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

Effects of the *Exxon Valdez* Oil Spill on Murres: A Perspective From Observations at Breeding Colonies

Bird Study Number 3
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 and continued in 1990 and 1991. The study was designed to determine the nature and extent of the injury, loss or destruction of murres (*Uria* spp.) in the oil spill zone. These data will provide a base for developing a recovery monitoring and restoration plan.

Abstract: We surveyed murres (*Uria* spp.) annually from 1989 through 1991 at breeding colonies within the trajectory of the oil to determine whether numbers had declined and to evaluate the effects of oil on nesting phenology and reproductive success, following the 1989 *Exxon Valdez* oil spill. The colonies we surveyed contained the majority of the estimated 200,000 murres attending colonies in the affected area, and we found reduced numbers at all study colonies following the spill. In addition, nesting was delayed and productivity rates were far below normal following the spill. In contrast, numbers of murres did not decline and reproductive parameters were normal at 2 colonies we surveyed outside the trajectory.

The only indication of recovery since the spill was a slight increase in reproductive success at monitored colonies in 1991. The most likely cause of reduced numbers of murres at cliffs following the oil spill was direct mortality from the oil. Since breeding murres were congregating near colonies at the time of the spill, most murres killed were probably experienced breeders. We concluded that reduced densities and skewed age structures were the most likely causes of abnormal breeding after the spill.

Key Words: *Exxon Valdez*, oil spill, Common Murre, Thick-billed Murre, *Uria*, Gulf of Alaska, Middleton I., Chiswell Is., The Triplets, Barren Is., Puale Bay, Ugaiushak I., Semidi Is.

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EXECUTIVE SUMMARY

Following the *T/V Exxon Valdez* oil spill in March 1989, we surveyed murres (*Uria* spp.) annually from 1989 through 1991 at breeding colonies within the trajectory of the oil to determine whether numbers had declined and to evaluate the effects of oil on nesting phenology and reproductive success. The colonies we surveyed contained the majority of the estimated 200,000 murres attending colonies in the affected area, and we found reduced numbers at all study colonies following the spill. In addition, nesting was delayed and productivity rates were far below normal following the spill. In contrast, numbers of murres did not decline and reproductive parameters were normal at 2 colonies we surveyed outside the trajectory.

The only indication of recovery since the spill was a slight increase in reproductive success at monitored colonies in 1991. The most likely cause of reduced numbers of murres at cliffs following the oil spill was direct mortality from the oil. Since breeding murres were congregating near colonies at the time of the spill, most murres killed were probably experienced breeders. We concluded that reduced densities and skewed age structures were the most likely causes of abnormal breeding after the spill.

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INTRODUCTION

Oil spilled from the *T/V Exxon Valdez* in March 1989 either surrounded, passed close by, or came ashore at approximately 27 seabird breeding colonies in the western Gulf of Alaska. Over 200,000 common (*Uria aalge*) and thick-billed (*U. lomvia*) murres normally attended these colonies; 80% were common murres (U.S. Fish and Wildlife Service 1990). The oil slick surrounded nesting sites mostly in April and early May when murres were congregating near colonies prior to breeding (Piatt et al. 1990).

Murres are particularly susceptible to injury from oil spills because they spend the majority of their time on the water and are often concentrated in dense flocks (King and Sanger 1979, Gaston 1980, Piatt et al. 1991, Ford et al. 1991). Over 30,000 dead birds were retrieved in the Gulf of Alaska following the spill, and about 75% were murres (Piatt et al. 1990). Using general information about the populations at risk in the path of the oil, Piatt et al. (1990) estimated that 100,000 to 300,000 birds were killed in the immediate aftermath of the spill. Ford et al. (1991), using a modelling technique that incorporated more specific information about the search effort and carcass recoveries, estimated that the kill was likely between 375,000 and 435,000. Even the lower estimates represent an unprecedented toll of birds from acute oil pollution (Piatt and Lensink 1989).

Common and thick-billed murres are diving fish-eaters that nest on cliff ledges and tops of islets throughout the subarctic and arctic (Tuck 1961). A single egg is incubated for about 1 month. Chicks are reared on ledges for only about 3 weeks before they jump from cliffs and accompany a parent to feeding areas at sea. Long-lived seabirds, such as murres, have low reproductive rates. Their populations may therefore be affected by relatively small increases in adult mortality (Hatchwell and Birkhead 1991).

We conducted a monitoring program from 1989 through 1991 to evaluate the initial impacts of the *T/V Exxon Valdez* oil spill on murres breeding at selected colonies within the trajectory of the oil. The distribution and relative abundance of breeding murres within the spill area was known from baseline surveys primarily conducted in the mid-1970s (U.S. Fish and Wildlife Service 1990). Murres were not always identified to species, and we therefore refer to the species collectively in this report. Breeding sites selected to assess the impacts of the oil spill on murres included colonies containing approximately 90% of the murres within the bounds of the oil's trajectory: the Chiswell Islands, the Barren Islands, The Triplets, Puale Bay and Ugaiushak Island. We found oil at all these colonies. In addition, murres were studied at Middleton Island and in the Semidi Islands--the colonies closest to the oil that were not with the path of the slick.

By reviewing information on the locations where dead murres were retrieved (e.g., Piatt et al. 1990), we concluded that breeding populations of murres at all 5 study sites within the oil's trajectory sustained direct mortality in spring 1989. Furthermore, numbers of birds attending colonies following the spill were lower than pre-spill counts at all 5 oiled areas we surveyed, but not at sites outside the oil trajectory. The magnitude of decline was difficult to assess because pre-spill counts were of unknown accuracy.

Nesting phenology and reproductive success are more sensitive indicators of responses to environmental perturbations than population indices alone. An attempt was therefore made to gather information about these parameters at sites which offered suitable observation opportunities within the trajectory of the oil. Available data suggested the onset of laying was significantly delayed following the spill. Reproductive success also was far below normal. No changes were detected after the spill at Middleton Island or the Semidis, which were the unoiled comparison sites for this study.

OBJECTIVES

A. Determine whether populations of murres breeding within the trajectory of the oil declined following the spill in contrast to populations breeding at nearby sites not affected by the oil.

B. Determine whether the onset of egg laying and productivity for murres were abnormal at colony sites within the oiled area.

METHODS

Study Area

Oil spilled from the *T/V Exxon Valdez* was carried west in the Alaska Coastal Current from Prince William Sound at least as far as Chignik Bay in the western Gulf of Alaska Region (Alaska Dept. of Environmental Conservation (ADEC), unpubl. data). The majority of the oil remained near shore along the Kenai and Alaska Peninsulas (Fig. 1). We monitored the status of murres at most of the large breeding colonies within the trajectory of the oil: Chiswell Islands (Natoa, Matushka, Chiswell, Chiswell "B", Beehive and Beehive "B"), Barren Islands (East Amatuli and Nord), The Triplets near Kodiak, Puale Bay (Cape Unalishaguak, Oil Creek, and a site at the head of the bay) on the Alaska Peninsula, and Ugaiushak Island. Observations at Middleton Island and Chowiet Island (Semidi Islands), both outside the trajectory of the oil (Fig. 1), provided a basis for comparisons. Although Middleton was not in the path of the slick, oiled murres were seen at the colony in 1989 (Piatt et al. 1990). It is possible that a portion of the Middleton population was affected by the oil spill.

The sites we surveyed varied from inaccessible rocky islets, where we had to observe from boats (e.g., the Chiswells and The Triplets), to nearly ideal study areas where murre cliffs could be viewed from elevated land-based points (e.g., Puale Bay, Ugaiushak, Chowiet). East Amatuli and Nord Islands in the Barrens had a few vantage points from land but most work had to be done from a boat. Middleton provided land-based observation from below the cliffs.

All study sites are situated in the western Gulf of Alaska and have generally similar environmental conditions. Nevertheless, oceanographic conditions probably varied among sites.

Timing and Extent of Oiling at Murre Colonies

We looked for oil on beaches and in nearshore waters at selected murre colonies between Prince William Sound and the Semidi Islands in 1989. Some sites were visited only once, but at other sites we made frequent surveys to document arrival of the oil slick and to determine when no new oil was visible nearby. The most frequent surveys were conducted in the Barren Islands where approximately weekly trips were made from 6 April to 16 June (Bailey 1989). In addition, we used information from overflights (ADEC, unpubl. data), hindcasts of the trajectory of the oil from the NOAA "Hazmat" model (Galt et al. 1991), and reviews by Piatt et al. (1990) and Ford et al. (1991) to characterize the timing and extent of oiling at murre colonies.

Populations

Survey Design.--We selected target populations (e.g., birds on index plots, total island counts) that would make our counts comparable with previous surveys at each location. All numbers refer to the population attending a colony during the census period. These numbers represent an unknown proportion of the breeding and non-breeding population associated with nesting colonies. At most study locations, counts were made of all murres in entire colonies. At the Barren Islands, Middleton Island, and the Semidi Islands, colonies which are too large to be counted, index plots containing only a portion of the colonies either supplemented or replaced counts of whole colonies.

Data Collection.--Attendance of murres at nesting cliffs is variable, thus when possible, we counted target populations several times each year so that confidence levels could be specified (Appendix A). All counts were conducted during the optimal count interval (usually late June to August), the period of relatively stable attendance after most eggs have been laid, but before the first chicks have fledged (Nettleship 1976, Birkhead and Nettleship 1980, Murphy et al. 1986, Hatch and Hatch 1989, Byrd 1989). To reduce observer error, 2 or more counts were made, often by multiple observers, of murres on each cliff. If counts between observers differed by more than 10% they were repeated.

Land-based plots are ideal for surveying ledge-nesting seabirds (Nettleship 1976), but as indicated above, colonies at the Chiswell Islands, The Triplets, and the Barren Islands had few, if any, spots affording visibility from land. In addition, some of the study areas at Puale Bay were not visible from land. At these locations, counts were made from a boat anchored or drifting just offshore on calm days. To facilitate counting and record keeping, cliffs were subdivided into discrete segments and these segments were counted separately.

Population surveys were made at most study sites annually from 1989 to 1991 except at Ugaiushak Island and The Triplets where counts were less frequent following the spill.

Data Analysis.--At each study location we treated counts before 1989 as samples of pre-spill populations, and compared the pre-spill and post-spill means. Where only 1 count was available for either period, we tested the single count to determine whether it differed from the average of the other counts. Count data were log-transformed to reduce the possibility of violating assumptions required for parametric tests. One-tailed t-tests were usually employed.

Nesting Phenology

Survey Design.--Since only a portion of murre nest sites can be seen from land at any colony, the target population for studies that require observing nest contents is the viewable portion of the colony (Harris et al. 1983). There were essentially no viewable populations at the Chiswells or The Triplets, and relatively few sections of cliff could be viewed from above in the Barrens. Viewable populations were more extensive at Puale Bay and the Semidis. Ugaiushak and Middleton Islands had adequate viewing points, but we were unable to visit these colonies regularly.

Data Collection.--Repetitive observations at plots throughout the breeding seasons (June to September) of 1989-1991 provided the basis for describing nesting phenology at Puale Bay and the Semidis, the 2 sites where land-based plots were available. At other sites, the onset of nesting was estimated by recording the first date eggs were seen. Although this method was relatively inexact, it provided some basis for comparisons because even at sites where ledges were not visible from above, shells from eggs depredated by gulls could be seen below cliffs or on low ledges soon after the first eggs were laid. The tendency of the majority of murres to remain on ledges instead of being flighty at the approach of observers was another indication of egg laying used to approximate the onset of laying.

Data Analysis.--We compared first egg dates for murres at various colonies in the Gulf of Alaska within and outside the trajectory of the oil and median hatch dates at Puale Bay and the Semidis by Fisher's exact test.

Reproductive Success

Survey Design.--The target population for monitoring reproductive success was the same as for phenology. In the Barrens, a few spots were found where an observer could climb to an elevated position to view segments of cliffs when sea conditions allowed access to the beach below. This afforded an opportunity to record eggs or chicks per adult, a statistic which provides a crude index to reproductive success. At Puale Bay and the Semidi Islands we employed standard methods to estimate reproductive success (Byrd 1989). Murres nesting close together tend to be more synchronous than the colony as a whole (Birkhead

1977, 1980), and birds within particular concentrations are exposed to similar mortality factors (Schauer 1991). As a result, statistics on reproductive success from nests in close proximity to each other probably lack statistical independence (Byrd 1989). Observations of individual nests within clusters are more properly considered subsamples. Thus, the sample unit for productivity was a cluster of nests rather than individual nests.

Data Collection.--Season-long observations of clusters of murres at established plots at Puale Bay and the Semidis were made 1989-1991. Observers viewed plots at 1-3 day intervals from before the onset of laying until most chicks had fledged. Binoculars or spotting scopes were used from marked observation points to scrutinize murres. Individual nest sites were identified on photographs or drawings of plots. We could rarely see murre eggs because adults seldom exposed them, but incubating murres have a distinctive posture which is a relatively reliable indicator that an egg is present (Byrd 1989). After we recorded incubating posture at a nest site during 3 successive checks, we assumed an egg was present. Chicks are easier to see than eggs, and brooding murres often extended one wing over chicks. This obvious behavior indicated the presence of a chick in cases where the chick itself was not visible.

In the Barren Islands, we climbed to overlook spots at the peak of the hatch, when the maximum number of chicks were present, to view murres from above. We counted the number of active nest sites (adults in incubating or brooding posture and eggs or chicks). In addition, the number of murres present at each plot was recorded. A similar approach was used during a single visit to Ugaiushak Island in 1990.

Data Analysis.--For data at Puale Bay and the Semidi Islands we used standard ratio estimation techniques to estimate productivity annually [e.g., chicks/active site (site where an egg was laid) for each plot was the sample used to estimate the overall ratio]. Differences among years and sites were tested by expressing plot data as proportions and conducting analysis of variance. Arcsine square root transformation reduced the probability of violating assumptions required for parametric tests. For the Barren Islands and Ugaiushak, the ratios of chicks or eggs per adult were used as indices of productivity.

RESULTS

Timing and Extent of Oiling at Murre Colonies

Following the grounding of the *T/V Exxon Valdez* on 24 March 1989, oil spread south and west from Prince William Sound (Galt et al. 1991, Piatt et al. 1990). By 4 April, oil had reached the Chiswell Islands (Galt et al. 1991), and 10 days later (14 April) the first oil was noted in the Barren Islands (Bailey 1989, ADEC, unpubl. data). The Hazmat simulation indicated that the main portion of the oil slick remained in a gyre near the Barren Islands for several days. Thereafter, the coastal current carried oil past the mouth of Cook Inlet and into Shelikof

Strait. In addition, northerly winds pushed a portion of the slick south along the east side of Kodiak to the vicinity of The Triplets (Galt et al. 1991). By 30 April there was heavy mousse (water-in-oil-emulsion, Galt et al. 1991) along the entire coast of the Alaska Peninsula as far west as Wide Bay, a stretch which includes Puale Bay. By 6 May, the leading edge of the slick had extended past Ugaiushak Island to Sutwik Island (ADEC, unpubl. data). Thereafter, the slick became increasingly difficult to trace, and direct effects on birds probably diminished (Piatt et al. 1990).

Specific information about each colony we surveyed follows:

Chiswell Islands.--The leading edge of the oil passed just south of the Chiswells on 5 April in a 15-km wide band (the approximate width of the coastal current) that moved west at a rate of about 10-13 km per day (Galt et al. 1991). The coastal current deflects south, away from shore, in the vicinity of the Chiswells, and these islands apparently were not completely encircled with oil. However, oil may have remained nearby for an extended period, possibly until late April (ADEC, unpubl. data). Vequist et al. (1990) indicated that "moderate" amounts of oil drifted past the Chiswells, but little remained on the shoreline. Murres were present near the breeding colonies on April 9 (Piatt et al. 1990), 5 days before the oil arrived.

Barren Islands.--From 14 April, the date oil first appeared, until 21 May, new oil continued to be seen near the Barrens, but after 22 May no new oil was detected on the water (Bailey 1989).

Accounts by Galt et al. (1990), Piatt et al. (1990), the NOAA Hazmat hindcasts, and Bailey's narrative indicated that oil periodically washed back and forth through the Barren Islands for approximately one month. During an aerial survey on 6 April, a week before the leading edge of the oil arrived, nearly 50,000 murres were seen during aerial surveys near the Barrens (Rod King, U.S. Fish and Wildlife Service, unpubl. data). Piatt et al. (1990) estimated 100,000 murres were present in the area in early April 1989. A number of these birds must have been killed when the oil arrived. Bailey's crew retrieved 2163 oiled bird carcasses (79% murres), an unknown proportion of the total mortality, during periodic visits to beaches in the Barrens.

The Triplets.--In April and early May northerly winds pushed oil into the Kodiak area (Galt et al. 1991, Piatt et al. 1990). We received reports of oil near The Triplets in April, and we found patches of mousse in July just south of the islands. MacIntosh (1989) found oil on beaches just south of The Triplets when he went there to count murres in August. It is unknown exactly when, or if, oil completely surrounded The Triplets, but a portion of the slick was in the vicinity during the pre-breeding attendance period for murres.

Puale Bay.--"Heavy mousse" was seen all along this area on April 30 (ADEC, unpubl. data), and over 1,000 dead murres washed up on beaches here during the spring and summer of 1989 (Piatt et al. 1990). Piatt et al. (1990) suggested that many of these murres may have been killed elsewhere and drifted to Puale Bay, but local breeders must also have been included in the totals.

Ugaiushak Island.--Mousse and sheen extended as far west as Mitrofania Bay (ADEC, unpubl. data), so Ugaiushak was almost certainly hit by drifting oil in late April or early May 1989. Moreover, we saw oil spots on rocks and old tar balls near the storm-tide line on the island's north side in August 1990.

Populations

The following is an annotated summary of counts of murres at colonies within the trajectory of the oil spilled by the *T/V Exxon Valdez* and just outside the affected area (e.g., Middleton and the Semidi islands). Both pre-and post-spill counts are considered here. Details of historic and recent counts are provided in Appendix A.

Chiswell Islands.--Bailey and Rice (1989) counted about 2400 murres on 6 islands in the Chiswell group in 1989 after the spill (Table 1). We found similar numbers of birds on cliffs in 1990 and slightly more birds on cliffs in 1991 (Table 1). We also saw nearly 2000 additional murres on the water near the Chiswells in 1990, far more than in 1991 (Table 1). Because pre-spill counts included birds seen on the water, we combined water and cliff totals during post-spill counts to facilitate comparisons.

In 1976, Bailey and Rice (Bailey 1976b, Bailey 1977) counted nearly 7500 murres on the same 6 islands in the Chiswell group where our surveys were conducted. This count was significantly higher ($P < 0.025$) than counts made following the spill (Table

1). During the only other pre-spill survey, in 1986, fewer than 3500 murres were observed (Nishimoto and Rice 1987). We believe this count was unrepresentatively low, because rain and fog reduced the proportion of birds that observers could see, and high winds probably reduced the proportion of birds attending cliffs (Martin et al. 1985).

Barren Islands.--At Nord Island, we counted approximately 12,000 to 13,000 murres annually from 1989 to 1991, and we counted 5500 to 7000 murres on East Amatuli Light Rock (Table 2). Significantly fewer birds were present at Nord Island ($P < 0.001$) and East Amatuli Light Rock ($P < 0.05$) following the oil spill than were estimated to have been there earlier (Table 2). In addition, fewer birds were present on index plots during the count period in 1989 than in subsequent years (Table 3).

The Triplets.--We counted an average of 843 murres in 1989 (Table 4). We did not survey murre populations in The Triplets in 1990 or 1991. Counts prior to the oil spill ranged from 1200 to 1300 birds, significantly ($P < 0.005$) more than in 1989 (Table 4).

Puale Bay.--Approximately 34,000 to 35,500 murres were counted at three colonies near Puale Bay from 1989 to 1991 (Table 5). Murres on the water near colonies were not included in the totals but amounted to only a few hundred birds (D. Dewhurst, U.S. Fish and Wildlife Service, pers. comm.). The average of these post-spill counts was significantly lower ($P < 0.005$) than the average of the two pre-spill counts.

Ugaiushak Island.--We were unable to count murres at Ugaiushak in 1989, but in 1990 and 1991 about 5000 murres were recorded during single surveys (Table 6). The counts following the oil spill were significantly lower ($P < 0.001$) than the single pre-spill count--8340 birds recorded in 1976 (Wehle 1978). The 8 sub-areas surveyed contained most of the murres on Ugaiushak. Hoberg and several other observers estimated the entire island had about 9200 murres in 1976 (Appendix A).

Middleton Island.--At Middleton Island, 4400 to 5800 murres were counted on annual surveys from 1989 to 1991 (Table 7). The average of these post-spill counts was not significantly different ($P = 0.87$) from the average of pre-spill counts (Table 7). Nevertheless, fewer murres were present following the spill than in the 3 years just prior to 1989. On 9 index plots, there was insufficient evidence ($P = 0.12$) to conclude that lower counts following the spill were significantly different from pre-spill counts (Table 8).

Semidi Islands.--We counted about 2800 to 3100 murres on index plots on Chowiet Island from 1989 to 1991, slightly more birds ($P = 0.07$) than the average prior to the oil spill (Table 7).

Nesting Phenology

Prior to the oil spill, murres at colonies in the western Gulf of Alaska usually began egg laying in June (Appendix B). Following the spill, the onset of laying was delayed significantly (P = 0.02) until mid- to late July at most portions of the murre colonies in the Barrens and Puale Bay, the 2 colonies within the trajectory of the oil for which we had data (Fig. 2). First egg laying dates following the spill remained relatively early at Middleton and the Semidis (Fig. 2).

Median hatching dates for common murres were 20 to 23 days later at Puale Bay, the oiled site, than in the Semidis (Table 9). Both first egg dates and median hatch dates suggested the delay in onset of laying persisted through 1991 at most areas in the Barrens and Puale Bay (Fig. 2, Table 9). Murres nesting in one spot in the Barrens, the top of East Amatuli Light Rock, appeared to begin egg laying earlier than elsewhere in the group, but we did not collect adequate data to understand the magnitude of difference.

Reproductive Success

In 1989, we found that murres experienced nearly complete reproductive failure at every site we could monitor within the trajectory of the oil (Table 10, Appendix C). Success remained lower than normal in 1990 and 1991. The following is a summary of information about breeding performance at sites we surveyed.

Chiswell Islands.--We were not able to measure reproductive success directly in the Chiswell Islands, but in 1989, murres probably failed to lay or lost their eggs soon after laying because birds never regularly attended cliffs (Table 10, Appendix C). Attendance was more regular, at least at the beginning of the incubation period, in 1990 and 1991, but we were unable to return to the Chiswells later in either year to check for continued regular cliff attendance which would have suggested more normal reproductive efforts. We found no historical information about reproductive rates of murres at the Chiswells.

Barren Islands.--In 1989, murres never attended cliffs regularly, so we surmised they either failed to lay eggs or lost eggs soon after laying. At least some eggs were laid on top of East Amatuli Light Rock. In 1990, an area at Nord Island which contained approximately 360 murres was observed periodically, and no eggs or chicks had been seen by 18 August, our last check (Appendix C). It is very unlikely egg laying began after that date. In 1990 an exception to reproductive failure may have occurred on top of East Amatuli Light Rock where murres appeared to be less flighty than elsewhere indicating at least some incubation was occurring. In 1991 some murres at Nord Island produced chicks, but a large proportion either never laid or lost eggs. Ten different plots were checked once during late incubation and early chick-rearing, and we found an average of 0.13 chicks or still active eggs per adult murre (Table 10). Additional evidence of improved nesting success in 1991 over 1989 and 1990 was the type of behavior indicated for East Amatuli Light above, i.e., most birds remained on cliffs during our visits indicating involvement in reproduction. The only historical records of productivity at the Barrens suggested approximately 40% to 50% of the pairs of murres produced chicks at East Amatuli Light Rock in the mid to late 1970's (Table 11, Appendix C).

Puale Bay.--Puale Bay was the only site within the trajectory of the oil where we could estimate the proportion of murres attending the colony that bred. In 1990 only 0.37 eggs were recorded per adult (D. Dewhurst, U.S. Fish and Wildlife Service, King Salmon, unpubl. data), a significantly smaller ($t_{0.01(1),2} = 13.56$, $P < 0.005$) percentage than at the Semidi Islands (1989-1991 mean = 0.60 eggs per adult) where oil never occurred (D. Dragoo, U.S. Fish and Wildlife Service, Homer, unpubl. data). In spite of reduced numbers, approximately 50% to 70% of the laying pairs successfully hatched eggs annually from 1989 to 1991 at Puale Bay (Dewhurst and Moore 1992). Nevertheless, most of the chicks died in 1989 and 1990 causing overall reproductive success to be less than 10% in both years (Table 11, Appendix C). Chick mortality was associated with abandonment by adults late in the season (Dewhurst and Moore 1992).

Although the onset of nesting was again late in 1991, reproductive success was approximately 50% (Table 11), average for Alaska (Byrd et al. in press). Adults did not abandon chicks in 1991, perhaps due to better fall weather at colonies than in the previous 2 seasons.

Ugaiushak Island.--Less than 1% of the nearly 1700 murres observed on 5 August 1990 had eggs (Table 10, Appendix C). We were unable to visit the island earlier in the season, so it was not possible to determine whether birds had laid and lost eggs. It is unlikely birds laid eggs after 6 August, the last day we observed cliffs. No information was obtained on breeding success at Ugaiushak in 1989 or 1991.

The only information about reproductive success of murres at Ugaiushak prior to the oil spill was collected in 1977 (Wehle 1978). We used these data to calculate reproductive rates of 31% for common murres at a plot Wehle frequently disturbed, and 48% for thick-billed murres, mostly at an undisturbed site (Table 11, Appendix C).

Semidi Islands.--Throughout the period 1989-1991, productivity of murres in the Semidi Islands, just outside the trajectory of the oil, remained similar to pre-spill rates at about 50% to 60% for common murres and approximately 45% to 60% for thick-billed murres (Table 11).

DISCUSSION

Murres were congregating near their breeding colonies at the time of the T/V *Exxon Valdez* oil spill; thus, many birds were killed at colonies within the trajectory (Piatt et al. 1990, Ford et al. 1991). Most of the murres killed were probably experienced breeders, because younger birds do not return to colonies until later in the season if at all (Birkhead 1977, Stowe 1982). Murres usually do not begin to breed until they are at least 4 years old (Hudson 1979, Baillie and Mead 1982). Pre-breeding prospectors, mostly 2- and 3-year olds, do not attend colonies until after adults have begun incubation, and murres under 2-years old seldom come to colonies (Birkhead and Hudson 1977, Hudson 1979).

Our annual counts of murres from 1989 to 1991 at colonies within the trajectory of the oil were 40% to 60% lower than pre-spill counts (Fig. 3a), whereas counts at other colonies nearby did not decline (Fig. 3b). Strong conclusions about the magnitude of the changes caused by the spill are inappropriate because pre-spill data were not collected for the purpose of detecting population changes. Instead, the objective of the surveys was to describe the distribution and relative abundance of all breeding species of seabirds at colonies over broad areas (Bartonek et al. 1977). Early surveys were typically made during brief visits which necessitated single counts or crude estimates, and survey methods were seldom clearly documented.

Despite uncertainties about the accuracy of historical counts, significant differences in numbers before and after the spill indicated definite declines--only the magnitude of the declines was equivocal. Since populations of murres at colonies just outside the trajectory of the oil did not decline following the spill and direct mortality within the trajectory was so pronounced, it seems likely that oil mortality caused the population declines at affected colonies.

Mortality is not the only possible cause of reduced counts at murre colonies. In cases where environmental perturbations are severe (e.g., El Nino Southern Oscillation), food webs can be so disrupted near colonies that many murres abandon cliffs during the breeding season (Stowe 1982, Murphy et al. 1986, Boekelheide et al. 1990). Reduced numbers at colonies during such phenomena resulted from absence, not mortality, of breeding adults. Colonies therefore generally increased to former numbers within 1 or 2 years after these events (Birkhead and Hudson 1977, Stowe 1982, Boekelheide et al. 1990). Since the reductions in numbers of murres at colonies within the trajectory of the *T/V Exxon Valdez* oil spill have persisted for 3 years, we think it is unlikely that murres were only temporarily away from colonies. Furthermore, a perturbation other than the spill sufficient in magnitude to affect colonies from the Chiswells to Ugaiushak should have similarly affected Middleton and the Semidi islands, yet populations at the Semidis actually appeared to increase slightly following the spill. There was a dip in numbers immediately after the spill at Middleton, but there was no evidence of an overall declining trend there since the mid-1970's.

Following the spill, murre nesting behavior at colonies within the trajectory was significantly disrupted, and delayed nesting phenology and reduced reproductive success persisted for up to 3 years at monitored sites after the oil spill. Delays, and indeed failures to lay eggs, in 1989 could have been due to the loss of breeding birds, hydrocarbon contamination, food web disruptions, frequent disturbances due to spill cleanup activities or a combination of these factors. By 1990 oil was apparently no longer present near breeding colonies, and the level of human activity had diminished. Therefore, probable causes of disruptions to murres in 1989 were no longer a factor.

Persistent delays in nesting could have resulted from the abrupt declines in breeding populations which probably reduced densities at most breeding ledges. Reduced densities could have caused social disruption at colonies. Social stimulation apparently is an important factor in the timing of laying in murres (Birkhead 1985) because murres within clusters tend to lay more synchronously than the colony as a whole (Birkhead 1977, Birkhead 1980, Harris and Wanless 1988, Schauer 1991). A critical density of murres on nesting ledges may be necessary to stimulate ovulation. Clusters of potential breeders may not have reached adequate densities until the arrival of young birds prospecting for nest sites, an event that normally happens after incubation is underway (Tuck 1961).

The removal of many of the experienced birds probably resulted in a population containing a much higher proportion of young, inexperienced breeders than normal. We speculated that surviving experienced breeders had a high probability of pairing with inexperienced birds, and more young birds may have been present at nesting cliffs due to available nest sites. According to Bourne (1992), age of first breeding is frequently lower in populations following unusual adult mortality. The low proportion of birds with eggs present at colonies following the oil spill is consistent with this hypothesis. Young birds tend to lay relatively late, even under normal conditions (Perrins 1970, Birkhead and Nettleship 1981, Gaston 1991, Nobel 1991), so a skewed age distribution could have caused a delay in the onset of laying.

Drastic changes in neighbors at nesting cliffs could also have caused disruption of normal nesting behavior. Murres occupy the same nest ledges annually (Hedgren 1980). Normally a concentration of murres would thus be composed of a high proportion of birds that had spent previous summers on the same ledge with each other.

Persistently low reproductive success following the oil spill, like phenology, may be due to reduced densities and skewed age ratios. Murre reproductive success is positively correlated with the density of nests (Birkhead 1977, Gilchrist 1991, Hatchwell and Birkhead 1991), and densities must have been lower at all colonies with reduced populations after the spill. Birkhead (1977) found that a decline of common murre populations reduced the density of breeding groups and exposed the eggs and chicks of the remaining birds to gull predation. Furthermore, young murres are usually less successful than older birds, thus a colony with a high percentage of inexperienced breeders would be expected to have low productivity (Hedgren 1980, Gaston 1991, Nobel 1991).

Delayed nesting phenology seemed to be partially responsible for chick mortality at Puale Bay, and probably contributed to reduced reproductive success elsewhere. For murres there is usually a seasonal decline in reproductive success (i.e., late laying results in poor success) (Birkhead and Nettleship 1981, 1982; Gaston et al. 1983, Boekelheide et al. 1990), therefore delayed phenology would also contribute to lower productivity of murres.

Another possible cause of abnormal laying phenology and reproductive performance is food shortages near the breeding colonies. We had no direct measure of food availability. Nevertheless, tufted puffin (*Fratercula cirrhata*), a diving fish-eating species like common murre, did not experience reproductive failures at the Barren Islands in 1990 or 1991 (D. Boersma and A. Kettle, Univ. of Washington, Seattle, unpubl. data). Food may have been available at somewhat lower than normal rates however, because puffin chicks grew more slowly than usual 1990 and 1991 (A. Kettle, unpubl. data). Puffin populations at the Barrens were probably not substantially diminished by the oil spill because breeding puffins normally do not arrive at colonies in the western Gulf of Alaska until May, after the oil slick had dispersed.

If social disruption and a skewed age distribution were causing reduced reproductive rates, productivity should have begun to increase as birds became more experienced. Indeed, success rates were slightly higher at the Barren Islands and substantially higher at Puale Bay in 1991 than in 1989 or 1990. Nevertheless, it is too soon to know whether this trend will continue. Most likely, a return to more normal laying dates will have to precede a sustained improvement in reproductive success.

CONCLUSIONS

Oil spilled from the *T/V Exxon Valdez* probably killed low hundred thousands of murres near breeding colonies in the western Gulf of Alaska. Most were probably experienced breeders, and populations at colonies within the trajectory of the oil were reduced approximately 40% to 60%. Counts of murres at nearby colonies outside the trajectory indicated no region-wide declines were underway that might account for reduced numbers at colonies within the path of the oil. In addition to reduced populations, the timing of nesting events was delayed, and reproductive success was well below normal at colonies inside the trajectory in contrast to nearby colonies outside. We concluded that besides direct injury to breeding populations in 1989, surviving murre populations likely had disrupted social structures due to a preponderance of young, inexperienced breeders and reduced densities on nesting ledges. By 1991, populations had not obviously begun to increase, and the timing of nesting events remained later than normal. Nevertheless, reproductive success was slightly higher in 1991 than in previous post-spill seasons.

The kind of observations we were able to make were inadequate to prove that oil mortality caused the effects we observed. We were unable to totally discount the possibility that disrupted food webs caused by factors other than the oil spill contributed to abnormal breeding behavior. Nonetheless, the evidence we obtained suggested, through correlation, that the high mortality of murres near breeding colonies within the path of the oil played a major role in declines and disruptions of breeding efforts at colonies in the western Gulf of Alaska.

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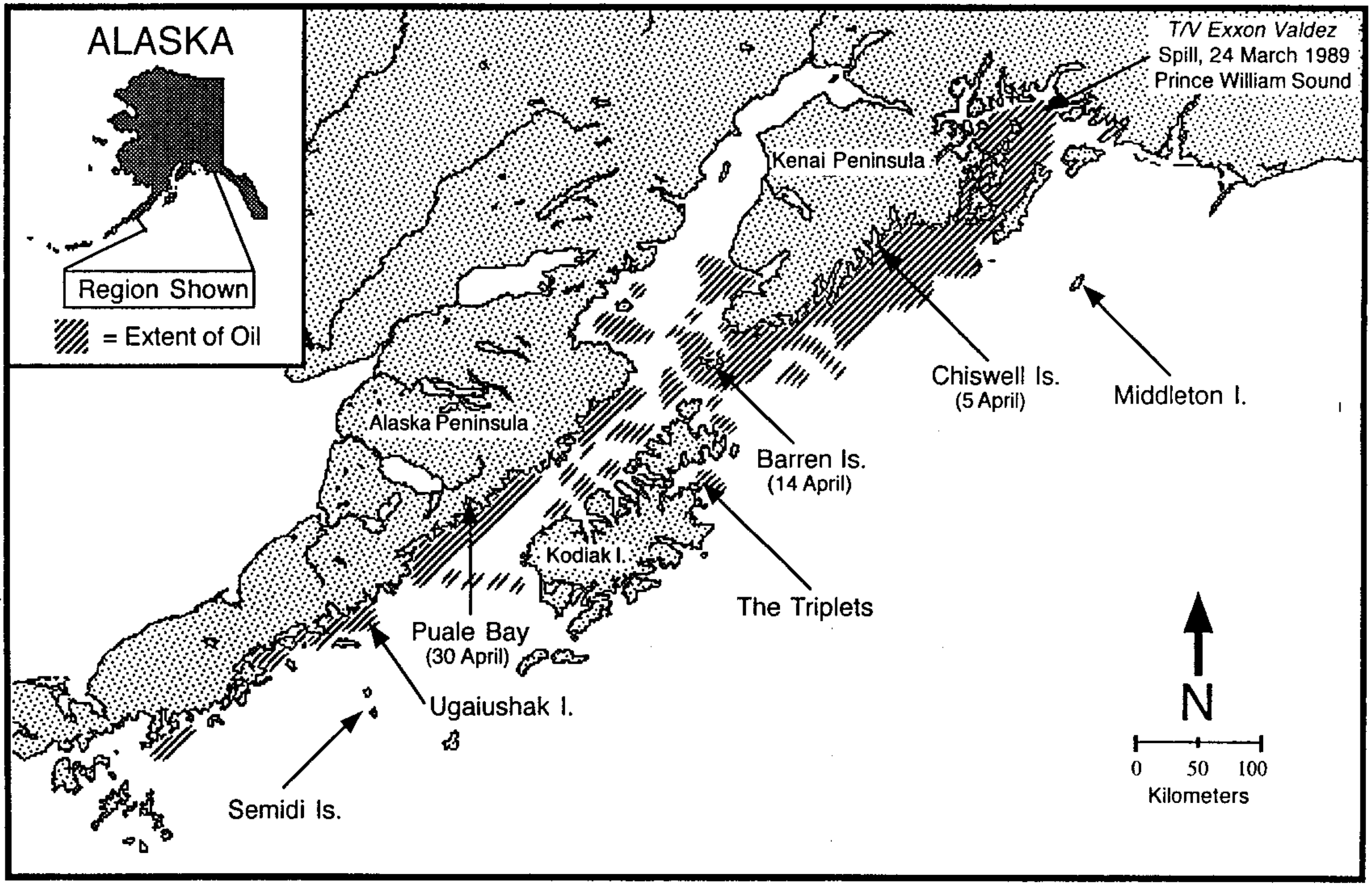

Figure 1. Maximum extent of surface oiling due to the wreck of the *T/V Exxon Valdez*, and locations where murre colonies were surveyed.

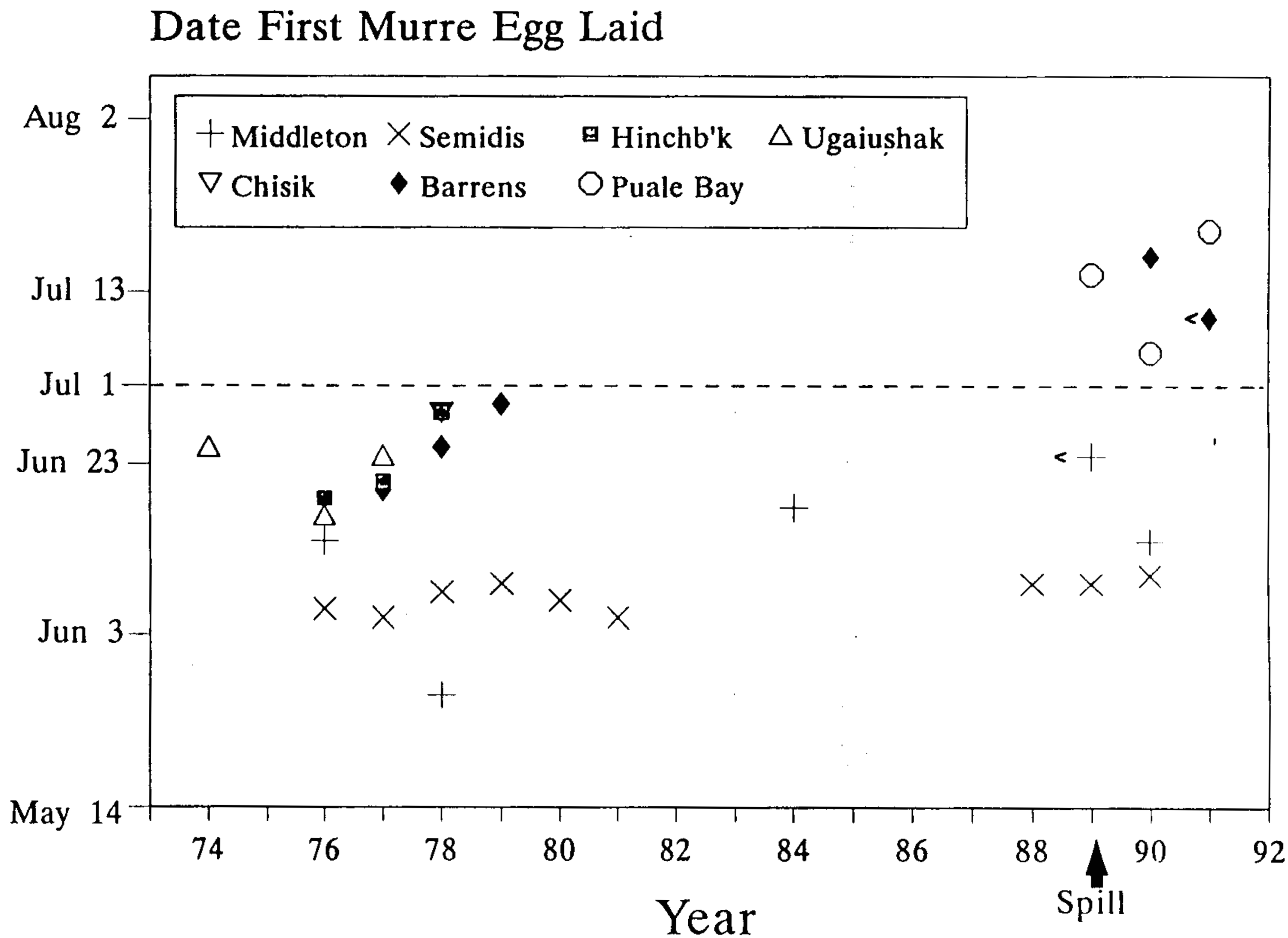

Figure 2. First egg dates for murres breeding at colonies in the western Gulf of Alaska before and after the *T/V Exxon Valdez* oil spill. Dates above the 1 July line are significantly later than others (Fisher's exact test, P = 0.02).

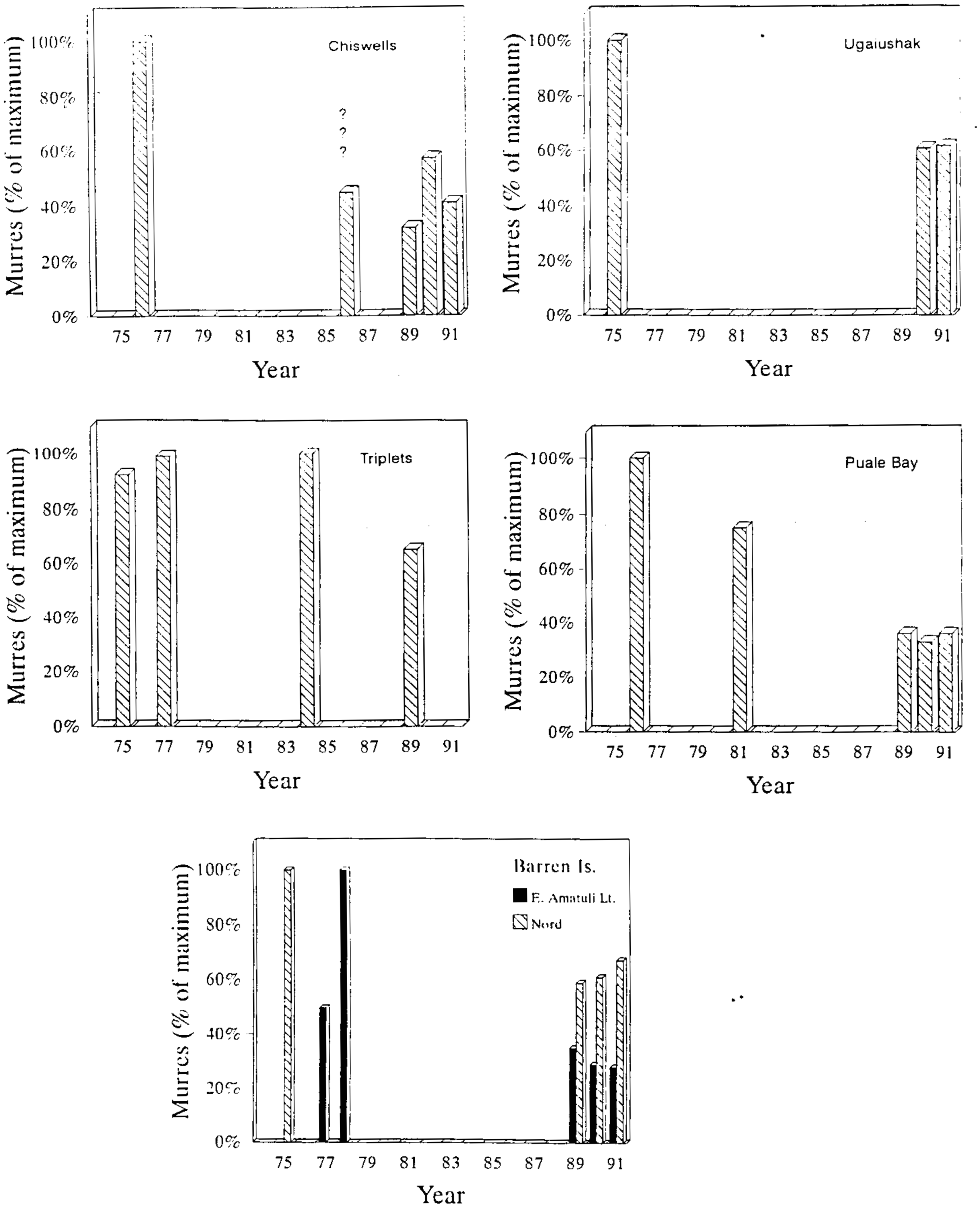

Figure 3a. Relative magnitude of counts (expressed as a percentage of the maximum historical count) of common and thick-billed murres at breeding colonies within the trajectory of the oil spilled by the *T/V Exxon Valdez*.

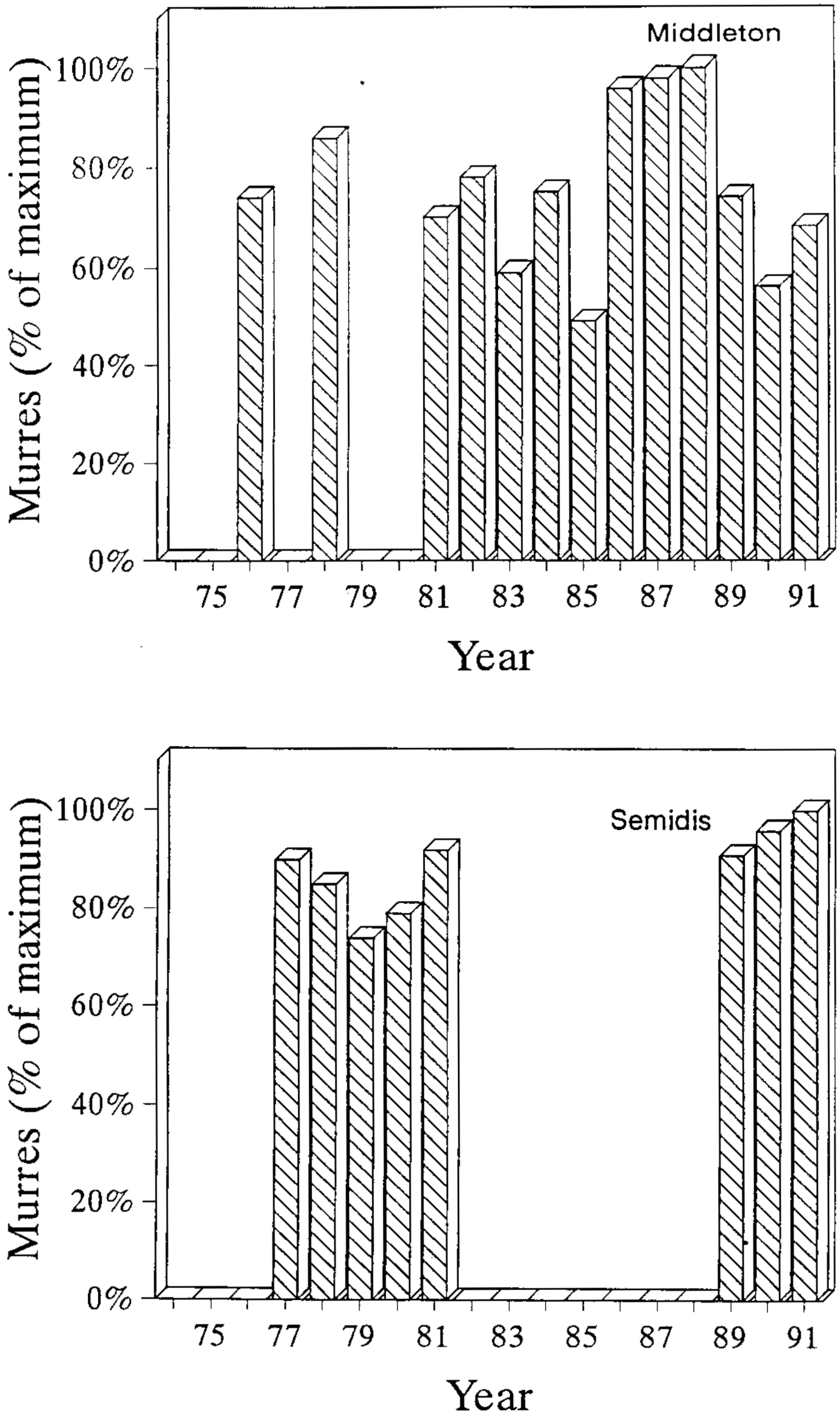

Figure 3b. Relative magnitude of counts (expressed as a percentage of the maximum historical count) of common and thick-billed murres at breeding colonies outside the trajectory of the oil spilled by the *T/V Exxon Valdez*.

Table 1. Counts of murres[a] during the optimal count period at the Chiswell Islands (Natoa, Matuska, Chiswell, Chiswell "B", Beehive, and Beehive "B"), Alaska, before and after the *T/V Exxon Valdez* oil spill.

Year	Total on cliffs and in water nearby	On cliffs	On water[b]
Before spill			
1976[c]	7,476	7,476[d]	
1986[e]	3,387	2,387	1,000
After spill			
1989[f]	2,383	2,383 (0.24,2[g])[h]	
1990	4,283	2,348[i] (0.07,3)	1,935
1991	3,042	2,818[i] (0.13,4)	224

[a]Common murres comprise 90% of the total.
[b]All are single counts.
[c]From Bailey (1976b), who indicated many of the birds near Chiswell Island were on water, but did not report actual numbers.
[d]Significantly higher ($t_{0.05(1),2}$) = 5.10, $P < 0.025$) than mean of log-transformed 1989-1991 counts. The 1986 count was excluded because it was made under poor viewing conditions.
[e]From Nishimoto and Rice (1987); made under conditions of poor visibility so the count is probably an underestimate.
[f]From Bailey and Rice (1989).
[g]Replicate counts for only 3 of 6 islands.
[h]Where number of counts (n) is greater than 1, coefficient of variation and sample size are in parenthesis (CV,n).
[i]Marginally significant differences ($t_{0.01(2),5}$ = 2.06, $P = 0.10$) in means of log-transformed counts.

Table 2. Numbers of common murres counted on Nord Island and East Amatuli Light Rock in the Barren Islands, Alaska, before and after the *T/V Exxon Valdez* oil spill.

Year	Nord Island	East Amatuli Light Rock
Before spill		
1975	20,000[a]	
1977		10,000[b]
1978		20,000[b]
After spill		
1989	11,838[c]	6,912[d]
1990	12,277[c]	5,865[d]
1991	13,333[c]	5,529[d]

[a]From Bailey (pers. commun.); Bailey (1976b) erroneously reported "30,000" murres at Nord.
[b]From Manuwal and Boersma (1978), Manuwal (1980).
[c]Mean of log-transformed pre-spill count significantly higher ($t_{0.05(1),3}$ = 13.67, $P < 0.001$) than mean of counts after the spill.
[d]Mean of log-transformed pre-spill counts significantly higher ($t_{0.05(1),3}$ = 3.10, $P < 0.05$) than mean of counts after the spill.

Table 3. Counts of common murres on plots in the Barren Islands (Nord, East Amatuli, and East Amatuli Light Rock), Alaska, 1989-1991.

Year	Statistic[a]		
	$\bar{x}$	CV	n
1989	3,283[b]	0.05	2
1990	4,653[c]	0.03	2
1991	4,417[c]	0.09	2

[a] $\bar{x}$ = mean, CV = coefficient of variation, n = sample size (number of counts).

[b] Significantly lower ($F_{0.05(1),2,2} = 26.90$, $P < 0.02$; multiple comparisons at 0.05 level) than mean of log-transformed counts for 1990 and 1991; ANOVA.

[c] No difference ($Chi^2_{0.01,2} = 2.92$, $P = 0.23$) between 1990 and 1991 counts; Friedman's test.

Table 4. Counts of common and thick-billed murres[a] in The Triplets islands, Alaska, before and after the *T/V Exxon Valdez* oil spill.

Year	Statistic[b]		
	$\overline{x}$	CV	*n*
Before spill			
1975	1,200[c]		1
1977	1,297[d]		1
1984	1,300[e]		1
After spill			
1989	843[f]	0.22	3

[a]Approximately 85% were common murres (MacIntosh 1989).
[b]$\overline{x}$ = individual counts, CV = Coefficient of variation, *n* = sample size (number of counts).
[c]From Dick and Warner, AK seabird colony status record (CSR), site 034046, 26 July 1975, U.S. Fish and Wildl. Serv., Anchorage (Appendix A).
[d]From Trapp et al., AK seabird CSR, site 034046, 29 June 1977, U.S. Fish and Wildl. Serv., Anchorage (Appendix A).
[e]From MacIntosh (1989).
[f]Significantly lower ($t_{0.05(1),2}$ = 11.83, $P < 0.005$) than the mean of log-transformed pre-spill counts.

Table 5. Counts of common and thick-billed murres[a] in the vicinity of Puale Bay, Alaska, before and after the *T/V Exxon Valdez* oil spill.

Year	Site[b]			
	Cape Unalishagvak	Oil Creek	Puale Bay	Totals
Before spill				
1976	>16,500[c]	73,000[c]	8,000[d]	100,500
1981	38,000[e]	30,000[e]	6,500[e]	74,500
After spill				
1989	14,246 (0.02,2)[g]	20,400	1,790	36,436[f]
1990	14,496 (0.14,2)	16,970 (0.05,2)	2,805 (0.32,3)	34,271[f]
1991	14,374	19,088	2,980 (0.09,3)	36,442[f]

[a]Most were common murres at Cape Unalishagvak, 90% were common murres at Oil Creek and at Puale Bay.

[b]In Sowls et al. (1978) colony designations for these plots are: site 013 (Puale Bay), site 005 (Cape Unalishagvak), site 008 (Oil Creek).

[c]From Gould and Powers, Alaska seabird colony status record, site 035005 and 035005, 4 July 1976, U.S. Fish Wildl. Serv., Anchorage (Appendix A).

[d]From Bailey and Shad, Alaska seabird colony status record, site 035013, 29 July 1976, U.S. Fish and Wildl. Serv., Anchorage (Appendix A).

[e]From Bailey and Faust (1984).

[f]Mean of log-transformed counts after the spill was significantly lower ($t_{0.05(1),3} = 7.61$, $P < 0.005$) than the mean of log-transformed counts prior to the spill.

[g]Where number of counts (n) is greater than 1, coefficient of variation and sample size are in parenthesis (CV,n).

Table 6. Counts of common and thick-billed murres[a] at Ugaiushak Island, Alaska, before and after the *T/V Exxon Valdez* oil spill.

	Before spill	After spill	
Site[b]	1976	1990	1991
Main Talus (exposed)	586	313	541
Murre Point	1,737	1,644	1,742
Secluded Bay	856	238	337
Kittiwake Cove	298	233	458
Kittiwake Bluffs	939	313	296
Square Bay	585	549	609
Murre Cove	3,200	1,687	1,105
Hole-in-the-Wall	139	56	25
Totals	8,340[c]	5,032[d]	5,113[d]

[a]90% were common murres.
[b]Sites are cliff sections on the island as located by Wehle (1978).
[c]From Wehle (1978).
[d]Mean of log-transformed counts is significantly lower ($t_{0.05(1),1} = 61.40$, $P < 0.001$) than the count prior to the spill.

Table 7. Counts of murres[a] at Middleton Island and the Semidi Islands before and after the *T/V Exxon Valdez* oil spill.

Year	Middleton Island	Semidi Islands
Before spill		
1974	5,770[b]	-
1975	-	-
1976	5,851	-
1977	-	2,816[j]
1978	6,803[b]	2,635[j]
1979	-	2,308[j]
1980	-	2,451[j]
1981	5,521[c]	2,856[j]
1982	6,161[d]	-
1983	4,629[e]	-
1984	5,832[f]	-
1985	3,851[g]	-
1986	7,595[h]	-
1987	7,714[h]	-
1988	7,899[h]	-
After spill		
1989	5,846[h,i]	2,823[k]
1990	4,431[h,i]	2,980[k]
1991	5,400[h,i]	3,117[k]

[a]Less than 5% of murres were thick-billed at Middleton (Hatch et al. 1979), 5% were thick-billed at Semidis (Dragoo et al. 1991b).

[b]From Hatch et al. (1979).

[c]From Gould and Zabloudil (1981).

[d]From Gould and Nysewander (1982).

[e]From Gould et al. (1983).

[f]From Gould et al. (1984).

[g]From Nysewander et al. (1986).

[h]From S.A. Hatch (unpubl. data).

[i]Mean of log-transformed counts after the spill was not significantly different ($t_{0.10(2),11} = -0.17$, $P = 0.87$) from the mean of pre-spill counts.

[j]From Hatch and Hatch (1989).

[k]The mean of log-transformed counts after the oil spill was slightly higher ($t_{0.10(2),6} = -2.25$, $P = 0.07$) than prior to the spill.

Table 8. Counts[a] of common murres on 9 index plots at Middleton Island, Alaska, 1987 - 1991.

	Before spill[b]		After spill[b]		
Statistic[c]	1987	1988	1989	1990	1991
$\bar{x}$	932	786	747	598	705
CV	0.04	0.07	0.07	0.05	0.04
n	9	9	9	9	9

[a]From S. Hatch and B. Fadely (unpubl. data).
[b]Means of log-transformed data for the 2 periods, pre-spill and post-spill, are not significantly different ($t_{0.10(2),3} = 2.15$, $P = 0.12$).
[c]$\bar{x}$ = mean, CV = coefficient of variability, *n* = same size (number of counts).

Table 9. Median hatch dates of murres at Puale Bay and Semidi Islands, Alaska, after the *T/V Exxon Valdez* oil spill.

Species	Year	Puale Bay	Semidi Islands
Common murre			
	1989	13 Sept[a] (128)[b]	26 July (124)
	1990	4 Sept[a] (296)	23 July (128)
	1991	10 Sept[a] (374)	26 July (114)
Thick-billed murre			
	1989		25 July (79)
	1990		19 July (60)
	1991		25 July (90)

[a]Median hatch dates for common murres at Puale Bay were significantly later ($P < 0.001$) than at the Semidis; Fisher exact test.
[b]Sample size (n) = number of eggs.

Table 10. Chicks per adult common murre at Alaskan colonies following the *T/V Exxon Valdez* oil spill.

Location	Year	Chicks per adult[a]	Reference
<u>Outside Trajectory of Oil</u>			
Bluff	1989	0.34	Murphy 1991
Semidis	1989	0.36	Baggot et al. 1989
	1990	0.40	Dragoo et al. 1991a
	1991	0.32	Dragoo et al. 1991b
Agattu	1989	0.26	Williams and Byrd 1992
	1990	0.48	Williams and Byrd 1992
	1991	0.21	Williams and Byrd 1992
Mean		0.34[b]	
<u>Within Trajectory of Oil</u>			
Ugaiushak	1990	0.01	Nysewander et al. 1992
Nord	1989	0.01	Nysewander et al. 1992
	1990	0.01	Nysewander et al. 1992
	1991	0.13	Nysewander et al. 1992
Mean		0.04	

[a]This variable was calculated for all sites during the early chick-rearing period.
[b]The mean proportion outside the spill zone was significantly higher ($Z = 1.829$, $P < 0.05$) than within the trajectory of the oil.

Table 11. Number of chicks fledged per nest site of common murres at colonies in the western Gulf of Alaska before[a] and after the *T/V Exxon Valdez* oil spill.

	Within trajectory				Outside trajectory
Year	Chiswells	Barrens	Puale Bay	Ugaiushak	Semidis
Before spill					
1977		<0.47		>0.31	
1978		>0.48			
1979		0.48			0.48
1980					0.64
1981					0.59
After spill					
1989	<0.01[b]	<0.01[b]	0.07		0.58
1990			0.10		0.54
1991			0.38		0.52

[a]Sources of pre-spill data are: Barrens - Manuwal (1980); Ugaiushak - Wehle (1978); Semidis - Baggot et al. (1989), Hatch and Hatch (1990), Dragoo et al. (1991b). See Appendix A for details.

[b]Inferred from flightiness of murres throughout the breeding season (Appendix C).

APPENDIXES

Appendix A. Detailed summary of data on counts of murres at sites in the western Gulf of Alaska before and after the *T/V Exxon Valdez* oil spill.

<u>Chiswell Islands</u> [all counts from boats]

1976

Bailey (1976b and field notes)

On July 2-3, 1976, 7,476 murres were tallied in a single count of each of the 6 islands in the Chiswell group.

1986

Nishimoto and Rice (1987)

On July 5-8, 1986, 3387 murres were counted in a single count of each of the 6 islands, but these surveys were conducted under poor viewing conditions. Nishimoto rated viewing conditions "3", a code which means it was difficult to see. Furthermore, there was rain and 6 foot seas driven by 20-25 kt winds throughout the period.

1989-1991

see Table A-1

<u>Barren Islands</u>

<u>Nord Island</u> [all counts from boats]

1974

Ed Bailey's Field Notes [Incomplete count]

Entry from 7/02/74: "Ar [arrive] Nord 12N [12 noon]--400 CM [common murre],... N side--3,500 CM, ..NW end--2,000 murres. "

1975

Ed Bailey's Field Notes

Entry from 7/12/75: "Proceeded to Nord Island. Dense ... CM colony on east side--20,000 CM. Seems like more than last year."

1976

Bailey (1976a)

Table 1 lists Nord I. as having 30,000 murres [E. Bailey, pers. comm. discovered the published version was an error; 20,000 was the number of murres he recorded in the field]

1978

Simons and Pierce (1978a) [Incomplete count]

07/01/78: "1500, rafting offshore <100 on cliffs...surveyed by zodiak. We feel estimates given are accurate although 7/1 may have been an off day for murres. Bailey's 1975 estimate is probably maximum."

1989-91

see Table A-2

E. Amatuli Island and E. Amatuli Light Rock [All counts from boats except Manuwal's 1978 estimates based upon observations from land on E. Amatuli Light Rock]

1975

Ed Bailey's Field Notes

Entry from 7/11/75: "Covered south side of E. Amatuli. ...Small CM colony (300 pr) at Look ....East end of island and EA [East Amatuli] Light [Rock]--water and sky filled with birds, 60,000 CM....EA Light to NE corner covered yesterday--750 CM nesting."

1976

Bailey (1976a)

Table 1 list E. Amatuli I. as having 61,000 common murres. This includes the large island and East Amatuli Light Rock, and there was no reasonable way to arrive at an estimate for the birds on Light Rock alone.

1977

Manuwal, D.A. and D. Boersma. 1978. (p. 611)

"Although there was a small murre colony of 500 pairs located on the southern edge of the island, most murres nested on East Amatuli Lighthouse and the rocky eastern headland...From counts of incubating birds we estimate that 5000 pairs of murres occupy East Amatuli Lighthouse."

1978

Manuwal, D.A. 1978. (p. 69)

"There are an estimated 25,000 murres nesting on East Amatuli, of which almost 20,000 nest on the small lighthouse rock off the southeast tip of the island. This colony was visited throughout the summer of 1978 and on three occasions we landed at the lighthouse to inspect the colony more carefully."

Simons and Pierce (1978b)

5/78-8/78--"9000 birds on main island-lighthouse colony being evaluated-prob. 10-30,000 on lighthouse rock"

1979

Manuwal, D.A. 1980. (p. 81)

"[for East Amatuli I.] Although there was a small murre colony of 500 pairs located on the southern edge of the island, most murres nested on East Amatuli Lighthouse and the rocky eastern headland. From counts of incubating birds we estimate that 5000 (1977) to 10,000 pairs (1978 and 1979) of murres occupy East Amatuli Light rock."

1989-91

see Table A2

Appendix A. Murre Counts (continued)

Triplets [All counts from boats]

1975
Dick and Warner (1975)
On July 26, 1975, 1200 murres were counted.
1977
Trapp et al. (1977)
On June 29, 1977, 1297 murres were counted on the 3 islands.
1984
R. MacIntosh (pers. comm.)
In July 1984, 1300 murres were counted.
1989
R. MacIntosh (pers. comm.)
Between July 23-25, 1989 MacIntosh recorded counts of 913, 630, and 987 on 3 consecutive days.

Puale Bay Area

Cape Unalishagvak (Jute Peak) [All counts from boats]

1976
Gould and Powers (1976a)
On July 4, 1976, 16,500 murres were counted. The observers indicated that this count was a minimum because they were unable to be sure they saw all the birds.
1981
Bailey and Faust (1984)
In late July 1981, 38,000 murres were recorded.
1989-1991
see Table A-3

Oil Creek (Cape Aklek) [All counts from boats]

1976
Gould and Powers (1976b)
On July 4, 1976, 80,000 murres were counted; 6,000 - 7,000 were on the water, thus 73,000 - 74,000 were on the cliffs.
1981
Bailey and Faust (1984)
In late July 30,000 murres were recorded in a single count.
1989-1991
see Table A-4

Puale Bay [All counts from boats]

1976

Bailey and Schad (1976)

On July 29, 1976, 8000 murres were counted.

1981

Bailey and Faust (1984)

In late July 1981, 6500 murres were counted.

1989-1991

See Table A-5

Ugaiushak Island [Combination of land and boat counts]

1976

Wehle et al. (1977)

In late July murres in each of 8 locations for a total of 8340 birds.

Hoberg et al. (1977)

In July, 1976, 9200 murres were counted on the entire island.

1990-1991

Total island counts were made on 5 August in both years (see Table 7 in Results section)

Semidi Islands [All counts from land]

1977-1981

Hatch and Hatch (1989)

Replicate counts of sample plots throughout the breeding season made each year.

1989-1991

Dragoo et al. (1991a, 1991b)

Replicate counts of sample plots (see Table A6)

Middleton Island [All counts from land]

1976-1991

Hatch (unpubl. data)

In 1976, 1978, and 1981-1991 one-time counts were made of the entire island. Between 1986-1992 replicate counts were made at sample plots (see Table 7 in Results section).

Table A1. Counts of common murres on plots at selected islands in the Chiswell Islands group, Alaska, 1989-1991.

Date	Natoa	Matuska	Chiswell "B"	Chiswell	Beehive "B"	Beehive	Sub Total	On Water	Total
1989									
3 Jul	267	1,076	274	375	528	93	2,613		
3 Aug	252	639	264						
Mean	260	858	269	375	528	93	2,383		2,383 (24%)[a]
1990									
27 Jun	372	706	158	260[b]	552	135	2,183		
28 Jun	444	380	305	380	623	210	2,342		
29 Jun	456	435	525	114	698	290	2,518		
Mean	424	507	329	251	624	212	2,348 (167.6)[c]	1,935	4,283 (7%)
1991									
26 Jun	515	918	454	191	592	71	2,741		
28 Jun	328	985	349	196	435	73	2,366		
30 Jun	657	1,008	271	602	582	144	3,264		
2 Jul	583	1,145	284	358	439	93	2,902		
Mean	521	1,014	340	337	512	95	2,818 (372.5)	224	3,043 (13%)

[a]Coefficient of variation in parenthesis following annual estimated totals (in 1989 based on counts at Natoa, Matushka, and Chiswell "B" only).
[b]Birds flushed prior to count so the average of other counts for this island was used.
[c]Standard deviation in parenthesis.

Table A2. Counts of common murres on plots at Nord and East Amatuli Light Rock, and East Amatuli mainland, Barren Islands, Alaska, 1989-1991.

	Nord													East Amatuli			
Date	A1	A2	B	C	D	E	G	H1	H2	I	NW Islet	Total		Main-land	Lt. Rock	Total	
1989																	
26 Jul	154	127	7	139	460	531	74	274	375	159	219	2,519		339	424	763	
12 Aug	147	125	10	115	203	480	81	542	250	159[a]	231	2,343		406	535	941	
Mean	151	126	9	127	331	506	78	408	312	159	225	2,431	(124.5)[b]	373	480	852	(125.9)
1990																	
19 Jul	136	436	13	249	1,240	726	110	1,460	252	127	242	4,991					
14 Aug	134	310	13	231	875	468	155	898	380	144	261	3,869		292	416	708	
18 Aug	34	377	14	102	1,016	780	168	978	460	133	226	4,288		233	208	441	
Mean	115	341	14	157	992	694	118	1,112	364	135	236	4,383	(567.0)	263	312	575	(188.8)
1991																	
17 Aug	139	291	14	153	833	711	147	595	407	165	204	3,659		529	496	1,025	
22 Aug	140	220	12	126	830	514	103	825	358	129	200	3,457		375	318	693	
Mean	129	274	13	140	832	613	125	710	383	147	202	3,558	(142.8)	452	407	859	(234.8)

[a]Missing value estimated.
[b]Standard deviation in parentheses.

Table A3. Counts of common and thick-billed murres[a] on plots in the vicinity of Cape Unalishagvak, Puale Bay, Alaska, 1989-1991.

	Plots																						
Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21"A"	21"B"	Total
1989																							
21 Jul	454	538	299	542	1,193	343	546	551															
18 Aug	18	389	926	786	974	419	638	393	990	540	737	1,094	793	430	715	248	734	405	512	1,458	0	1047	14,246
Mean	236	464	613	664	1,084	381	592	472															
1990																							
3 Aug	17	260	370	1,435	910	333	244	730	850	1,095	390	740	1,375	395	479	154	385	500	990	1,484	0	1360	14,496
18 Aug	25	628	712	905	1,693	310	252	1,203	920	1,043	375	1,670	885										
Mean	21	444	541	1,170	1,302	322	248	967	885	1,069	383	1,205	1,130										
1991																							
12 Aug	20	466	660	909	716	217	1,036[b]		606	759	419	2,395[c]		566	770	158	1083	1,263[d]		1,473	858[e]		14,374

[a]Thick billed murres comprise an unknown but small proportion.
[b]Combined count for plots 7 and 8.
[c]Combined count for plots 12 and 13.
[d]Combined count for plots 18 and 19.
[e]Combined count for plots 21"A" and 21"B".

Table A4. Counts of common and thick-billed murres[a] on plots in the vicinity of Oil Creek (Cape Aklek), Puale Bay Alaska, 1989-1991.

Date	Plots 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Total
1989																				
20 Aug.	1,915	1,087	317	914	543	620	600	740	405	220	640	2,720	1,605	1,740	2,037	1,610	2,102	385	230	20,400
1990																				
2 Aug.	1,970	670	31	770	340	670	1,363	510	385	430	1,230	1,670	303	1,670	1,743	1,635	930	280	305	16,905
4 Aug.	1,925	1,015	224	505	345	535	870	500	420	570	1,305	1,845	375	1,660	1,810	1,505	1,030	320	276	17,035
Mean	1,948	843	128	638	343	603	1,117	505	403	500	1,268	1,758	339	1,665	1,777	1,570	980	300	291	16,970
1991																				
10 Aug.	2,496	1,086	170	560	317	2102	387	2,133	310	307	2096[b]		354	1,600	2,005	1,647	1,135	204	179	19,088

[a]Thick-billed murres comprise an unknown but small proportion.
[b]Combined count for plots 11 and 12.

Table A5. Counts of common and thick-billed murres[a] on plots in the vicinity of Puale Bay[b], Alaska, 1989-1991.

	Plot		
Date	13"A"	13"B"	Total
1989			
21 Jul	1,585		
25 Jul	1,955	400	
14 Aug	1,187	28[c]	
Mean	1,576	400	1,976
1990			
15 Jul	1,878		
25 Jul	2,811		
2 Aug	1,532	780	
1 Sep	1,877		
Mean	2,025	780	2,805
1991			
8 Aug	2,739	498	
19 Aug	2,422		
4 Sep	2,284		
Mean	2,482	498	2,980

[a]Thick-billed murres comprise an unknown but small proportion.
[b]Areas 13"A" and 13"B" encompass the entire colony.
[c]Colony had been largely abandoned.

Table A6. Counts of common and thick-billed murres on index plots at Chowiet Island, Semidi Islands, Alaska, 1989-1991.

		Replicate													Statistic[a]			
Year	Species	1	2	3	4	5	6	7	8	9	10	11	12	13	$\overline{X}$	S.D.	CV	n
1989	COMU[b]	2,814	2,542	2,646	2,398	3,210	2,883	2,782	2,836	2,534	2,799	2,645	2,826	2,245	2,705	2,44	0.09	13
	TBMU	115	100	143	97	199	145	148	227	82	84	91	64	36	118	53	0.45	13
	Total	2,929	2,642	2,789	2,495	3,409	3,028	2,930	3,063	2,616	2,883	2,736	2,890	2,281	2,882	283	0.10	13
1990	COMU	2,408	2,735	2,658	2,914	2,777	2,855	3,071	2,888	3,051	2,991				2,834	201	0.07	10
	TBMU	139	152	114	139	130	144	185	137	155	152				145	19	0.13	10
	Total	2,547	2,887	2,772	3,053	2,907	2,999	3,256	3,025	3,206	3,143				2,980	212	0.07	10
1991	COMU	2,906	2,714	3,023	2,993	2,850	3,033	3,093	3,129	3,013	3,001				2,976	122	0.04	10
	TBMU	156	137	161	146	140	131	161	134	134	113				141	15	0.11	10
	Total	3,062	2,851	3,184	3,139	2,990	3,164	3,254	3,263	3,147	3,114				3,117	124	0.04	10

[a] $\overline{X}$ = mean, SD = standard deviation, CV = coefficient of variation, n = sample size (number of counts).
[b] COMU = common murre, TBMU = thick-billed murre.

Appendix B. First egg laying dates for common murres at colonies in the western Gulf of Alaska.

Location	Year	Date Laying Began[a]	Reference
Middleton	1976	14 June	Frazer and Howe 1977
	1978	27 May	Hatch et al. 1979
	1989	<24 June	B.Fadely and S.Hatch unpubl.
	1990	14 June	B.Fadely and S.Hatch unpubl.
Hinchinbrook	1976	19 June	Nysewander and Knudtson 1977
	1977	21 June	Sangster et al. 1978
	1978	29 June	Baird et al. 1983
Barrens	1977	20 June	Manuwal and Boersma 1978
	1978	25 June	Manuwal 1980
	1979	30 June	Manuwal 1980
	1989	<26 July[b]	This Study
	1990	17 July	This Study
	1991	10 July	This Study
Paule Bay	1989	15 July	Dewhurst 1991
	1990	6 July	Dewhurst 1991
	1991	20 July	Dewhurst and Moore 1992
Chisik	1978	29 June	Jones and Peterson 1979
Ugaiushak	1974	25 June	G. Van Vliet unpubl.
	1976	17 June	Wehle et al. 1977
	1977	24 June	Wehle 1978
Semidis	1976	6 June	Leschner and Burrell 1977
	1977	5 June	Hatch 1978
	1978	8 June	Hatch and Hatch 1979
	1979	9 June	Hatch and Hatch 1990
	1980	7 June	Hatch and Hatch 1990
	1981	5 June	Hatch and Hatch 1990
	1989	9 June	Baggot et al. 1989
	1990	9 June	Dragoo et al. 1991a
	1991	10 June	Dragoo et al. 1991b

[a]The date eggs were first observed; in all cases observers were present prior to the first egg date except at 2 sites (Middleton and the Barrens in 1989 (note "<" to indicate these cases.

[b]No eggs were present 5 July, but eggs seen during next check on 26 July.

Appendix C. Summary of information upon which conclusions were based about reproductive success of murres at various colonies in the western of Gulf of Alaska.

Chiswell Islands: In 1989, E.P. Bailey and B. Rice visited the Chiswells from 2 July to 6 July and from 4 August to 8 August. During both surveys murres were flighty, with most birds leaving the cliffs at their approach. This type of behavior indicated that few if any birds were incubating. It is unlikely that laying would have begun after 8 August.

Barren Islands: The following data summarize information we extracted from reports of others and our observations.

	Methods	Results
1977	Checks of 242 eggs in one plot on E. Amatuli Light Rock.	Hatching success was 47%-60%, but "heavy rains and high winds" caused few birds to fledge (Manuwal 1978).
1978	Checks of at least 186 eggs on E. Amatuli Light Rock (Manuwal 1980).	On 22 August 1978 Manuwal found 60 eggs and 126 chicks in a 5 X 5 m plot on E. Amatuli Light Rock; the same plot where he found 165 eggs on 26 July 1979. If success was about 48% in 1979 (see below) it must have been higher in 1978. (e.g. > 48%).
1979	Checks of at least 165 eggs on E. Amatuli Light Rock (Manuwal 1980).	At last check there were 43 eggs and 36 chicks (48%) left; Manuwal (1980) reported that a storm "may have killed many chicks" prior to his last check.
1989	Observations: 28 June, 3-5 July, 20 July, 26-27 July, 6 Aug, 12-13 Aug.	Probably totally failed. Birds flighty throughout the summer indicating few had eggs. Top of E. Amatuli Light Rk had some eggs.
1990	Observations: 10-12 July, 15-20 July, 9 Aug, 13-15 Aug, 17-19 Aug, 3-5 Oct.	Murres irregularly attended cliffs; very few eggs seen; probably totally failed on Nord I.; no eggs or chicks 20 July or 17 August on plots with 360 adults at Nord Island. Observations at E. Amatuli Light Rock indicated at least some pairs were successful there.
1991	10 plots checked once during late incubation and early chick-rearing after earlier checks indicated some laying had occurred.	(See Table C1).

Puale Bay: No data were available on murre reproductive success prior to 1989, but from 1989 to 1990 there was intensive observation of birds on plots (Table C2).

Ugaiushak Island: Wehle (1978) had 3 murre study plots in 1977. His estimates of productiviy based on repeated visits follow:

> To evaluate effects of disturbance Wehle flushed birds from one plot (with 41 active common murre nest sites) every 2 days throughout the season, so it was frequently perturbed; 22 chicks (54% of nest sites) hatched and 10 (24% of nest sites) fledged. One of 3 thick-billed murres that laid fledged a chick.
>
> At Murre Cove 2 additional ledges were viewed without disturbing them. Wehle saw only 4 common murre eggs -- all hatched and fledged. He also observed 25 thick-billed eggs on the 2 ledges; 14 (56%) hatched, and 11 (44%) fledged.
>
> Combining the samples from all 3 plots, we calculatd that 45 pairs of common murres produced 26 chicks (58% hatch success), and successfully fledged young (31% reproductive success). For thick-billed murres 25 pairs hatched 15 eggs (60%) and fledged 12 young (48%).

On 5 August 1990, we checked a cliff face in the same area of Wehle's 1977 plots, and counted 1,687 adults. The next day, 6 August, only 15 adults were present, and we counted 5 eggs. A maximum of 15 eggs were present, even if every bird was incubating, indicating less than 1% of the 1,687 birds were on eggs.

Semidi Islands: From 1979 to 1981, Hatch (1981) monitored reproductive success of murres on 10 undistured plots at Chowiet Island by regular observations throughout the breeding period. The same plots were used to monitor productivity during 1989-1991 (Table C3).

Table C1. Murre counts and chicks or eggs per adult at plots in the Barren Islands, Alaska, 1991.

Area	Date	Adults	Chicks[a]	Chicks/adult
E. Amatuli Lt. Rock				
1	Sept. 11	65	5	0.08
2	Sept. 11	161	23	0.16
3	Sept. 11	36	3	0.09
4	Sept. 11	190	34	0.18
Nord Island				
D	Sept. 11	95	6	0.06
T	Sept. 12	87	14	0.13
1	Sept. 12	32	4	0.16
2	Sept. 12	53	4	0.08
3	Sept. 12	69	10	0.15
6	Sept. 12	40	6	0.15
E. Amatuli Lt. Rk. and Nord Is.				
$\bar{x}$				0.12
SD				0.04
n				10

[a]Included a few eggs still being incubated.

Table C2. Reproductive success of common and thick-billed murres, Puale Bay, Alaska, from 1989-1991[a].

	Year		
Parameters	1989	1990	1991
Common murre			
Total plots	14	15	8
Total sites with ≥ 1 egg	266	388	109
Total chicks	133	289	64
Total chicks fledged	20	39	41
Hatching success[b]	0.50	0.74	0.59
Fledging success[c]	0.15	0.13	0.64
Productivity[d]	0.07	0.10	0.38
Thick-billed murre			
Total plots	3	4	3
Total sites with ≥ 1 egg	20	43	21
Total chicks	4	15	15
Total chicks fledged	1	2	10
Hatching success	0.20	0.42	0.71
Fledging success	0.25	0.13	0.67
Productivity	0.05	0.06	0.48

[a]From Dewhurst (1991).
[b]Chicks observed per eggs laid.
[c]Chicks fledged per chicks hatched.
[d]Chicks fledged per eggs laid.

Table C3. Reproductive success of common and thick-billed murres at Chowiet Island of the Semidi Islands, Alaska, 1989-1991.

	Year		
Parameter	1989[a]	1990[b]	1991[c]
Common murre			
Total plots	16	7	7
Total sites with ≥ 1 egg	180	213	208
Total chicks fledged	104	115	108
Productivity[d]	0.58	0.68	0.52
Thick-billed murre			
Total plots	17	4	4
Total sites with ≥ 1 egg	129	134	133
Total chicks fledged	55	56	63
Productivity	0.43	0.42	0.47

[a]From Baggot et al. (1989).
[b]From Dragoo et al. (1991a).
[c]From Dragoo et al. (1991b).
[d]Chicks fledged per eggs laid.