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

Marbled Murrelet Abundance and Breeding Activity at Naked Island, Prince William Sound, and Kachemak Bay, Alaska, Before and After the *Exxon Valdez* Oil Spill

Bird Study Number 6
Final Report

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Study History: This damage assessment study was initiated in 1989 as part of a detailed study plan and modified to capture the effects of disturbance due to cleanup and other spill related activities occurring in the study area. The study was designed to determine the nature and extent of the injury, loss or destruction of marbled murrelets in the oil spill zone. In 1990 and 1991, damage assessment work on marbled murrelets was continued on Naked Island as an objective within Bird Study Number 2: Surveys to Determine Distribution and Abundance of Migratory Birds in Prince William Sound and the Northern Gulf of Alaska. Bird Study Number 6 was again implemented in 1992 to continue injury assessment of the marbled murrelet. This final report contains a comprehensive data synthesis and analysis of all these studies. These data provide a base for developing the recovery monitoring and restoration plan.

Abstract: I compared pre- and post-spill abundance and breeding activity of murrelets near the Naked Island group in central Prince William Sound, and in Kachemak Bay in lower Cook Inlet. Murrelet numbers at Naked Island were lower in 1989 than in 1978-1980 but not in 1990-1992. At Kachemak Bay, where oiling was minimal, murrelet densities did not change between 1988 and 1989. I observed fewer juvenile murrelets at Naked Island in post-spill years, but data were insufficient to determine if reproduction was disrupted. There was no change in juvenile counts in Kachemak Bay. My results suggest that the murrelet population at Kachemak Bay, further removed temporally and spatially from the spill epicenter, was not affected as the Naked Island populations in 1989. Murrelet numbers were negatively correlated to numbers of boats at both study sites, and cleanup activities likely contributed to disruption in 1989.

Key Words: Alaska, *Brachyramphus*, Kachemak Bay, Marbled Murrelets, Naked I., oil spill, Prince William Sound, *Exxon Valdez*

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EXECUTIVE SUMMARY

The marbled murrelet (*Brachyramphus marmoratus*) is the most abundant seabird in Prince William Sound (PWS), Alaska, and breeds throughout the area affected by the 1989 *Exxon Valdez* oil spill. I compared pre- and post-spill abundance and breeding activity of murrelets near the Naked Island group in central PWS, and in Kachemak Bay in lower Cook Inlet. Murrelet numbers at Naked Island were lower in 1989 than in 1978-1980 but not in 1990-1992. At Kachemak Bay, where oiling was minimal, murrelet densities did not change between 1988 and 1989. I observed fewer juvenile murrelets at Naked Island in post-spill years, but data were insufficient to determine if reproduction was disrupted. There was no change in juvenile counts in Kachemak Bay. My results suggest that the murrelet population at Kachemak Bay, further removed temporally and spatially from the spill epicenter, was not as affected as the Naked Island population in 1989. Murrelet numbers were negatively correlated to numbers of boats at both study sites, and cleanup activities likely contributed to disruption in 1989.

Murrelets, presumably at wintering areas outside PWS, did not arrive in PWS until after most surface oil had dispersed. Murrelets near Kodiak Island and the southern Kenai Peninsula in April, during migration, may have died in higher numbers than in PWS. A minimum of 8,400 *Brachyramphus* murrelets were killed by oil, perhaps 7% of the population in the spill zone. This estimate is probably low due to the low recovery rate for this small bird. The 66% decline in the PWS murrelet population since the 1970's complicated the identification of spill-related effects on murrelets.

Key Words: Alaska, *Brachyramphus*, Kachemak Bay, Marbled Murrelets, Naked Island, Oil Spill, Prince William Sound, *T/V Exxon Valdez*

INTRODUCTION

On 24 March, 1989, the supertanker *T/V Exxon Valdez* spilled 11 million gallons of crude oil into Prince William Sound (PWS), Alaska. The oil eventually evaporated or traveled 750 km south (Fig. 1) to the Kenai Peninsula, Kodiak Island and the Alaska Peninsula (Galt et al. 1991). The *Exxon Valdez* oil spill, while not the world's largest, killed more birds than any other spill (Piatt and Lensink 1989). At the time of the spill an estimated one million birds were at risk of being oiled (Piatt et al. 1990). Alcids, being diving seabirds, have died in disproportionately high numbers in other oil spills (Jones 1978, Nettleship and Birkhead 1985) and had the highest rate of mortality compared to the population at risk in the *Exxon Valdez* oil spill (Piatt et al. 1990, Ecological Consulting, Inc. 1991).

Among the alcids, marbled murrelets (*Brachyramphus marmoratus*) are considered one of the most susceptible to oil spills, due to their small size and nearshore foraging habits (King and Sanger 1979). However, because of their limited contact with benthic or intertidal zones and their dispersal during breeding, most murrelet mortality likely occurred during the initial oiling event. Potentially, continued mortality in post-spill years could result from reduced prey abundance, consumption of contaminated prey or from surface oil reentering nearshore waters at oiled beaches. I studied the abundance of marbled murrelets in two areas in the *Exxon Valdez* spill zone with historic population data, to assess injury to this species from the spill.

Exposure of birds to surface oil can cause death by drowning or hypothermia. In addition to the immediate mortality, secondary and long-term impacts to seabirds can occur. Oil is known to affect bird reproduction and metabolism. Adult birds can transfer oil during incubation to the surface of eggs, which reduces embryo survival or reduces hatching success (Szaro and Albers 1977, Nero and Associates, Inc. 1987). Birds can ingest oil by preening or consuming contaminated prey, which can impair metabolic rates, thus adversely altering the behavior of adults (Cavanaugh et al. 1983, Nero and Associates, Inc. 1987, Epply and Rubega 1990) and retarding chick growth (Miller et al. 1978, Peakall et al. 1980). Furthermore, increased human activities related to spill clean up are a potential source of disruption to seabirds during the breeding season.

The marbled murrelet is the most abundant seabird in PWS in the summer, but its population has declined 66% since the early 1970's (Isleib and Kessel 1973, Klosiewski and Laing ms). The species is common year-round throughout the spill zone. An estimated 95% of marbled murrelets in the U.S. occur in Alaska (Mendenhall 1992). The major centers of the marbled murrelet population in Alaska appear to be in southeastern Alaska, PWS and the Kodiak Archipelago (Piatt and Ford 1993). Therefore, a large portion of the U.S. breeding population was at risk from the spill. The marbled murrelet is listed as threatened in California, Oregon and Washington under the Endangered Species Act. In Alaska the murrelet is a Category II species, meaning it is a species of concern, but there are insufficient data to determine its status. In the spill zone, murrelet counts may include Kittlitz's murrelets (*B. brevirostris*), which comprise <8 % of the *Brachyramphus* murrelets (USFWS, Migratory Bird Management, Anchorage, Alaska, unpubl. data).

During the breeding season, marbled murrelets tend to be widely dispersed and, unlike most seabirds, do not nest in colonies. Marbled murrelets lay one egg and throughout most of its range are only known to nest inland on the branches of conifers (Marshall 1988, Singer et al. 1991, Naslund et al. in review). In southcentral Alaska they also nest on the ground (Day et al. 1983).

Murrelets are usually in pairs and forage < 2 km from shore (Carter 1984, Carter and Sealy 1990). They feed primarily on mid-water and surface schooling fish such as Pacific sand lance (*Ammodytes hexapterus*), capelin (*Mallotus villosus*), juvenile Pacific herring (*Clupea pallasii*) and cod (*Gadidae spp*) (Sealy 1975, Sanger 1987). Occasionally they feed on salmon fry (*Oncorhynchus spp.*) in river mouths or freshwater lakes (Carter and Sealy 1986).

Little is known about the life history of marbled murrelets, but like other alcids, they are probably long-lived (Nettleship and Birkhead 1985, S.K. Nelson, pers. comm.), and rely on high adult survivorship to compensate for low reproduction. For such species, the disruption of breeding pairs or the loss of a large portion of the breeding population has long-term consequences.

Investigating injury to murrelets was difficult because few areas had adequate pre-spill counts for determining post-spill population trends, and little was known about the biology or migratory patterns of murrelets in Alaska. Because murrelets do not nest on open cliff faces or in burrows like many seabirds, we could not count birds at their nests or measure reproductive success directly. Nesting areas and habitat within the spill zone were largely unknown. In 1989, only 10 marbled murrelet nests had been documented worldwide. A protocol was in development at that time for surveying marbled murrelet breeding activity (Paton et al. 1988), but the method had not been tested in Alaska.

I monitored murrelets on Naked Island from 1978 to 1980 as part of a U. S. Fish and Wildlife Service project to gather baseline information on seabirds along the oil tanker route from Valdez to Hinchinbrook Entrance. Pigeon guillemots (*Cepphus columba*) and marbled murrelets were, and remain, the two most common seabirds in the Naked Island group (Oakley and Kuletz 1979). The murrelet population within 5 km of the Naked Island group is about 3,000 in the summer (Kuletz et al. 1994a), approximately 3% of the PWS population. In 1988 I also studied variability in at-sea counts of murrelets in Kachemak Bay. Thus, both the Naked Island and Kachemak Bay areas had pre-spill data.

In this study, I compared murrelet counts at-sea before and after the spill at the Naked Island group in central PWS and Kachemak Bay, in lower Cook Inlet. Dawn surveys of inland murrelet activity and counts of juveniles on the water at these sites were used as indices of reproductive activity. I synthesized available information on the abundance and distribution of murrelets to infer migration patterns and used carcass counts of murrelets to estimate direct mortality from the spill.

My results suggest that murrelets breeding at Naked Island were more affected by the spill than murrelets breeding in Kachemak Bay. The decline in nearshore abundance of adult murrelets at Naked Island appeared to be limited to 1989, and disturbance from the cleanup operations may have contributed to their displacement.

OBJECTIVES

1. Determine if marbled murrelet numbers were lower in post-spill years compared to pre-spill years at two sites with pre-spill data. As a subobjective, determine if boat and airplane activity in 1989 influenced murrelet counts.

2. Examine evidence of marbled murrelet breeding activity at sites in oiled areas.

3. Determine if petroleum hydrocarbons were present in marbled murrelets in oiled and unoiled areas.

It was apparent in 1989 that the level of human activity in the study area was much greater than in the years when pre-spill surveys had been conducted, due to cleanup and other spill-related activity. Therefore, I added the subobjective related to disturbance under objective one. The third objective will be presented in a separate report (Oakley et al., in prep). The fourth objective of the study was to identify alternative methods and strategies for restoration of populations or habitat where injury was identified. This objective is addressed in the Discussion section of the report.

METHODS

I tested for changes in murrelet abundance before and after the spill, at two sites with pre-spill data -- Naked Island and Kachemak Bay. In 1989, Eaglek Bay and the Ingot/northern Knight Island area (Fig. 2) were also surveyed to determine the abundance of murrelets, with the intention of determining if changes in murrelet abundance differed between the unoiled site (Eaglek Bay) and heavily oiled site (Ingot/northern Knight islands) following the spill. However, Bird Study 6 was not funded after 1989, and no follow-up studies were conducted. Therefore, data from Eaglek and Ingot/northern Knight islands are not presented in this report. The data are on file at the U.S. Fish and Wildlife Service, Anchorage, Alaska.

Study Area

General Characteristics.-- The primary study area was the Naked Island group in central PWS, Alaska (Fig. 2). The three islands that form the Naked Island group are Naked Island (35 km^2), Storey Island (8 km^2) and Peak Island (5 km^2). Surface water temperatures in PWS range from -2°C to 18°C and tidal range is 3-4 m (Muench and Schmidt 1975). The islands are part of the Chugach National Forest. Low-lying broken cliffs and cobble beaches are typical features throughout the Naked Island group. Steep exposed cliffs occur along the eastern sides of all three islands. Upland vegetation is a mosaic of bog meadows and mixed Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*) and mountain hemlock (*T. mertensiana*) forests. The islands are forested to their summits, with 460 m the highest elevation, on Peak Island.

Kachemak Bay is a 62 km long embayment, 24 km wide at its entrance, which opens into eastern lower Cook Inlet on the southern Kenai Peninsula. There were two study sites in the bay: the south inner bay and south outer bay (Fig. 2). The southern portion of Kachemak Bay is characterized by coves, fjords and small islands. The uplands consist of river valleys, steep forested slopes, alpine vegetation, glacial moraine and icefields. Mean diurnal tide range in the bay is 4.7 m. Kachemak Bay averages 46 m in depth, but the deepest waters are along the southern half (Trasky et al. 1977). For a detailed description of the Kachemak Bay marine and upland habitat, see Trasky et al. 1977.

Oiling of the Study Area. --The Naked Island complex, 30 km southwest of Bligh Reef, was one of the first land masses hit by the oil from the *T/V Exxon Valdez*. Naked Island was first oiled on 27 March 1989, three days after the tanker's grounding (Galt et al. 1991). The oil largely missed Storey Island. Peak Island, although surrounded by oil sheen from 27-30 March, only had shoreline oil in one cove on the north side, which was not evident in August, 1989 surveys. Between 27 March and 2 April, shorelines on the northern and eastern sides of Naked Island were moderately to heavily oiled. The northwestern corner of the island was lightly to moderately oiled (Fig. 3). The oil moved south with prevailing winds, and the southern and western sides of Naked Island initially remained free of oil. However, on about 7-9 April, southerly winds brought oil back into the Naked Island area, and small sections of shoreline on the western and southern sides of the island were lightly oiled.

The oil hit Knight Island by 28 March and progressed along the southern Kenai Peninsula between 29 March to 11 April (Fig. 1). Most of the oil remained around the Barren Islands between 13 - 16 April before moving north into Cook Inlet or south towards Kodiak Island (Galt et al. 1991). Kachemak Bay received oil sheen in mid April, with tar balls reaching the southern shoreline near the mouth of the bay. Glacier Spit, in the inner bay survey area, received light oiling in the form of weathered tar balls (Fig.4).

Abundance Indices at Naked Island

I used two types of surveys to determine the abundance of *Brachyramphus* murrelets at the Naked Island group: 1) offshore counts of murrelets on five mid-bay transects and 2) shoreline surveys of all three islands. Pre-spill data were from 1978-1980 and post-spill data from 1989-1992. In 1978-1980, all murrelets were considered marbled murrelets, and, since only a few Kittlitz's murrelets (*B. brevirostris*) have been observed in the area, this assumption is largely accurate for Naked Island.

Offshore Counts. -- Abundance indices were determined for marbled murrelets on five transects on the western side of Naked Island (Fig. 3). These transects were derived from frequently used boat routes in 1978-1980 and were conducted from a 5 m inflatable boat. Routes were defined by prominent landmarks. Being within the bays or across the bay mouth, the approximated routes were probably consistent.

The transect viewing distance was not consistent among years. In 1978, birds were counted out to 100 m from the boat. In 1979-1980 and 1989-1990, birds were counted as far as 200 m from the boat. In 1990 we also recorded the bird's distance from the boat as either $\leq$ 100 m from the boat or 101-200 m from the boat, to determine the percentage of birds in each distance zone.

Time of day, weather, and sea conditions were recorded prior to each survey. Most transects were surveyed before 1200 h from an inflatable boat in fair conditions. In post-spill years, some surveys were done from a 7.7 m whaler.

Shoreline Surveys. -- The shoreline surveys were conducted by circumnavigating Naked, Storey and Peak islands. Early June surveys were done in 1978-1980 and 1989-1992 at Naked Island, and in 1978-1979 and 1989-1992 at Storey and Peak islands. Partial shoreline surveys were also done in late July or August in 1978, 1979 and 1989-1992 at Naked Island and at Storey and Peak islands in 1978, 1980, 1989 and 1990. The surveys were conducted between 0500-1000 hours, during morning high tides. Two observers in a 5 m or a 7.7 m boat traveled at 5-7 knots within 50-100 m of the shoreline and counted all seabirds. In 1978, all murrelets within view were counted, which could have included birds >200 m from shore. However, because our focus in 1978 was toward the guillemot colonies near shoreline and because of the low detectability of murrelets beyond 100 m, I have assumed that the counts were comparable to those of later years, when birds were counted $\leq$ 200 m from the shoreline.

Data Analysis. -- Before pooling the offshore transect counts for analysis, I had to determine if murrelet counts on surveys were biased by seasonal, diel or environmental factors. Murrelet counts at-sea are highly variable, but consistent sources of variation have not been clearly identified (Carter 1984, Carter and Sealy 1990). Carter (1984) did not find changes in murrelet density relative to tidal state or weather. Carter and Sealy (1990) found murrelet densities in British Columbia to generally decline from dawn to dusk, but they found no significant difference between surveys done at 0500, 1000 and 1500 hours; densities were significantly higher at 0500 h and 1000 h than at 2000 h. Although their results did not suggest a need to standardize for most survey conditions, I conducted preliminary analyses to determine if seasonal, diel, tidal, sea state and platform conditions significantly affected murrelet counts in PWS (see Appendix). My results were similar to previous studies in that I found no consistent correlation between murrelet counts and tidal phase, season, time of day or weather. However, conditions which resulted in consistently lower murrelet counts were surveys in late August or late in the day or in rough seas. Therefore, I used surveys conducted between 6 June - 6 August and between 0500 - 1700 h on days when seas were < 0.6 m in height. Seventy-five pre-spill and 207 post-spill counts satisfied these criteria.

The change in transect viewing distance was more problematic. Murrelet detectability declines dramatically beyond 100 m (C.J. Ralph, pers. comm.). In 1990 I found that on average, 84 % (SE = 1.6 %) of the murrelets we counted were $\leq$ 100 m from the boat. Therefore, rather than use densities, I used the total number of murrelets counted in 1978 ($\leq$ 100 m), 1979, 1980, and 1989 ($\leq$ 200 m), with the assumption that the majority of murrelets we detected were $\leq$ 100 m from the boat. For 1990 surveys, I used the number of birds $\leq$ 100 m of the boat.

Murrelet counts were transformed (natural log) prior to all tests because there was no assumption of normality in the counts. Pre- and post-spill means were tested with two-sample t-tests. I also used an outlier-t test to determine if 1989 counts were lower than pre-spill counts. One-tailed tests at α = 0.05 were considered significant.

To determine whether the spill affected murrelet abundance on all offshore transects at Naked Island I tested for declines in 1989 only. First, the yearly mean number of murrelets was calculated for each transect, the 1989 mean subtracted from that transect's pre-spill mean and the combined difference between 1989 and post-spill means was tested for deviation from zero. Second, for transects with at least 2 years pre-spill data (N1, N3 and N4), the mean number of murrelets per survey in 1989 was tested for significant deviation from the annual pre-spill means. Finally, the mean number of murrelets counted for each of these three transects was compared between pre- and post-spill years.

For the shoreline surveys I tested for a decline in the numbers of murrelets after the spill for each of the three islands surveyed. The 1989 counts were tested separately to determine if a temporary change occurred. I also tested for a decline in murrelet counts between pre- and post-spill years.

<u>Murrelet Counts along Oiled and Unoiled Shorelines</u>. -- Since 1978, the shoreline of Naked Island has been divided into seven areas defined by landmarks (Fig. 3). After the spill, these areas were designated as primarily oiled (>50 % oiled shoreline) or unoiled (<50 % oiled shoreline), based on a map of "Cumulative Oil Impact" as of August 21, 1989 (EVOSDAGP 1990). The unoiled areas were

McPherson Passage, Bass Harbor, Outside Bay and Cabin Bay of Naked Island, and Storey and Peak islands. The oiled areas were NW Naked, McPherson Bay and East Naked. I tested for a decline in the proportion of murrelets counted in oiled areas after the spill with a two sample t-test. Only 1978 and 1980 pre-spill years had data for all three islands.

Abundance Indices in Kachemak Bay

In Kachemak Bay, murrelets were considered *Brachyramphus* murrelets unless identified to species, due to the difficulty differentiating the two species in the field. Kittlitz's murrelets were more commonly observed in Kachemak Bay than in the Naked Island area. Of the murrelets I identified to species in Kachemak Bay (n =), 19% were Kittlitz's murrelets.

In Kachemak Bay, murrelets were counted from a 7.7 m boat on four transects in the south inner bay and six transects in the south outer bay (Fig. 4). Two transects surveyed in 1988 were not surveyed in 1989. To locate the transects we used landmarks, followed bottom contours with a depth sounder, and used marine radar to stay a fixed distance from shore. Transects were surveyed between 0600 - 1000 h in calm seas. I conducted surveys on 22 days between 17 May and 5 August, 1988, and on 16 days between 4 May and 18 August, 1989.

The viewing distance was not the same for the two years. In 1988, I experimented with a distance used by Carter (1984), counting birds out to 500 m from the boat. In 1989, I returned to a viewing distance of 200 m. Because the 1989 transect width was substantially smaller than the 1988 transect width, I took a conservative approach and compared murrelet densities (birds/km^2) rather than numbers. For the six transects which were the same in both 1988 and 1989, the difference in murrelet density between 1988 and 1989 was tested for deviation from zero. The range of survey dates at Kachemak Bay was greater than at Naked Island and survey dates were more clumped. The 1988 surveys were conducted mid-July to early August, a period not surveyed in 1989, and often associated with very high murrelet counts (Carter 1984). Therefore, I examined the mean daily densities within four periods: Period 1 (7 May - 6 June), Period 2 (7 June - 12 July), Period 3 (13 July - 5 August) and Period 4 (6 August - 5 September).

Effects of Boat Traffic.

In 1989, vessels $\leq$ 200 m from the transect were recorded to test for an effect on murrelet numbers. Of the Naked Island transects, only N4, across Outside Bay, had sufficient boat traffic for this test. At Kachemak Bay, boat traffic in the inner bay was rare, so I used the transects in the outer bay to test the correlation between boats and murrelets.

Land-based counts of murrelets were also used to determine if boat and plane activity influenced murrelet numbers. Land-based counts were done in Outside

Bay, Naked Island (Fig. 3) on 9 days (N = 55 h, x = 6.1 h / d) between 0500 - 2000 h. The number of murrelets on the water within a portion of the bay defined by landmarks was counted each hour by an observer sweeping the area once using a 20x spotting scope. Simultaneously, boats and low-flying aircraft were recorded.

I used Kendall's tau-b correlation to test for a correlation between the number of boats and aircraft present and the number of murrelets counted that hour or on each transect.

Breeding Activity

Dawn Watch Surveys. -- As a measure of murrelet breeding activity, I conducted dawn watches, wherein the number of detections, defined as the audio or visual sighting of murrelet(s) flying inland, were recorded before dawn (Paton et al. 1988). I conducted dawn watches at Cabin Bay (Fig. 3), on the west side of Naked Island, on 13, 14 and 15 June, 1989. Between 1990 - 1992, as part of restoration studies (see Kuletz et al. 1994b), six dawn watches were conducted in June at the same site.

Juvenile Murrelet Counts. -- Once fledged, juvenile murrelets are independent and have a distinctive plumage which is similar to adult winter plumage (Carter and Sealy 1984). I recorded the number of juveniles on the water during the offshore and shoreline surveys. Because I did not know the percentage of non-breeding murrelets at the study sites, I could not estimate the number of juveniles per breeding pair from the counts. Rather, I used the percentage of juveniles of the total murrelet counts as an index of reproductive success.

At Naked Island we recorded juveniles in 1978, 1979 and 1989-1992. For the five offshore transects on the west side of Naked Island and the shoreline surveys, I used surveys between 15 July - 15 August. Using surveys from this time period minimized identification errors between juveniles and older birds in transitional plumage. Because the number of adult murrelets declined quickly after mid-August (Oakley and Kuletz 1979), this time period also minimized the possibility of artificially inflating the ratio of juveniles late in the season. Because few complete late summer shoreline surveys were done, I included partial surveys. In post-spill years, I included murrelets identified as adults in basic plumage as juveniles (observed in 1991 and 1992), in the event that identification in pre-spill years was uncertain.

For offshore surveys, I used total counts for the day (all transects combined) to calculate the daily percentage of juveniles. These daily percentages were used to calculate the yearly average percentage of juveniles. Differences between pre- and post-spill years were tested with a two-sample t-test.

In Kachemak Bay, juveniles were observed the first week of July, and murrelets remained abundant and in breeding plumage into late August (pers. obs.). Therefore, I included data from 4 July - 18 August for comparing the percentage of juveniles before and after the spill. Because juveniles and species of murrelet could not be identified at a distance, I compensated for the effect of the wide transect in 1988 by only using the number of murrelets identified as marbled murrelets in 1988 and 1989. The percentage of juveniles observed before and after the spill was tested with a two-sample t-test of the daily mean percentages of juveniles.

RESULTS

Abundance Indices at Naked Island

Offshore Counts. -- The number of murrelets declined on only one of five transects between 1989 and post-spill years (Table 1). However, murrelet counts on all five transects were lower in 1989 than their pre-spill averages, and the differences in counts for the five transects showed a significant decline ($t = 2.31$, $P = 0.04$). High numbers of murrelets were observed in 1990, and the post-spill mean number of murrelets on each of transects N1, N3 and N4 was not significantly lower than the pre-spill mean (Table 1).

Shoreline Surveys. -- Compared to pre-spill years, the total number of murrelets counted during shoreline surveys of Naked Island was significantly lower in 1989 (Table 2). Murrelet numbers increased in the following years. Thus, although there was a 33% decline in post-spill years, the mean number of murrelets was not significantly lower than in pre-spill years. When shoreline areas were analyzed separately, the numbers of murrelets found in Cabin Bay, Bass Harbor and McPherson Bay were significantly lower in 1989 than in pre-spill years (Table 2). Only McPherson Bay murrelet numbers remained significantly lower in all post-spill years ($t = 2.61$, $df = 4.9$, $P = 0.05$).

Both Peak and Storey Island had significantly fewer murrelets along their shorelines in June 1989, compared to pre-spill years (Table 3). However, murrelet numbers at both islands were back to pre-spill levels or higher in July 1989. For both Peak and Storey islands, the 1990 counts were the highest June counts on record.

Murrelet Counts Along Oiled and Unoiled Shorelines. -- The proportion of murrelets counted along oiled shorelines of the study area did not decline significantly after the spill ($t = -0.23$, $df = 4$, $P = 0.41$). However, in 1990, when the highest number of murrelets were counted, only 10% of them were along previously oiled shorelines, which was the lowest proportion for all years surveyed (Table 4).

Abundance Indices at Kachemak Bay

At Kachemak Bay, there was no significant decline in murrelet density between 1988 and 1989 at six transects surveyed both years (Table 5). For all of the surveys combined, the average murrelet density in the inner bay was 37% lower in 1989, but the decline was not significant. Within a given survey period, murrelet densities were similar pre- and post-spill in both the inner and outer bay (Table 6).

Effects of Boat Traffic

In 1989 murrelet counts showed a negative relationship with boat traffic during offshore surveys (Fig. 4). At Outside Bay, the number of boats on or near the transect ranged from 0 - 4 per day. The number of murrelets was negatively correlated with the number of boats on or near the transect ($n = 27$, $tau = -0.516$, $P= 0.0011$). At Kachemak Bay, the number of boats per transect ranged from 0 - 8, and murrelet numbers were again negatively correlated ($n = 70$, $tau = -0.206$, $P = 0.030$).

Land-based counts of murrelets in Outside Bay were also negatively correlated with the number of boats and low flying aircraft in the bay during each count (Fig. 5; $n = 55$, $tau\text{-}b = -0.214$, $P = 0.038$).

Breeding Activity

There was evidence of murrelet breeding activity at both Naked Island and in Kachemak Bay in 1989. Murrelets collected in 1989 for the contaminants study had fully developed brood patches (K.J. Kuletz, unpubl. data). We observed murrelets flying inland at both study sites and juveniles were observed late in the summer. However, it was not possible to quantify breeding attempts or nesting success. The indices of breeding activity and success were the dawn watch surveys and counts of juveniles at sea.

<u>Dawn Watch Surveys</u>. -- We recorded a total of 112 detections of murrelets flying inland at the Cabin Bay dawn watch site in 1989 ($x = 37.3$ detections per dawn watch, $SD=10.9$). In subsequent years (1990-1992) at this site, the mean number of detections in June was 27.5 ($SD=0.7$), 46.5 ($SD=24.7$) and 56.0, respectively.

<u>Juvenile Murrelet Counts</u>. -- A higher percentage of juveniles was recorded during shoreline surveys in pre-spill years than in post-spill years (Table 7; $t = -2.46$, $df = 4$, $P = 0.035$). No juveniles were observed during shoreline surveys in 1989, although some were observed on transects. On the five offshore transects at Naked Island, the percentage of juveniles was also lower after the spill (Table 8; $t= -10.03$ $df = 2$, $P = 0.005$). At Kachemak Bay, there was no change in the percentage of juveniles observed per day between 1988 and 1989 (Table 8; $t = -0.122$, $df = 15$, $P = 0.45$).

DISCUSSION

Murrelet Abundance at Naked Island

Both offshore and shoreline surveys indicated that marbled murrelet numbers were lower in 1989 compared to pre-spill years in the nearshore waters of the Naked Island group, at least through mid-summer. Both methods also showed a return to pre-spill numbers in the following years, suggesting that the local effect of the spill on the presence of murrelets was temporary.

How representative of the local murrelet population were the surveyed areas at Naked Island? The Naked Island offshore transects, which were in and near Cabin Bay, appeared to have higher than average murrelet densities compared to randomly selected transects surveyed at Naked Island during 1991 and 1992 studies (see Kuletz et. al. 1994a). The average murrelet density on offshore transects surveyed in 1978-1990 ranged from 22 - 128 birds/km^2 (x = 55.4, SD = 28.8, n = 20). In contrast, Kuletz et al. (1994a) found average densities of 15 - 17 birds/km^2 on randomly selected transects abutting the Naked Island shoreline. The consistently high densities in Cabin Bay and northwest Naked Island suggest that these areas were frequently used foraging sites. Therefore, although these transects could provide indices of murrelet concentration for a specific area, they were not typical of the Naked Island area in general.

The shoreline surveys were complete surveys of all three islands. In the Naked Island study area Kuletz et al. (1994a) found, on three separate surveys, that murrelets within 200 m of shore were consistently 18 - 19 % of the estimated population within 5 km of the islands.

One possible reason for the low numbers of murrelets observed in 1989 was the loss of resident breeding birds during the initial oiling event. However, murrelets were unlikely to have been killed at Naked Island, because few murrelets were there at the time of the spill. Only four murrelets were observed during a shoreline survey of the Naked Island group on 27-28 March, 1989, before oil arrived (K.D. Wohl and S.P. Klosiewski, USFWS, Anchorage, unpubl. data). Incidental observations suggest that few murrelets were in the area before late April (M.E. Isleib, pers. comm.). Murrelets were present and in breeding plumage by early May in 1978 (Oakley and Kuletz 1979). Surface oil was mostly absent from the area by 19 April, 1989, thus most of the summer population arrived after the main oil slick was gone. Of the 229 identified marbled murrelet carcasses returned to the Valdez morgue for which location of recovery was given, only six were found on Naked and Peak islands. Eighty percent of the PWS carcasses were found south of Eleanor Island (USFWS, Anchorage, unpubl. data).

Avoidance of the oil by murrelets could have been another reason for lower counts in 1989. Aerial surveys throughout PWS in the first weeks after the spill found that the number of birds in oiled areas decreased, whereas the numbers in unoiled areas increased (Piatt et al. 1990). Similarly, in the Kenai Fjords National Park, Vequist and Nishimoto (1990) recorded a 30% increase in the number of murrelets between early and late April 1989. However, the increase in murrelets was in areas that had not been oiled between the two surveys, and murrelet numbers decreased in oiled areas. How much of the decrease in oiled areas was due to mortality was unknown.

My surveys did not find a greater decrease in murrelets near oiled shoreline, suggesting that the amount of surface oil left in the Naked Island area by June was not affecting murrelet distribution at that scale. However, a very low percentage of the birds were counted in oiled areas of Naked Island in 1990, and some unknown factor associated with oiled areas may have affected murrelet distribution -- such as a lack of sufficient prey to attract the murrelets. The high number of murrelets recorded in 1990 on the offshore transects, which were in unoiled bays, was a reflection of the high numbers in the unoiled areas of Naked Island in general.

Finally, the low number of murrelets at Naked Island in 1989 could have been due to temporary displacement from cleanup and carcass recovery operations, as discussed in the section on the effects of boat traffic.

Murrelet Abundance in Kachemak Bay

I found no changes in murrelet density between 1988 and 1989 in the southern half of Kachemak Bay. Historical data on murrelet abundance in Kachemak Bay is anecdotal or incomplete, but there is no indication that the population has changed since the 1970's. The murrelet densities I observed in the south outer bay were not lower than those reported for the south portion of the bay mouth (12 - 20 murrelets/km^2) in 1976 (Erickson 1977).

The Kachemak Bay transects were in an area of the bay with relatively high murrelet densities. The transects were located in the southern portion of the bay because concentrations of murrelets had been noted there during reconnaissance surveys (Nishimoto 1988). When I surveyed the northern shoreline of Kachemak Bay in July, 1988, I found murrelet densities of 0.7 - 4.5 birds/km^2, compared to average densities of 20 - 50 birds/km^2 along the southern shoreline.

Murrelets are present in Kachemak Bay in low numbers in the winter (Sanger 1987, Nishimoto 1988). In 1989, I made reconnaissance surveys in the bay by boat from mid-March through mid-May and noted a steady increase in murrelets throughout April, with summer densities observed by May. Thus, when the oil entered the bay several weeks after the spill, a large portion of the murrelet population would have already been in the bay.

Due to the relatively small amount of weathered oil reaching Kachemak Bay, direct mortality of murrelets in the bay was probably low. However, birds which nested in Kachemak Bay could have been exposed to oil before entering the bay, if they were near the southern tip of the Kenai Peninsula in mid-April. Few murrelet carcasses were recovered in Kachemak Bay, although carcasses found further south could have originated there. The same physical characteristics of the bay which may have kept oil from the beaches would also have kept carcasses off the beach in Kachemak Bay. Trasky et al. (1977) noted that strong surface water outflow in spring and summer could prevent surface oil from entering the bay, and summer southerly winds would keep oil from moving onshore in the southern portion of the bay.

Effects of Boat Traffic

The low numbers of murrelets observed when boat traffic was high suggested that boat activity can affect murrelet numbers in nearshore waters, and human disturbance probably influenced murrelet activity at Naked Island in 1989. Such disturbance could have also affected birds breeding outside the Naked Island area, since an unknown proportion of birds foraging around Naked Island could have been non-breeders and birds nesting in other areas. For example, in 1993 two murrelets radio tagged in Unakwik Inlet, 30 km north of Naked Island in the unoiled zone, were recorded as traveling between Naked Island and Unakwik (Burns et al. 1994).

At the peak of cleanup operations in PWS in 1989, Exxon reported mobilization of over 600 marine vessels plus 85 aircraft which logged nearly 6,000 flight hours (Carpenter et al. 1991). A reduced operation was conducted in 1990. Given the potential for disruption of murrelet nearshore activity, it is possible that disturbance from rescue and clean-up activity was a source of injury to murrelets in 1989 and to a lesser degree in 1990. At Naked Island in 1989 there were clean-up activities in McPherson Bay and support activities in Outside Bay, where the *T/V Exxon Valdez* was anchored until 22 June. The one area that continued to have lower numbers of murrelets after 1989 was McPherson Bay, where a large oil spill response barge has been anchored in summer months since 1989. However, McPherson Bay was also the only large bay on Naked Island to have > 50 % of its shoreline oiled, so oil effects cannot be dismissed.

Breeding Activity

There was evidence of murrelet breeding activity in the Naked Island area, and the amount of murrelet dawn activity in Cabin Bay increased in 1991 and 1992, compared to 1989 and 1990. However, it is not possible at this time to determine if higher detection levels reflect more breeding attempts. In California and Oregon, S.W. Singer (pers. comm.) and S.K. Nelson (pers. comm.) found lower inland activity at known breeding areas in 1992, an El Nino year, when numbers at sea were higher than normal. Singer and Nelson speculated that the low inland activity reflected fewer breeding attempts, which resulted in higher numbers at sea. The murrelets counted on the water around Naked Island in 1990 were similarly high, with low inland detections that year. It is possible, although not directly testable, that murrelets at Naked Island were making fewer breeding attempts, or that breeding birds failed early, thereby increasing their numbers at sea beyond historical counts. The high number of adult murrelets observed in 1990 was not associated with an increase in the ratio of juveniles.

My results, based on the percentages of juveniles counted on the offshore and shoreline surveys, suggest that reproduction was disrupted at Naked Island in post-spill years. At Kachemak Bay, the ratio of juveniles to adults was higher than at Naked Island, and I found no difference between 1988 and 1989 there. These results suggest that any disruption to murrelet breeding was limited to heavily oiled areas. However, the dispersal patterns of juvenile murrelets is unknown, and considerable variability has been recorded. At study sites in Oregon and California (S.K. Nelson, S.L. Miller, pers. comm.), the percentage of juveniles observed on the water was similar to Naked Island, whereas juvenile ratios were up to 30% of all murrelets in Desolation Sound, British Columbia (I.A. Manley, pers. comm.) and 10% in Puget Sound, Washington (D.R. Nysewander, pers. comm.). Furthermore, because the percentage of juvenile seabirds at sea is not a standard measure of reproductive success, interpretation of these results remains speculative. Thus, at this time, no firm conclusions can be made about the effect of the spill on the reproductive success of murrelets. However, opportunistic observations recorded in my field notes support the evidence for low reproductive success after the spill. Juvenile murrelets foraged in south Cabin Bay near our camp, and between 1978 - 1980 I observed up to eleven juveniles there on a given day. The highest number observed in one day in this cove between 1989 - 1992 was three juveniles in 1991.

Seabird breeding can be disrupted by changes in prey availability (review in Furness and Nettleship 1991), and prey could have influenced murrelet distribution and breeding in the Naked Island area. Surface schooling fish used by murrelets in the summer, such as herring and sand lance, were infrequent deliveries to Naked Island pigeon guillemot chicks, relative to other prey species, in 1989 and 1990 compared to pre-spill years (Oakley and Kuletz 1994). Kittiwakes in Prince William Sound also had reduced feeding rates of juvenile herring in 1990 (Irons 1992). Thus, murrelets may face long-term effects if the abundance of sand lance, capelin and young herring was affected by the spill. Naked Island herring had high levels of sublethal damage and larval malformations, and herring did not spawn at Naked Island in 1991 (Hose et al. 1993). As intertidal spawners, these species of fish, including their eggs and larvae, are more susceptible to oil pollution than pelagic spawners (Trasky et al. 1977).

Breeding could also have been disrupted by direct mortality of breeding adults and disruption of breeding pairs. Alcids tend to be monogamous and exhibit strong pair bonds. Marbled murrelets are usually seen in pairs, which suggests that they maintain pair bonds or practice cooperative foraging (Sealy 1975). Marbled murrelets fly to inland nesting areas in winter as well, indicating year-round maintenance of pair bonds or proprietorship of nesting sites (Naslund 1993). We do not know what proportion of the approximately 25,000 murrelets in PWS in winter are breeding adults, but in other alcids, breeding birds tend to stay in the vicinity of breeding areas in the winter, while immatures move further away (Nettleship and Birkhead 1985). Thus it is likely that those birds at risk in PWS were resident breeding birds. For birds which lost mates, breeding could have been delayed, which could have affected timing of chick rearing relative to prey availability. Colonial seabird pairs which nest late relative to the colony tend to have lower reproductive success, perhaps due to lower prey availability late in the season (review in Nettleship and Birkhead 1985).

Seasonal Migration and Direct Mortality

In PWS, a higher than expected proportion of murrelet carcasses (11.6% of all birds) were recovered, and of the six species of small alcids in the spill zone, marbled murrelets suffered the greatest mortality (Piatt et al. 1990, Ecological Consulting, Inc. 1991). However, the PWS boat surveys (Klosiewski and Laing ms) found no oiling effect in population changes after the spill between oiled and unoiled areas of PWS. I propose that the murrelet's foraging behavior and their dispersal to widely scattered breeding sites would mask any oiling effect, but not necessarily preclude an effect on the population.

Fidelity to breeding sites is high among the Alcidae (review in Nettleship and Birkhead 1985) and murrelets would likely return to established breeding sites. Birds entering PWS from the south could have dispersed into either oiled or unoiled areas, and their July distribution would not necessarily have been related to the degree of oiling at breeding locations. Species which have shown reduced numbers or breeding effects along oiled shorelines are the pigeon guillemot and black oystercatcher (*Haematopus bachmani*), both species which rest on shoreline rocks and forage in subtidal kelp or rocks close to their nests (Oakley and Kuletz 1994, Andres ms). In contrast, murrelets forage widely and may make round trips between forage sites of 150 km (Burns et al. 1994). Such distances would reduce the effectiveness of designating oiled and unoiled areas of PWS relative to murrelets. Furthermore, murrelets do not contact intertidal or shoreline rocks, thus it is unlikely they would be exposed to oil at their breeding sites once it was onshore.

An examination of morgue collection dates and locations, together with evidence for migration patterns, indicates that many murrelets encountered oil during migration into nearshore waters of southcentral Alaska. The migration patterns can only be ascertained by at sea surveys or opportunistic observations. Murrelet counts around Kodiak Island were higher in winter than in fall (Zwiefelhofer and Forsell 1989). Other areas of the spill zone, such as Kachemak Bay (Nishimoto 1988), Cook Inlet (Agler et al. ms) and Prince William Sound (Klosiewski and Laing ms) recorded highest numbers in summer Where late spring surveys have been conducted, such as Kachemak Bay (K.J. Kuletz, unpubl. data) and the Kenai Peninsula (Vequist and Nishimoto 1990), murrelet numbers increased throughout April. Records kept by M.L. McAllister (pers. comm.) suggested that the migration route for birds entering western PWS was from the southwest region of the Kenai Peninsula coast and through Montague Straight. Murrelets migrating north along the southern Kenai Peninsula or the southwestern corner of PWS would have been affected throughout April, as the oil flowed south. Most of the murrelet carcasses were recovered in April (Piatt et al. 1990). Thus, it is likely that most of the direct murrelet mortality occurred during this northward and inshore murrelet migration in April.

The majority of marbled murrelets were retrieved in PWS, but recovery rates of carcasses generally decreased with distance from PWS (Ecological Consulting, Inc. 1991). As a result, the estimated mortality for murrelets, based on carcass recoveries and recovery rates for each region, was actually higher south of PWS (Table 9). Using these figures, I estimated the total *Brachyramphus* mortality at approximately 8,400 birds, including 900 murrelets killed in PWS. This estimate is probably low, due to the small size of murrelets and low likelihood of small carcasses being recovered on cobble beaches (Ecological Consulting, Inc. 1991).

The summer murrelet population has declined in PWS from 300,000 in the 1970's to 100,000 today and there is evidence that the decline began before the spill (Klosiewski and Laing ms). Nonetheless, the loss of a minimum of 900 murrelets in PWS due to the spill represents about 1% of the PWS population. It is probable that murrelets which breed in PWS were also killed in the southern portion of the spill zone. Good population estimates do not exist for murrelets for the entire spill zone. However, if the spill zone supports roughly half of the hypothesized 250,000 murrelets in Alaska (Mendenhall 1992, Piatt and Ford 1993), then the estimated mortality of 8,400 murrelets represents a minimum of 7% of the murrelet population in the spill zone.

The murrelet population in the spill zone has been subject to other forms of anthropogenic and environmental stress. Murrelets are killed as incidental take in gillnets in PWS (Wynne et al. 1991, 1992) and nesting habitat continues to be lost as private lands in the spill zone are logged. Predation on adult murrelets (Marks and Naslund, in press; J.H. Hughes, ADF&G, Anchorage, pers. comm.) and on eggs and chicks (Naslund et al., in review) appears to be high, and may increase with fragmentation of nesting habitat and increased corvid populations associated with human development. Additionally, there is evidence that forage fish populations have declined in PWS in the past decade, which could reduce reproduction and increase adult mortality.

Restoration studies between 1990 - 1993 (Kuletz et al. 1994b and Kuletz et al. ms) did not address the larger question of why murrelets have declined, but were intended to assist possibilities for mitigation. Two steps that could help restore murrelet populations affected by the spill are: i) reduction of gillnet mortality in the Copper River Delta salmon driftnet fishery, and ii) protection of high density nesting habitat in coastal Alaska. Perhaps of equal importance is the need to determine if large scale perturbations in PWS have altered food availability for murrelets and affected their productivity.

CONCLUSIONS

Adult murrelets in the Naked Island area, a known breeding site in central Prince William Sound, were temporarily displaced or eliminated in 1989 following the *Exxon Valdez* oil spill. There is evidence that cleanup and other spill related activity disrupted nearshore murrelet distribution. Breeding may also have been disrupted at Naked Island, although the data are too limited to make firm conclusions. Numbers of adult murrelets in the Naked Island area returned to pre-spill levels between 1990 - 1992. At lightly oiled Kachemak Bay, there is no evidence that the spill significantly affected the murrelet population there.

Pending results of contaminant analysis of murrelets collected in 1989 (Oakley et al. ms), the strongest direct link to the oil spill is the number of murrelet carcasses recovered in 1989. A minimum of 8,400 murrelets were killed directly by the oil spill, which represents at least 7% of the murrelet population in the spill zone. It is possible that long-term effects would not be evident at the population level for many years, but our ability to separate spill-related causes from other perturbations is limited. The 66% decline in the PWS murrelet population since 1973, although not entirely attributable to the spill, remains a concern for the recovery prospects of this species.

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Table 1. Mean number of marbled murrelets counted on five Naked Island offshore transects in Prince William Sound, Alaska, before and after the *Exxon Valdez* oil spill. Means before and after the oil spill for each transect were tested with a 1-tailed t-test. Counts from 1989 were tested for deviation from pre-spill means with an outlier t-test. All numbers were log-transformed for analysis. Dash (--) means no counts were made. n = number of individual surveys, X = mean numbers of murrelets counted per survey, SD = standard deviation.

	Transect N1			Transect N2			Transect N3			Transect N4			Transect N5		
Year	n	X	SD	n	X	SD	n	X	SD	n	X	SD	n	X	SD
Before Spill															
1978	9	40.3	30.9	4	43.3	25.6	9	75.8	50.0	8	34.6	21.6	6	40.5	21.2
1979	13	44.6	18.3	--	--	--	8	54.8	25.6	2	127.5	106.7	--	--	--
1980	14	51.3	21.6	--	--	--	2	66.0	29.7	--	--	--	--	--	--
After Spill															
1989	26	43.4	30.0	25	40.4	26.2	29	21.0	22.8	22	27.5	22.3	22	27.3	35.7
1990	18	113.0	57.8	17	95.9	63.8	17	106.8	92.6	16	23.1	18.7	15	69.0	43.1
Two-samplet-test															
t		-0.89			-0.66			0.71			1.77			0.17	
p		0.220			0.314			0.303			0.109			0.447	
df		3.0			1.0			1.0			2			1	
1989 Outlier t-test															
t		-0.58			insufficient			-10.95			-1.07			insufficient	
p		0.309			data			0.004			0.239			data	
df		1						1			1				

Table 2. Number of marbled murrelets counted on June shoreline surveys of Naked Island, Prince William Sound, Alaska, before and after the *Exxon Valdez* oil spill. Counts for 1989 were tested separately for a decline from pre-spill counts with an outlier t-test (df=2 for all tests). All numbers were log-transformed for analysis. See Figure 2 for area locations.

	Number of Murrelets Counted in Area							
Year	Cabin Bay	Outside Bay	Bass Harbor	East Side	McPherson Bay	McPherson Pass	NW Side	Total
Before Spill								
1978	67	25	62	5	47	15	9	230
1979	77	17	7	20	71	6	1	198
1980	106	34	38	31	77	43	18	347
After Spill								
1989	17	18	3	12	18	8	1	76
1990	42	9	25	6	27	122	14	245
1991	48	0	12	8	46	30	2	146
1992	88	25	13	18	44	28	14	230
Outlier t-test								
1989								
t	-5.78	-0.75	-1.62	-0.18	-4.13	-0.59	-0.97	-3.56
p	0.01	0.26	0.01	0.44	0.03	0.31	0.22	0.04

Table 3. Number of marbled murrelets counted on shoreline surveys of Storey and Peak islands, Prince William Sound, Alaska, in June and July. Mean counts before and after the spill were tested with a t-test and 1989 was tested separately against pre-spill counts with an outlier t-test. All numbers were log-transformed for analysis. Dashes (--) mean no count was made.

	Storey Island		Peak Island	
	June	July	June	July
Before Spill				
1978	37	11	49	69
1979	41	--	44	--
1980	--	74	--	94
After Spill				
1989	5	214	5	52
1990	132	361	73	59
1991	54	--	26	--
1992	60	--	32	--
t-test -2 means (pre vs post spill)				
t	0.026	-2.30	0.81	2.24
p	0.49	0.07	0.23	0.08
df	3	2	4	2
Outlier t-test				
1989				
t	-23.09	1.22	-23.91	-1.63
p	0.014	0.78	0.013	0.17
df	1	1	1	1

Table 4. Number of marbled murrelets counted during June shoreline surveys of oiled and unoiled areas[a] of Naked, Storey and Peak islands, Prince William Sound, Alaska, before and after the *Exxon Valdez* oil spill.

Year	Number in Unoiled[b]	Number in oiled[c]	Proportion in oiled
Before Spill			
1978	255	61	0.19
1979	192	91	0.32
After Spill			
1989	56	30	0.35
1990	403	47	0.10
1991	170	58	0.25
1992	246	76	0.24

[a] Each section of shoreline was classified as predominately oiled or unoiled based on a map showing "Cumulative Oil Impact" as of August 21, 1989 (Exxon Valdez Oil Spill Damage Assessment Geoprocessing Group 1990).

[b] Areas considered unoiled were Cabin Bay, Outside Bay, Bass Harbor, and McPherson Passage on Naked Island, Peak Island, and Storey Island.

[c] Areas considered oiled were McPherson Bay, East Naked and NW Naked Island.

Table 5. Mean densities of *Brachyramphus* murrelets (no. birds/km^2) on 6 offshore transects in Kachemak Bay, Alaska, which were repeated in 1988 and 1989 between 7 June-12 July. There was no significant difference between years. See Figure 3 for location of transects.

Transect	N 1988	N 1989	Mean Density 1988	Mean Density 1989	Difference 1988-1989
K1	1		7.6	10.4	+2.8
K2	1	3	69.1	100.2	+31.1
K3	1	3	55.1	33.8	-21.4
K4A	1	3	31.1	10.2	-20.9
K71A	3	1	41.1	18.8	-22.7
K8	10	6	32.7	20.1	-12.5

Table 6. Densities of *Brachyramphus* murrelets (birds/km^2), by date and location (Inner and Outer Bay) in Kachemak Bay, Alaska, in 1988 and 1989. Mean = average murrelet density for those dates, SD = standard deviation, N = number of days the transects (4 in Inner Bay, 6 in Outer Bay) were surveyed. See Figure 3 for the transect locations. Dashes (--) mean no counts were made.

	Murrelets Km^2	Period 1 (7 May-6 Jun)	Period 2 (7 Jun-12 Jul)	Period 3 (13 Jul-5 Aug)	Period 4 (6 Aug-5 Sep)	Murrelets/Km^2 for all Survey days
Inner Bay						
1988	Mean	--	35.0	57.5	--	50.0
	SD	--	--	28.9	--	24.3
	N	--	1	2	--	3
1989	Mean	35.0	33.7	--	19.0	31.7
	SD	20.5	2.31	--	--	10.9
	N	2	3	--	1	6
Outer Bay						
1988	Mean	18.2	14.7	45.3	--	20.6
	SD	7.4	4.8	12.5	--	12.9
	N	6	10	3	--	19
1989	Mean	18.0	16.7	--	60.3	29.9
	SD	--	--	--	24.3	24.3
	N	1	6	--	3	10

Table 7. The number of marbled murrelets and percentage of juveniles counted during shoreline surveys conducted between 25 July-15 August at Naked, Storey and Peak islands, Prince William Sound, Alaska, before and after the *Exxon Valdez* oil spill.

Year	Survey Area	Total Number of Murrelets	Percentage of Juveniles
Before Spill			
1978	Storey & Peak	80	6.25
1979	South Naked	14	14.29
After Spill			
1989	Storey & Peak	266	0.0
1990	Naked, Storey & Peak	592	0.67
1991	Naked	65	4.62
1992	Naked	222	4.95

Table 8. The mean percentage of juveniles per day, of the total number of marbled murrelets, counted on offshore transects at Naked Island, Prince William Sound, and at Kachemak Bay, Alaska, before and after the *Exxon Valdez* oil spill. Only surveys conducted between 4 July-15 August were used. Dashes (--) indicate no surveys.

	Naked Island Transects			Kachemak Bay Transects		
	Number of Days	Total Murrelets	Mean (±SD) percentage of Juveniles/day	Number of Days	Total Murrelets	Mean(±SD) percentage of Juveniles/day
Before Spill						
1978	15	1298	2.88 (3.29)	--		
1979	9	381	2.78 (4.12)	--		
1988	--			10	1756	1.98 (1.80)
After Spill						
1989	13	3765	0.40 (0.78)	7	622	2.09 (1.82)
1990	10	2279	0.83 (0.79)	--		

Table 9. Estimates of direct mortality of *Brachyramphus* murrelets from the *Exxon Valdez* oil spill in Alaska in 1989. Carcasses were identified as marbled murrelets (MAMU), Kittlitz's murrelet (KIMU) or unidentified murrelet (UNML). The total number of murrelets are *Brachyramphus* murrelets.

		Carcass Counts at Receiving Stations						
Region	Estimated[1] Recovery Rate	NO. MAMU Carcasses	Est.[2] MAMU Mortality	NO. KIMU Carcasses	Est.[2] KIMU Mortality	NO. UNML Carcasses	Est.[2] UNML Mortality	Est.[3] TOTAL Mortality
Prince William Sound	0.35	289	826	23	66	21	60	952
Kenai Peninsula	0.14	113	807	23	164	73	521	1,492
Barren Islands	0.49	17	35	4	8	14	29	72
Kodiak Island	0.06	64	1,066	1	17	71	1,183	2,266
Alaska Peninsula	0.02	45	2,250	0	0	27	1,350	3,600
Total		528	4,984	51	255	206	3,143	8,382

1. From Ecological Consulting Inc., 1991.
2. Based on recovery rate for that region and number of carcasses recovered.
3. Does not include the proportion of ancient murrelets, based on carcasses identified to species.

Figure 1. Timing and extent of surface oiling from the 1989 *Exxon Valdez* oil spill.

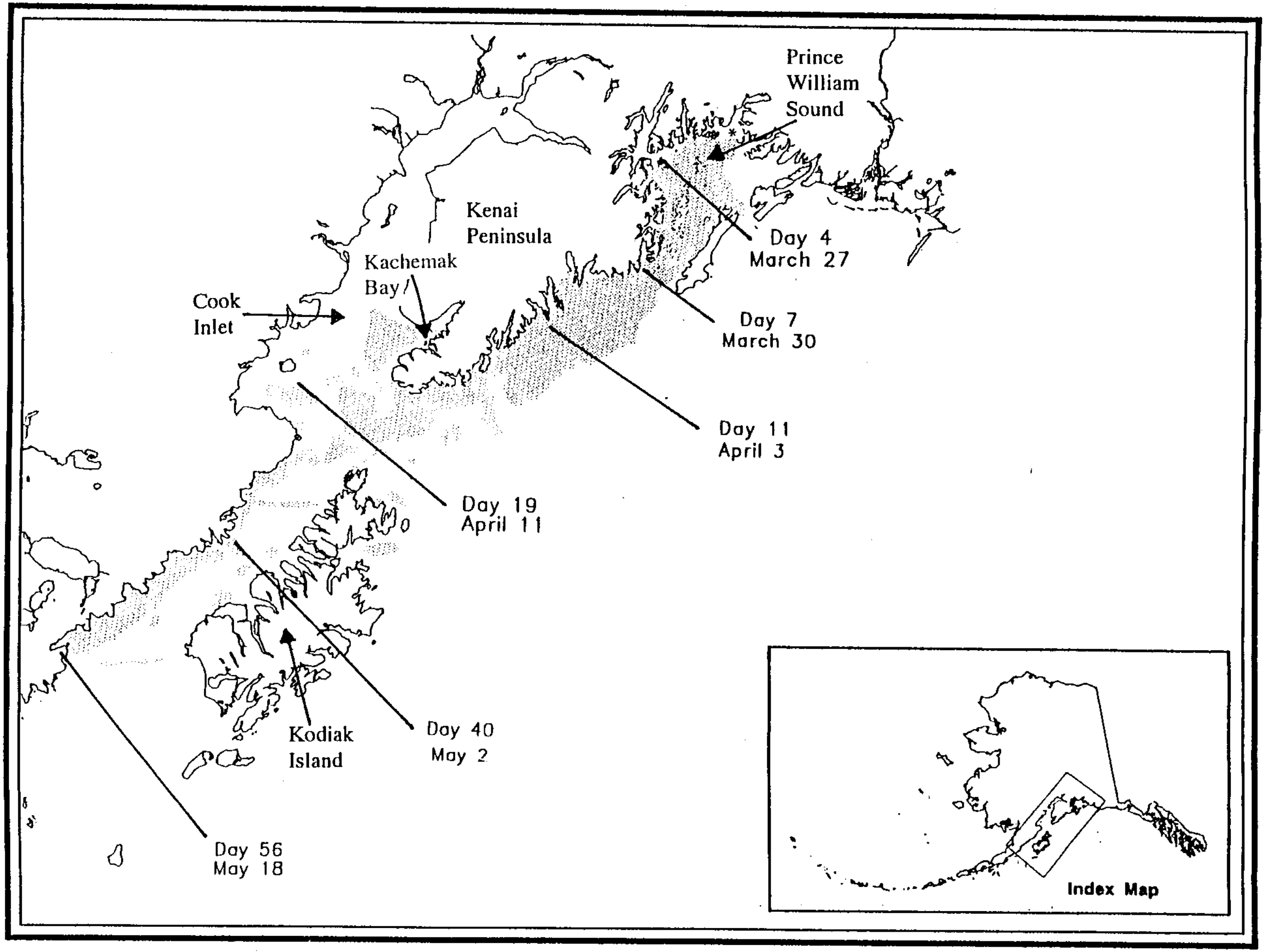

Prince
William
Sound
Kenai
Peninsula
Kachemak
Bay
Cook
Inlet
Day 4
March 27
Day 7
March 30
Day 11
April 3
Day 19
April 11
Day 40
May 2
Day 56
May 18
Kodiak
Island
Index Map

Figure 2. Location of study sites for Bird Study 6, the Naked Island group in Prince William Sound, and south inner and south outer Kachemak Bay, Alaska.

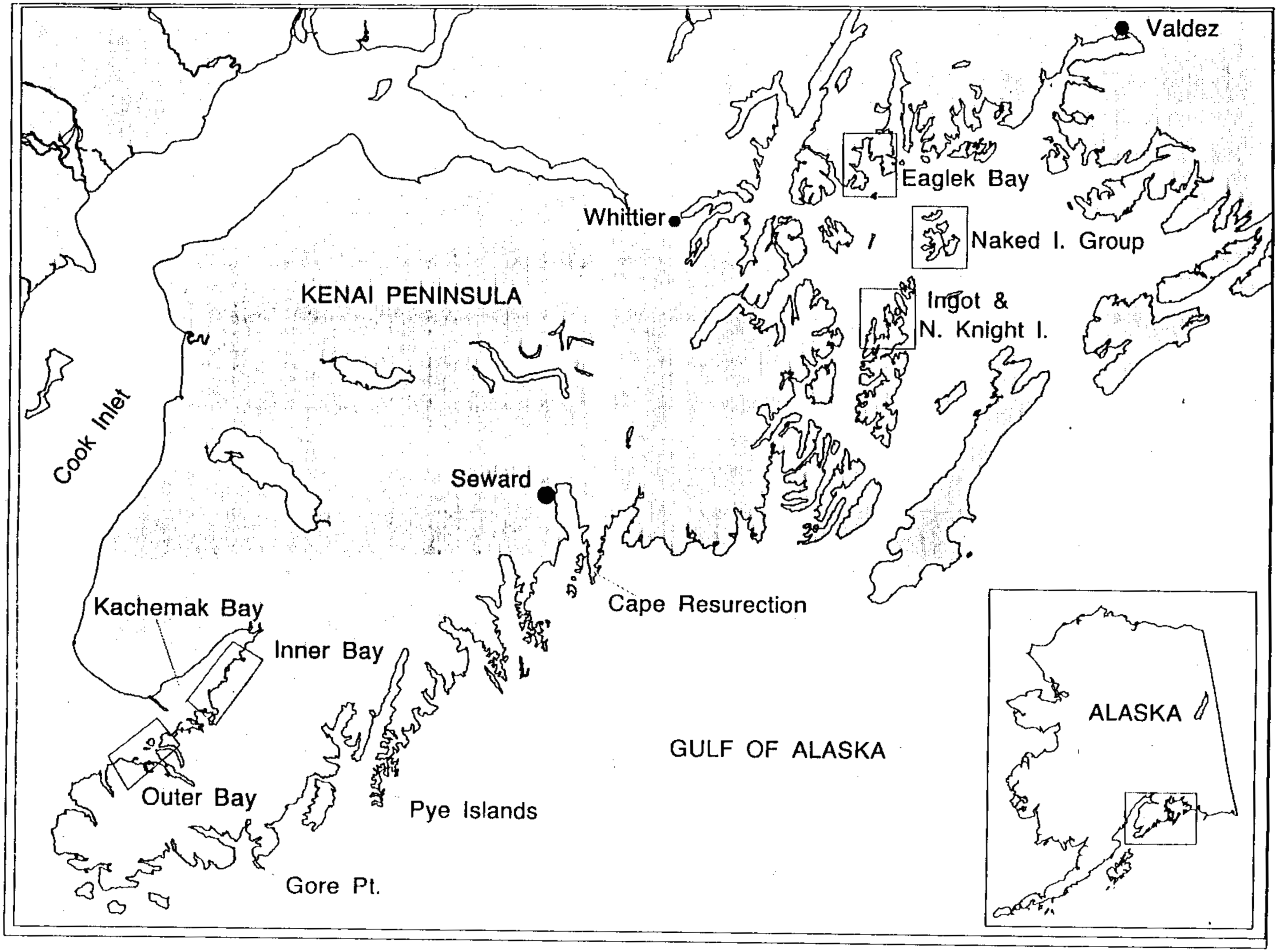
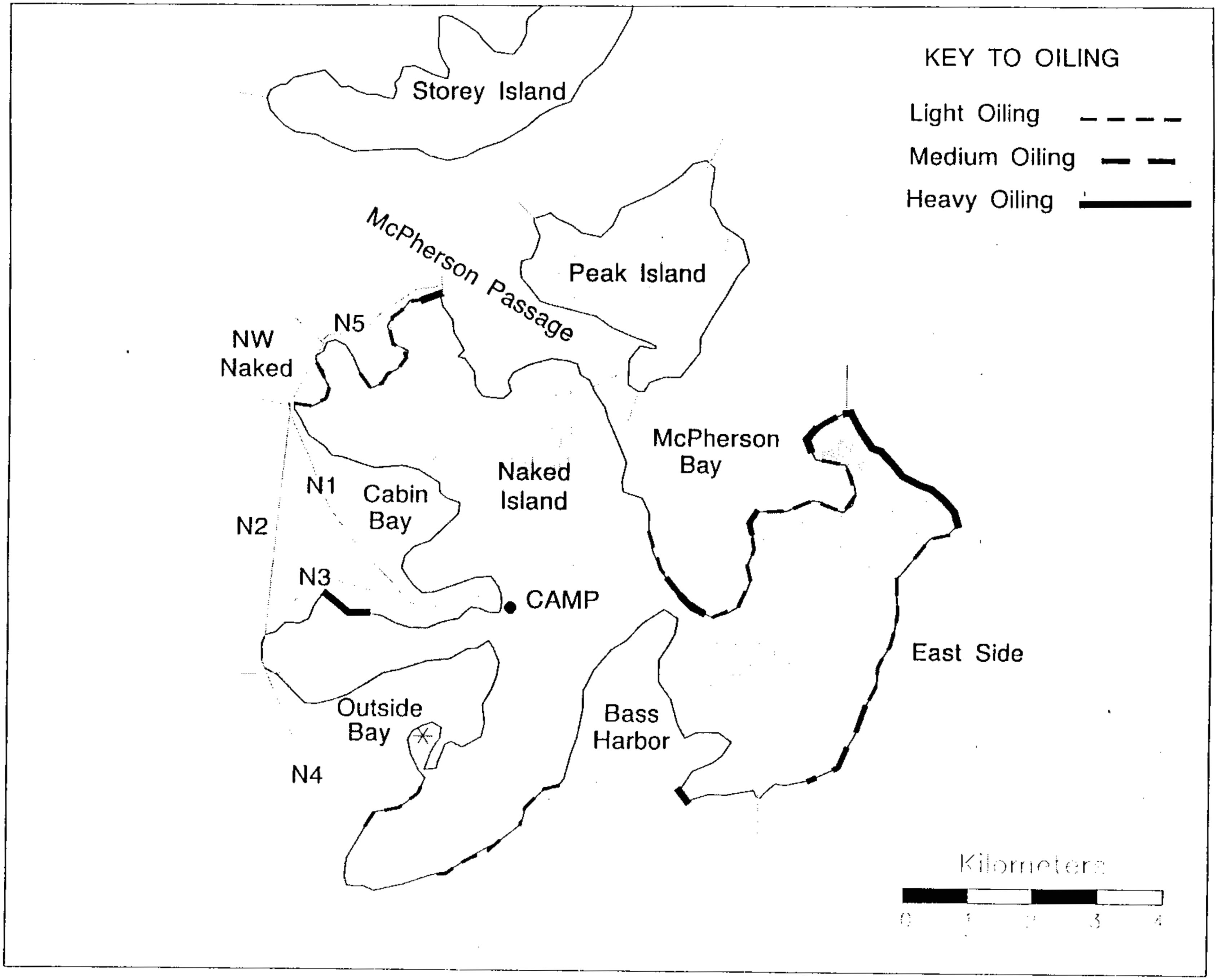
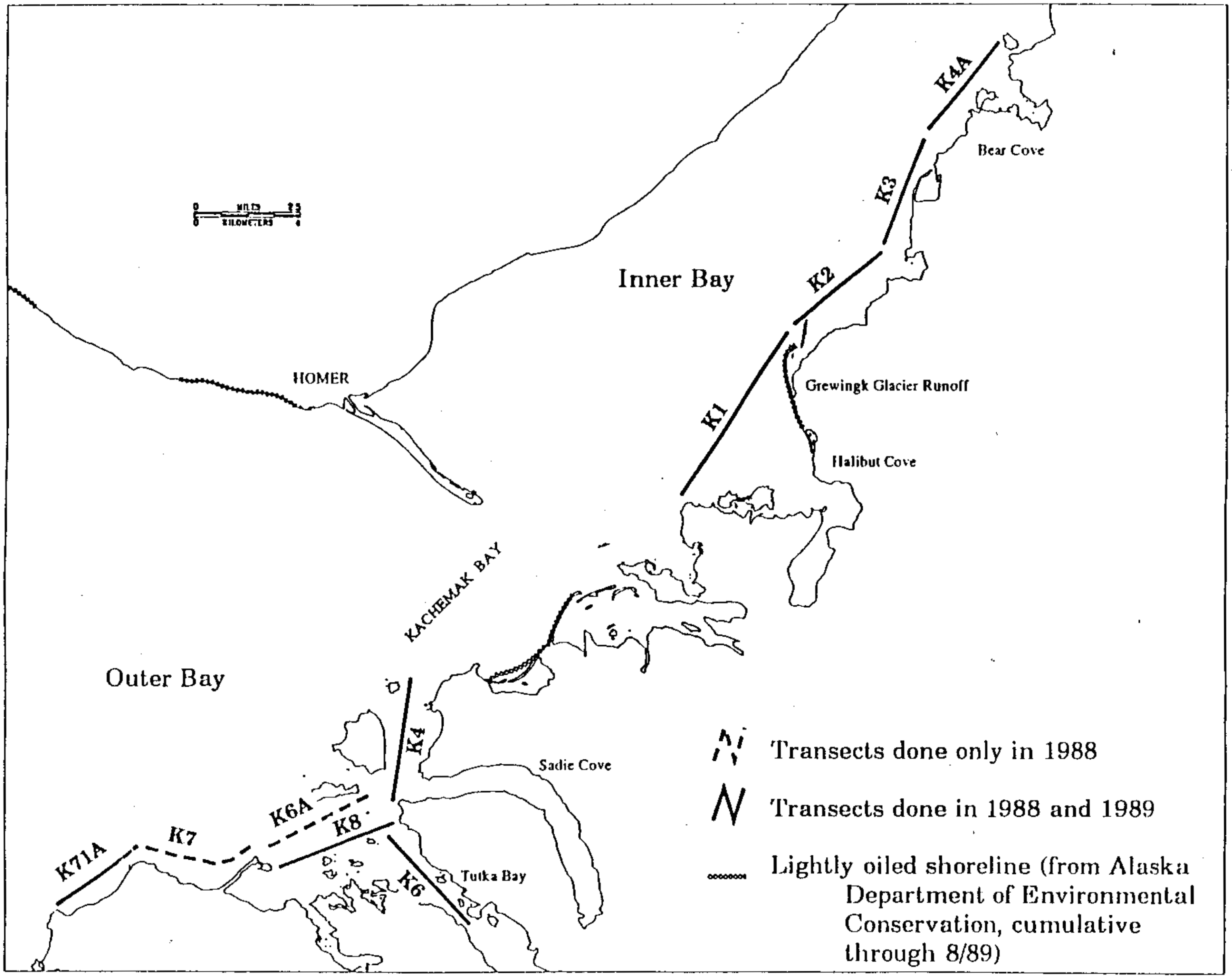

Valdez
Eaglek Bay
Whittier
Naked I. Group
Ingot &
N. Knight I.
KENAI PENINSULA
Cook Inlet
Seward
Cape Resurection
Kachemak Bay
Inner Bay
ALASKA
GULF OF ALASKA
Outer Bay
Pye Islands
Gore Pt.

Figure 3. The Naked Island study area and extent of shoreline oiling, cumulative to August 1989 (EVOSDAGP 1990). The five Naked Island transects (N1 - N5), boundaries of seabird survey areas and the land-based observation point (asterisk) are also shown.



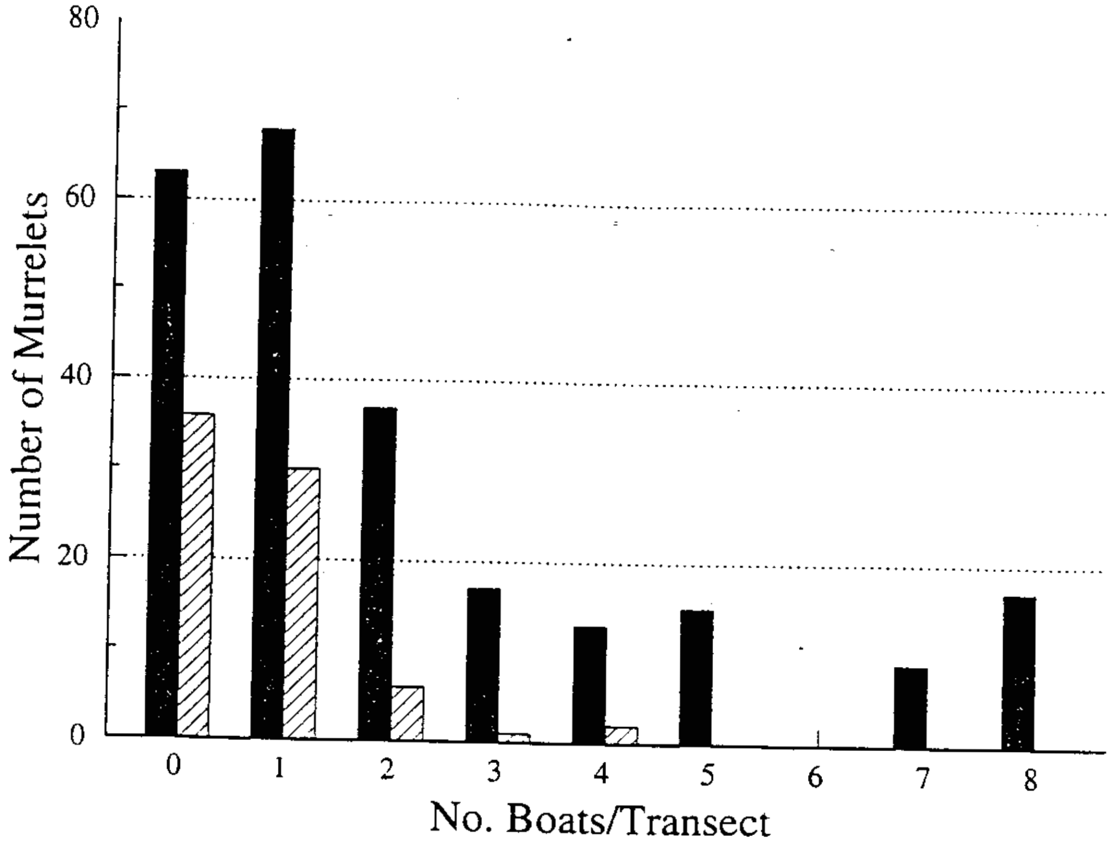
KEY TO OILING
Light Oiling
Medium Oiling
Heavy Oiling
Storey Island
Peak Island
McPherson Passage
NW Naked
N5
N1
Cabin Bay
Naked Island
N2
N3
CAMP
McPherson Bay
East Side
Outside Bay
Bass Harbor
N4
Kilometers
0
1
2
3
4

Figure 4. Kachemak Bay transects surveyed in 1988 and 1989 and the cumulative amount of oiling.



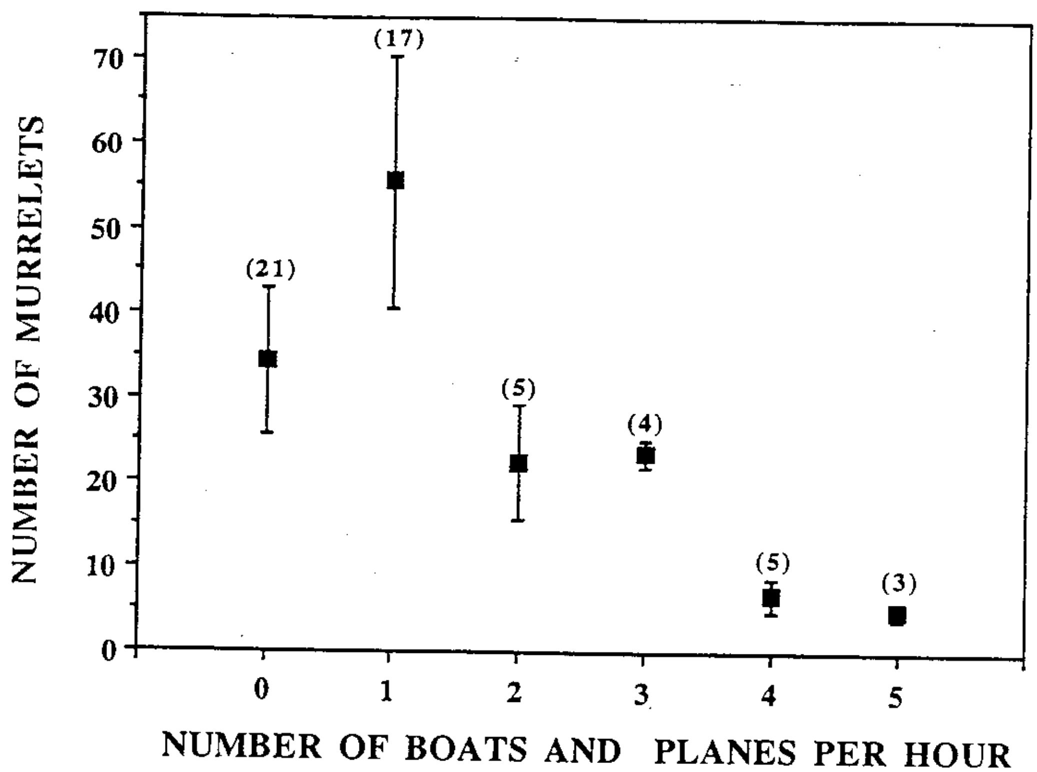
HOMER
Inner Bay
Outer Bay
KACHEMAK BAY
K4A
Bear Cove
K3
K2
Grewingk Glacier Runoff
K1
Halibut Cove
K4
Sadie Cove
K6A
K8
K7
K71A
K6
Tutka Bay
Transects done only in 1988
Transects done in 1988 and 1989
Lightly oiled shoreline (from Alaska Department of Environmental Conservation, cumulative through 8/89)

Figure 5. Average number of *Brachyramphus* murrelets counted per transect, relative to the number of boats counted on or near the transect, at Naked Island, Prince William Sound (hatched bars; n = 22) and at Kachemak Bay (black bars; n = 30), Alaska, during the summer of 1989.



80
60
40
20
0
Number of Murrelets
0
1
2
3
4
5
6
7
8
No. Boats/Transect

Figure 6. Mean and standard error for the number of murrelets per hour (n = 55) counted from a land-based site, relative to the number of boats and low-flying planes in the bay that hour. Counts were made in Outside Bay, Naked Island, Prince William Sound, Alaska, in June and July 1989.



NUMBER OF MURRELETS
70
60
50
40
30
20
10
0
(17)
(21)
(5)
(4)
(5)
(3)
0
1
2
3
4
5
NUMBER OF BOATS AND PLANES PER HOUR

APPENDIX

Variability In At-Sea Counts of Marbled Murrelets at Naked Island, Prince William Sound, Alaska

Following the 1989 Exxon Valdez Oil Spill in Alaska, I tested for changes in indices of murrelet abundance in the Naked Island area in central Prince William Sound. The historical data consisted of complete shoreline surveys of Naked, Storey and Peak islands and repeated surveys of five offshore transects on the western side of Naked Island. The transect routes and detailed survey methods were described in the main portion of this report (Kuletz 1994). Prior to testing for differences between pre and post spill murrelet numbers, I conducted preliminary analyses to determine if the Naked Island murrelet counts were biased by survey conditions. Based on these results, I determined which surveys could be used in the final analyses.

The shoreline surveys were relatively consistent in seasonal, diurnal, tidal and sea conditions, because the surveys were designed to census pigeon guillemots at their colonies during peak attendance. However, the offshore transects were surveyed opportunistically throughout the summer because they were frequently traveled routes among other seabird colonies. Murrelet counts repeated in the same area are highly variable, but the sources of variation have not been clearly established (Carter 1984, Carter and Sealy 1990). Potential sources of variation in murrelet counts at-sea include viewing platforms, sea conditions, seasonal and diel patterns, and tidal phases. For the Naked Island surveys, none of these factors were *a priori* controlled for, although the majority of surveys were conducted in calm seas before 1200 h.

The results presented below indicated that the aforementioned factors did not significantly bias these specific surveys. However, these surveys, and land-based counts of murrelets at-sea in the study area (see Methods, this report), revealed consistently low numbers of murrelets after mid-August, or from evening through dawn (1700 - 0500 h), or in seas with waves >0.6 m. Therefore, for the analyses of Naked Island offshore surveys presented in the main portion of this report, I did not include surveys that were conducted under any one of these conditions.

Viewing Platform

Most of the surveys at Naked Island were conducted from a 4 m inflatable raft, but some shoreline surveys of Storey and Peak Islands, and five of the offshore transect surveys in 1989, were conducted from a 7.7 m whaler. Because the higher viewing platform of the whaler could potentially increase murrelet detectability for observers, I tested for bias in murrelets counts between observers using the two platforms. I tested the null hypothesis that there was no significant difference between murrelet counts made by observers on the inflatable and the whaler by conducting 17 paired surveys of the five offshore transects at Naked Island. Within a two hour period, the same transect was surveyed by both boats. These surveys were conducted over five days in July, 1989. I used a paired comparison t-test (SAS Institute, 1988) to test for deviation from zero for the differences between murrelet numbers counted from the whaler and the inflatable.

There was a non-significant tendency for higher murrelet counts when surveys were conducted from the whaler. The mean number of murrelets counted from the inflatable was 31.4 (SD = 29.6) and the mean number counted from the whaler was 34.2 (SD = 25.7). The number of murrelets counted on paired surveys were not significantly different (N = 17, T = -0.34, P = 0.74). Therefore, I included the five offshore surveys conducted from the whaler in 1989 in the final analyses for this report. Similarly, the shoreline surveys conducted from the whaler were assumed to be comparable to shoreline surveys conducted from the inflatable.

Sea Conditions

I compared the number of murrelets observed with respect to sea conditions at the time of the survey using a General Linear Model (SAS Institute, 1988). Each year was tested separately, with all surveys combined within a given year. Sea conditions were sea state 0 (glassy), 1 (rippled or with small wavelets) or 2 (small wavelets to seas < 0.6 m). The few surveys conducted in seas > 0.6 m were not included in this or the final analyses, because our surveys under these conditions were rare and our ability to detect murrelets was obviously reduced. Sea state did not vary significantly by year (Chi-square = 14.8, DF = 8, P = 0.063), although there was a higher proportion of days with sea state 2 in 1989 and 1990. However, in post-spill years the sea state was averaged over conditions at the beginning and end of the survey, and the average was rounded up to the next whole number. This may have inflated the number of days with a rating of sea state 2.

The number of murrelets observed did not vary significantly with sea conditions in any year, although there was a trend of decreased numbers of murrelets with increasing wave activity (Table A.1). Sea conditions under which we surveyed did not significantly affect murrelet detectability and therefore we did not correct for sea conditions in the final analyses.

Seasonal Effects

I examined seasonal trends by graphing the number of murrelets by date throughout each year. Although numbers of murrelets peaked at certain times, the timing was not consistent among years (Fig. A.1). However, murrelet numbers were consistently lower by mid-August. Because no surveys were done during period 1 (5 May - 5 June) in post-spill years, I did not include this period in the final analysis. Because murrelet abundance after 5 August was consistently low, I did not include any offshore surveys done after 5 August in the final analysis.

I then tested for differences in murrelet abundance between period 2 (6 June - 12 July) and period 3 (13 July - 5 August) for all surveys combined and for each year, with Cochran's t-test (SAS Inst. 1990). The dates for periods 2 and 3 were based on the beginning of chick hatching in early June and chick fledging in mid July. Numbers at-sea typically increase once fledging begins (Sealy 1975, Carter 1984).

There was no significant difference in numbers of murrelets counted per transect between periods 2 and 3 overall (N = 282, T = 1.72, DF = 246.9, P = 0.086). In period 2, the average number of murrelets per transect was 56.4 (SD = 60.1) and in period 3 the average was 46.8 (SD = 31.9). For each year separately, the three pre-spill years did not show significant differences in murrelet abundance between periods 2 and 3, although period 2 tended to have higher numbers of murrelets per transect (Table A.2). Both post-spill years showed significant differences in abundance between periods, but their trends were opposite (Table A.2). Because surveys within these dates were either similar between periods or showed opposite trends, I combined surveys conducted in periods 2 and 3 for the final analyses.

Time of Day

The majority of offshore transect surveys were conducted between 0600 - 1200 h. However, in 1978 roughly half of the offshore surveys were conducted after 1200 h. I tested for differences between the number of murrelets before and after 1200 h for transects N1 and N3, the transects with the most repetitions in 1978. I found no significant difference between the number of murrelets counted before and after noon for transect N1 (N = 9, T = 0.62, DF = 7, P = 0.55) or for transect N3 (N = 9, T = 0.76, DF = 11, P = 0.46).

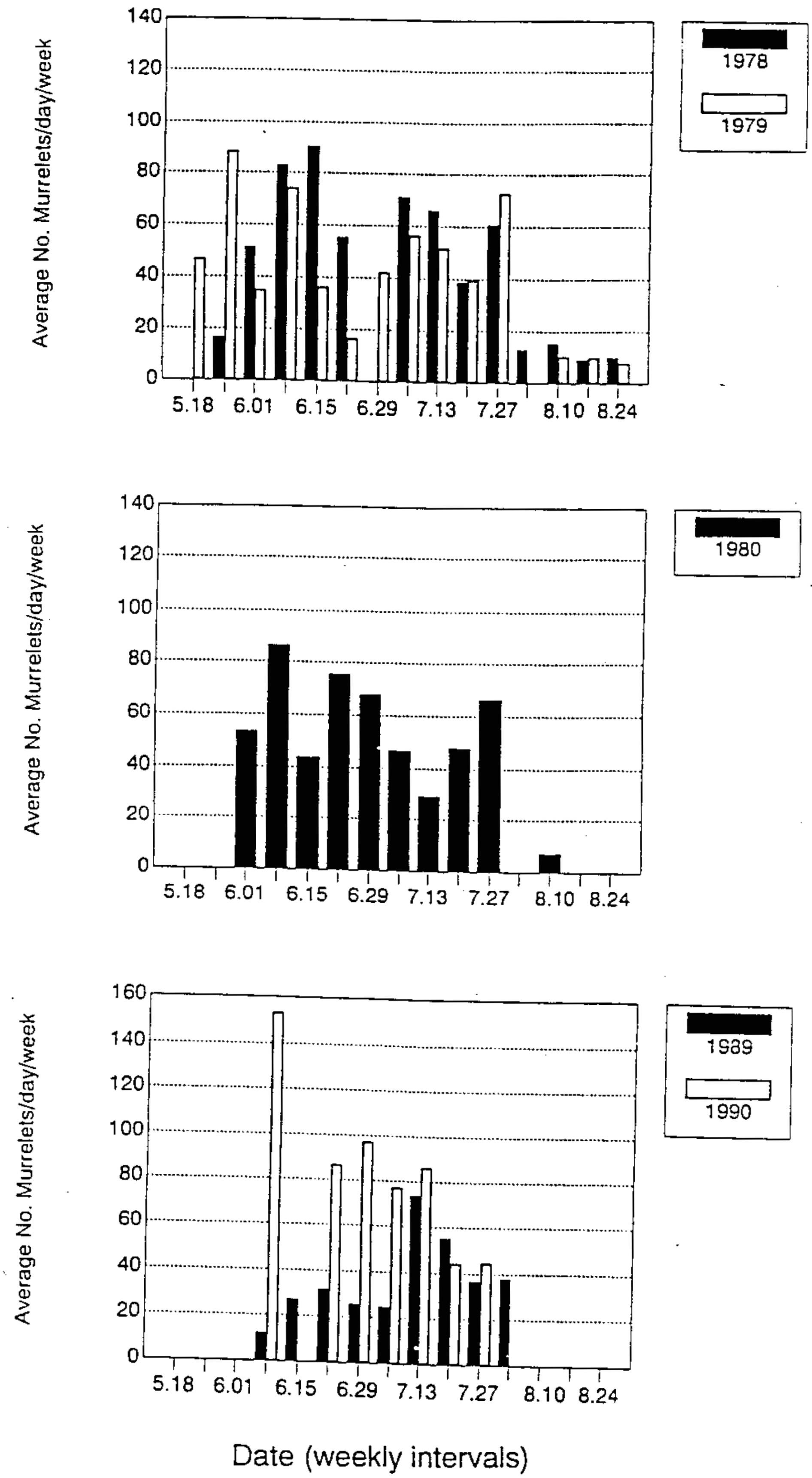
Land-based counts of murrelets in Outside Bay were highly variable over the course of the day, but the number of murrelets was consistently low before 0500 and after 1700 h. Based on the results from transects N1 and N3 and the observations from land-based counts, surveys conducted between 0500 - 1700 were included in the final analyses.

Tidal Phases

Because murrelets often feed nearshore on tidally influenced schooling fish such as sand lance, herring and capelin, the presence of murrelets may be influenced by tidal phases. Although murrelet presence may fluctuate with the tides, the effect may be very localized, and has not been predictable (Carter and Sealy 1990).

I tested for effects of tidal phase on the offshore transect counts of murrelets from 1978, 1979, 1980 and 1989, using three types of tidal phases. First, I tested for a difference between ebb and flood tides with a t-test. Second, I tested for a difference between high and low tides (two six-hour phases, with high being three hours before and after high tide and low being three hours before and after low tide). Finally, I used a General Linear Model (SAS Institute, Inc.) to test for differences among four tidal phases. The four, three-hour phases were: low flood (1-3 h after low tide), high flood (1-3 h before high tide), high ebb (1 - 3 h after high tide) and low ebb (1 - 3 h before low tide). None of these tidal phases showed significant differences in numbers of murrelets, although there was a non-significant trend of higher numbers of murrelets during ebb tides (Table A.3). Therefore, I did not use tidal phase as a factor in selecting surveys to include in the final analyses.

Figure A.1. The average number of murrelets per day, in weekly intervals, counted during offshore surveys on the west side of Naked Island, Prince William Sound, before and after the *Exxon Valdez* oil spill. The transects used for these surveys are described in the Methods section of this report and in Figure 3 of this report.



Average No. Murrelets/day/week
1978
1979
1980
1989
1990
5.18
6.01
6.15
6.29
7.13
7.27
8.10
8.24
Date (weekly intervals)

Table A.1. Number of marbled murrelets counted per transect under three types of sea conditions for 1978-1980 and 1989-1990, on five offshore transects at western Naked Island, Prince William Sound, Alaska. Sea state 0 = glassy, Sea state 1 = seas rippled or small wavelets, Sea state 2 = small wavelets to seas <0.6m.

Year	Sea state	Mean number of murrelets per transect ($\pm$ sd)		N	F	DF	P
1978	0	61.4	(46.8)	7	1.19	2,34	0.316
	1	46.9	(34.7)	24			
	2	30.7	(23.2)	6			
1979	0	72.6	(56.6)	8	3.03	2,27	0.065
	1	46.6	(17.8)	17			
	2	28.8	(19.9)	5			
1980	0	42.5	(36.2)	4	0.22	2,17	0.806
	1	47.5	(23.9)	13			
	2	36.3	(31.5)	3			
1989	0	40.1	(36.2)	25	1.44	2,124	0.240
	1	31.0	(27.7)	53			
	2	28.5	(23.9)	49			
1990	0	130.9	(125.5)	19	1.35	2,76	0.265
	1	114.5	(116.6)	35			
	2	80.2	(70.7)	25			

Table A.2. Number of marbled murrelets counted per transect during two survey periods on five offshore transects at western Naked Island, Prince William Sound, Alaska, in 1978-1980 and 1989-1990. The survey periods were Period 2 (7 June-12 July) and Period 3 (13 July-5 August).

Year	Survey Period	N	Mean number of murrelets per transect (± SD)		T	DF	P
1978	2	16	52.3	(39.8)	0.589	28.8	0.564
	3	20	45.1	(32.6)			
1979	2	16	57.1	(43.6)	0.403	19.9	0.696
	3	7	51.4	(23.2)			
1980	2	10	59.9	(22.7)	1.803	13.0	0.118
	3	6	41.8	(17.1)			
1989	2	67	23.7	(26.3)	-3.622	115.6	0.0006
	3	57	41.6	(28.3)			
1990	2	48	102.6	(78.0)	3.548	72.7	0.0007
	3	35	56.4	(38.8)			

Table A.3. The mean number of marbled murrelets counted on each offshore survey (transects N1-N5) in 1978, 1979, 1980 and 1989 at Naked Island, Prince William Sound, Alaska, relative to tidal phase. The murrelet counts were examined under three types of tidal phases, and tested with a T-test or General Linear Model.

Tidal Phase	N	Mean	SD	Test	DF	P
ebb[a]	96	42.9	34.4	T= 1.55	224	0.122
flood	130	36.4	28.9			
High[b]	88	38.2	33.7	T=-0.38	224	0.705
Low	138	39.9	30.0			
Low flood[c]	74	36.6	29.1	F=0.82	3;222	0.48
High flood	56	36.2	28.9			
High ebb	32	41.7	41.0			
Low ebb	64	43.6	30.9			

[a] Tide in two 6-hour phases: ebb and flood.

[b] Tide in two 6-hour phases: high (3 hours either side of high tide)
low (3 hours either side of low tide)

[c] Tide in four 3-hour phases:
Low flood = < 3 hours after low tide
High flood = < 3 hours before high tide
High ebb = < 3 hours after high tide
Low ebb = < 3 hours before low tide