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

Population, Reproduction and Foraging of Pigeon Guillemots at Naked Island, Alaska, Before and After the *Exxon Valdez* Oil Spill

Bird Study Number 9
Final Report

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Study History: Bird Study 9 was one of the original damage assessment studies initiated immediately after the spill. Although Bird Study 9 was canceled after 1989, data on pigeon guillemots nesting at Naked Island were collected in 1990-1992 by field crews stationed at Naked Island to carry out various marbled murrelet restoration studies. Results of Bird Study 9 have previously been reported in draft reports dated May 1990 and June 11, 1993. Results were also presented at the 1993 *Exxon Valdez* Oil Spill Symposium, and a paper under the title Population, reproduction and foraging of pigeon guillemots at Naked Island, Alaska, before and after the *Exxon Valdez* oil spill has been accepted for publication in the symposium proceedings.

Abstract: Following the 1989 *Exxon Valdez* oil spill in Prince William Sound (PWS), Alaska, we studied pigeon guillemots (Cepphus columba) breeding just 30 km from the grounding site. The post-spill population was 43% less than the pre-spill population, but we could not attribute the entire decline to the spill because a decline in the PWS guillemot population may have predated the spill. However, relative declines in the population were greater along oiled shorelines, suggesting that the spill was responsible for some of the decline. Reproduction appeared largely unaffected, but the cryptic nature of guillemot nests undoubtedly reduced our ability to detect failed nests. Nesting success was lower but the apparent cause--greater losses of chicks to predators--was not obviously related to the spill. Fledgling weight and growth rates of chicks and the rate at which adults delivered food to their chicks were not lower following the spill. The most likely explanation for the few effects observed is that oil was present on the surface waters of the study area for a relatively short period before the guillemots returned to begin their annual reproductive activities.

Key Words: Alaska, *Cepphus columba*, foraging ecology, oil spill, pigeon guillemot, population, Prince William sound, reproduction, *T/V Exxon Valdez*

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Following the 1989 *Exxon Valdez* oil spill in Prince William Sound (PWS), Alaska, we studied the population, reproduction and foraging of pigeon guillemots (*Cepphus columba*) breeding at Naked Island, just 30 km from the grounding site, to determine if any spill-related changes occurred.

We compared four years of post-spill population data and two years of post-spill reproduction and foraging data to pre-spill data collected during 1978-1981.

Most of the guillemots had not yet returned to the Naked Island area at the time oil was present, and few guillemots were likely killed there. We found that the population declined by 50%, but we could not attribute the entire decline to the spill because available data suggested a decline in the PWS guillemot population predated the spill. Relative declines in the Naked Island guillemot population were greater along oiled shorelines, suggesting that the spill reduced the population to some extent. The number of attending birds per active nest was higher in 1989 than in 1990, suggesting that in 1989 some pairs did not initiate nests or lost nests before we could find them.

Nesting chronology was not delayed, and hatching success was not lower following the spill. Nesting success was lower following the spill but the apparent cause--increased predation during the chick stage--was not obviously related to the spill. Fledging weight and growth rates of chicks and the rate at which adults delivered food to their chicks were not lower following the spill, indicating that the ability of adults to provision their chicks was not affected.

Schooling fish and bottom fish still composed the major types of prey fed to chicks, although schooling fish, particularly sand lance (*Ammodytes hexapterus*), were delivered less frequently after the spill. Based on minnow trapping of guillemot feeding areas, the availability of certain bottom fishes used by guillemots was not decreased following the spill.

The most likely explanation for the apparently low mortality is that oil from the *Exxon Valdez* was present on the surface waters of the study area for a relatively short period before most of the guillemots had returned to the area to begin their annual reproductive activities.

INTRODUCTION

In 1978, the U.S. Fish and Wildlife Service (USFWS) sent us to Naked Island, located in the center of PWS, Alaska (Fig. 1), to study the local seabird population, and one of us (Kuletz) carried out studies there through 1981 (Oakley and Kuletz 1979, Eldridge and Kuletz 1980, Kuletz 1981, Oakley 1981, Kuletz 1983). Our studies centered on the pigeon guillemot, a small diving seabird, which bred abundantly there. The impetus for these studies was the beginning of the transport of Prudhoe Bay crude oil from the Trans-Alaska Pipeline System terminus in Valdez to west coast and gulf coast refineries via supertankers. The tanker route lay 30 km to the east of Naked Island, and the USFWS wanted baseline data on the seabird population of the area in the event of a major spill.

Just such a spill happened on March 24, 1989, when the *T/V Exxon Valdez* ran aground on Bligh Reef spilling 11 million gallons of Prudhoe Bay crude oil into PWS. Oil from the spill eventually travelled over 750 km from the grounding site, affecting not only PWS, but the waters and shores of the Kenai Peninsula, the Kodiak archipelago, and the Alaska Peninsula. Roughly 35,000 bird carcasses were recovered from the spill area in the months following the spill, and total direct mortality from the spill was estimated to be a few to several hundred thousand birds, primarily common murres (*Uria aalge*) (Piatt et al. 1990, Ecological Consulting, Inc. 1991). This level of bird mortality due to a single spill was and remains unprecedented (Piatt and Lensink 1989).

The grounding site of the *Exxon Valdez* was only 30 km from Naked Island, and Naked Island was the first land mass to be hit by the oil. Oil was observed on the waters surrounding Naked Island between 29 March and 19 April, and oil remained on certain Naked Island guillemot colony sites throughout the 1989 breeding season. We returned to Naked Island in 1989-1992 to duplicate our earlier work and learn to what extent the spill affected the pigeon guillemot population. These post-spill studies formed Bird Study Number 9 of the Natural Resources Damage Assessment performed under the provisions of the Comprehensive Environmental Response, Compensation and Liability Act, the federal law governing oil spills at the time of the *Exxon Valdez* spill.

The pigeon guillemot, in the family Alcidae, breeds ubiquitously in small colonies on rocky shores throughout the eastern North Pacific (Ewins 1993). Guillemots feed in inshore waters, primarily on benthic fishes and invertebrates (Thoreson and Booth 1958, Drent 1965, Follett and Ainley 1976, Oakley 1981, Kuletz 1983). Nest sites are found in pre-existing cavities, generally rock crevices among talus boulders or on cliff faces (Drent 1965, Oakley 1981 and others). Guillemots lay a clutch of one or two eggs, and the young are nidicolous, remaining in the nest for a little over a month after hatching (Drent 1965). During this period, the adults feed the chicks by delivering single whole fish to the nest throughout the day (Thoreson and

Booth 1958, Drent 1965). The wintering habits of the pigeon guillemot are not well-known, but they appear to disperse throughout coastal waters.

Guillemots, because of their diving habit and coastal distribution, are among the bird species considered most vulnerable to oil spills (King and Sanger 1979). The oil from the *Exxon Valdez* spill could have affected the guillemots breeding at Naked Island by killing a large percentage of the population. Hatchability of eggs contaminated by crude oil is reduced due to the embryotoxicity of aromatic compounds in the oil (Lewis and Malecki 1984, Walters et al. 1987, Hoffman 1990), and reduced hatching success was another likely effect.

The oil could have had sublethal effects. Black guillemot (*C. grylle*) chicks dosed with weathered South Carolina crude oil and raised by their parents in their own nests, grew significantly slower than controls and had impaired osmoregulatory function (Peakall et al. 1980). Cassin's Auklets (*Ptychoramphus aleuticus*) dosed externally prior to egg laying abandoned nesting, and those that did not abandon nesting were delayed in egg laying by more than 20 days, presumably because egg formation was disrupted (Nero and Associates, Inc. 1987). Auklets dosed externally during incubation had a higher frequency of abandonment, lower hatching success and lower net breeding success than controls.

Oil from the *Exxon Valdez* was therefore most likely to have disrupted guillemot breeding at Naked Island by delaying egg laying, decreasing hatching success, increasing abandonment and slowing the growth of chicks. Guillemot breeding could also have been disrupted if the oil spill caused changes in the distribution and abundance of guillemot prey.

We found that the population was reduced following the spill but could not attribute the entire decline to the spill. Reproduction was probably disrupted to some degree in 1989, but based on the nests we were able to study, appeared largely unaffected. Foraging ecology of guillemots during chick provisioning was also not different, other than some changes in the apparent availability of certain prey species. We concluded that the spill had few effects on Naked Island guillemots most likely because the spill preceded the annual return of the guillemots to the area, and because the study area was not heavily oiled.

OBJECTIVES

1. Determine if the pigeon guillemot population of the Naked Island area declined following the *Exxon Valdez* oil spill.

2. Determine if the nesting chronology, nesting success, fledging weight and chick growth rates for pigeon guillemots breeding at Naked Island following the *Exxon Valdez* oil spill were different from prior years.

3. Determine if the rate of prey delivery and the types of prey fed to chicks by adult pigeon guillemots at Naked Island following the *Exxon Valdez* oil spill were different from prior years.

4. Determine if the relative abundance of guillemot prey at Naked Island following the *Exxon Valdez* oil spill was different from prior years.

Another objective of Bird Study 9 was to determine if petroleum hydrocarbons were present in adult pigeon guillemots, unhatched eggs, dead chicks or prey items in oiled areas. Results from this aspect of the study are presented in a separate report (Oakley and Wade ms).

The final objective of the study was to identify alternative methods and strategies for restoration of populations or habitat where injury is demonstrated. This objective is addressed in the Discussion section of this report.

METHODS

Study Area

General Characteristics.--The study area comprised the shorelines and nearshore waters of Naked, Peak, Storey, Smith and Little Smith islands, PWS (Fig. 2). PWS is a fjord-type estuarine system located off the northern Gulf of Alaska. The region is part of the Pacific coastal belt of spruce (*Picea sitchensis*) and hemlock (*Tsuga heterophylla, T. mertensiana*) forest (Cooper 1942). The islands of the study area are low and wooded to their summits. Shores in the Naked Island area are rocky and consist of cliffs, broken cliffs, and escarpments interspersed with boulder beaches. The climate of PWS is maritime, characterized by moderate temperature ranges and much precipitation.

The bathymetry and chemical and physical oceanographic properties of PWS have been described by Muench and Schmidt (1975). Surface water temperatures range from -2° to 18° C. Surface salinities are strongly influenced by input of glacial and river fresh water and range from 20 o/oo in summer to 30 o/oo in winter. PWS is deep, and the deepest part is an 800 m trench just west of Naked Island. The three main bays of Naked Island, and the passages between Naked, Peak and Storey islands, form a large area of waters less than 100 m in depth.

Oiling and Cleanup Activities.--Naked Island, located about 30 km southwest of the grounding site, was first hit with oil on 27 March, three days after the initial spill, when strong winds moved the oil southwest (Galt et al. 1991). The entire island was surrounded with oil from 29 March through 1 April. Naked Island waters were observed to be oiled on various days through 19 April.

Oiling of Naked Island beaches was variable--some beaches were heavily oiled, some were lightly oiled and some were unoiled. Booms were deployed in the southern cove of Cabin Bay, in inner Outside Bay, and at a private residence on the western side of Peak Island. The high energy beaches on the eastern side of Naked Island were heavily hit, but waves apparently removed much of the oil from these beaches early in the summer. The feasibility of using high-pressure cold water washing as a beach cleanup technique was tested on some McPherson Bay beaches during May. At the request of the USFWS, no Naked Island beaches were cleaned as part of the official cleanup until after the seabirds had completed breeding. Thus, beaches in protected bays of Naked Island remained oiled throughout the summer. The most heavily oiled beaches on Naked Island were treated, apparently using the bioremediation technique, in September 1989.

Fig. 2 shows the distribution of pigeon guillemot colonies on Naked, Peak and Storey islands, and the locations of the colonies on the western side of Naked Island where our studies were focused. We considered the beaches at the Parakeet Point, Row, Nomad, and South Cabin colonies to be heavily oiled. The beach at Hook colony was lightly oiled, and we found negligible oil on beaches at the Thumb, North Cabin and North Outside colonies.

Although Naked Island was not the center of cleanup activities for PWS, a number of spill-related activities occurred there. The *Exxon Valdez* was anchored in the mouth of Outside Bay from shortly after the spill until 22 June. A boom washing station was present in inner Outside Bay during June and July, and a kelp washing "task force" was present there during August. A dry dock, used for boat repairs and washing, was located in the eastern portion of McPherson Bay. The Naked Island area beaches were patrolled for oiled birds and mammals through mid-June by boat-based crews under contract to Exxon. The camp supporting Bird Studies 9 (this study) and 6 (marbled murrelets) was located in Cabin Bay. Due to these spill-related activities at Naked Island, considerable boat and plane traffic was present throughout the summer of 1989.

Population

To determine if the pigeon guillemot population of the Naked Island area declined following the *Exxon Valdez* oil spill, we examined changes in population census counts for the entire study area and maximum counts at the five colonies where our reproductive studies were focused. We also considered the change in the proportion of the population attending colonies in oiled sections of the shoreline.

Population Census.--The pigeon guillemot population of Naked, Peak, Storey, Smith and Little Smith islands was censused by circumnavigating each island in a small boat between 50 and 100 m from shore and counting all guillemots (Nettleship 1976, Cairns 1979). All censuses were conducted between 04:00 and 10:00 (Alaska

Daylight Time) when tides were high in good weather. In all years except 1989, censuses were conducted during the first week of June (3-6 June), when the maximum number of breeding birds attending colonies is thought to occur. In 1989, due to logistic constraints, Naked Island was censused 13-14 June, and Peak and Storey islands were censused 17 June; the Smith islands were not censused. In 1978, 1989 and 1990 censuses were repeated in late July when nonbreeders, not present earlier in the breeding season, are believed to be present (Drent 1965, Nelson 1987).

Maximum Colony Counts.--We compared the maximum number of guillemots counted at the Nomad, Thumb, Row, Hook and Parakeet Point colonies in each year. Counts were made during population censuses, chick food watches, nest check visits, and transects. Population censuses were timed to obtain a maximum count, and each colony was censused at least once each year. Except in 1978, watches to observe adults provisioning chicks were made at most of the colonies. During these watches, which generally lasted at least 6 hours, the number of guillemots present at the colony was counted hourly. Counts were also made during visits to colonies to search for nests or check on known nests. Colony counts were also made while conducting counts of birds from small boats on five transects in western Naked Island waters. Transects passed by all of the colonies except Hook, and the number of guillemots present at each colony was generally noted. We examined all counts made at each colony in each year to find the maximum count.

Proportion Attending Colonies Along Oiled Shorelines.--To determine whether shoreline oiling had local effects on the guillemot population, we compared the number of guillemots counted during June censuses of oiled and unoiled sections of the study area before and after the spill. We considered the shorelines of Cabin Bay, Outside Bay, Bass Harbor and McPherson Passage on Naked Island, Peak Island, Storey Island and the southwestern shore of Smith Island to be unoiled, and the shorelines of McPherson Bay and the eastern and northwestern shores of Naked Island, Little Smith Island and the northern and southeastern shores of Smith Island to be oiled (EVOSDAGP 1990). Since the population of the entire study area declined between pre-spill and post-spill counts, we considered whether the proportion of the population attending colonies along oiled sections of the shoreline was less than expected following the spill.

Reproduction

At Naked Island, pigeon guillemots nest in talus crevices, cliff crevices and cliff-edge burrows; the majority of nest sites are cryptic and inaccessible, or only partially accessible, to investigators (Oakley 1981). For this reason, estimates of reproductive parameters were based on observations at a relatively small number of accessible nests. Guillemot pairs typically re-use their nest sites (Drent 1965), and our sample of nests in each year included previously used nests and likely some of the same pairs observed in previous years.

In the 1978-1981 studies, reproductive data were collected from 85 accessible nest sites on the western side of Naked Island. The majority of these nests were located at five colonies--Nomad, Thumb, Row, Hook and Parakeet Point (Fig. 2). In 1984, Kuletz made brief visits to the Row, Nomad and Thumb colonies in June and August. In 1989, we were only able to relocate 40 of the known nest sites, and only 8 of these nests were used. We also found 64 new nest sites in 1989 of which 20 were accessible. In 1990, 71 of the previously known nests were relocated of which 62 were active. In addition, 34 new nests were found of which 18 were accessible for nesting studies. In all years, the status of each nest was checked once every several days throughout the breeding season. Five aspects of reproduction were compared: the number of active nests, chronology, success, fledging weight and chick weight growth rates.

Active Nests.--We used the number of active nests, defined as any nest in which at least one egg was laid, as a measure of nesting effort in each year. We compared the number of active nests at Nomad, Thumb, Row, Hook and Parakeet Point colonies in prior years with the number active in 1989 and 1990. Because the guillemot population declined, pre-spill to post-spill, we used the number of birds attending each colony, based on maximum counts, per active nest, to compare relative nesting effort between 1989 and 1990.

Chronology.--Because nests were only checked once every several days, exact laying, hatching and fledging dates were rarely known. The chronology of nesting for each year was therefore constructed from estimated dates of laying, hatching and fledging derived for all nests with sufficient nest check data. For each egg or chick, we estimated the dates of laying, hatching and fledging from whichever date was known with the least uncertainty. The mean length of the incubation period for Naked Island guillemots was unknown, so we used the mean values for incubation period of 32 d for first eggs and 30 d for second eggs found by Drent (1965) for British Columbia guillemots. From a small sample of chicks on Naked Island whose length of stay in the nest was known (n=8), we estimated the mean length of the chick period for Naked Island guillemots to be 36 d which was similar to the mean length of the chick period of 35 d for British Columbia guillemots (Drent 1965).

Success.--Mean clutch size and hatching, fledging and nesting success rates were calculated for each year. To avoid biasing our estimates of hatching and nesting success towards successful nests, we defined hatching and nesting success as the average number of chicks hatched or fledged per nest for all nests found during the egg stage. We defined fledging success as the mean number of chicks fledged per nest for all nests whether found in the chick or egg stage. Reasons for partial or complete nest failure were noted.

Fledging Weight.--Chicks in accessible nests were weighed with Pesola hand-held scales, typically once every 3-5 days. Mean fledging weight for each year was calculated using the weights of all chicks weighed within one week of fledging.

Chick Growth Rates.--We calculated the rate of change in weight (g/d) for each accessible chick during the period of straight line growth, reported by Koelink (1972) to occur between 8 and 18 days after hatching.

Foraging

We gathered information about guillemot foraging by observing adults feed their chicks. We determined the rate of food delivery and the types of fish fed to chicks during chick food watches. During a watch, an observer using a 15-45 power telescope and binoculars was stationed inside a blind for periods of 5-6 h. When an adult guillemot arrived with a fish, the time of arrival was recorded. The nest to which each fish was delivered and the times of delivery and departure were also recorded. Each fish was classified as either a schooling fish or bottom fish and identified to the lowest possible taxon. Schooling fish had a distinct silvery appearance and included Pacific sand lance, Pacific herring (*Clupea harengus pallasi*), and smelts (Osmeridae); bottom fish had a variety of shapes, sizes and colors and included blennies (Stichaeidae, Pholidae), sculpins (Cottidae), cods (Gadidae), ronquils (Bathymasteridae), and others (e.g., Zoarcidae, Agonidae, Pleuronectidae). Watches were conducted at each colony about every five days throughout the nestling period (mid-July to late August).

In 1979-1981, Kuletz (1983) conducted watches primarily at the Nomad, Thumb and Row colonies. She observed 17 nests in 1979, 11 nests in 1980, and 9 nests in 1981. In 1989, we observed deliveries to 21 nests at five colonies. The colonies included two of the three colonies studied by Kuletz (Row and Nomad) as well as two colonies in Cabin Bay (North Cabin and South Cabin) and a single colony in Outside Bay (North Outside). We did not conduct watches at Thumb colony because only one nest there had chicks in 1989. In 1990, we observed deliveries to 43 nests at the Nomad, Row, North Cabin, North Outside, and Parakeet Point colonies.

Relative Prey Abundance

Information on the relative abundance of pigeon guillemot prey species susceptible to minnow traps was obtained by setting minnow traps in tidal and subtidal waters on the western side of Naked Island used by guillemots for feeding (Fig. 3). Traps were set in 1979-1981 and 1989-1990; effort varied considerably among years (Table 1). In all years, each set consisted of three traps, baited with meat, bread, or vegetables set together for periods of 8 to 24 hours. Traps were set on the bottom in depths ranging from 3 to 25 m. The number of each species caught was recorded.

Data Analysis

To determine whether the spill affected the pigeon guillemots breeding at Naked Island, we compared pre-spill means to post-spill means using a two-sample t-test. Our alternative hypothesis was that the spill had a negative effect on guillemots, and all tests were therefore one-tailed. We used $\alpha = 0.05$ as the level of significance.

RESULTS

Population

Population Census.--Guillemots breed ubiquitously in the Naked Island area (see Fig. 2), and their general breeding distribution in 1989-1992 was not different from prior years (Appendix B). Although the general distribution of breeding guillemots was not different, the number of guillemots attending colonies in June 1989 was less than the number attending in prior years (Table 2). Pre-spill counts for the entire study area were around 2000 guillemots, and post-spill counts were about 1000 guillemots, indicating that the post-spill population was roughly half of the pre-spill population. Declines in June counts for populations around individual islands within the study area were found for Naked and Little Smith islands (Table 2).

Less data were available to evaluate changes in the number of guillemots attending colonies during July (Table 3). Generally, more guillemots were counted during July than in June; in 7 the 11 cases where a count was made of the number of guillemots attending colonies around an island in both June and July, more guillemots were counted in July than in June. As for June counts, post-spill July counts were lower than pre-spill counts.

Maximum Colony Counts.--The maximum number of guillemots counted at the five colonies on the western side of Naked Island where our reproductive studies were focused declined following the spill (Table 4; $t=-12.41$, $df=1.1$, $p=0.02$). As for the population of the Naked Island area as a whole, the number of guillemots attending these five colonies following the spill was roughly half the number attending before the spill.

Proportion Attending Colonies Along Oiled Shorelines.--The proportion of the population attending colonies along oiled shorelines declined following the spill (Table 5; $t=-8.10$, $df=3.0$, $p=0.002$).

Reproduction

Active Nests.--After the spill, the total number of active nests at the five colonies we studied was less than the number present before the spill (Table 6; t=-5.38, df=2.9, p=0.01). This decline matched the decline in the maximum number of guillemots attending these colonies (Table 3), thus making it difficult to discern any change in nesting effort.

A better measure of nesting effort was provided by comparing the number of birds attending the colony to the number of active nests. The maximum number of guillemots attending these colonies was stable between 1989 and 1990, but the number of active nests increased by 66%. The number of attending birds per active nest therefore declined from 4.5 birds/nest in 1989 to 2.5 birds/nest in 1990, suggesting that nesting effort increased in 1990.

Chronology.--Nesting chronology of guillemots at Naked Island after the spill was not delayed in comparison to chronology in pre-spill years (Table 7; egg laying: t=0.93, df=1.3, p=0.25; hatching: t=0.71, df=3.9, p=0.26; fledging: t=0.34, df=3.3, p=0.38).

Success.--As in pre-spill years, the majority of pairs laid 2-egg clutches, and mean clutch size was not lower following the spill (Table 8; t=-0.39, df=1.9, p=0.37). The mean number of chicks hatched per nest was also not lower following the spill (Table 9; t=1.18, df=2.8, p=0.83). The fledging success rate was lower following the spill (Table 10; t=-2.93, df=4.9, p=0.02), as was the overall nesting success rate (Table 11; t=-2.38, df=4.3, t=0.04). The lower rates of fledging success and overall nesting success following the spill appeared to be due to a higher incidence of nest loss due to predation, particularly during the chick stage (Table 12).

Fledging Weight.--Mean fledging weight of chicks following the spill was not less than the mean fledging weight of chicks raised in prior years (Table 13; t=-0.1750, df=1.7, p=0.44).

Chick Growth Rates.--Mean growth rates after the spill were not less than mean growth rates observed before the spill (Table 15; t=-2.13, df=2.8, p=0.07).

Foraging

Feeding Rate.--Guillemots at the five colonies we observed in 1989 delivered fish to their nests at a mean rate of 1.00 fish/nest/hour (f/n/h). In 1990, guillemots at these colonies delivered fish to their nests at a similar rate--0.95 f/n/h. Mean feeding rates in prior years were 1.06 f/n/h in 1979, 0.86 f/n/h in 1980 and 0.65 f/n/h in 1981. The mean rate at which guillemots delivered fish to their chicks following the spill was not less than the mean of mean feeding rates observed in pre-spill years (t=0.98, df=2.2, p=0.78).

Prey Species.--Both before and after the spill, the guillemots delivered the same types of prey to their chicks: schooling fish and bottom fish. In 1989, 36% of fishes observed delivered to chicks were identified as schooling fish; 54% were identified as bottom fish (Table 15). In 1990, schooling fish represented an even smaller percentage--only 10%--of fish delivered to chicks, while bottom fish represented 61% of fish deliveries. However, a relatively high percentage of all deliveries observed in 1990--25%--were not identified, making it difficult to make rigorous comparisons of prey use in 1990 with prey use in other years.

In general, the bottom fish species delivered to chicks were the same among years. Sculpins, gunnels and pricklebacks were typically the most important bottom fish species in chick diets. Cods were the only bottom fish species that showed major changes in their relative importance in chick diets. Cods were delivered much more frequently in 1989 and 1990 than in pre-spill years.

While the bottom fish species composing the chick diet were relatively stable among years, the schooling fish species delivered to chicks changed. Sand lance, which were the most important schooling fish in 1978 (Oakley 1981) and in 1979-1981 (Table 15; Kuletz 1983), represented only 14% of deliveries observed in 1989 and only 8% of deliveries observed in 1990. In 1989, herring were the most important schooling fish. Herring were never observed as food for guillemot chicks in 1978 (Oakley 1981) or in 1979-80 (Table 15). They were first observed in chick deliveries in 1981.

Relative Prey Abundance

Minnow traps set in tidal and subtidal Naked Island waters caught primarily shrimp and some bottom fishes, typically sculpins, gunnels, and pricklebacks (Table 16). The traps did not catch any schooling fishes.

In all years, minnow trapping was conducted ancillary to other work, and trapping effort varied too much among years to allow statistical comparison of 1989 and 1990 capture rates to those in prior years. However, minnow traps set in 1989 and 1990 caught the same species of shrimp and bottom fish caught in prior years, and the primary species groups were caught in the same relative abundance (shrimp > blennies > sculpins) as in prior years.

Among the fishes caught by the traps, some species were caught more regularly than others. Sculpins, crescent gunnels (*Pholis laeta*) and snake pricklebacks (*Lumpenus sagitta*) were numerically important in at least 2 of the 5 years when trapping was conducted. Following the spill, 2 blenny species that had not been caught before the spill were numerically important--daubed shanny (*L. maculatus*) in 1989, and arctic shanny (*Stichaeus punctatus*) in 1990.

DISCUSSION

Population

It is tempting to conclude that the spill was the cause of the decline we observed in the Naked Island guillemot population. However, available evidence suggests that few guillemots were present at Naked Island when the oil went through and that few guillemots were killed there. In addition, the PWS population as a whole may have been declining prior to the spill. These circumstances make it more difficult to reach a conclusion about the causation of the population decline we observed at Naked Island following the spill.

Oil from the *Exxon Valdez* was present on Naked Island waters from 29 March to 19 April 1989. At this time of year, the PWS guillemot population is lower and has a more dispersed distribution than in summer (Isleib and Kessel 1973, Klosiewski and Laing ms). Incidental observations suggest that few guillemots were present in the Naked area at the time of the spill and that only a small percentage of the Naked Island breeding guillemot population may have been killed directly by *Exxon Valdez* oil in the Naked Island area.

Steven P. Klosiewski and Kenton D. Wohl, USFWS, Anchorage (unpubl. data), surveyed birds within 200 m of shore at Naked, Peak and Storey islands on 27-28 March 1989, before the oil had surrounded Naked Island. They saw only 47 guillemots: 6 at Storey Island, 11 at Peak Island and 30 at Naked Island. In a similar survey conducted on 26 March 1989, Kimball Sundberg, Alaska Department of Fish and Game, Anchorage (pers. commun.) observed 10-15 guillemots while traveling by skiff from the head of Outside Bay, along the outer portion of Bass Harbor, around the east side of Naked Island, and along the shores of McPherson Bay to the private residence on Peak Island. D. Erickson, Dames and Moore, Homer, (pers. commun.) observed few guillemots in Bass Harbor and Outside Bay during this same time period.

These observations indicate that most of the breeding population of the Naked Island area had not yet returned to the island at the time of the spill. Because few guillemots were in the Naked Island area when the oil went through, relatively few guillemots were probably killed there. This conclusion is supported by the oiled bird recovery data. Most of the oiled birds recovered from beaches in the Naked Island area after the spill were waterfowl; only 2 of the 69 dead birds recovered were identified as guillemots (USFWS, Anchorage, unpubl. data). If Naked Island breeders were killed by the oil, they must have been killed elsewhere.

Possibly some Naked Island breeders were killed in the Naked Island area, and their carcasses were carried south with the oil. Of the 136 guillemot carcasses recovered from PWS beaches, the majority were found in the Knight Island area south of Naked Island (USFWS, Anchorage, unpubl. data).

What portion of the reduced number of guillemots present at Naked Island in 1989-1992 was due to the *Exxon Valdez* oil spill is also difficult to assess because the guillemot population of PWS as a whole appears to have declined since the early 1970s. Based on shoreline and open water boat surveys in the winters and summers of 1972 and 1973, Dwyer et al. (ca. 1975) estimated the summer population to be 15,000 birds and the winter population to be 4000 birds. They found 2.1 guillemots/km of shoreline surveyed, so the guillemot population within 200 m of shore at that time was probably about 10,000 birds. David B. Irons, USFWS, Anchorage, (unpubl. data) counted 4660 guillemots within 200 m of shore in his survey by boat of the entire PWS shoreline (4066 km) in the summers of 1984 and 1985 (1.1 guillemots/km). These data suggest that the PWS guillemot population declined, perhaps by as much as 50%, between the early 1970s and the mid-1980s.

The strongest evidence that the spill caused some of the population decline we found at Naked Island was the relatively greater decline in the number of guillemots attending colonies during June along shorelines that were oiled in 1989. How the spill would have caused this decline is unknown, given that few breeders were in the area when the oil went through. The most likely mechanism may be related to the guillemot's use of beach rocks at their colony sites. Guillemots socialize on the rocks at their colonies, particularly during pre-breeding when pair bonds are being formed and maintained. Guillemots walking on the rocks at their colonies could have come in contact with oil. Whether this type of contact would have caused enough oiling to result in death is unclear. Such oiling could have resulted in the transfer of oil from adults to their eggs. Death of eggs may have caused pairs to abandon nesting and leave the area prior to our June counts. In this case, the relatively greater decline in the population along oiled shorelines we observed may have been due to displacement rather than the death of birds. However, the relatively greater decline in the proportion of guillemots attending colonies along shorelines that were oiled persisted through 1992, indicating that the losses were not temporary.

Klosiewski and Laing (ms) also found evidence for a spill-related decline in the PWS guillemot population. The March guillemot population in the oiled zone of the PWS declined more than expected, based on the pre-spill to post-spill population change in the unoiled zone. These observations suggest that the spill was responsible for some of the decline in the guillemot population at Naked Island and within PWS as a whole.

Reproduction

We predicted that oil from the *Exxon Valdez* spill was most likely to have disrupted breeding by delaying egg laying, decreasing hatching success, increasing nest abandonment and slowing the growth of chicks. We observed none of these effects based on the nests we studied. Nesting chronology was identical to that observed in pre-spill years. Hatching success was not less, and chicks grew at similar rates and fledged at similar weights as in pre-spill years. We did not observe definitive cases of nest abandonment.

The primary difference in reproduction that we observed following the spill was a decreased nesting success rate which was due to an increased rate of nest loss during the chick stage from predation. Losses due to predation might have been indirectly related to the spill if the spill had affected prey availability. Guillemots rely on cryptic and inaccessible nests to avoid predation. Hungry chicks will come to the nest entrance and thereby become more vulnerable to predators. However, based on our chick feeding observations, food availability was not reduced. We found no obvious connection between the spill and the reduced nesting success we observed following the spill.

Although reproduction appeared to be largely unaffected by the spill, some disruption of breeding likely occurred in 1989. Nesting effort appeared to be less in 1989. We had difficulty finding nests in 1989, and some of this difficulty may have been because fewer pairs initiated nests. At the five colonies where we studied reproduction, the maximum number of birds attending did not change between 1989 and 1990, but the number of active nests increased 66%. This increase suggests that in 1989 some birds did not breed at all. Failure to breed could have been due to mate loss or physiological impairments related to ingestion of oil.

Alternatively, what appeared to us to be reduced nesting effort may have actually been an increased rate of nest loss during the egg stage. The guillemots at Naked Island nest in inaccessible and cryptic sites, and nests which do not hatch are difficult--if not impossible--to detect. Some of the attending birds that we thought failed to nest may have initiated nests but lost them early in the breeding season, possibly due to transfer of oil from the adults' legs and feet to the eggs. We suspect that there was some disruption of breeding for the guillemots during 1989 due to the spill.

Foraging

The foraging behavior of guillemots while provisioning their chicks did not change following the spill. Guillemots fed chicks at an average rate not less than in prior years; the diet still comprised schooling fish and bottom fish. Chick growth rates and fledging weights, which would be expected to reflect any significant decreases in the amount or quality of foods delivered to chicks, were not less. Starvation of chicks, which was an important cause of nest failure in 1981 when the weather was particularly bad (Kuletz 1983), was not observed as a cause of nest failure, except at one nest in 1990. These data support our conclusion that the spill did not cause any abrupt change in food availability.

Our minnow trap data suggest a similar conclusion for those prey species susceptible to minnow traps. The relative abundance of the primary species groups caught in minnow traps was not different between the early 1980s and 1989 and 1990, suggesting that the oil spill did not have an immediate detrimental effect on shrimp, sculpin or blenny populations at Naked Island. These findings are relevant to understanding prey availability for guillemots because all of the bottom fish species caught in traps were observed to be eaten by Naked Island guillemots or delivered by adults to their chicks (Oakley 1981, Kuletz 1983, this study). In addition, the majority of shrimps caught were pandalid shrimps, which adult guillemots at Naked Island are known to eat based on stomach contents analysis (Oakley 1981, Eldridge and Kuletz 1980).

Inferential information on relative prey abundance from chick feeding observations suggested changes in the availability of cods, herring and sand lance, pre-spill to post-spill. Cods were used more frequently after the spill, and sand lance were used less frequently. Herring were important in only year--1989. Whether changes in the apparent availability of these species were due to the oil spill is unknown.

Our observations based on chick feeding and minnow trapping that overall prey abundance did not decline following the spill are supported by the work of Laur and Haldorson (1993). They compared the subtidal fish populations in oiled and unoiled eelgrass (*Zostera marina*) and *Agarum/Laminaria* habitats in PWS, including sites at Naked Island, following the spill, and they found higher abundances of fish in oiled habitats. The higher abundance was due to higher numbers of the dominant young-of-the-year (YOY) fishes, including many of the species known to be eaten by Naked Island guillemots. These species included Pacific cod (*Gadus macrocephalus*), gunnels (Pholidae), greenlings (Hexigrammidae), arctic shanny, and sculpins. The relationship between the spill and the higher abundance of YOY fishes in oiled habitats was unclear. Greater numbers of pelagic larvae may have settled into oiled areas, YOY fishes in oiled areas may have had lower mortality following settlement, or juvenile fishes may have migrated into oiled areas following settlement. Ebeling et al. (1972) also found greater numbers of larval and YOY fishes in oiled sites relative to control sites after the 1969 Santa Barbara Channel oil spill.

Restoration of Guillemot Populations

Oil spills and chronic oil pollution from shipping have killed large numbers of seabirds, but whether such pollution has directly caused declines in seabird populations is debatable (Evans and Nettleship 1985). The pigeon guillemot and its Atlantic counterpart, the black guillemot, are among the few seabird species for which researchers have attributed declines in local populations to oil pollution. Rov (1982) reported a oil-related decline in a Norwegian black guillemot population. Heubeck and Richardson (1980) reported that the *Esso Bernicia* spill, which occurred in Scotland in the winter of 1978-1979, caused a decline in the black guillemot population there (Ewins and Tasker 1985, Nettleship and Evans 1985). Asbirk (1978) reported that the black guillemot population in the Danish Baltic Sea declined dramatically during 1965-1972, and he attributed the decline to the 7 major oil spills that occurred during the same period. Ainley and Lewis (1974), in their history of the marine bird populations of the Farallon Islands, California, from 1854-1972, attributed the decline in the pigeon guillemot population there during the early 20th century to oil pollution. Ships enroute to San Francisco Bay routinely discharged their ballast water near the Farallon Islands, and two major oil spills also occurred.

Local guillemot populations that are known to have declined due to oil pollution appear to have recovered relatively quickly. In Scotland, the black guillemot population apparently recovered within 7 years of the *Esso Bernicia* spill (Nettleship and Evans 1985). Once ships stopped discharging their ballast water near the Farallon Islands in the 1940s, the pigeon guillemot population there reached 1,000 birds by 1959, and the population reached its current--and nest-site limited--level of 2,000 birds by 1972 (Ainley and Lewis 1974). Most alcids lay a single egg clutch, and the larger clutch of the guillemot, typically 2 eggs, gives guillemots the potential to rebuild their populations faster than other alcid species.

No method of artificially restoring a decimated guillemot population is known. The Atlantic puffin (*Fratercula arctica*), also a cavity nester, was re-established in Maine by hand rearing chicks in nests at a former colony site (Kress 1982), and this method might also work for guillemots. Such a reintroduction program for guillemots could make use of the guillemot's ability to nest in artificial structures. Guillemot populations in some areas appear to be limited by the availability of nest sites, and guillemots are often found nesting in cavities in docks, bridges and other man-made structures in these areas (Divoky et al. 1974, Campbell 1977, Kyut et al. 1976, Byrd et al. 1974). By creating cavities with oil drums, driftwood and other debris, G. Divoky (unpubl. data) facilitated the increase of the black guillemot population on a barrier island in the Alaska Beaufort Sea. Because the guillemot population at Naked Island does not appear to be limited by nest sites, any reintroduction project using artificial nest sites, although feasible, would be inappropriate there.

Because the PWS guillemot population appears to have been declining, attempts to artificially restore the PWS guillemot population to its pre-spill level may prove futile. At this point, the causes of this decline are unknown. The decline could be related to some of the disturbances, both natural and anthropogenic, that have affected the PWS ecosystem in recent years. Such disturbances include the Great Alaska Earthquake of 1964, a gradual increase in sea surface temperatures since 1975, enhancement of salmon stocks and protection of sea otters (McRoy 1988). Further understanding of the causes of the long term decline is required to properly design any guillemot restoration project for PWS.

CONCLUSIONS

This study provided a case study of the immediate effects of a major oil spill on the population, reproduction and foraging of pigeon guillemots breeding at one site at the upstream end of the spill trajectory.

The oil spill did not decimate the Naked Island guillemot population. We found a 50% population decline, but because the regional guillemot population as a whole appeared to have declined prior to the spill, we could not attribute the decline we observed in our study area entirely to the spill. We also found that few guillemots were present in the Naked Island area at the time of the spill and concluded that if major mortality of Naked Island guillemots occurred, it occurred elsewhere. The strongest evidence we found that the spill reduced the population was that the proportion of the population attending colonies along oiled shorelines was less than expected following the spill. This decline was still apparent in 1992--three years after the spill.

The oil spill did not appear to significantly disrupt guillemot reproduction, but the cryptic nature of guillemot nests may have reduced our ability to detect one of the most likely effects of the spill--an increased incidence of unhatched eggs. Nesting effort appeared to be lower in 1989 than in 1990, but most attributes of nesting were not different following the spill. Nesting success was lower after the spill, but the proximate reason appeared to be an increased rate of nest loss during the chick stage due to predation; no specific link to the spill was apparent.

Foraging ecology of adults provisioning chicks was not different following the spill. Food availability was not decreased, and evidence gathered by others suggested that populations of some fishes used by guillemots for prey may have increased following the spill.

The most likely explanation for the apparently low mortality we observed is that oil from the *Exxon Valdez* was on the surface waters around Naked Island for a relatively short period before most of the guillemots had returned to the area to begin their annual reproductive activities. Although oil was cast upon shorelines at Naked Island, overall, the severity of oiling was much less than at places farther south within PWS. The amount of oil that remained in the study area was apparently not enough to cause the types of sublethal effects to guillemot reproduction that were predicted based on oil dosing studies.

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Table 1. Minnow trap effort in tidal and subtidal waters used by pigeon guillemots for foraging at Naked Island, Prince William Sound, Alaska, before and after the *Exxon Valdez* oil spill.

Year	Dates	Number of Days	Number of Sets[a]	Trap-hours	Number of Sites
Before Spill					
1979	June 13-15 July 7-8	5	12	668	6
1980	June 15 August 14-18	4	10	440	6
1981	July 8-11 August 10	3	6	200	4
After Spill					
1989	June 24-July 17	18	29	2500	25
1990	June 10-August 16	11	20	770	17

[a]Each set consisted of 3 traps set together for 8 to 24 hours.

Table 2. Counts of pigeon guillemots during June censuses at Naked, Storey, Peak, Smith and Little Smith islands, Prince William Sound, Alaska, before and after the *Exxon Valdez* oil spill. Dashes indicate no survey was conducted.

Year	Naked Island	Storey Island	Peak Island	Smith Island	Little Smith Island	Total
Before spill						
1978	1115	392	94	175	72	1965
1979	1226	495	150	301	58	2230
1980	891	--	--	--	--	--
After spill						
1989	615	193	73	--	--	--
1990	729	293	102	124	31	1279
1991	755	293	102	76	35	1261
1992	586	266	87	100	23	1062
t	-3.80	-3.22	-1.07	-2.14	-4.51	-5.99
df	2.7	1.4	1.1	1.1	1.5	1.6
p	0.02	0.07	0.23	0.13	0.05	0.03

Table 3. Counts of pigeon guillemots during July censuses at Naked, Storey, Peak, Smith and Little Smith islands, Prince William Sound, Alaska, before and after the *Exxon Valdez* oil spill. Dashes indicate no survey was conducted.

Year	Naked Island	Storey Island	Peak Island	Smith Island	Little Smith Island	Total (Except Naked)
Before spill						
1978	--	507	161	272	54	994
1980	--	649	130	344	58	1181
After spill						
1989	769	359	74	--	--	--
1990	--	397	105	161	22	685

Table 4. Maximum number of pigeon guillemots counted at five colonies on the western side of Naked Island, Prince William Sound, Alaska, before and after the *Exxon Valdez* oil spill. Number of counts shown in parens. Counts were made during population censuses, chick food watches, nest check visits and transects. Dashes indicate no survey was conducted.

Year	Nomad	Thumb	Row	Hook	Parakeet Pt.	Total
Before Spill						
1978	24 (5)	21 (3)	55 (12)	48 (6)	60 (13)	208
1979	30 (53)	28 (19)	52 (78)	47 (30)	70 (27)	227
1980	23 (111)	--	55 (143)	43 (12)	--	--
1981	21 (110)	22 (112)	44 (129)	--	--	--
After Spill						
1989	15 (91)	20 (20)	20 (100)	16 (13)	28 (19)	99
1990	21 (43)	6 (2)	29 (51)	15 (5)	24 (13)	95

Table 5. Number of pigeon guillemots counted during June censuses of oiled and unoiled shoreline sections[a] of Naked, Peak, Storey, Smith and Little Smith Islands, Prince William Sound, Alaska, before and after the *Exxon Valdez* oil spill. Dashes indicate no survey was conducted.

Year	Number in Unoiled[b]	Number in Oiled[c]	Proportion in Oiled
Before Spill			
1978	1139	709	0.3837
1979	1339	891	0.3996
After Spill			
1989	--	--	--
1990	899	380	0.2971
1991	895	366	0.2902
1992	784	278	0.2618

[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, Storey Island, and the southwestern shore of Smith Island.

[c]Areas considered oiled were McPherson Bay and the eastern and northwestern sides of Naked Island, Little Smith Island, and the northern and southeastern shores of Smith Island.

Table 6. Number of active pigeon guillemot nests at five colonies on the western side of Naked Island, Prince William Sound, Alaska, before and after the *Exxon Valdez* oil spill. Dashes indicate no survey was conducted.

Year	Nomad	Thumb	Row	Hook	Parakeet Point	Total
Before Spill						
1978	7	11	9	12	19	58
1979	8	6	15	14	10	53
1980	5	4	10	8	6	33
1981	4	5	7	--	--	--
After Spill						
1989	3	4	7	2	5	21
1990	4	3	13	2	12	34

Table 7. Nesting chronology of pigeon guillemots at Naked Island, Prince William Sound, Alaska, before and after the *Exxon Valdez* oil spill. Chronology constructed from known dates of laying, hatching and fledging using mean values for chick period (36 d) and incubation period (32 and 30 d, for first and second eggs, respectively).

	n	Mean Date	Median Date	Earliest Date	Latest Date
Egg Laying					
Before Spill					
1978	48	June 4	June 5	May 22	June 22
1979	62	June 4	June 4	May 22	June 25
1980	40	June 6	June 5	May 23	June 18
1981	25	June 2	June 2	May 22	June 28
After Spill					
1989	22	June 4	June 3	May 22	June 23
1990	43	June 8	June 7	May 24	June 28
Hatching					
Before Spill					
1978	40	July 4	July 3	June 23	July 24
1979	52	July 5	July 6	June 23	July 23
1980	19	July 10	July 7	July 3	July 20
1981	22	July 4	July 3	June 23	July 28

	n	Mean Date	Median Date	Earliest Date	Latest Date
After Spill					
1989	20	July 6	July 5	June 23	July 23
1990	41	July 8	July 7	June 23	July 24
Fledging					
Before Spill					
1978	38	August 10	August 10	July 29	August 29
1979	46	August 9	August 13	July 29	August 21
1980	15	August 14	August 11	August 6	August 24
1981	18	August 6	August 6	July 29	August 12
After Spill					
1989	16	August 9	August 8	July 29	August 23
1990	31	August 12	August 11	July 29	August 26

Table 8. Mean number of eggs per nest found during the egg stage (mean clutch size) for pigeon guillemots at Naked Island, Prince William Sound, Alaska, before and after the *Exxon Valdez* oil spill.

Year	Number of Nests	Mean Number of Eggs Per Nest Found During the Egg Stage	Standard Deviation
Before Spill			
1978	13	1.54	0.52
1979	33	1.85	0.36
1980	27	1.78	0.42
1981	22	1.59	0.50
1984	7	1.86	0.38
After Spill			
1989	7	1.57	0.53
1990	27	1.78	0.50

Table 9. Mean number of chicks hatched per nest found in the egg stage (hatching success rate) for pigeon guillemots at Naked Island, Prince William Sound, Alaska, before and after the *Exxon Valdez* oil spill.

Year	Number of Nests	Mean Number of Chicks Hatched Per Nest Found in the Egg Stage	Standard Deviation
Before Spill			
1978	9	1.22	0.83
1979	32	1.34	0.83
1980	20	1.05[a]	0.89
1981	21	1.14	0.79
1984	7	1.43	0.98
After Spill			
1989	7	1.43	0.79
1990	25	1.28	0.78

[a]Nests of birds subjected to netting and tagging for foraging studies were not included, but reproduction of neighboring pairs at colonies where netting and tagging occurred may have been affected (Kuletz 1983:49).

Table 10. Mean number of chicks fledged per nest found in the egg or chick stage (fledging success rate) for pigeon guillemots at Naked Island, Prince William Sound, Alaska, before and after the *Exxon Valdez* oil spill.

Year	Number of Nests	Mean Number of Chicks Fledged Per Nest Found in the Egg or Chick Stage	Standard Deviation
Before Spill			
1978	30	1.60	0.56
1979	23	1.48	0.73
1980	12	1.00[a]	0.85
1981	17	1.06	0.75
1984	6	1.17	0.75
After Spill			
1989	14	0.93	0.83
1990	29	0.79	0.76

[a]Nests of birds subjected to netting and tagging for foraging studies were not included, but reproduction of neighboring pairs at colonies where netting and tagging occurred may have been affected (Kuletz 1983:49).

Table 11. Mean number of chicks fledged per nest found in the egg stage (nesting success rate) for pigeon guillemots at Naked Island, Prince William Sound, Alaska, before and after the *Exxon Valdez* oil spill.

Year	Number of Nests	Mean Number of Chicks Fledged Per Nest Found in the Egg Stage	Standard Deviation
Before Spill			
1978	8	1.25	0.56
1979	30	1.13	0.73
1980	18	0.61[a]	0.85
1981	19	0.74	0.75
1984	7	1.00	0.75
After Spill			
1989	6	0.50	0.83
1990	24	0.68	0.79

[a]Nests of birds subjected to netting and tagging for foraging studies were not included, but reproduction of neighboring pairs at colonies where netting and tagging occurred may have been affected (Kuletz 1983:49).

Table 12. Reasons for nesting failure of pigeon guillemots at Naked Island, Prince William Sound, Alaska, before and after the *Exxon Valdez* oil spill.

Year	Number of Nests	Number of Nests in which at least one egg failed to hatch or chick failed to fledge due to:					
		Unhatched Egg[a]	Young Chick Death[b]	Depredation[c] of: Egg	Depredation[c] of: Chick	Starvation or Exposure	Unknown Reason
Before Spill							
1978	32	4	0	0	0	0	2
1979	30	6	1	2	1	1	4
1980	19	5	0	2	0	4	2
1981	22	6	1	2	0	6	0
After Spill							
1989	15	3	1	1	4	0	0
1990	38	2	1	3	4	1	5

[a]"Unhatched egg" includes eggs which failed to hatch due to infertility, embryo death or nest desertion.

[b]"Young chick death" refers to chicks, generally less than a week old, dying in the nest for no apparent reason.

[c]We rarely witnessed predators taking eggs or chicks, and most cases of nest failure due to predation were presumed based on disappearance of eggs or chicks. Possible predators include mink (*Mustela vision*) and northwestern crow (*Corvus caurinus*).

Table 13. Fledging weights of pigeon guillemot chicks raised at Naked Island, Prince William Sound, Alaska, before and after the *Exxon Valdez* oil spill.

Year	Number of Chicks	Mean Fledging Weight (g)	Standard Deviation	Minimum (g)	Maximum (g)
Before Spill					
1978	29	467	50	291	542
1979	17	506	49	427	590
1980	2[a]	517	73	466	569
1981	13	428	105	202	546
After Spill					
1989	10	507	52	420	570
1990	13	438	57	310	510

[a]Few chicks were measured in 1980 due to loss of nests from netting and tagging of adults for foraging studies (Kuletz 1983).

Table 14. Growth rates of pigeon guillemot chicks raised at Naked Island, Prince William Sound, Alaska, before and after the *Exxon Valdez* oil spill.

Year	Number of Chicks	Mean Growth Rate (g/d)[a]	Standard Deviation	Minimum (g/d)	Maximum (g/d)
Before Spill					
1978	15	19.6	5.5	7.4	31.7
1979	16	23.8	4.7	17.1	32.0
1980	1[b]	19.0	--	--	--
1981	11	19.2	6.1	11.4	34.3
After Spill					
1989	5	18.1	5.6	11.5	23.4
1990	12	16.6	4.2	10.1	23.6

[a]Mean number of grams gained per day during the period of straight line growth. In pigeon guillemots, this period occurs between 8 and 18 days after hatching (Koelink 1972).

[b]Few chicks were measured in 1980 due to loss of nests from netting and tagging of adults for foraging studies (Kuletz 1983).

Table 15. Percentage of fish observed delivered by adult pigeon guillemots to their chicks at Naked Island, Prince William Sound, Alaska, that were schooling fish and bottom fish, before and after the Exxon Valdez oil spill. SL=Pacific sand lance (Ammodytes hexapterus), HE=Pacific herring (Clupea harengus pallasi), SM=smelts (Mallotus villosus and other Osmeridae), UN=unidentified, TOT=total, BL=blennies (Lumpenus maculatus, L. sagitta, L. fabricii, Allolumpenus hypochromus, Pholis laeta, Apodichthys flavidus, Ronquilus jordani, Bathymaster signatus, Liparis spp., Stichaeus puctatus), SC=sculpins (Oligocollus maculosus, Triglops pingeli and unidentified sculpins), CO=cods (Microgadus proximus, Gadus macrocephalus, Theragra chalcogramma), OT=other bottom fish (Ophiodon elongatus, Sebastes spp., Lyposetta exilis, and unidentified bottom fish, IN=invertebrates (Rossia pacifica, Pandalus spp., and unidentified invertebrates).

Year and Sample Size	Schooling Fish					Bottom Fish					Other	
	SL	HE	SM	UN	TOT	BL	SC	CO	OT	TOT	IN	UN
Before Spill												
1979 (n=579)	55	0	0	0	55	19	14	1	2	36	>1	9
1980 (n=711)	35	0	0	0	35	30	9	7	6	51	1	13
1981 (n=493)	23	8	8	0	38	19	11	1	17	49	>1	13
After Spill												
1989 (n=565)	14	21	1	0	36	19	9	25	>1	54	0	10
1990 (n=906)	8	1	>1	3	13	28	9	14	10	61	>1	25

Table 16. Number of shrimp and fish caught in minnow traps set in tidal and subtidal waters used by pigeon guillemots for feeding at Naked Island, Prince William Sound, Alaska, before (1979-1981) and after (1989-1990) the *Exxon Valdez* oil spill.

Species	1979	1980	1981	1989	1990	Total
Shrimp[a]	136	80	63	607	146+[b]	1032
Fish	87	4	13	65	50	219
Cods						
Pacific tomcod (*Microgadus proximus*)	1	0	4	0	1	6
Sculpins						
tidepool sculpin (*Oligocottus maculosus*)	9	0	1	0	0	10
unidentified sculpin	2	0	3	7	4	16
Ronquils						
northern ronquil (*Ronquilus jordani*)	1	1	2	0	4	8
searcher (*Bathymaster signatus*)	1	0	0	0	0	1
Blennies						
crescent gunnel (*Pholis laeta*)	34	1	1	13	14	63
snake prickleback (*Lumpenus sagitta*)	29	1	0	21	1	52
y-prickleback (*Allolumpenus hypochromus*)	1	0	1	0	0	2
daubed shanny (*Lumpenus maculatus*)	0	1	0	24	0	25

Species	1979	1980	1981	1989	1990	Total
arctic shanny (*Stichaeus punctatus*)	0	0	0	0	12	12
unidentified blenny	9	0	1	0	11	21

a. Includes *Pandalus danae, P. hypsinotus, P. borealis, P. platyceros, Heptacarpus brevirostris, Eualus suckleyi, Crangon alaskensi*, and unidentified shrimp.

b. Not all shrimp caught were counted.

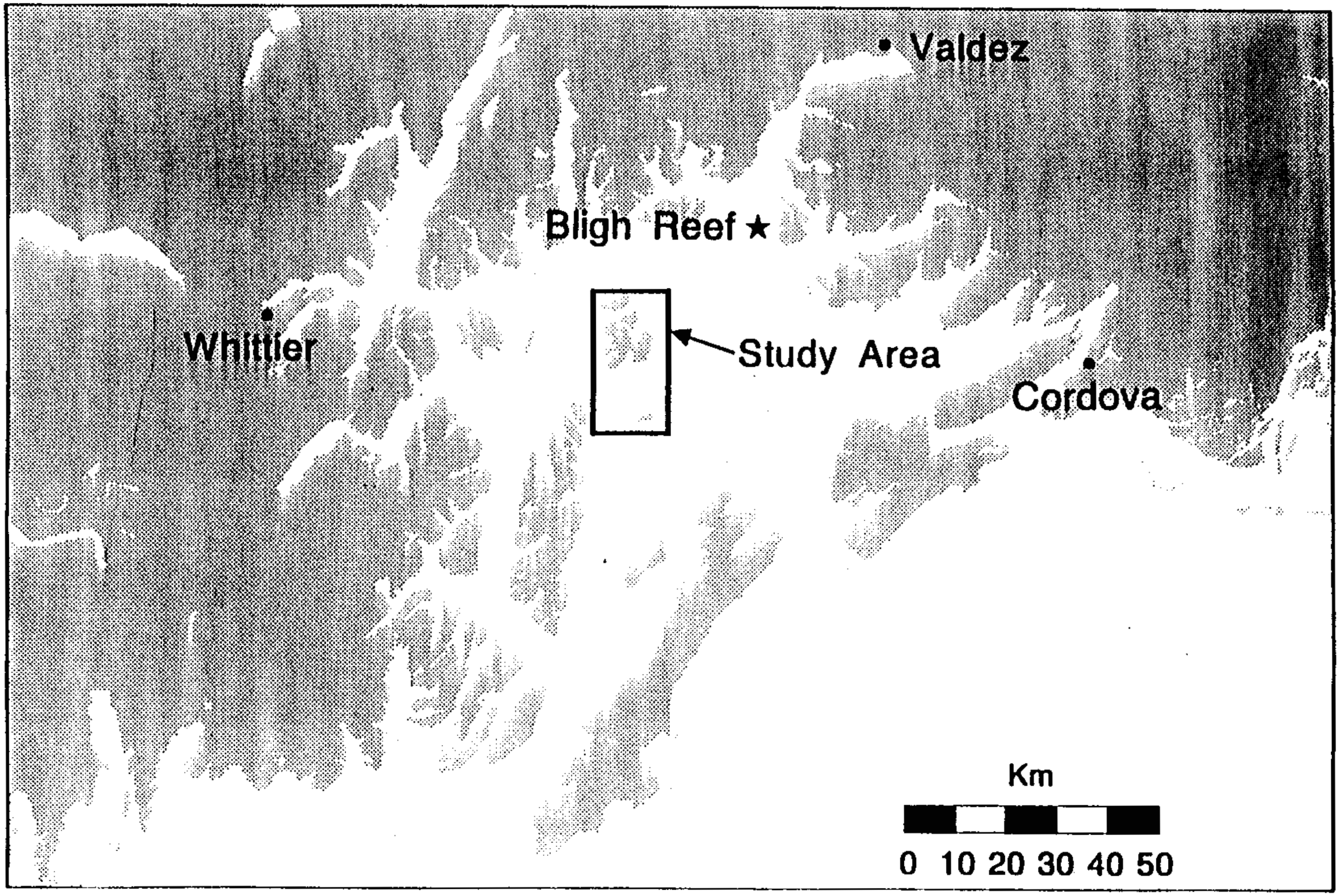

Fig. 1. Naked Island study area, Prince William Sound, Alaska.

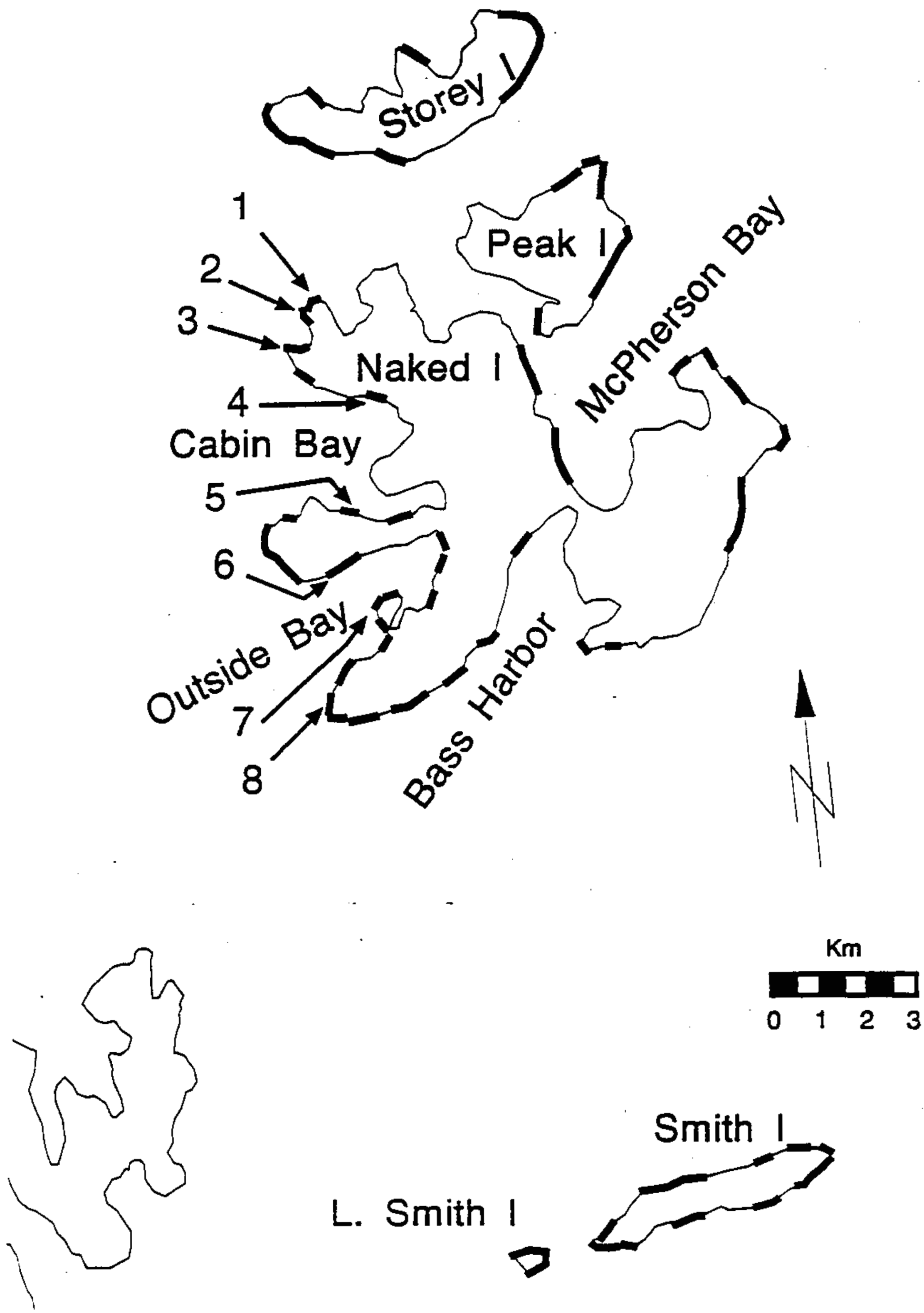

Fig. 2. Pigeon guillemot colonies (dark lines) of Naked, Storey, Peak, Smith and Little Smith islands, Prince William Sound, Alaska, showing the location of colonies on the western side of Naked Island where we conducted reproductive and foraging studies before and after the *Exxon Valdez* oil spill.

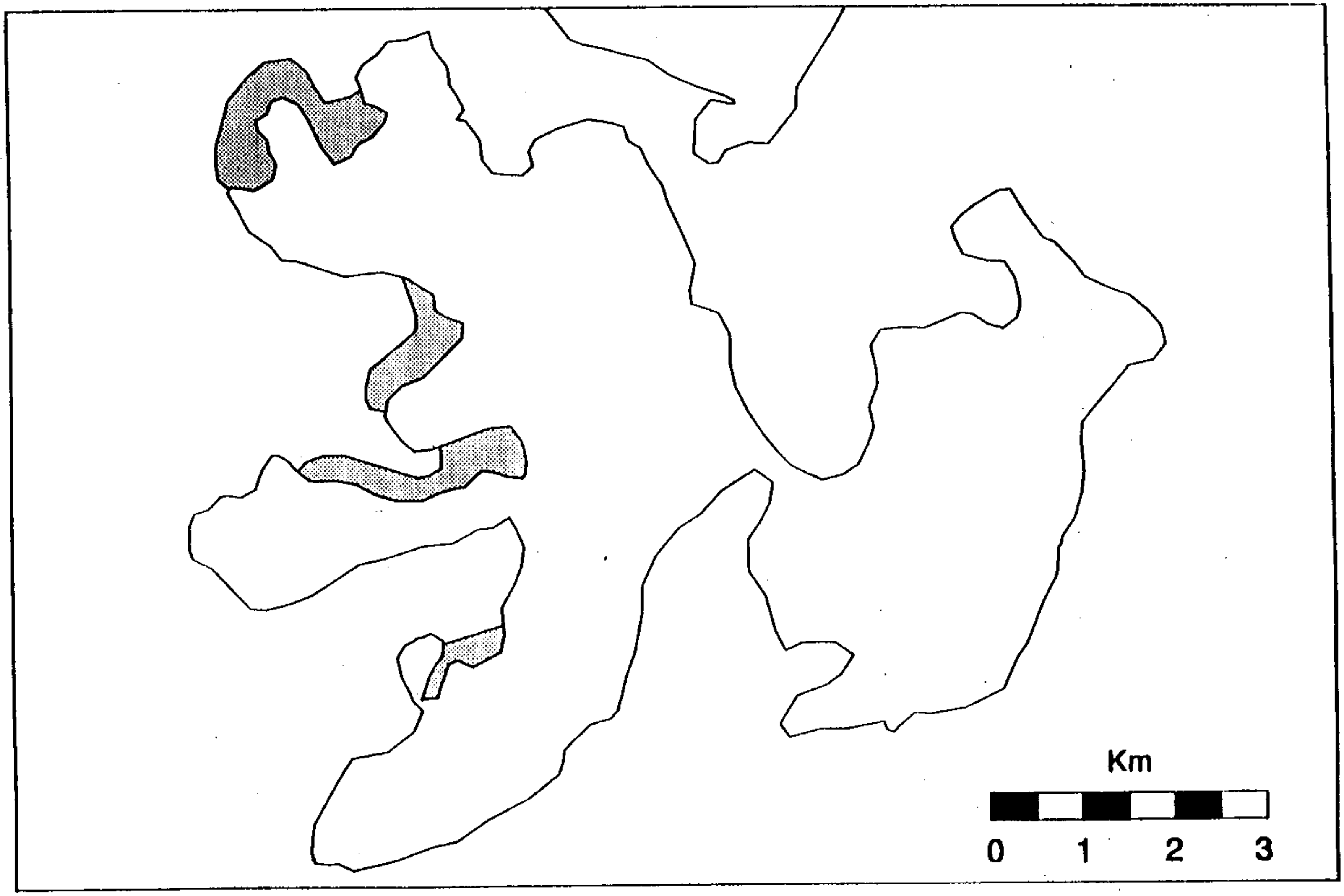

Fig. 3. Areas (shaded) where minnow traps were set in shallow tidal and subtidal waters used by pigeon guillemots for feeding at western Naked Island, Prince William Sound, Alaska, before and after the *Exxon Valdez* oil spill.

Appendix A

Number of pigeon guillemots counted by shoreline segment in June censuses at Naked, Peak, Storey, Smith and Little Smith islands, Prince William Sound, Alaska, in 1989-1992, after the *Exxon Valdez* oil spill. Location of shoreline segments in shown in Figure A-1.

Island and Shoreline Segment	1989	1990	1991	1992
Naked Island				
Cabin Bay				
1	22	15	20	16
2	17	13	7	20
3	37	39	38	41
42	11	20	21	16
43	34	26	26	29
44	5	3	1	3
45	6	0	0	3
46	3	2	1	1
Outside Bay				
4	19	4	18	12
5	42	5	28	26
6	10	27	28	11
7	3	20	5	1
8	5	17	5	9
9	11	14	9	10
10	35	32	34	17
11	10	7	4	5

Island and Shoreline Segment	1989	1990	1991	1992
12	1	9	6	4
13	0	3	53	13
14	25	22	6	10
Bass Harbor				
15	18	16	5	6
16	7	8	1	9
17	19	13	10	13
18	2	2	11	5
19	15	15	10	23
20	26	31	29	26
21	4	0	4	5
22	9	4	3	0
23	15	7	3	2
24	25	37	35	21
47		9	4	
48		5	3	
East Side				
25	13	9	13	11
26	7	7	7	7
27	34	46	36	38
28	13	32	20	1
29	7	16	18	14

Island and Shoreline Segment	1989	1990	1991	1992
McPherson Bay				
30	9	18	16	16
31	3	1	8	5
32	4	7	4	2
33	15	1	8	3
34	20	40	43	33
35	18	44	42	29
McPherson Pass				
36	0	13	15	17
37	3	6	11	8
NW Naked				
38	1	0	6	1
39	7	5	5	4
40	31	28	24	21
41	11	31	50	19
Storey Island				
49	0	12	8	13
50	24	41	22	49
51	19	43	25	33
52	16	9	16	14
53	22	50	53	42
54	3	4	3	5
55	33	15	28	27

Island and Shoreline Segment	1989	1990	1991	1992
56	11	22	25	20
57	10	20	36	11
58	23	33	29	14
59	14	43	35	24
60	7	0	0	14
61	11	1	13	0
Peak Island				
62	0	6	1	1
63	2	8	16	15
64	25	31	32	15
65	11	6	2	13
66	12	34	31	14
67	10	7	11	11
68	7	4	4	13
69	5	6	4	7
70	1	0	1	0
Little Smith Island				
71		18	17	6
72		13	18	17
Smith Island				
73		7	5	1
74		20	4	21
75		19	0	7

Island and Shoreline Segment	1989	1990	1991	1992
76		10	19	8
77		13	14	19
78		28	10	22
79		27	24	22

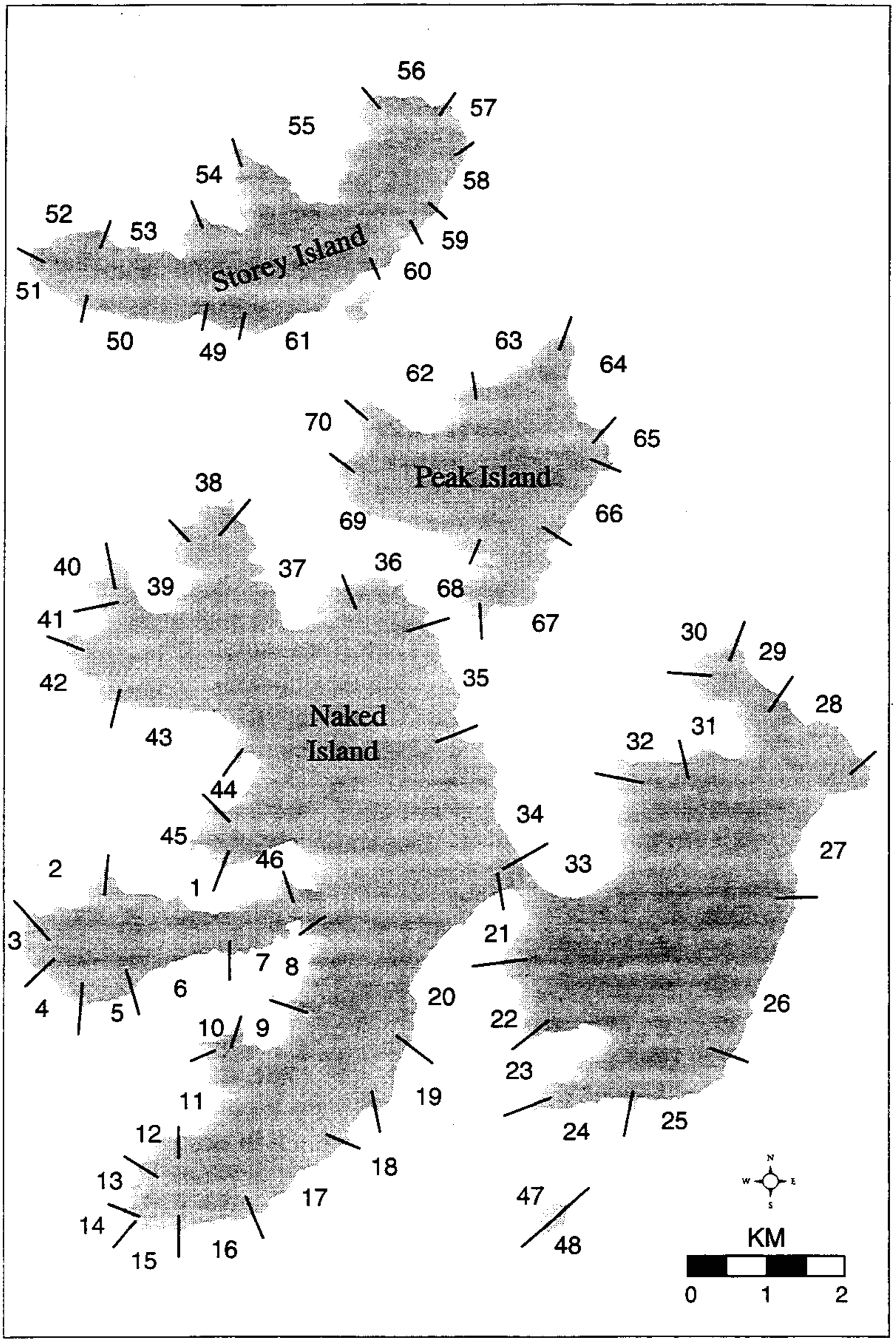

Fig. A-1. Location of shoreline segments used in censusing the pigeon guillemot population of the Naked Island area, Prince William Sound, Alaska.

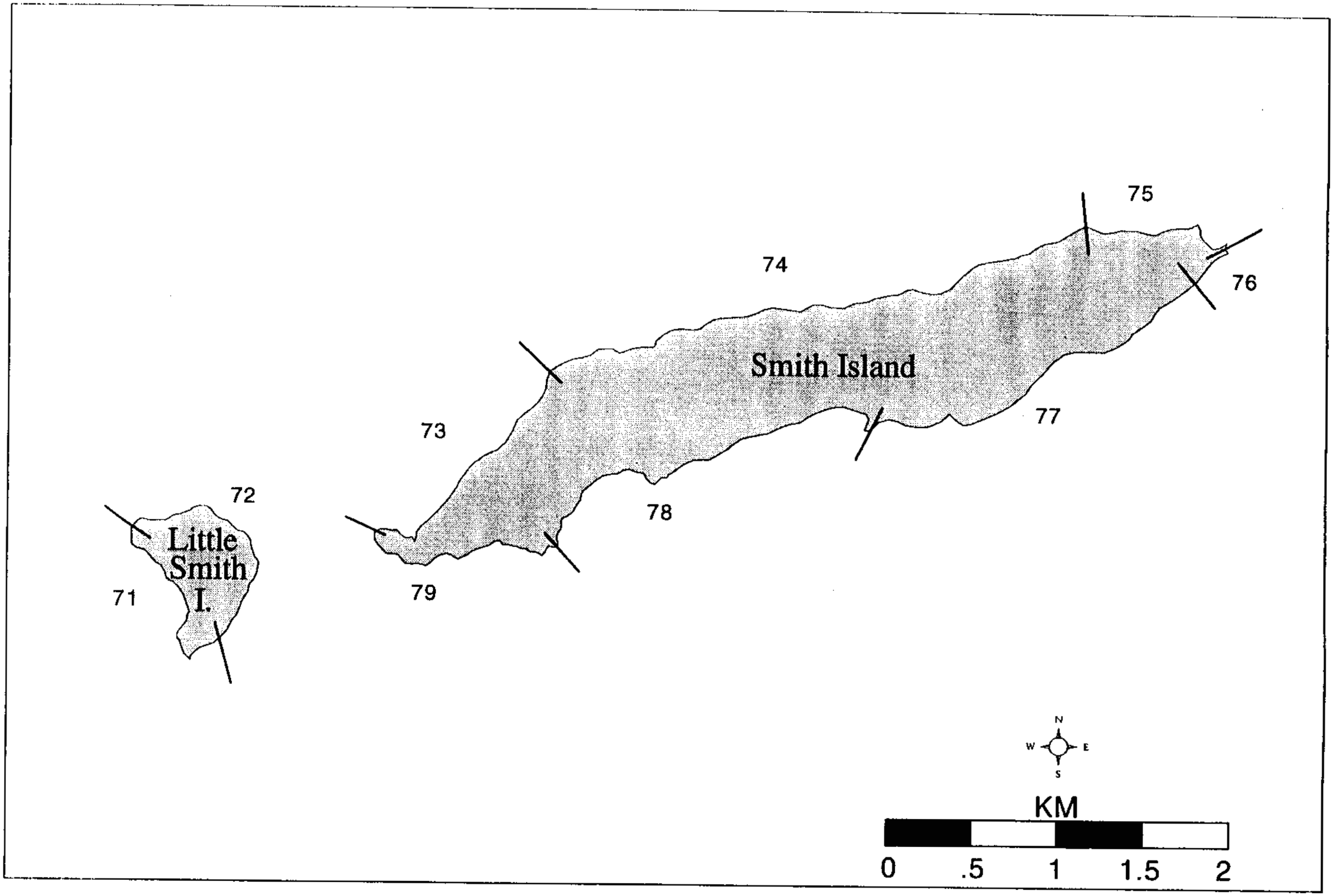
Smith Island
Little Smith I.
71
72
73
74
75
76
77
78
79
N
W
E
S
KM
0
.5
1
1.5
2

Fig. A-1 cont'd.