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Population Levels and Reproductive Performance of Murres Based on Observations at Breeding Colonies Four Years After the *Exxon Valdez* Oil Spill

Restoration Study Number 11
Final Report

Donald E. Dragoo
G. Vernon Byrd
David G. Roseneau
Joel A. Cooper

U.S. Fish and Wildlife Service
Alaska Maritime National Wildlife Refuge
2355 Kachemak Bay Drive, Suite 101
Homer, Alaska 99603

Donna A. Dewhurst
J. H. McCarthy

U.S. Fish and Wildlife Service
Alaska Peninsula/Becharof National Wildlife Refuge
P.O. Box 277
King Salmon, Alaska 99613

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Study History: An assessment of the damage to murre populations and reproductive performance due to the 1989 *Exxon Valdez* oil spill was conducted from 1989 to 1991 (Bird Study Number 3, Nysewander *et al.* 1993). In 1992, Restoration Study Number 11 continued monitoring these parameters at three murre nesting colonies located in the path of the oil in an effort to begin measuring recovery. This is the final report for this project.

Abstract: An assessment of the damage to murre populations and reproductive performance due to the 1989 *Exxon Valdez* oil spill was conducted from 1989 to 1991. In 1992, we continued monitoring these parameters at three murre (*Uria aalge* and *U. lomvia*) nesting colonies located in the path of the oil in an effort to begin measuring recovery. Numbers of murres were significantly reduced at all three study colonies following the spill. We found no recovery to pre-spill numbers. Timing of breeding and productivity of murres at the Barren Islands and Puale Bay returned to near normal levels in 1992.

Key Words: Alaska, Barren Islands, Chiswell Islands, Gulf of Alaska, Puale Bay, populations, productivity, breeding chronology, seabirds, common murre, thick-billed murre, *Exxon Valdez*, oil spill, *Uria aalge, Uria lomvia.*

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EXECUTIVE SUMMARY

An assessment of the damage to murre populations and reproductive performance due to the 1989 *T/V Exxon Valdez* oil spill was conducted from 1989 to 1991. In 1992, we continued monitoring these parameters at three murre (*Uria aalge* and *U. lomvia*) nesting colonies located in the path of the oil in an effort to begin measuring recovery.

Objectives were to assess whether murre numbers were beginning to recover to pre-spill levels, and to determine whether breeding chronology and productivity had returned to pre-spill schedules or levels.

Numbers of murres were significantly reduced at all 3 study colonies following the spill. No signs of recovery toward pre-spill numbers were seen at any colony by 1992, nor were there indications of further declines. The onset of laying returned to near pre-spill dates at both the Barren Islands and Puale Bay, but mean laying dates remained later than pre-spill estimates at both colonies.

Productivity of murres in the Barren Islands and at Puale Bay was progressively higher in each year since the spill. Productivity in the Barren Islands in 1992 was similar to that at other Alaskan colonies from outside the spill area. Productivity of murres at Puale Bay also returned to average levels by 1992.

Direct mortality from oil was the most likely reason fewer murres were found at nesting colonies after the oil spill, although other factors cannot be completely discounted. The spill occurred just prior to the murre breeding season when predominately experienced breeders normally are congregating near colonies. Therefore, most of the birds killed during the spill were probably experienced breeders. The loss of these birds probably resulted in reduced densities at nesting ledges and skewed age structures--factors which are known to cause delayed laying and reduced productivity in murres elsewhere. Although both timing of laying and productivity apparently are returning to normal at oiled colonies, several more years probably must pass before murres produced at these colonies can recruit as breeders and thus contribute to population increases.

INTRODUCTION

The estimated 11 million gallons of crude oil released in Prince William Sound during the 24 March 1989 *T/V Exxon Valdez* grounding was the largest oil spill in American history (Galt et al. 1991). Oil carried southwestward out of Prince William Sound by prevailing currents fouled hundreds of kilometers of the Alaskan coastline as far west and south as Mitrofania Bay. The resultant fouling adversely affected pelagic and nearshore water columns, benthic substrates, and intertidal and supratidal coastal habitats (Exxon Valdez Oil Spill Trustee Council 1993).

During the spill, floating oil either surrounded, passed near, or washed ashore at about 27 seabird nesting colonies in the western Gulf of Alaska (Nysewander et al. 1993). The vast majority of the murres (*Uria* spp.) normally attending these colonies were common murres, *U. aalge* (DeGange and Sanger 1986, U. S. Fish and Wildlife Service 1990). Large numbers of these birds were concentrated in pre-breeding aggregations near the colonies when the oil slick passed through this region in April and early May (Piatt et al. 1990). Direct mortality of murres was probably on the order of low hundreds of thousands (Piatt et al. 1990, Ford et al. 1991), an unprecedented loss of birds from acute oil pollution (Piatt and Lensink 1989).

Because seabirds are predators that feed near the top of oceanic food webs, they are useful indicators of changing conditions in marine environments (Anderson and Gress 1984, Harris and Wanless 1990). Also, most seabird species are numerous and conspicuous. They nest in concentrated colonies and are relatively easy to study compared to other upper trophic level marine species such as whales, seals, sea lions and fishes (Harris and Wanless 1990). Seabirds that dive for food, including common and thick-billed murres (*U. lomvia*), are particularly vulnerable to oil in water (Bourne 1968, Clark 1969, Vermeer and Vermeer 1975, King and Sanger 1979, Piatt et al. 1991). Populations of long-lived seabirds, including murres, have low reproductive rates and therefore may be adversely effected by relatively small increases in adult mortality (Hatchwell and Birkhead 1991).

In 1992, we continued the monitoring program begun in 1989 to evaluate the impacts of the *T/V Exxon Valdez* oil spill on murres at breeding sites within the trajectory of the floating oil (Nysewander et al. 1993). We also began to evaluate the recovery of murre populations and productivity at breeding colonies affected by the oil. We collected data on murre numbers in the Barren and Chiswell islands and Puale Bay. We also obtained information on murre reproductive performance at the Barren Islands and Puale Bay. The timing and length of our visit to the Chiswell Islands precluded our gathering information on the reproductive performance of murres at that colony.

OBJECTIVES

A. Document the rate of recovery of breeding populations of murres at the Barren and Chiswell islands and Puale Bay.

B. Determine whether murre breeding behavior, specifically timing of reproductive events and productivity, had returned to pre-spill values at the Barren Islands and Puale Bay.

METHODS

Study Area

The Barren Islands (58°55'N, 152°10'W) are located near the southern entrance to Cook Inlet between Afognak Island and the Kenai Peninsula (Fig. 1). The seven named islands in this group range in size from 10 to 2,775 ha (Fig. 2) and total about 4,000 ha. The topography, habitats and environment of the Barren Islands were previously described by Bailey (1976*a*) and Manuwal (1980).

The Chiswell Islands (59°37'N, 149°36'W) are situated in the Gulf of Alaska about 55 km southwest of Seward (Fig. 1). The six islands surveyed during this study vary in size from 6-ha Chiswell Island to 108-ha Natoa Island (Fig. 3). The topography, habitats and environment of the Chiswell Islands were previously described by Bailey (1977) and Nishimoto and Rice (1987).

Puale Bay (57°41'N, 155°29'W) is located on the southern coast of the Alaska Peninsula (Fig. 1) within the Becharof portion of the Alaska Peninsula/Becharof National Wildlife Refuge. Murre study colonies were located at Jute Peak near Cape Unalishaguak, Cape Aklek (Oil Creek) and a site at the head of Puale Bay (Fig. 4). The topography, habitats and environment of Puale Bay have been described by Dewhurst and Moore (1992) and McCarthy and Dewhurst (1992).

Populations

Data Collection.--Because murres were not always identified to species during population counts, we refer to them collectively in this report. We used data from historical surveys conducted in the mid-1970's and early 1980's to describe pre-spill distribution and relative abundance of breeding murres (U. S. Fish and Wildlife Service 1990).

Methods used in 1992 to count murres were similar to methods used by Nysewander et al. (1993) to facilitate comparison of results. These authors discussed the sources of variation in colony count data. All murres were counted at least once at selected islands in the Chiswell and Barren islands, and at 2 of the 3 colonies previously studied in the vicinity of Puale Bay (Cape Aklek #008 and Puale Bay #013, Map #35 in Sowls et al. 1978). In addition, replicate counts were made at selected Chiswell islands as well as on plots in the Barren Islands and at Puale Bay to provide a basis for comparing estimates from post-spill years.

Data Analysis.--We used one-way analysis of variance to examine differences among years since 1989, the first year for which replicate counts of islands or plots were available. Tukey HSD multiple comparisons were performed after ANOVA tests proved significant ($P < 0.10$). We used the 0.10 level of significance for the Type I error rate throughout this report. This was done in an effort to maximize power, given the small sample sizes. We were willing to relax the α-level to strengthen β. If replicate counts were not available for a particular year, we used t-tests to compare the non-replicate count from that year with replicated counts from other years ($P < 0.10$). All data were log-transformed to reduce possibilities of violating assumptions required for parametric tests.

Breeding Chronology

Data Collection.--We visited the 6 Nord Island land-based plots on 2, 4, and 15 July; 6, 10, 22 and 25 August to record the timing of reproductive events on each plot. These observations were supplemented on portions of plots 2 and 3 with time-lapse footage. Some active nest sites (sites where an egg was laid) were also tracked throughout the season with the time-lapse footage. We noted the dates when evidence of murre egg-laying first occurred in other areas as well.

At Puale Bay, we made direct observations of murre nest sites almost daily from before egg-laying began until most chicks fledged. We used a series of 11 plots to obtain data for common murres and 4 plots for thick-billed murres.

Data Analysis.--We used data graphed in Manuwal (1980) to estimate laying dates for common murres at East Amatuli Island in 1979. We used one-way analysis of variance procedures ($P < 0.10$) to compare these data with those from Nord Island in 1992 (all data log-transformed). We used a t-test ($P < 0.10$) to compare the dates when eggs were first seen at Nord Island in 1992 to similar data for East Amatuli Island from 1977-1979 (all data log-transformed). We estimated mean dates of nesting events from direct observations at the land-based plots and from time-lapse cameras on Nord Island. We used mean dates rather than medians to allow for comparisons of our data with those from past years, which were reported as means.

First and mean egg laying dates at Puale Bay were calculated from direct observations and converted to Julian dates. We used a t-test ($P < 0.10$) to compare log-transformed first egg dates from Puale Bay in 1992 with those from Ugaiushak Island in 1974, 1976 and 1977 (all dates were converted to Julian dates).

Productivity

Data Collection.--In the Barren Islands, the same plots and nest sites (sites where an egg had been laid) used on Nord Island to obtain information on timing of nesting events were used to collect data on reproductive success. We visited plots on 2, 4, and 15 July; 6, 10, 22, and 25 August. On each visit, we recorded the number of sites with eggs or chicks (active nest site) and the number of adult murres on each plot. These observations were supplemented with time-lapse cameras on small portions of 2 plots to determine the fate of eggs and chicks in these areas. We used these observations to estimate the proportion of adult murres with eggs or chicks on our productivity plots late in the season. Also, on 11 September, we recorded the proportion of adult murres in brooding posture or with chicks on 11 Nord Island population plots visible from the boat or offshore rocks to provide comparisons of this index to productivity with past years.

We estimated productivity of murres at Puale Bay from observations at the same plots used to study timing of nesting events. Observers visited the plots on a daily basis, weather permitting, throughout the nesting season and recorded the status of nest sites (site where an egg had been laid) on plots during each visit. We recorded data separately for common and thick-billed murres.

Data Analysis.--Due to a lack of precise estimates of murre productivity from the Barren Islands, we were unable to use standard ratio estimation techniques to quantify this parameter. As a result, we estimated the productivity of murres based on the number of eggs or chicks seen per adult during a count made at Nord Island on 11 September, and at each of the 6 land-based productivity plots using both observations and time-lapse data. The mean of the proportions (eggs or chicks seen per adult) from these two areas was used as the index of productivity for murres at the Barren Islands in 1992. We made comparisons between the mean post-spill proportion for other colonies from outside the spill trajectory and that from the Barren Islands in 1992 with a z test ($P < 0.10$).

At Puale Bay, where more precise estimates of past murre productivity were available, we were able to use standard ratio estimation techniques. We made comparisons among post-spill years by testing for significant heterogeneity ($P < 0.10$) using contingency tables and calculating log-likelihood ratios (G). Unfortunately, the productivity estimates from the Barren Islands (chicks/adult) are not directly comparable to those from Puale Bay (chicks fledged/site where an egg was laid).

RESULTS

Populations

Barren Islands.--In 1992, we counted a total of 11,212 murres on Nord Island and 5960 murres on East Amatuli Light Rock (Table 1). The 1992 counts were about half the pre-spill estimates and similar to other counts made at these sites after the *T/V Exxon Valdez* spill. There was no evidence that numbers were recovering to pre-spill levels, based on annual counts of murres on entire islands or post-spill index plots (where more rigorous comparisons were possible due to replicate annual counts, Tables 2, A1 and A2). We found differences among counts of murres on plots in post-spill years (1989-1992, $F = 9.34$, $P = 0.008$), but numbers of murres were highest in 1990 (Table 2), not in 1992, as expected if the population was increasing.

Chiswell Islands.--In 1992, a total of 2480 murres was counted on the cliffs of the 6 Chiswell Islands selected for study (Tables 3 and A3). The 1992 count was about two-thirds smaller than the number reported at these colonies in 1976 (Table 3). Although the counts of murres on the 3 islands with replicate post-spill counts (Table A3) were higher in 1991 than in 1990 (F = 5.26, $P = 0.023$), fewer birds were counted on these islands in 1992 than in 1991. We found no evidence suggesting that murre populations were increasing in the Chiswell Islands.

Puale Bay.--A total of 22,697 murres was counted at the Cape Aklek and Puale Bay colonies in 1992 (Tables 4, A4 and A5). The 1992 count was nearly two-thirds lower than average pre-spill numbers. We were unable to completely count the third study colony at Jute Peak in 1992; however, data obtained on several subplots provided information for comparison with that from other post-spill years (Table 5).

We found no evidence of recovery of Puale Bay murre populations to pre-spill levels. The number of murres we counted on study plots at the Jute Peak colony in 1992 was similar ($P = 0.780$) to other post-spill counts on these plots (where annual replicate counts were available, Table 5). This suggests that increases have not occurred at this colony since 1989. Numbers on these plots in 1991, when only one count was made, were significantly lower ($t = 3.58$, $P = 0.070$) than those from other years since the spill (Table 5). Counts at the only other Puale Bay area with replicate post-spill counts (area 13A) also indicated that there has been no significant recovery ($P = 0.129$) of murre populations since 1989 (Table A6).

Breeding Chronology

Barren Islands.--In 1992, the first eggs were recorded on 2 July at East Amatuli Light Rock, where several dozen broken egg shells were seen. In addition, 4 incubating murres were seen on top of the rock where several thousand murres normally nest (Manuwal 1980). Also on 2 July, we found 2 broken murre egg shells below the cliffs at Nord Island. There were as yet no murres on eggs on any of the Nord Island productivity plots. From this information, we concluded that a very small proportion of the murres at East Amatuli Light Rock and Nord Island had laid by 2 July (Fig. 5, Tables 6 and A7). The date when we first observed murre eggs at the Barren Islands in 1992 was not significantly different ($P = 0.137$) from the first-egg dates at East Amatuli Island in 1977-1979 (Fig. 5).

Apparently most murres did not lay until after mid-July because we did not observe eggs on our study plots at Nord Island until 17 July. The mean laying date for the small sample of sites where eggs were laid on our plots was 28 July (Table 7). This was significantly later ($F = 283$, $P < 0.001$) than that for East Amatuli Island in 1979.

Puale Bay.-- The date of first egg laying for murres at Puale Bay in 1992 was the earliest since the oil spill (Fig. 6), but was significantly later ($t = -3.843$, $P = 0.062$) than pre-spill dates from Ugaiushak Island (Table 6). The mean laying dates for murres at Puale Bay in 1992 were also earlier than for any year since the oil spill (Table 7).

Productivity

Barren Islands.--In 1992, we recorded an average of 0.29 chicks per adult on Nord Island plots from periodic observations throughout the breeding season, supplemented with time-lapse footage (Table A8). On 11 September, we found a proportion of 0.34 chicks per adult on 11 additional plots on Nord Island (Table A9). The overall 1992 average proportion was 0.32 chicks per adult murre (Table 8).

Since 1989, when a complete breeding failure probably occurred at the Barren Island colonies, murre productivity has increased annually at Nord Island. The proportion of chicks to adults for 1992 was more than twice as high as in 1991 (Table 8). No comparative pre-spill data were available from the Barren Islands, but recent post-spill estimates from Alaskan sites outside the path of the oil averaged 0.34 chicks per adult (Table 8). This was similar to the proportion observed in the Barren Islands in 1992 ($P > 0.10$).

Puale Bay.--Productivity estimates (chicks fledged/site where an egg was laid) for both common and thick-billed murres were significantly different among the four post-spill years ($G = 401$, $P < 0.001$ for common, $G = 33$, $P < 0.001$ for thick-billed). Murre productivity at Puale Bay was higher in each ensuing year after the spill (Tables 9 and A10). Following a gradual increase in each year since 1989, the 1992 productivity estimate for common murres was similar to that found at colonies outside the spill trajectory (Table 9). Although fewer data were available for thick-billed murres, it appeared that productivity rates for this species followed a pattern similar to that for common murres after the oil spill (Table A10).

DISCUSSION

Large numbers of murres, probably belonging to colonies in the Chiswell and Barren islands and portions of the Alaska Peninsula, died as a result of the *T/V Exxon Valdez* oil spill in March 1989 (Piatt et al. 1990, Ford et al. 1991). Murre populations at these colonies were found to be significantly lower after the spill (Nysewander et al. 1993). Murre populations at colonies within the oil trajectory have not increased during the 4-year period following the spill, nor have murre numbers substantially declined since 1989 (Fig. 7).

The lack of population increases suggests that any surplus birds present were not abundant enough to occupy all of the territories left vacant by direct, oil-caused mortality. The reproductive success of the remaining birds also may have been depressed initially due to the toxic effects of oiling on breeding adults (Fry et al. 1985, Burger and Fry 1993), but it is unlikely that this effect would have persisted until 1992 (M. Fry Pers. Comm.). Restoration of the populations we studied will therefore probably depend on recruitment of birds produced at or near affected colonies. Because murres normally do not breed until they are 3-6 years old (Birkhead and Hudson 1977, Gaston et al. 1994), meaningful recruitment will probably not occur until several years after productivity returns to pre-spill levels.

Murres have been known to abandon breeding sites because of environmental perturbations (e.g., El Niño Southern Oscillation) or severe disruptions of food webs near nesting colonies during the breeding season (Stowe 1982, Murphy et al. 1986, Boekelheide et al. 1990). In these situations low counts are usually the result of the absence of the birds rather than mortality (Nysewander et al. 1993), and birds generally return to nesting colonies 1 or 2 years after these events (Birkhead and Hudson 1977, Stowe 1982, Boekelheide et al. 1990). The continuing low numbers of murres at the colonies within the spill zone suggest that the missing birds died. It is possible that unknown environmental changes near the study colonies may be preventing or slowing the recovery of these murre populations to pre-spill levels (e.g., Clark 1984).

In 1989, following the *T/V Exxon Valdez* oil spill, murres nesting within the spill zone began laying eggs nearly 1 month later than normal (Table A7). The onset of laying continued to be significantly later through 1991 (Nysewander et al. 1993), but as indicated, first egg dates returned to near pre-spill values by 1992 (Figs. 5 and 6).

Nevertheless, in 1992, mean laying dates of murres at Nord Island and Puale Bay remained later than expected based on comparisons with pre-spill dates at East Amatuli and Ugaiushak islands, respectively (Manuwal 1980, Wehle et al. 1977, Wehle 1978). This suggests that, although some murres were laying their eggs as early as before the spill, egg-laying was still delayed for many breeders at these two spill-affected colonies.

Murre breeding chronology can vary by several days from year to year (Birkhead 1980, Hatch and Hatch 1990, Hedgren 1979). Dates of first egg-laying for murres in the Barren Islands varied by as much as 10 days prior to the oil spill (Fig. 5). Researchers in other areas have concluded that annual variations in the timing of breeding may be attributed to such factors as annual differences in oceanographic (Boekelheide et al. 1990, Birkhead and Nettleship 1981) or meteorological conditions (Hedgren 1979) near breeding colonies.

As noted above, we found evidence that both egg laying dates and productivity were beginning to return to normal in 1992. Nysewander et al. (1993) suggested that disruption of the age structure of murres, due to differentially high mortality of experienced breeders during the oil spill, was at least partially responsible for delayed onset of breeding and reduced reproductive success. If the 1989 breeding populations were indeed composed of abnormally high proportions of young birds, these cohorts have now aged and should be gaining the experience that apparently contributes to earlier nesting times and higher success rates (Hedgren 1980, Gaston et al. 1994).

In Alaska, typically 50% to 70% of nesting pairs of murres produce chicks (Byrd et al. 1993). Catastrophic reproductive failures of murres do not appear to be frequent anywhere in the world (Gaston and Nettleship 1981, Harris and Birkhead 1985, Harris and Wanless 1988, Byrd 1989, Boekelheide et al. 1990). When such events occur, they usually are attributed to factors such as reduced prey availability, poor weather, unfavorable sea-ice conditions, or severe El Niño events (e.g., Manuwal 1980, Boekelheide et al. 1990). Based on the information collected after the *T/V Exxon Valdez* oil spill, high mortality of adults appears to be another factor that can cause reproductive failures in murres (Nysewander et al. 1993).

CONCLUSIONS

Results from monitoring efforts in 1992 suggest that timing of breeding events and productivity of murres were beginning to return to pre-spill levels, while population levels showed no recovery toward pre-spill numbers. Continued monitoring of reproductive parameters and population trends will provide an opportunity to document recovery rates from this spill and predict the effects of future spills on seabirds.

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Table 1. Total counts of murres on Nord Island and East Amatuli Light Rock in the Barren Islands, Alaska, before and after the 1989 *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	6,912
1990	12,277	5,865
1991	13,333	5,529
1992	11,212	5,960

[a]Bailey (1976b) erroneously reported "30,000" murres at Nord Island (Nysewander et al. 1993).
[b]From Manuwal and Boersma (1978), Manuwal (1980).

Table 2. Counts of murres on study plots at Nord and East Amatuli Islands and East Amatuli Light Rock in the Barren Islands, Alaska, after the 1989 *T/V Exxon Valdez* oil spill[a].

	Statistic[b]		
Year	$\bar{x}$	s	*n*
1989	3283[c]	1.4	2
1990	4653[c]	107.5	2
1991	4417[c]	377.6	2
1992	3716[c]	357.8	5

[a]Data from Nysewander et al. 1993 and this study.
[b]$\bar{x}$ = mean, s = standard deviation, *n* = sample size (number of counts).
[c]Significant difference among years ($F = 9.34$, $P = 0.008$, all data log-transformed).

Multiple comparisons-Tukey HSD test (0.10 level):

1989 1992 1991 1990

Table 3. Counts of murres[a] at Natoa, Matushka, Chiswell, Chiswell "B", Beehive, and Beehive "B" colonies in the Chiswell Islands, Alaska, before and after the 1989 *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	0
1986[d]	3,387	2,387	1,000
After spill			
1989[e]	2,383	2,383 (--,2[f])[g]	0
1990[h]	4,283	2,348 (168,3)	1,935
1991[h]	3,042	2,818 (373,4)	224
1992	2,641	2,480 (106,3)	161

[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]From Nishimoto and Rice (1987); made under conditions of poor visibility so the count is probably an underestimate.
[e]From Bailey and Rice (1989).
[f]Replicate counts for only 3 of 6 islands.
[g]Where number of counts (*n*) is greater than 1, standard deviation and sample size are in parenthesis (s,*n*).
[h]From Nysewander et al. 1993.

Table 4. Counts of murres at the Puale Bay, Alaska colonies, before and after the 1989 *T/V Exxon Valdez* oil spill[a].

Year	Puale Bay	Cape Aklek	Total
Before Spill			
1976	8,000	73,000	81,000
1981	6,500	30,000	36,500
After Spill			
1989	1,976	20,400	22,376
1990	2,805	16,970	19,775
1991	2,980	19,088	22,068
1992	2,426	20,271	22,697

[a]Data from Sowls et al. 1978, Bailey and Faust 1984, Nysewander and Dippel 1990, 1991, Nysewander et al. 1993, Dewhurst and Moore 1992, and this study.

Table 5. Counts of murres on study plots (1-8) at the Jute Peak colony in Puale Bay, Alaska, after the 1989 *T/V Exxon Valdez* oil spill[a].

Year	Statistic[b] $\bar{x}$	s	n
1989	4505[c]	54	2
1990	5014[c]	1010	2
1991	4024[d]	--	1
1992	4412[c]	1105	2

[a]Data from Dewhurst 1991, Dewhurst and Moore 1992 and this study.
[b]$\bar{x}$ = mean, s = standard deviation, n = sample size.
[c]No significant difference (F = 2.71, P = 0.780) between counts from 1989, 1990 and 1992 (all data log-transformed).
[d]Significantly lower (t = 3.58, P = 0.070) than mean of other post spill counts (all data log-transformed).

Table 6. Dates common murre eggs were first observed at selected colonies in the Gulf of Alaska before and after the 1989 *T/V Exxon Valdez* oil spill.

Year	Location	First Egg Date	Reference
Before Spill or Outside Path of Oil			
1974	Ugaiushak	25 June	G. Van Vliet unpubl.
1976	Ugaiushak	17 June	Wehle et al. 1977
1977	Barrens	20 June	Manuwal and Boersma 1978
	Ugaiushak	24 June	Wehle 1978
1978	Barrens	25 June	Manuwal 1980
1979	Barrens	30 June	Manuwal 1980
After Spill in Path of Oil			
1989	Puale Bay	15 July	Dewhurst 1991
1990	Barrens	17 July	Nysewander et al. 1993
	Puale Bay	6 July	Dewhurst 1991
1991	Barrens	<10 July	Nysewander et al. 1993
	Puale Bay	20 July	Dewhurst and Moore 1992
1992	Barrens	2 July	This study
	Puale Bay	30 June	This study

Table 7. Mean egg laying dates for common and thick-billed murres at colonies in the Gulf of Alaska before and after the 1989 *T/V Exxon Valdez* oil spill.

Location	Year	Mean Egg Laying Date: Common	Mean Egg Laying Date: Thick-billed	Reference
Before Spill or Outside Path of Oil				
E. Amatuli	1979	1 July		Manuwal 1980
After Spill or Within Path of Oil				
Nord	1991	25 July		Nysewander et al. 1993
	1992	28 July		This study
Puale Bay	1989	6 Aug.	31 July	Dewhurst 1991
	1990	1 Aug.	26 July	Dewhurst 1991
	1991	1 Aug.	30 July	Dewhurst and Moore 1992
	1992	16 July	15 July	This study

Table 8. Chicks per adult common murre at Alaskan colonies following the *T/V Exxon Valdez* oil spill.

Location	Year	Chicks per adult[a]	Reference
Outside Path of Oil			
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	
Within Path of Oil			
Ugaiushak	1990	0.01	Nysewander et al. 1993
Nord	1989	0.01	Nysewander et al. 1993
	1990	0.01	Nysewander et al. 1993
	1991	0.13	Nysewander et al. 1993
Mean		0.04	
	1992	0.32[b]	This study (Tables A8 & A9)

[a]This variable was calculated for all sites during the early chick-rearing period.
[b]1992 proportion not significantly different from the mean of proportions from colonies outside of spill trajectory ($Z = 0.60$, $P > 0.10$).

Table 9. Productivity of common murres at colonies in the western Gulf of Alaska before and after the *T/V Exxon Valdez* oil spill[a].

	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]		0.07		0.58
1990			0.10		0.54
1991			0.38		0.52
1992			0.66		

[a]Sources of data are: Barrens - Manuwal (1980); Ugaiushak - Wehle (1978); Semidis - Baggot et al. (1989), Hatch and Hatch (1990), Dragoo et al. (1991b).
[b]Inferred from flightiness of murres throughout the breeding season (Nysewander et al. 1993).

APPENDIX A

Counts and productivity of murres at selected colonies in the western Gulf of Alaska since the 1989 *T/V Exxon Valdez* oil spill

Table A1. Counts of murres on common plots at Nord and East Amatuli Light Rock, and East Amatuli mainland, Barren Islands, Alaska, 1989-1992[a].

	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	2519		339	424	763	
12 Aug	147	125	10	115	203	480	81	542	250	159[b]	231	2343		406	535	941	
Mean	151	126	9	127	331	506	78	408	312	159	225	2431	(124.5)[c]	373	480	852	(125.9)
1990																	
19 Jul	136	436	13	249	1240	726	110	1460	252	127	242	4991					
14 Aug	134	310	13	231	875	468	155	898	380	144	261	3869		292	416	708	
18 Aug	34	377	14	102	1016	780	168	978	460	133	226	4288		233	208	441	
Mean	101	374	13	194	1044	658	144	1112	364	135	236	4383	(567.0)	263	312	575	(188.8)
1991																	
17 Aug	139	291	14	153	833	711	147	595	407	165	204	3659		529	496	1025	
22 Aug	140	220	12	126	830	514	103	825	358	129	200	3457		375	318	693	
Mean	140	256	13	140	832	613	125	710	383	147	202	3558	(142.8)	452	407	859	(234.8)
1992[d]																	
1	95	181	9	143	688	473	71	873	285	84	106	3008		232	235	467	
2	63	195	0	65	618	493	76	610	242	117	158	2637		440	508	948	
3	85	169	10	178	682	380	114	523	301	168	134	2744		388	538	926	
4	70	321	0	163	780	541	150	760	311	165	188	3449		392	501	893	
5	42	151	7	113	730	488	101	855	251	142	136	3016		199	294	493	
Mean	71	203	5	132	700	475	102	724	278	135	144	2971	(314.2)	330	415	745	(243.2)

[a]Data from Nysewander et al. 1993 and this study.
[b]Missing value estimated using the mean from other counts.
[c]Standard deviation in parentheses.
[d]1 = 6-9 Aug.; 2 = 9,10 Aug.; 3 = 10 & 18 Aug; 4 = 18 & 24-25 Aug.; 5 = 26 Aug.

Table A2. Counts of murres on plots at the Barren Islands, Alaska in 1992.

Plot	Replicate[a] 1	2	3	4	5	$\bar{x}$
NORD ISLAND						
A1	95	63	85	70	42	71
A2	181	195	169	321	151	203
B	9	0	10	0	7	5
C	143	65	178	163	113	132
Above C[b]	--	--	27	--	--	--
D	688	618	682	780	730	700
E	473	493	380	541	488	475
G	71	76	114	150	101	102
H1	873	610	523	760	855	724
H2	285	242	301	311	251	278
I	84	117	168	165	142	135
J[b]	--	--	33	--	--	--
P[b]	--	--	345	--	--	--
Q[b]	--	--	313	--	--	--
R[b]	--	--	963	--	--	--
S[b]	--	--	388	--	--	--
T_L	179	258	416	321	343	304
T_R	273	199	267	171	288	240
U	126	99	262	106	125	144
V[b]	--	--	43	--	--	--
W[b]	--	--	219	--	--	--
X[b]	--	--	1878	--	--	--
Y	884	485	972	493	919	751
Z	675	529	955	742	1079	796
NW Islet Plot	106	158	134	188	136	144
Remainder NW Is.	--	--	929	--	--	--
Smaller NW Islet	--	--	458	--	--	--
Nord Island Total	--	--	11,212	--	--	--
EAST AMATULI ISLAND						
E. Am. Mainland	232	440	388	392	199	330
E. Am. Light Rk.	235	508	538	501	294	415
E. Am Lt. Rk. Total	--	--	--	--	5960	--

[a]Replicate counts were made on the following dates: 1 = 6-9 Aug.; 2 = 9-10 Aug.; 3 = 10 & 18 Aug.; 4 = 18 & 24-25 Aug.; 5 = 26 Aug. Total counts of Nord Island and E. Amatuli Light Rock were conducted on 18 Aug.
[b]Plots not used in annual comparisons because they were not counted in all four years (1989-1992).

Table A3. Counts of murres at selected islands in the Chiswell Islands group, Alaska, 1989-1992[a].

Date	Natoa	Matuska	Chiswell "B"	Chiswell	Beehive "B"	Beehive	Sub Total	On Water	Total
1989									
3 Jul	267	1076	274	375	528	93	2613		
3 Aug	252	639	264						
Mean	260	858	269	375	528	93	2383		2,383
1990									
27 Jun	372	706	158	260[b]	552	135	2183		
28 Jun	444	380	305	380	623	210	2342		
29 Jun	456	435	525	114	698	290	2518		
Mean	424	507	329	251	624	212	2348 (167.6)[c]	1,935	4,283
1991									
26 Jun	515	918	454	191	592	71	2741		
28 Jun	328	985	349	196	435	73	2366		
30 Jun	657	1008	271	602	582	144	3264		
2 Jul	583	1145	284	358	439	93	2902		
Mean	521	1014	340	337	512	95	2818 (372.5)	224	3,043
1992									
2,4 Jul	164	728	270[d]						
11 Jul	416	862	197	295	507	99	2376		
12 Jul	342	1046	257	365	516	62	2588		
13-14 Jul	379[e]	980	233	213	500	171	2476		
Mean	325	904	239	291	508	111	2480 (106.1)	161	2,641

[a]Data from Bailey and Rice 1989, Nysewander et al. 1993 and this study.
[b]Birds flushed prior to count so the average of other counts for this island was used.
[c]Standard deviation in parenthesis.
[d]Counts made by Kenai Fjords National Park personnel.
[e]Missing value estimated using the mean from other counts.

Table A4. Counts of common and thick-billed murres[a] on plots in the vicinity of Cape Unalishagvak (Jute Peak), Puale Bay, Alaska, 1989-1992[b].

Date	Plots																						
	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[c]		606	759	419	2,395[d]		566	770	158	1083	1,263[e]		1,473	858[f]		14,374
1992																							
29 Jul	23	510	330	1,335	1,095	490	805	605													1,205[f]		6,398
26 Aug	13	362	446	697	920	132	186	875													1,135[f]		4,766
Mean	18	436	388	1,016	1,008	311	496	740													1,170		5,582

[a]Data from Dewhurst 1991, Dewhurst and Moore 1992, and this study.
[b]Thick billed murres comprise an unknown but small proportion.
[c]Combined count for plots 7 and 8.
[d]Combined count for plots 12 and 13.
[e]Combined count for plots 18 and 19.
[f]Combined count for plots 21"A" and 21"B".

Table A5. Counts of common and thick-billed murres[a] on plots in the vicinity of Oil Creek (Cape Aklek), Puale Bay Alaska, 1989-1992[b].

	Plots																			
Date	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	2,102	387	2,133	310	307	2096[c]		354	1,600	2,005	1,647	1,135	204	179	19,088
1992																				
30 Jul	2,025	1,995	175	390	400	1,415	2,080	510	255	720	2,255	1,805	845	560	2,070	1,073	1,173	250	275	20,271

[a]Thick-billed murres comprise an unknown but small proportion.
[b]Data from Dewhurst 1991, Dewhurts and Moore 1992, and this study.
[c]Combined count for plots 11 and 12.

Table A6. Counts of common and thick-billed murres[a] on plots in the vicinity of Puale Bay[b], Alaska, 1989-1992[c].

Date	Plot 13"A"[d]	13"B"	Total
1989			
21 Jul	1,585		
25 Jul	1,955	400	
14 Aug	1,187	28[e]	
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
1992			
1 Aug	1,835	460	2,295
13 Aug	2,166	390	2,556
Mean	2,001	425	2,426

[a]Thick-billed murres comprise an unknown but small proportion.
[b]Areas 13"A" and 13"B" encompass the entire colony.
[c]Data from Dewhurst 1991, Dewhurst and Moore 1992, and this study.
[d]No significant differences ($F = 2.55$, $P = 0.129$) between annual counts (all data log-transformed).
[e]Colony had been largely abandoned.

Table A7. Dates common murre eggs were first observed in the Gulf of Alaska before and after the 1989 *T/V Exxon Valdez* oil spill.

Year	Location	First Egg Date	Reference
Before Spill or Outside Path of Oil			
1974	Ugaiushak	25 June	G. Van Vliet unpubl.
1976	Middleton	14 June	Frazer and Howe 1977
	Hinchinbrook	19 June	Nysewander and Knudtson 1977
	Ugaiushak	17 June	Wehle et al. 1977
	Semidis	6 June	Leschner and Burrell 1977
1977	Hinchinbrook	21 June	Sangster et al. 1978
	Barrens	20 June	Manuwal and Boersma 1978
	Ugaiushak	24 June	Wehle 1978
	Semidis	5 June	Hatch 1978
1978	Middleton	27 May	Hatch et al. 1979
	Hinchinbrook	29 June	Baird et al. 1983
	Barrens	25 June	Manuwal 1980
	Chisik	29 June	Jones and Petersen 1979
	Semidis	8 June	Hatch and Hatch 1979
1979	Barrens	30 June	Manuwal 1980
	Semidis	9 June	Hatch and Hatch 1990
1980	Semidis	7 June	Hatch and Hatch 1990
1981	Semidis	5 June	Hatch and Hatch 1990
1989	Middleton	<24 June	B.Fadely and S.Hatch unpubl.
	Semidis	9 June	Baggot et al. 1989
1990	Middleton	14 June	B.Fadely and S.Hatch unpubl.
	Semidis	9 June	Dragoo et al. 1991a
1991	Semidis	10 June	Dragoo et al. 1991b
Median		15 June	
After Spill in Path of Oil			
1989	Puale Bay	15 July	Dewhurst 1991
1990	Barrens	17 July	Nysewander et al. 1993
	Puale Bay	6 July	Dewhurst 1991
1991	Barrens	<10 July	Nysewander et al. 1993
	Puale Bay	20 July	Dewhurst and Moore 1992
1992	Barrens	2 July	This study
	Puale Bay	30 June	This study
Median		11 July	

Table A8. Common murre chicks per adult at regularly visited land-based plots at Nord Island, Alaska, in 1992[a].

Plot	Chicks	Mean # of Adults[b]	Chicks/ Adult
1	8	31.0	0.26
2	9	62.0	0.15
3	14	51.3	0.27
4	19	76.5	0.25
5	15	43.5	0.35
6	12	25.8	0.47
Total	74	290.1	0.29

[a]Based on a combination of data from time-lapse and on-site observations.
[b]*n* = 4 counts.

Table A9. Common murre chicks per adult at plots on Nord Island, Alaska, visited on September 11, 1992.

Plot[a]	Adults(A)	Chicks(C)	BP[b]	C+BP	C+BP/A
H1	11	0	3	3	0.27
I	30	0	4	4	0.13
P	68	1	17	18	0.27
Q	90	11	18	29	0.32
R	180	4	41	45	0.25
S	53	1	20	21	0.40
T[c]	46	1	12	13	0.28
U	106	3	29	32	0.30
X	209	7	79	86	0.41
Y	118	24	33	57	0.48
Z	130	12	34	46	0.35
TOTAL	1041	64	290	354	0.34

[a]We counted sections of plots, not whole plots. Only the ledges that could be seen clearly from below were counted. These counts do not constitute all murres on any plot. Most were counted from a boat; some from rocks.
[b]BP=Those birds that appeared to be in brooding posture.
[c]Count included only the right side of plot T (subplot T-right).

Table A10. Reproductive performance of common and thick-billed murres at Colony 013, Puale Bay, Alaska after the 1989 *T/V Exxon Valdez* oil spill[a].

	Year			
	1989	1990	1991	1992
Common murre				
Total eggs laid[b]	266	388	109	415
Total chicks hatched[c]	133	289	64	369
Total chicks fledged[d]	20	39	41	274
Hatching success[e]	0.50	0.74	0.59	0.89
Fledging success[f]	0.15	0.13	0.64	0.74
Productivity[g]	0.07	0.10	0.38	0.66
Thick-billed murre				
Total eggs laid[b]	20	43	21	29
Total chicks hatched[c]	4	15	15	21
Total chicks fledged[d]	1	2	10	15
Hatching success[e]	0.20	0.42	0.71	0.72
Fledging success[f]	0.25	0.13	0.67	0.71
Productivity[g]	0.05	0.06	0.48	0.52

[a]Data from Dewhurst 1991, Dewhurst and Moore 1992, and this study.
[b]Three sequential incubating postures was considered equal to one egg.
[c]One brooding posture observed was considered equivalent to one chick.
[d]Chicks were presumed to have successfully fledged if observed a minimum of 15 days prior to disappearance.
[e]Chicks observed/eggs laid.
[f]Chicks fledged/chicks hatched.
[g]Chicks fledged/site where an egg was laid.

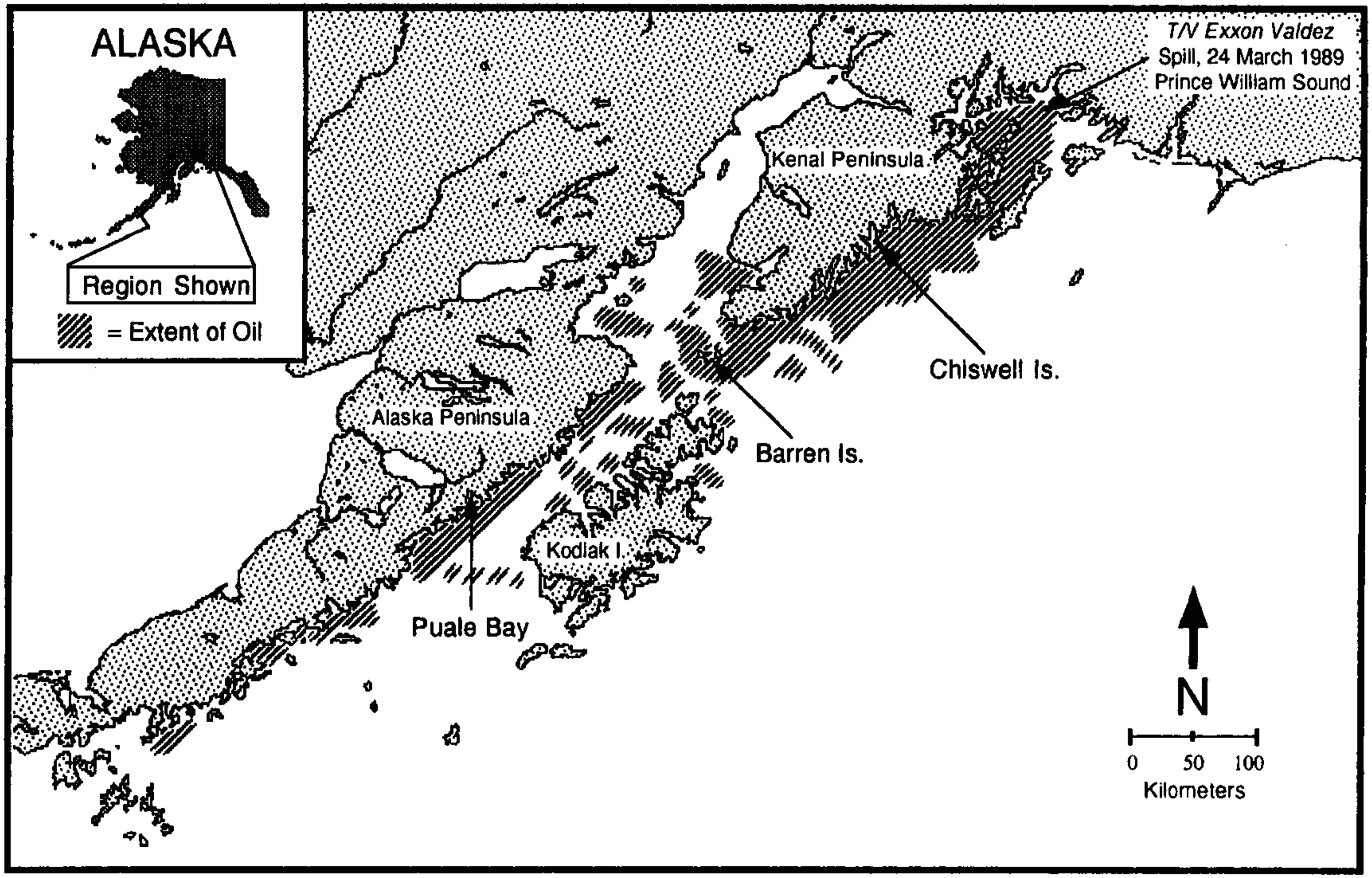

Figure 1. Locations of the murre colonies studied in 1992 in relation to distribution of oil following the wreck of the *T/V Exxon Valdez*.

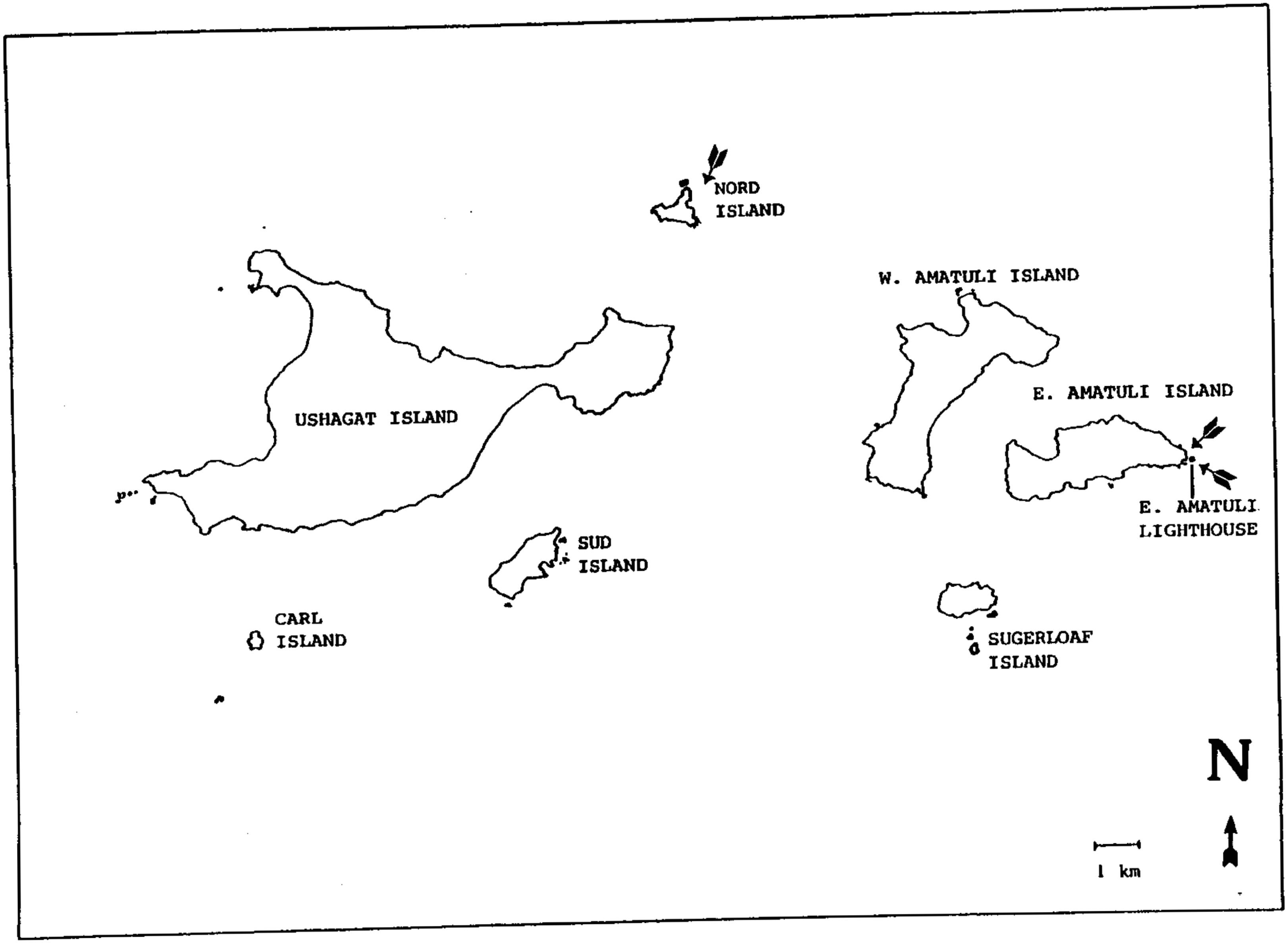

Figure 2. The Barren Islands, northeastern Gulf of Alaska. Arrows denote study areas.

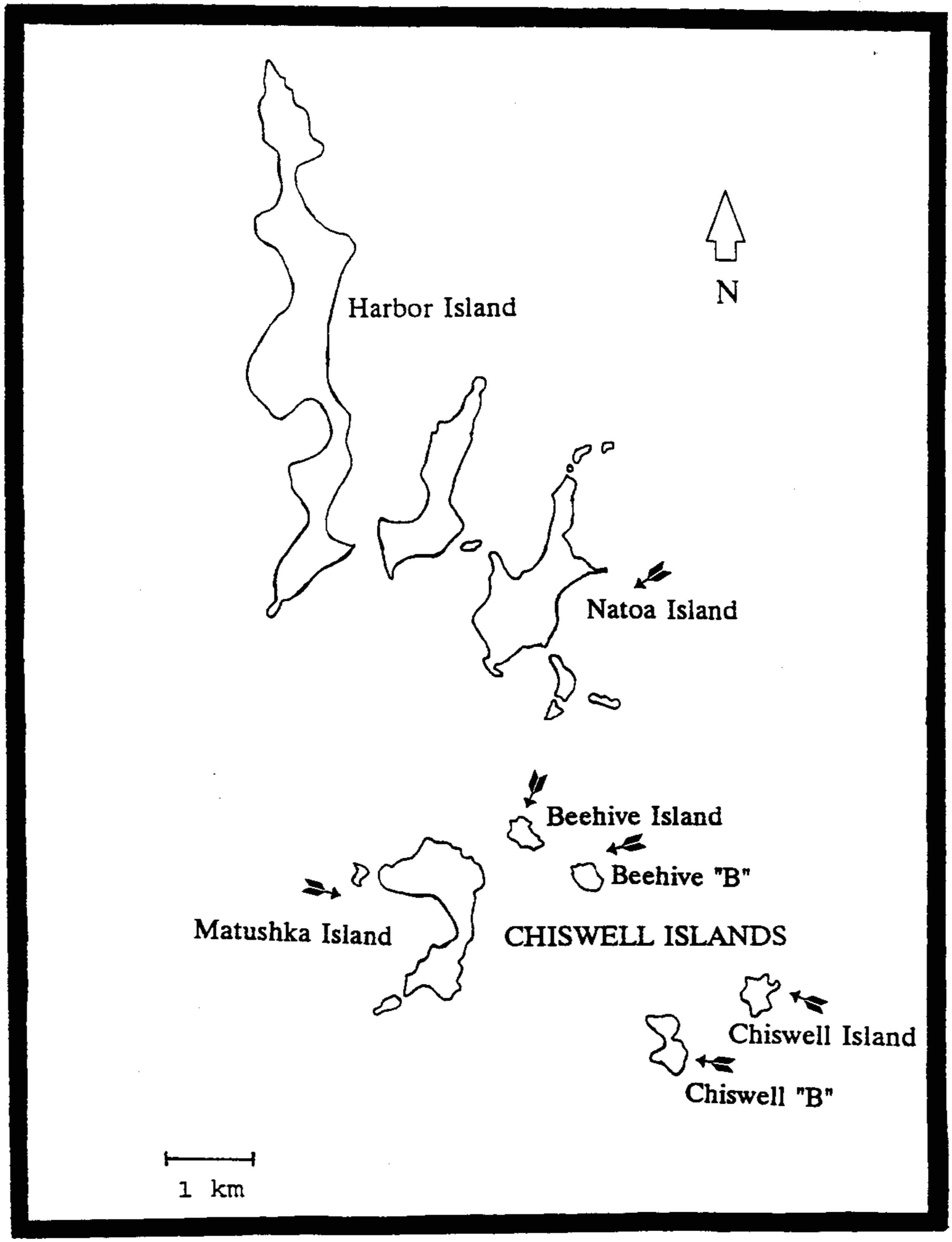

Figure 3. The Chiswell Islands, northeastern Gulf of Alaska. Arrows denote study islands.

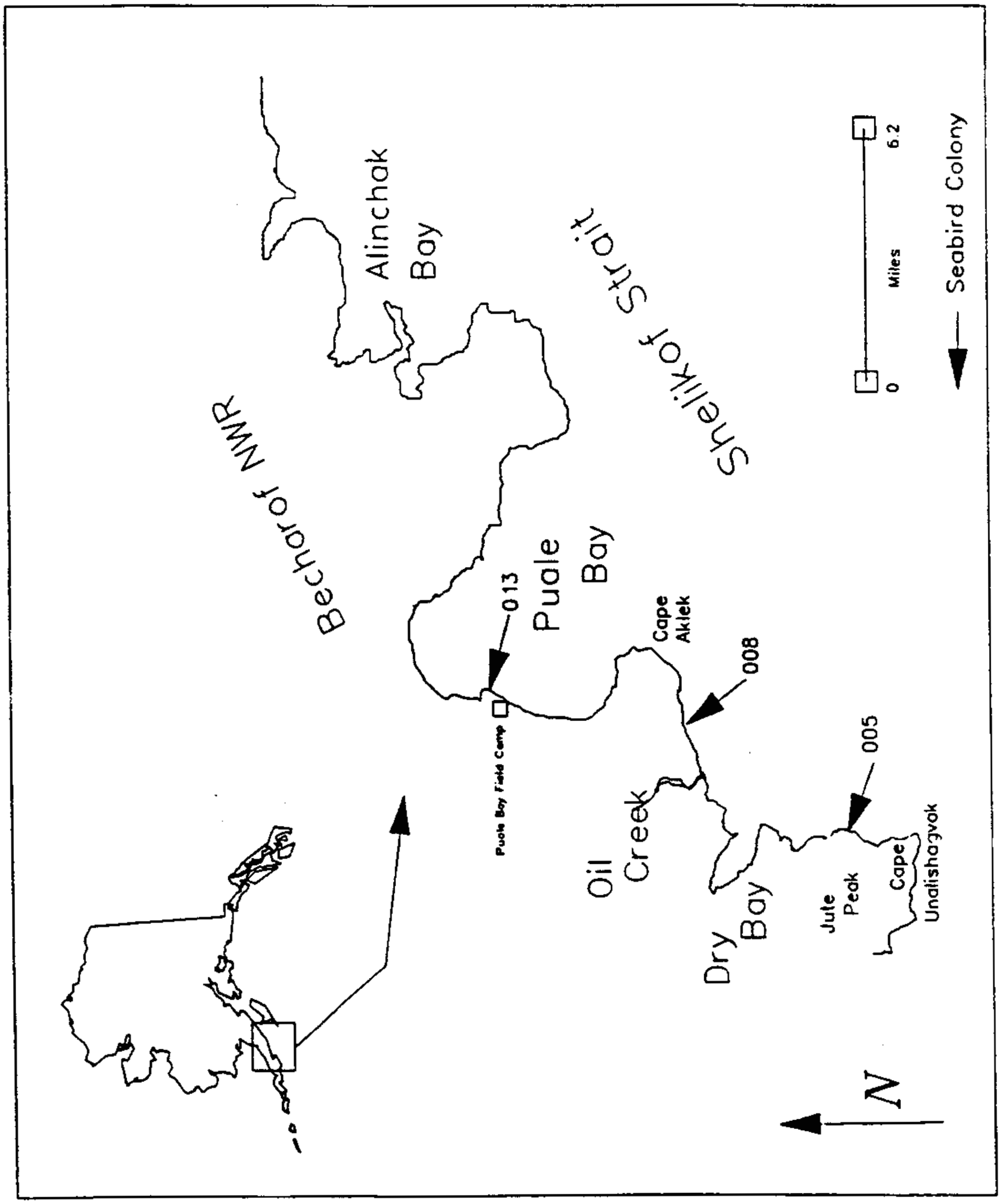

Figure 4. Puale Bay, Alaska Peninsula. Arrows denote study areas (005, 008, 013).

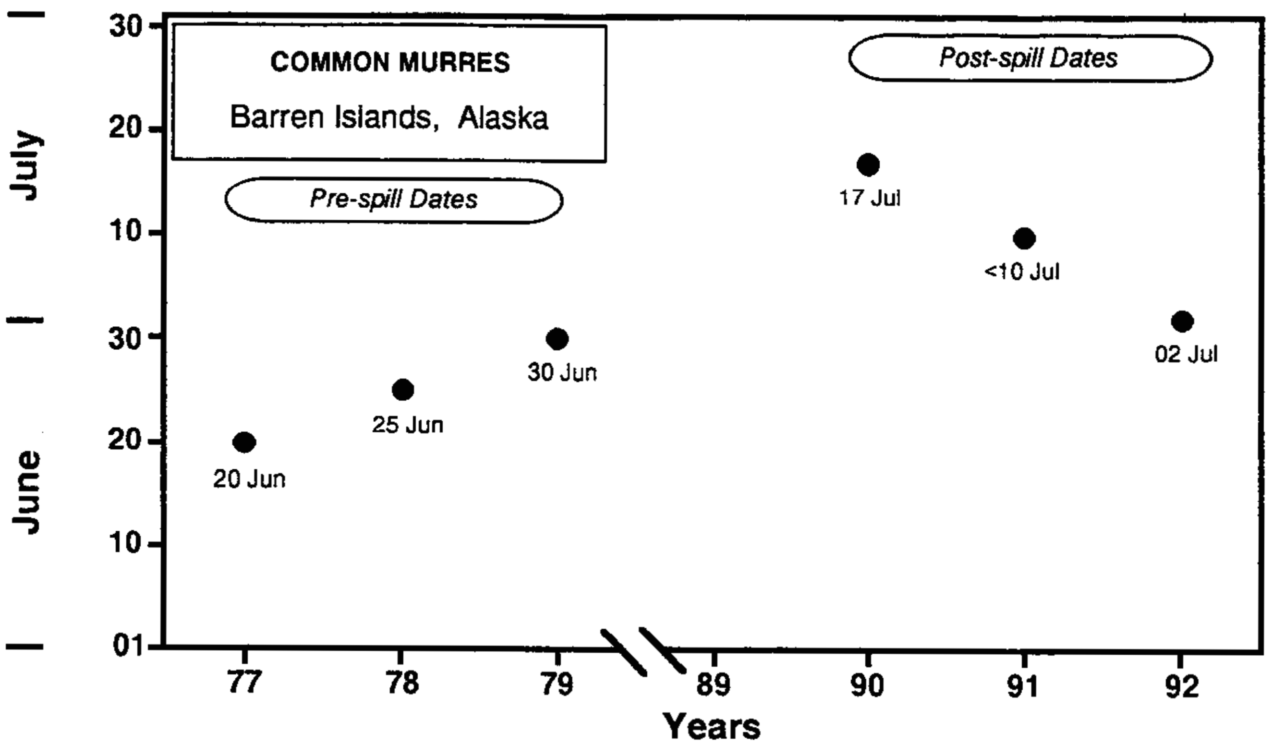

Figure 5. Dates of first egg laying in common murres in the Barren Islands, Alaska, before and after the *T/V Exxon Valdez* oil spill.

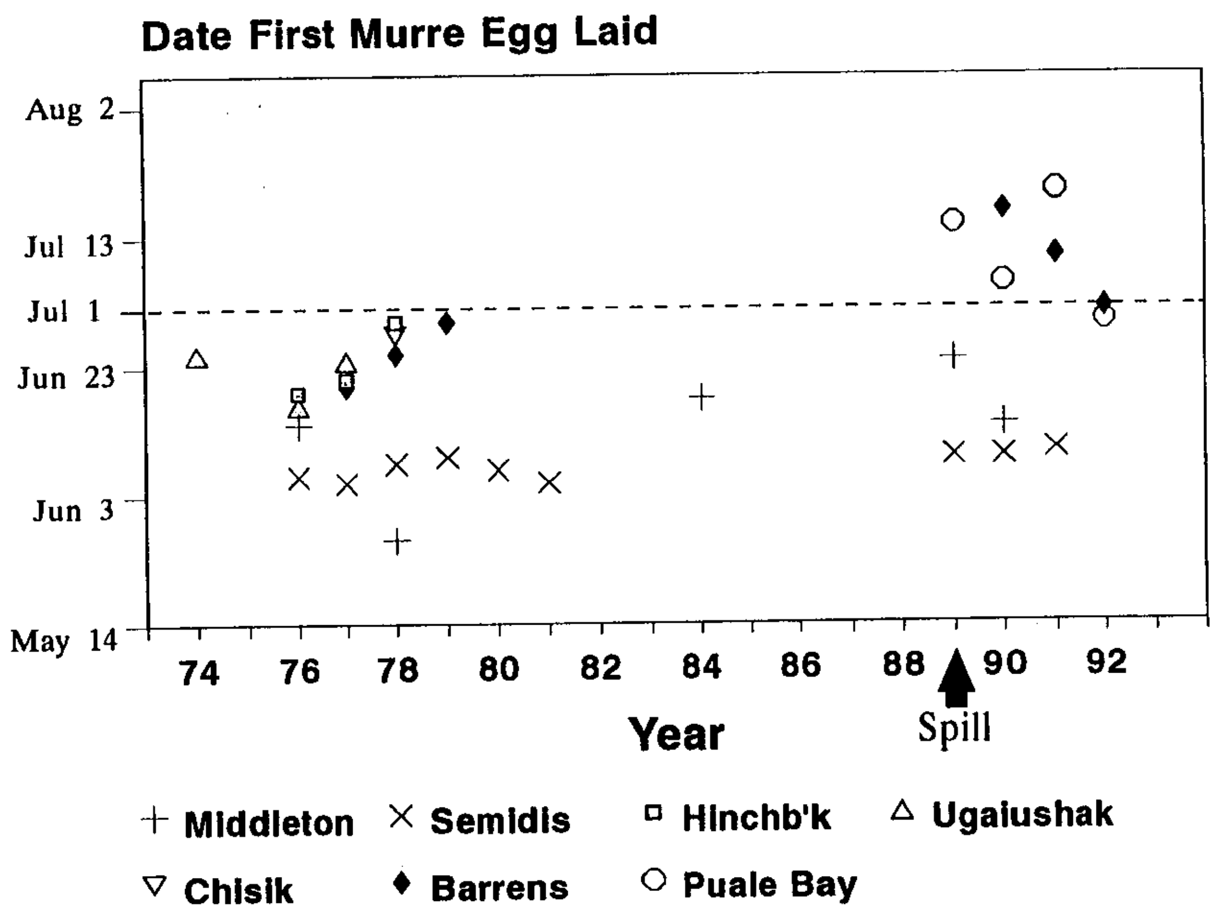

Figure 6. Dates of first egg laying in common murres at sites within and outside of the trajectory of oil from the grounding of the *T/V Exxon Valdez*.

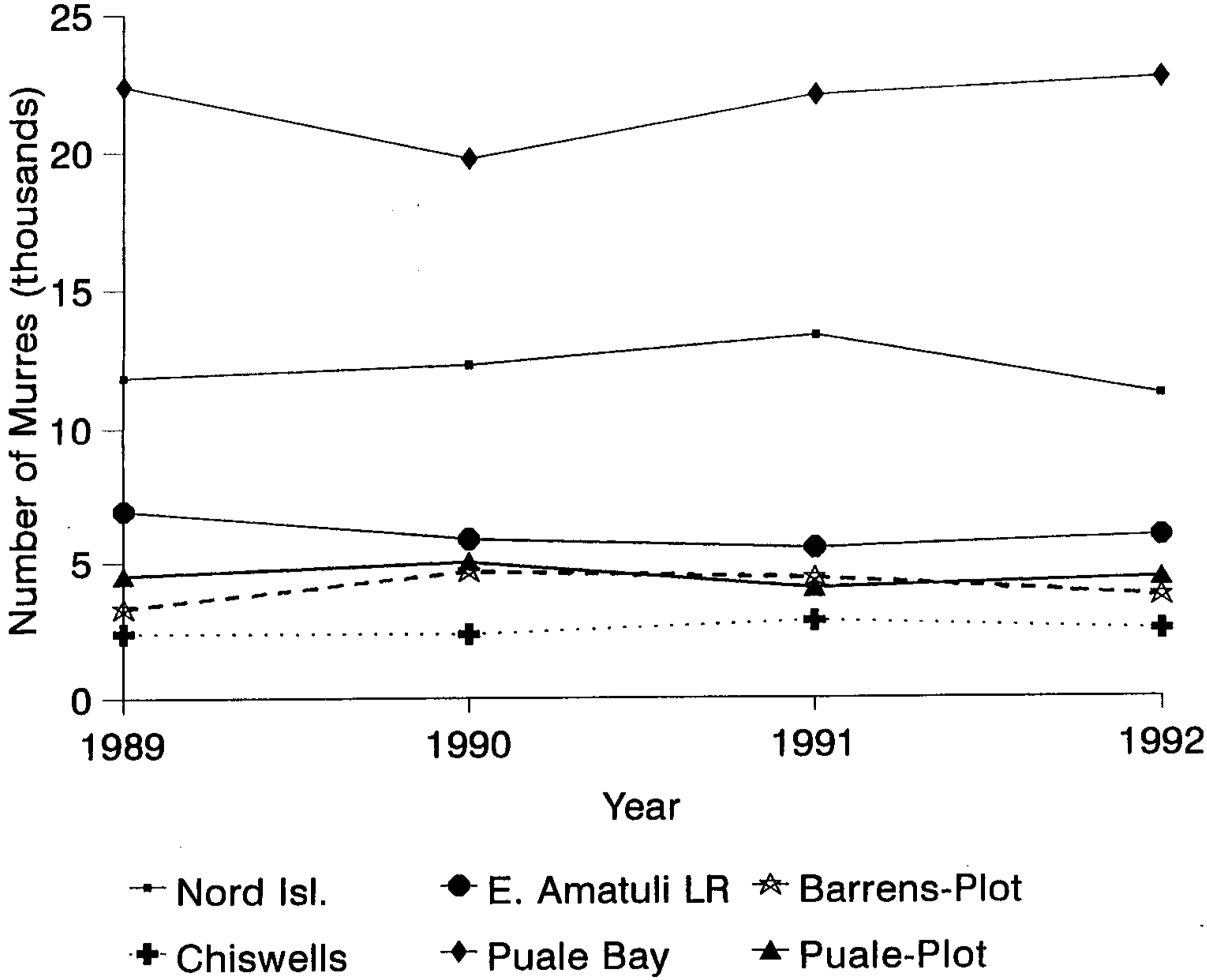

Figure 7. Post-spill murre counts from colonies within the trajectory of the *T/V Exxon Valdez* oil spill. Counts are of total islands unless otherwise noted.