. A., and L.A. Aumiller. 1994. Brown bear population characteristics at McNeil River, Alaska. International Conference on Bear Research and Management 9(1):283-293.

______, S.D. Miller, T.S. Smith, and R. Potts. 1993. Population dynamics and habitat partitioning of a naturally regulated brown bear population on the coast of Katmai National Park. 1993 Annual Progress Report. Alaska Department of Fish and Game, King Salmon, Alaska. USA.

Taylor, W.P., H.V. Reynolds III, and W.B. Ballard. 1989. Immobilization of grizzly bears with tiletamine hydrochloride and zolazepam hydrochloride. Journal of Wildlife Management 53: 978-981.

White, R.G., J.E. Blake, M. Sousa, and J.E. Rowell. 1992. Influence of oil hydrocarbons on reproduction in mink (*Mustela vison*). State/Federal Natural Resource Damage Assessment and Restoration Strategy Plan. Terrestrial Mammal Study #6. Institute of Arctic Biology, University of Alaska, Fairbanks, Alaska. USA.

Wolfe, D.A., M.J. Hameedi, J.A. Galt, G. Watabayasi, J.W. Short, C.E. O'Clair, S. Rice, J. Michel, J.R. Payne, J.F. Babcock, S. Hanna, and D.M. Sale. 1994. Fate of the oil spilled from the T/V *Exxon Valdez* in the Prince William Sound, Alaska. Environmental Science and Technology 28:561-568.