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MMS 96-0005

Annual Variation in Seabird Attendance and Productivity on East Amatuli Island, Barren Islands, Alaska: Natural and Human-Induced Effects

Final Report 1992-1994

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EXECUTIVE SUMMARY

The Barren Islands, (58° 55' N, 152° W), have the largest seabird breeding colonies in the North Gulf of Alaska (Bailey 1976). Because they are often abundant, conspicuous, and relatively high on the food chain, changes in seabird population dynamics can mirror changes in the bio-physical environment, including food supplies, oceanographic events such as El Niño-Southern Oscillation (ENSO), and marine pollution such as oil spills. Not all species will react similarly to a given environmental change; however, when several species within a single system are considered, patterns of environmental change may emerge. Aerial and ship-based surveys have shown that the waters surrounding the Barren Islands support a dense assemblage of foraging seabirds. However, the islands are particularly susceptible to marine perturbations, as evidenced by the Exxon Valdez oil spill of 1989. Some estimates of Barren Islands seabird losses resulting from this spill (e.g. murres) range as high as 50%. From 1990 through 1994, we monitored the population activity, diet, and reproductive success of two of the most abundant species of seabirds in the Barren Islands: Fork-tailed Storm-petrels (*Oceanodroma furcata*) and Common Murres (*Uria aalge*), in order to determine the degree to which each species responded to known changes in the environment, both natural and human-induced. For each species, methods were developed to monitor population activity, phenology, reproductive success, and, in the case of Fork-tailed Storm-petrels, chick growth. For the most part, methods and censusing sites were based on OSCEAP studies conducted by Boersma and Manuwal during the late 1970's and early 1980's. Seabird population monitoring usually commenced by the beginning of July and ended during the first week in September.

For Common Murres, patterns of population activity were estimated by counting murres present on four separate nesting areas (approximately 2-3% of total island attendance), after the murres had laid eggs but before chicks had fledged. Phenology was assessed from the timing of egg production on a 5x5m study plot on the top of Light Rock, established in 1977, as well as 35mm time-lapse movie cameras set up in 1991, 1993, and 1994. In addition, reproductive success was calculated for all pairs within the camera plots which could be visually followed. From 1975 through 1979, murre attendance estimates on East Amatuli Island ranged from a low of 19,000 to a high of 61,000. From 1990 to 1992, we counted between 31,000 and 35,000 murres in attendance on East Amatuli Island. Attendance in three of the four census areas increased steadily from 1990 to 1993; in total, attendance rose an estimated 18% annually. In all years, murres nesting on Light Rock produced eggs and chicks, although there were differences in both phenology and reproductive success. Egg laying on the 5

by 5 m plot in 1977 and 1978 was early relative to 1979; the former years are phenologically comparable to 1993 and 1994, while 1979 is closer to the timing of 1990. Reproductive success of murres in the time-lapse camera plots ranged from 0.65 to 0.93 fledglings per pair over the 243 pairs followed. Although there has been some concern that the *Exxon Valdez* oil spill caused a persistent decline in the reproductive output of the remaining East Amatuli population, we found no evidence to support or refute this contention. However, the pre-spill data available for accurate comparison was lacking, greatly weakening any firm conclusion about the effects of the spill.

For Fork-tailed Storm-petrels, patterns of population activity were estimated by assessing occupancy, reproductive success, and chick growth at approximately 650 marked burrows located in six study sites (A-E, Z). Throughout the 1990's, occupancy in marked nests has hovered between 40 and 50 percent. Hatching success and fledging success appeared to rise throughout the 1990's to a high of nearly 70% (hatching) and 90% (fledging) in 1994. Both tissue growth rate and weight gain fluctuated throughout the 1990's. In 1993 and 1994, it took approximately 57 days for the average chick to grow their wings from 10% (birth) to 90% of adult wingchord length. By contrast, the average length of time required in 1990 was 68 days, an approximately 20% difference. Weight gain followed a similar pattern. These dramatic differences in annual growth may reflect fledging success to some degree, but also reflect the fact that Fork-tailed Storm-petrel growth is regulated by food supply. Changes in weight gain probably reflect food quantity, while changes in wingchord growth rate reflect changes in food quality. Food availability may change on an intraseasonal basis and in an unpredictable fashion, while food quality may be changing over longer periods of time (e.g. decades).

Because seabirds can modify their behavior and foraging patterns, many species are able to ameliorate the effects of environmental change, regardless of source (i.e. natural or human-induced). For this reason, an understanding of natural biological variation and what causes variation to differ in direction or degree is also needed. Ainley, Sydeman and Norton (in press) argue that the intensity and geographical extent of the Aleutian Low Pressure System may alter wind patterns, upwelling patterns, and consequently affect the food supply, thereby affecting seabird reproductive and population biology in the Farallon Islands. It is interesting to note that in years when murre reproductive success is high in California, it is low on the Barren Islands. This "trade-off" effect may represent evidence of alternating strengths and weaknesses in the Alaska and California current systems, as both originate from the North Pacific Current. However, this alternating pattern is disrupted in years when the entire Pacific basin is affected, suggesting that major oceanographic perturbations can dwarf local

oceanographic trends. Thus, 1992 was a very poor reproductive year for murres in both the Farallon Islands and the Barren Islands, presumably because of El Niño.

In contrast to most natural perturbations, which can have either negative or positive impacts, most human perturbations have negative impacts on seabirds. Oil spills are among the most dramatic human perturbations in the marine environment. Without long-term monitoring of specific populations, it will be impossible to make blanket statements about the effects of oil spills on seabird populations, relative to other mortality agents, whether natural (e.g. ENSO, food availability, winterkill) or anthropogenic (e.g. gillnet bycatch, direct competition with fisheries, introduced predators). The Barren Islands data do not appear to shed light on this dilemma, in that although the *Exxon Valdez* oil spill killed many thousands of seabirds, it was impossible to detect long-term differences in response to the spill by Common Murres and Fork-tailed Storm-petrels. In part, our inability to detect change may be a result of the paucity of information on the non-breeding, or "at-sea" component of the Barren Islands population. Seabird populations may be buffered from adverse effects, both natural and human-induced, by their non-breeding pool. The level of resilience provided by non-breeders would thus be affected by the frequency and magnitude of disturbance. Additional human-induced disturbance in a system already susceptible to broad fluctuations in natural perturbation, may deplete the built-in reserve offered by non-breeders. Whether this is true, and how important the non-breeding pool of birds is, remains to be tested.

INTRODUCTION

Many authors argue for the use of seabirds as indicators of the marine environment (Boersma 1986, Furness 1987, Furness & Barrett 1991). Because they are often abundant, conspicuous, and relatively high on the food chain, changes in seabird population dynamics can mirror changes in: 1.) the food supply (Piatt 1990, Springer et al. 1986); 2.) oceanographic events such as El Niño-Southern Oscillation (ENSO) (Boersma 1978, Graybill & Hodder 1985, Wilson 1991, Massey et al. 1992); and 3.) levels of marine pollution, at the lethal (Piatt et al. 1990) as well as sublethal (Boersma 1986, Gilbertson et al. 1987) levels. It is generally accepted that not all species of seabirds will react similarly to a single environmental change (Furness & Barrett 1991). This is because each species has different foraging and nesting behavior, such that varying aspects of the physical/biological environment will impinge directly on each species' fitness. For instance, species with greater flight range may be less susceptible to changes in the food supply than species with limited range, because the former can adjust for nearshore food depletion by searching over greater distances from the colony.

Population-level measurements, such as attendance, diet, hatching success, chick growth rate, etc. may give us an integrated, albeit selective, window on the environment. However, when several species within a single system are considered, patterns of environmental change may emerge. The Barren Islands, with its abundant resident seabird colonies, provide such a system within which to quantify environmental change.

Located at the mouth of Cook Inlet, the Barren Islands, (58° 55' N, 152° W), have the largest seabird breeding colonies in the north Gulf of Alaska (Bailey 1976). East Amatuli Island, located on the east side of the island group (Figure 1), supports a particularly diverse assemblage of avian fauna that includes surface feeders and pursuit divers (Bailey 1976). These islands are ideally suited for seabirds due to three complimentary factors: First, the local topography and physical oceanography result in upwelling with a concomitant surge in productivity. Aerial and ship-based surveys have shown that the waters surrounding the Barren Islands support a dense assemblage of foraging seabirds (Piatt pers. comm.). Second, the system is not only uninhabited by man, but is protected as part of the Alaska Maritime National Wildlife Refuge (AMNWR). Lastly, although the island system supports a small number of raptors and river otters, predators are by-and-large absent. The latter two factors minimize disturbance to breeding habitats. All three factors contribute to the continuing reproductive success of the Barrens' seabirds and also highlight the importance of the islands as a population center for seabirds in the north Gulf of Alaska. However, the islands are particularly susceptible to marine perturbations because of their location at the mouth of Cook Inlet. As evidenced by the Exxon Valdez oil spill, pollutants that are introduced into Prince William Sound and the north Gulf of Alaska are likely to flow through the Barren Islands and may linger there for several weeks because of the large tidal exchange.

From 1990 through 1994, we monitored the population activity, diet, and reproductive success of two of the most abundant species of seabirds in the Barren Islands: Fork-tailed Storm-petrels (*Oceanodroma furcata*) and Common Murres (*Uria aalge*). Prior to 1990, extensive data was collected on Fork-tailed Storm-petrels (Boersma et al. 1980, Boersma unpub. data) and occasional data was collected on murres (Manuwal 1980). These datasets have allowed determinations of the degree to which each species responds to known changes in the environment, both natural and human-induced. For example, Fork-tailed Storm-petrel burrow occupancy (# occupied/# checked) and egg volumes were significantly lower in 1983 and 1984, years in which an El Niño-Southern Oscillation (ENSO) event was known to have affected physical

oceanography conditions in the Pacific (see chapters in Diaz & Markgraf 1992). During this period, sea-surface temperature (SST) anomalies in a four-degree sided square surrounding the Barren Islands were often in excess of 1.0°C (Figure 2). Anomalously high SST conditions have been associated with downturns in oceanic productivity (Sharp 1992), and thus potentially the food supply of lower food chain feeders such as Fork-tailed Storm-petrels (see references in Wooster & Fluharty 1985, Ainley & Boekelheide 1990). Thus, while not strictly causative, there is a definite, and biologically interpretable, correlation between a change in the larger physical environment and the reproductive biology of the seabird species.

Natural variation is not the only source of environmental change. Human-induced perturbations affect the environment on several scales. At a global level, changes such as rising CO^2 emissions can affect temperature, which in turn may affect both terrestrial and aquatic productivity (Halpert & Bell 1993). Regionally, human interaction with the oceanic environment may have produced changes in aquatic community structure due to fishing pressure (Springer et al. 1986). Such changes can often have far reaching effects on the food supply, and thus abundance, of regional seabird and marine mammal species (Springer et al. 1986).

Locally, point-source pollution can have a drastic effect on the marine environment. A case in point is the Exxon Valdez oil spill of 1989 (Piatt et al. 1990). Approximately 30,000 bird carcasses of 90 species were recovered following this spill (Piatt et al. 1990), and current estimates of total bird mortality have run as high as 500,000 (Parrish & Boersma, in press). Because over 70% of the recovered carcasses were murres, and the Barren Islands murre colonies (located on East Amatuli and Nord Island, respectively) comprise the largest murre colony in the path of the spill, both assessment of the damage to, and monitoring recovery of, the Barren Islands murre population is of serious scientific and management interest.

While it is possible to ascribe a potential cause, such as the Exxon Valdez oil spill, to a measured effect, such as a decline in the murre population, in general the pattern of population activity and reproductive effort of each species is going to be influenced by a complex combination of forces, both natural and anthropogenic (Hunt 1987). It thus becomes imperative to not only monitor seabird populations, but to also collect accurate measurements on the physical/biological environment (Hunt 1987, Parrish & Boersma 1995). These two pieces must then be superimposed such that measured environmental change is applicable on a biological scale appropriate to the species in question. In this context, scale is relevant to both time (as in the average life of a seabird) and space (as in the foraging range of the bird). For instance, nearshore

changes in food supply may affect the alcids, (murres and puffins), more than Fork-tailed Storm-petrels, because the former have a restricted foraging range around the nesting colony. Thus, localized shortages may affect the diet, and eventually the reproductive success, of these species. Fork-tailed Storm-petrels may be able to compensate for local shortages by increasing search distance and time. While this may increase egg neglect and slow chick growth, reproductive success, measured as fledglings per pair, may be unaffected. Furthermore, species with limited foraging ranges may be more susceptible to marine pollutants such as oil, should the oil cover a broad proportion of the species foraging range. During the breeding season, murres and Tufted Puffins should experience the brunt of any oiling in the Barren Islands' area, because their at-sea distribution is limited to close to the island. Thus, there is potential for naturally-induced downturns, such as those caused by changes in food supply, to be synergistically exacerbated by oiling events.

Because of the islands' high vulnerability to oil spill impacts due to its geographic location at the mouth of the Cook Inlet (an area of shipping traffic and potential oil and gas development), a three-year study to monitor the major marine avifauna was funded by the Outer Continental Shelf Environmental Assessment Program (OCSEAP) from 1977 through 1979 (Manuwal 1980). That study concentrated primarily on three species: Fork-tailed Storm-petrels, Tufted Puffins and Common Murres. For each species, methods were developed to monitor population activity, phenology, reproductive success, and in some cases chick growth. From 1980 through 1984, these studies were continued under Boersma and concentrated on the Fork-tailed Storm-petrel. Monitoring of the Fork-tailed Storm-petrel population and, to a lesser extent, Tufted Puffins and Glaucous-winged Gulls (*Larus glaucescens*) was conducted intermittently from 1985-1989 by the U.S. Fish & Wildlife Service AMNWR staff (Nishimoto et al. 1986, Nishimoto et al. 1987, Nishimoto & Beringer 1988, Nishimoto & O'Reilly 1989). In 1990, Boersma resumed monitoring, and has continued surveying the seabird activity on East Amatuli Island through 1994.

METHODS

General

At the beginning of each field season (late June), a crew of field technicians and volunteers was transported from Homer to East Amatuli. As in previous years, camp was set up in a depression in the primary dune on the east side of Amatuli Cove. In 1993 and again in 1994, the camp was expanded to accommodate U. S. Fish & Wildlife Servicepersonnel. Seabird population monitoring usually commenced by the beginning

of July and ended during the first week in September. In all years, camp was dismantled by mid-September. During years in which time-lapse movie cameras were installed on Light Rock, a brief dismantling trip was made in October. In 1991 and again in 1993, data on Fork-tailed Storm-petrels was also collected during the October visit. In 1994, three separate visits were made to East Amatuli, en lieu of a permanent field camp. Visit timing and adverse weather conditions precluded collection of murre population information. However, these data were collected by US Fish & Wildlife Service personnel.

Common Murre

Attendance

From 1990 through 1992, island attendance was estimated by counting murres present on the island after the murres had laid eggs but before chicks had fledged (see Wanless et al. 1982, Hatch & Hatch 1989). Counts were made when the water around the island was relatively calm (seas less than 1 m) and visibility was good. All counts were restricted to between 1100 H and 1900 H. Before censuses began, observers practiced counting selected areas by making independent counts and then comparing data. The practice area was then censused more closely by both observers counting together. Independent counts were then made again. If these counts differed by more than ten percent, the entire process was repeated until the counters agreed which birds had been missed or invented. Attendance was defined as the number of murres directly counted on the cliffs. This figure does not take into account the percentage of the population that was not present, (i.e. foraging). Therefore, we did not attempt to use the attendance count to calculate the number of pairs nesting on the island. Instead, islandwide attendance censuses were used to provide a broad-brush picture of changes in East Amatuli colony size. In 1993, US Fish & Wildlife Service personnel assumed the responsibility of estimating island murre attendance.

In addition to the island census, four areas (Oval, Swatch, and Triangle Rock NW and S, respectively; Figure 1) were censused several times throughout the day on different dates throughout the breeding season to provide a more in-depth dataset for the determination of interannual trends (1990-1993). Counts were made as described above. In 1990-1992, counts were made from beyond the kelp bed (far), at unspecified locations affording a clear view of the area. In 1993, counts were made much closer from within the kelp (near). It is possible that closer counts could be higher because individual birds would be easier to spot. To test for methods effects, far and near counts were conducted in 1993 on the same day and compared. There were no statistical differences, indicating

near counts did not bias attendance upwards. In 1993 and 1994, U.S. Fish & Wildlife Service personnel also made duplicate counts of these multiple-count areas.

Reproductive Activity

During all boat surveys murre phenology was qualitatively assessed. Specifically, we observed: 1) whether the murres were occupying breeding ledges or continuing to raft, and 2) whether "flyoffs", defined as large numbers of murres (>100) flying from the cliffs in unison, occurred. Flyoffs were taken as an indirect indication that laying had not started in an area. We also noted whether recently laid murre eggs or freshly eaten eggs were seen on Light Rock during occasional visits. As our field season started in early July, it was impossible to determine when ledges were initially colonized. However, we operationally defined the beginning of reproductive activity as the time when the majority of the murre population was present on the breeding ledges and remained there throughout the day (i.e. no flyoffs).

Phenology was also assessed from the timing of egg production on a study plot on the top of Light Rock, established in the densest part of the colony in 1977 (Manuwal 1980). Originally 17.6 m^2, the plot was expanded to 25 m^2 in 1978 and located in the same general area as in the previous year (Boersma pers. obs.). The plot was re-established in 1990, and surveyed through 1992. As in the 1970's the plot was visited after the initiation of egg laying (7 July and 1 August) and again after chicks started to hatch (1 September) in order to count eggs and chicks. Visits invariably flushed the resident adults, so an attendance count was never possible. The number of eggs and chicks appearing on the 5 x 5 m plot was used as an indication of relative reproductive success for the murre population. During the first two visits, all eggs within the plot were marked such that a loss rate between visits could be calculated. This loss rate is assumed to be the result of disturbance, primarily created by visiting the plot. Losses occurred because Glaucous-winged Gulls entered the plots after murres flushed, and preyed upon some percentage of the eggs. Because of this disturbance, our measures of egg and chick production from the 5 x 5 m plot are somewhat lower than what would actually have been produced.

During 1991, two 35mm time-lapse movie cameras were installed on Light Rock, one on the flat top and one on the North-sloping side. In 1993 and 1994, four such cameras were installed (1993 - two on flat top, two on North side; 1994 - three on flat top, one on North side). Cameras were set-up before the onset of the murre laying season (late June) and removed after murres had left for the season (late September - early October). Cameras took pictures every 6 (1991) or 10 minutes (1993; 1994), from dawn

to dusk. Subplots within the frame of each camera were used to assess daily and seasonal patterns of attendance and phenology. Reproductive success was calculated for all pairs within the plot which could be visually followed. Pairs whose position on the camera subplot occluded them from clear view were not followed, as it was difficult to impossible to clearly distinguish their reproductive output. Pair occlusion was a particular problem in the sloping plots, which led to the reduction in sloping camera plots from 1993 to 1994 as they were not useful with respect to accurate assessment of murre reproductive success. Although this method may be somewhat ambiguous, we had no *a priori* reason to believe there was a potential correlation between proximity to the camera and reproductive success.

For clearly visible pairs, all frames within each day were examined for sightings of eggs or chicks. As murres are protective of their eggs/chicks, and the cameras were taking "snapshots" in time (albeit tens of frames/day), there were days in which clear sightings for each pair's reproductive output were not possible. This was particularly true during stormy weather, when picture quality was reduced, as well as during hatching when parents remainded extremely close to new chicks. Therefore, we used a series of conservative operational definitions, based on range of days an egg or chick was sighted, to categorize the likelihood of hatching and fleding success. For each pair, successful fledgling production was operationally defined by one of the following: 1.) chick sightings over an 18+ day period, or 2.) chick sightings and sightings of adults with wings down (indirect evidence of chick presence) over a 20 day period, or 3.) chick sightings and sightings of adults with wings down over an 18 day period combined with egg sightings over a 30+ day period. Chicks were defined as having probably fledged if they were sighted directly or indirectly or less than 18 days and/or their eggs were sighted less than 30 days. Therefore, reproductive success was defined conservatively as:

fledglings/(eggs - relays)

and liberally as:

(fledglings + probable fledglings/(eggs - relays)

<u>Fork-tailed Storm-petrel</u>

Monitoring Areas

All permanently staked burrows in 6 study areas (A, B, C, D, E, and Z; Figure 1) were examined for evidence of nesting activity at the beginning, middle, and end of each field season. During each year, new burrows were identified and added to the

permanently staked list. Area checks were used to determine burrow usage and reproductive success of a known population as follows:

occupied burrow=presence of adult, egg, or chick
burrow occupancy=occupied burrows/total burrows checked
active burrow=presence of an egg or chick
burrow activity=active burrows/total burrows checked
hatching success=chicks produced/eggs
chick mortality=dead chicks/chicks produced
fledging success=chicks fledged/chicks produced
reproductive success=chicks fledged/active burrows

Because the field season ended before all chicks had actually fledged, the chick fledged category included actual fledgers plus all chicks in healthy condition at the end of the field season.

After the first complete area check, all active burrows were marked for the season with surveying flags. Active burrows were then monitored at three-day intervals throughout the nesting season as follows: Adults in the burrow were checked for band identification. Unbanded adults were banded. Once both birds of a pair were banded, adults were no longer removed from the burrow. If the burrow did not contain an egg or chick, and no adult was found for three consecutive visits, then the burrow was removed from the monitoring list. Burrow condition (dry, damp, wet, flooded) was also noted.

Eggs were removed from the burrow and measured to the nearest 0.1 mm with vernier calipers (length and width). Until hatching, relative egg temperature was consistently checked as a measure of incubation (warm, cool, or cold), and hatching state was recorded (presence and number of stars and pips). Pipped eggs usually hatched within 1-5 days. If an egg was cold for more than 6 sequential visits, it was considered dead and the nest was removed from the monitoring list.

Once the chick had hatched it was not removed from the burrow until the adult was no longer present, usually 2-5 days from hatching. Chicks were aged by classifying feather tracts on the back (small dots, large dots, lines), back skin color (red, pink, white/grey), and tarsus color (white, grey) Chick activity was noted on each visit as follows: responsiveness (active, lethargic, torporous), wing and feet temperature (warm, cool, cold), down condition (dry, damp, wet). Chick weight (to the nearest g) and wing measurements (to the nearest mm) were made on every visit. Wing chord was defined as the distance, on an unstretched wing, from the carpal joint to end of the bone, down, shaft, and/or feather as they appeared during chick growth. Chicks that were considered to be near fledging (identified by the presence of fully grown flight feathers and no

down) were banded. The yearly chick growth rate was calculated by taking mean weight and wing measurements from Day 1 through fledging and performing a best-fit growth-curve regression on the points (Boersma & Parrish, in prep.).

RESULTS AND DISCUSSION

Common Murre

Attendance Patterns

From 1990 to 1992, we counted between 31,000 and 35,000 murres in attendance on East Amatuli Island (Boersma et al. 1995). In 1993, US Fish & Wildlife Service personnel estimated the East Amatuli population at 33,000 (Roseneau pers. comm.). Attendance figures were unavailable for the 1994 season. In all years the majority of the murre population nested on the southeast side of the main island, and secondarily on East Amatuli Light Rock. Because whole island censuses were only made once, these figures should not be taken as accurate representations of either island attendance or population size. Instead, these figures represent a broad estimate of annual attendance.

There has been a large amount of controversy surrounding the degree to which the *Exxon Valdez* oil spill impacted, and continues to impact, the Barren Islands murre population (Boersma et al. 1995, Nysewander et al. 1993, Parrish & Boersma 1995). Although the attendance figures reported here can be used as broad-brush baselines for future years, they are, unfortunately, not directly comparable to earlier census data as the latter were estimates rather than actual counts. In addition, specific information about counting methods, including number of observers, platform, optics, time of day and time of season are lacking. From 1975 through 1979, murre attendance estimates on East Amatuli Island ranged from a low of 19,000 to a high of 61,000 (Boersma et al. 1995).

Four areas: Oval, Swatch, Triangle Rock NW and S, respectively, were counted between 2 and 10 times per season, allowing a more accurate estimation of annual changes and variation in attendance. These four areas represent 2-3% of the total East Amatuli population, and are located in three separate locations along the periphery of the main island. Attendance in three of the four areas increased steadily from 1990 to 1993 (Figure 3). In total, attendance rose an estimated 118 murres per year, or approximately 18% annually (Figure 3). These high annual increases are the strongest indication that there was a large negative impact on the pre-1990 population (presumably the *Exxon Valdez* oil spill of 1989). Annual increases of +20% indicate that following the *Exxon Valdez* oil spill either breeding murres stayed away from the colony for several years (see Sydeman 1993), or adults were immigrating into the Barren Islands population, or some

combination of the two. However, not all colony locations experienced such dramatic increases. On East Amatuli Light Rock, timelapse Camera 1 (located on the upper flat portion of the subcolony, to the immediate Northeast of the navigation light) attendance counts did not vary significantly (Table 1). That we did not see an island-wide pattern of dramatic increase suggests that all parts of the island are not necessarily affected in a similar manner by a single event such as an oil spill. Some locations on East Amatuli may be "optimal" nesting habitat, such that vacant spaces were quickly filled by migrating (local or regional) adults. There is some indication from long-term banded populations that movement between colonies of reproductively active adults does occur (Halley and Harris 1993). By 1991, the first year time-lapse camera data were collected, "optimal" locations may have already stabilized.

While the breeding population may appear to be in recovery, the total population (i.e. including the non-breeding component) may have sustained a serious loss. If what we are seeing is an equilibration of the breeding population at the expense of the "standing stock" of the non-breeding population, further perturbations could seriously affect murre population numbers and reproductive success. Thus, we still know little about the Exxon Valdez oil spill effect on murre population resiliency even though we can find no evidence of massive damage, either mortality or denigrated reproductive success, to the population.

Reproductive Success

In all years, murres nesting on Light Rock produced eggs and chicks, although there were differences in both phenology and reproductive success. During 1990-1992, eggs and chicks were observed directly by field personnel visiting Light Rock. In 1991, 1993, and 1994, time-lapse 35mm movie cameras recorded the reproductive activity of subplots of murres nesting on the flat top (1 to 3 cameras/year) and sloped sides (1 to 2 cameras/year) of the Rock. Because the latter method is remote and does not disturb the birds, a more accurate picture of reproductive success is possible.

For the time-lapse cameras, we defined reproductive success as a range of values bounding the probable true value (see Table 1). The pairs we followed do not represent 100% of the birds in each camera plot, but the number of pairs for which we were able to view eggs and/or chicks repeatedly. In the plots for which eggs, and especially chicks, could never be seen, the number of pairs followed is much lower than the probable number of reproductive pairs (i.e. Cameras 3 and 4). Reproductive success of followed pairs ranged from 0.65 to 0.93 fledglings per pair over the 243 pairs followed (Table 1). In 1993, pairs in the Camera 2 plot experienced lower reproductive success (0.58);

however, this low value was not a result of natural processes but instead stemmed from a Coast Guard helicopter landing on Light Rock on August 12, 1993 which caused many adults to temporarily desert and therefore led to the loss of eleven eggs. If these birds are not included in the reproductive success calculation, success increases to 0.79 fledglings per pair. In general, once eggs had hatched, the chance of chick mortality was quite small, even during large disturbances such as that caused by the helicopter landing in 1993.

In 1991, 1993, and 1994, phenology could be explicitly assessed on the timelapse camera plots. In other years (1977-1979; 1992) visits were made to the 5 x 5 m plot (location of Camera 2 in 1993 and 1994), and the number of eggs were counted. Thus, it is possible to assess whether egg presence is consistent with phenology patterns on the camera plots, or whether phenology was earlier in non-timelapse years. It is difficult to determine whether phenology was ever later, as lower egg values might be due to either later laying, lower overall production, or both. Because visits to the 5 x 5 m plot disturbed the murres, there was associated egg loss, primarily due to predation by Glaucous-winged Gulls. Although there was re-alying, egg predation undoubtedly decreased production, making absolute comparisons with time-lapse camera data inappropriate.

There are two evident phenological patterns. Within a year, laying was not necessarily synchronous across Light Rock, although it appeared to be synchronous within each camera plot. In 1993, murres nesting on the flat top of the rock laid 6 days earlier than murres nesting along side ledges. Between years phenology also changed (Figure 4). From 1991 on, lay date appears to get progressively earlier, although this pattern is somewhat confounded by 1992 (Figure 4). There have been claims that murre phenology following the Exxon Valdez oil spill has been significantly later than in previous years. It appears that egg laying on the 5 x 5 m plot in 1977 and 1978 was early relative to 1979, and that egg production in 1977 was very high. Visual inspection indicates that 1978 is phenologically comparable to 1993 and 1994, while 1979 is closer to 1990 (Figure 4). Acknowledging that these data are severely limited, we find no consistent pre-post spill pattern.

Although there has been some concern that the Exxon Valdez oil spill caused a persistent decline in the reproductive output of the remaining East Amatuli population, we found no evidence to support this contention. In reality, pre-spill reproductive data do not provide an accurate picture of reproductive success, as the only available data come from visits to the 5 x 5 m plot (Boersma et al. 1995). If the post-spill population was indeed severely hampered in egg and chick production, we would have expected that

reproductive success in 1991 would have been low relative to other closely monitored populations in Alaska. In fact, this is not the case. It is possible that the birds nesting on Light Rock occupy the most optimal habitat and, as such, experienced little of the post-spill repercussions ascribed to other sectors of the Barren Islands murre population. In 1993 and 1994, the U.S. Fish & Wildlife Service personnel collected data on reproductive success of pairs nesting on the East Amatuli headland immediately east of Light Rock.

Fork-tailed Storm-petrel

Reproductive Success

Throughout the 1990's, occupancy in marked nests has hovered between 40 and 50 percent (Figure 5, Table 2). Although occupancy in 1991 appears to drop, it is actually higher than calculated because unfound nests (i.e. previously marked nests which remained un-located through the season presumably because the stake disappeared; NNF) and collapsed nests (nest collapse occurred over the winter; COLL.) were not recorded, erroneously inflating the number of available but unoccupied nests. Hatching success (chicks/eggs) and fledging success (fledgings + healthy end-of-season chicks/hatchlings) of both marked and new nests appeared to rise throughout the 1990's (Figures 6 & 7). This pattern may be an artifact of a change in methods from 1990-1993 to 1994. During 1994, nests were only checked intermittently (2-3 times per trip), as opposed to a regular three-day schedule in prior years. The number of nest checks prior to mean hatch date for the colony within year is negatively correlated with hatching success in a stepwise fashion (Figure 8). In other words, five or fewer nest checks result in lower abandonment, and thus higher hatching success. Therefore, the higher hatching and potential fledging success in 1994 could be partially the result of lowered disturbance levels. For nests checked on a regular basis (i.e. 1990-1994), experienced adults from marked burrows appeared more likely to desert (as measured by relative hatching success) than unbanded adults from nests which were newly found that year (i.e. birds inexperienced with humans). It is unclear what is determining this behavioral pattern in the adults. However, once chicks had hatched, nest status (marked or new), as well as number of times nests were checked prior to fledging, appeared to have little influence on fledging success.

The negative correlation between nest-check frequency and hatching success, combined with the counter-intuitive difference in hatching success between old (marked) and new nests, suggests that long-term monitoring projects need to seriously consider researcher effects. Chronic trampling of the vegetation results in soil compaction and

gulley formation. Eventually, this erosional process may decrease the inherent worth of nearby nests, forcing the residents to find new nest sites. Therefore, long-term monitoring programs need to first assess what level of reproductive information is necessary relative to the expected reproductive impairment of the population as a result of collecting those data. We suggest a hierarchical approach: 1.) long-term marked nests should be used for chick growth studies as the latter does not appear to be affected by human disturbance and 2.) new nests in similar habitat to the marked nests should be used to determine annual reproductive success. Ideally, the nests used for reproductive success should be checked intermittently, 2-3 times early in the season to assess occupancy and forecast mean hatch, 3-4 times around mean hatch, and 2-4 times late in the season just prior to fledging.

Chick Growth

Both tissue growth rate and weight gain fluctuated throughout the 1990's (Figures 9A-E). In 1993 and 1994, it took approximately 57 days for the average chick to grow their wings from 10% (birth) to 90% of adult wingchord length (full adult wingchord length was set at 162 mm). By contrast, the average length of time required in 1990 was 68 days, an approximately 20% difference. Weight gain followed a similar pattern: at 70 days the average chick weighed 96 grams in 1994 and only 75 grams in 1990. These dramatic differences in annual growth may reflect fledging success to some degree, as a higher percentage of chicks fledged in faster growth, heavier years (i.e. 1994).

Boersma and Parrish (in prep.) hypothesize that the demonstrable changes in mean annual growth rate reflect the fact that Fork-tailed Storm-petrel growth is primarily externally regulated by food supply. Changes in weight gain probably reflect food quantity, while changes in wingchord growth rate reflect changes in food quality. Thus it is possible to have high availability of low quality prey (i.e. high lipid, low protein producing fat chicks with slow wing growth), as may have been the case in the 1990's. Conversely, it is also possible to have high availability of high quality food (i.e. high protein leading to fast wing growth) as was seen in the 1980's. This challenges the idea that seabird growth, particularly in the storm-petrels, is regulated by bottlenecks in anatomical development (Ricklefs 1979). Changes in both wing growth patterns and weight gain are likely the synergistic result of changing food availability as well as changing food quality. Food availability may change on an intraseasonal basis and in an unpredictable fashion. Food quality may be changing over longer periods of time (e.g. decades) as a result of several potentially interacting events: decadal shifts in oceanic warming (Royer 1989), chaotic disturbance such as El Niño-Southern Oscillation, shifts

in trophic structure as a result of long-term fishing pressure (Springer et al. 1986), and short-term shifts in trophic structure caused by oil pollution.

General Discussion

Determining how perturbations affect seabird biology is particularly difficult because both natural and human induced changes are occurring continuously. Furthermore, the strength and direction of natural perturbations are both variable and chaotic. However, if we can use these "natural experiments" as indicators of how the changing environmental conditions will impact seabirds, we will perhaps be able to forecast how additional human-induced changes will alter seabird population biology.

Because seabirds can modify their behavior and foraging patterns, many species are able to ameliorate the effects of environmental change. For this reason, it is difficult to use seabirds as indicators of environmental change without extensive information on their biology. An understanding of natural biological variation and what causes variation to differ in direction or degree is also needed (Wiens 1995).

Physical oceanography is largely driven by climatic changes. Intensity of upwelling and sea-surface temperature are known to be linked to some seabird demographic parameters (Boersma 1978). There is increasing evidence that seabirds are sensitive to changes in these physical variables. Population changes of seabirds in the Farallons appear to track temporal variation in some large-scale oceanic conditions (Ainley and Lewis 1974). Ainley, Sydeman and Norton (in press) argue that the intensity and geographical extent of the Aleutian Low Pressure System may alter wind patterns, upwelling patterns, and consequently affect the food supply, thereby affecting seabird reproductive and population biology in the Farallon Islands. For example, breeding of Common Murres in the Farallon Islands has become earlier and is correlated with an increase in sea-surface temperature along the coast of California from the 1970's through the 1990's (Sydeman and Ainley 1994). Both the Common Murre and Cassin's Auklet (*Ptychoramphus aleuticus*) delayed reproduction in the Farallon Islands in 1982-1983 and 1992-1993, apparently in response to El Niño. Apparently, higher productivity is associated with earlier egg laying dates in murres (Sydeman and Ainley 1994). Interestingly, only two species of seabirds on the Farallon Islands, both storm-petrels, appeared to show little response to annual variability in marine productivity.

Our data from the Barren Islands characterizes a very different system, but a strikingly similar pattern. Royer (1989) reports that the Gulf of Alaska has been warming since the mid-1970's. In general, warmer waters are associated with lower productivity. The negative trend in the onset of egg laying (i.e. delayed) in the Barren Islands murre

population is correlated with a general increase in sea surface temperature in the north Gulf of Alaska.

One of the most striking aspects of this comparison is the apparent dovetail effect of north versus south. For instance, egg laying of murres on East Amatuli Island appeared to be earlier in 1977 and 1978 and later in 1979. The opposite pattern is shown by murres on the Farallon Islands which laid later in 1977 and 1978 than they did in 1979. Egg laying in 1979 and 1991 appeared to be earlier than normal in the Farallon Islands but later than normal in the Barren Islands. This opposition may represent evidence of alternating strengths and weaknesses in the Alaska and California current systems, as both originate from the North Pacific Current. However, this alternating pattern is disrupted in years when the entire Pacific basin is affected, such as an ENSO year, suggesting that major oceanographic perturbations can dwarf local oceanographic trends. Thus, 1992 was a very poor reproductive year for murres in both the Farallon Islands and the Barren Islands, presumably because of El Niño.

Fork-tailed Storm-petrel data from the Barren Islands are consistent with the interpretation that major oceanographic changes are occurring in the north Gulf of Alaska. Generally, growth rates of storm-petrel chicks have been slower in the 1990's than in the mid-1970's and early 1980's, suggesting that food availability and/or quality has changed. This is perhaps a surprising result given that of the 12 species of breeding birds on the Farallon Islands, only 2 species showed little response to annual variability: Fork-tailed and Leach's storm-petrels.

In contrast to most natural perturbations, which can have either negative or positive impacts, most human perturbations have negative impacts on seabirds. Oil spills are among the most dramatic human perturbations in the marine environment. However, the relative importance of massive versus chronic oil spills in structuring seabird breeding populations is unclear. Oil spills often result in a spike in adult seabird mortality; however, the long-term effects on seabird populations are not known. Some researchers have pointed out that although oil spills undoubtedly kill thousands of seabirds, average winterkill can reduce a population by 5-20% each year (Dunnet 1982, Clark 1984), leading one to the conclusion that oil spills are a minor component of seabird mortality. However, other authors have pointed out that winterkill disproportionately removes young-of-the-year and juvenile birds, while oil spills can principally affect breeders, particularly if the spill occurs close to breeding colonies during the breeding season (Piatt et al. 1991). In sum, without long-term monitoring of specific populations, it will be impossible to make blanket statements about the effects of oil spills on seabird populations, relative to other mortality agents, whether natural (e.g. ENSO, food

availability, winterkill) or anthropogenic (e.g. gillnet bycatch, direct competition with fisheries, introduced predators).

The Barren Islands data do not appear to shed light on this dilemma, in that although the *Exxon Valdez* oil spill killed many thousands of seabirds, it was impossible to detect long-term differences in response to the spill by Common Murres and Fork-tailed Storm-petrels. The impact on these two species was expected to differ, as large numbers of murres were killed by the oil and apparently few Fork-tailed Storm-petrels were killed by the oil (Piatt et al. 1990).

Since we first began working in the Barren Islands in 1976, use of the waters around the islands and of the islands themselves has increased dramatically due to increased boat traffic, fishing, scientific visits, and tourism (Boersma pers. obs.). Distinguishing the negative effects on area seabirds of these increasing human uses of the area from impacts associated with oil development and transport in the Cook Inlet area would be difficult. When coupled with natural perturbations and long-term oceanographic trends, teasing out cause-and-effect becomes impossible without a solid, long-term database designed to detect subtle changes in population parameters on a broad scale.

With the effects of several scales of perturbations occurring why haven't there been more obvious changes in seabird populations in the Barren Islands? The answer to this question lies in seabird breeding biology. Seabirds are long-lived and hence changes in reproductive success may not be apparent for a decade or more. Many species have the ability to switch food sources should conditions change, a further buffer against environmental variability. Changes in the level of adult mortality are expected to produce long-term effects in population structure and reproductive function. Why then did we see few changes, other than direct mortality, from the *Exxon Valdez* oil spill? The answer may be in the non-breeding component of seabird populations. We know almost nothing about this component of the population: how big it is, its age structure, and its geographic range. Seabird populations may be buffered from adverse effects, both natural and human-induced, by their non-breeding pool. The level of resilience provided by non-breeders would thus be affected by the frequency and magnitude of disturbance. Additional human-induced disturbance in a system already susceptible to broad fluctuations in natural perturbation may deplete the built-in reserve offered by non-breeders. Whether this is true, and how important the non-breeding pool of birds is, remains to be tested.

The *Exxon Valdez* oil spill demonstrated that the Barren Islands are likely to be an important reference site. The location of the Barren Islands and extreme tidal

exchange that characterizes the area make them ideal for examining the effects of both natural and anthropogenic disturbance on seabird populations. Some baseline information is available and patterns of change can be detected. Reference areas will become increasingly important in determining both short and long-term environmental change. However, routine monitoring without scientific innovation will not be adequate for the challenge, because refinements in data collection must be made over time in order to test relevant, time-sensitive hypotheses. For instance, it is clear from our study and others (e.g. Hatch and Hatch 1989) that single, yearly censuses can only provide a broad estimate of population size, rather than a specific statistically robust number. However, the effort required to collect statistically adequate data at the level of entire colonies may be economically unfeasible in the long-term. Therefore, we recommend the adoption of methods, such as our timelapse camera system (allowing extremely accurate data collection on a small part of the colony), which speak to both long-term monitoring and statistical robustness; both are needed should future injury and damage assessment be necessary.

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REFERENCES

Ainley, D. G. & Boekelheide, R. J. 1990. Seabirds of the Farallon Islands. Stanford University Press, Stanford. 450pp.

Ainley, D. G. & Lewis, T. J. 1974. The history of Farallon Island marine bird populations 1843-1972. Condor 76:432-446.

Ainley, D. G., Sydeman, W. J., and Norton, J. In press. Apex predators indicate interannual negative and positive anomalies in the California Current food web. Mar. Ecol. Prog. Ser.

Bailey, E. P. 1976. Breeding bird distribution and abundance in the Barren Islands, Alaska. Murrelet 57:2-12.

Boersma, P. D. 1978. Galapagos penguins as indicators of oceanographic conditions. Science 200:1481-1483.

Boersma, P. D., Wheelwright, N. T., Nerini, M. K. & Wheelwright, E. S. 1980. The breeding biology of the Fork-tailed Storm-petrel (*Oceanodroma furcata*). Auk 97:268-282.

Boersma, P. D. 1986. Seabirds reflect petroleum pollution. Science 231:373-376.

Boersma, P. D., Parrish, J. K., and Kettle, A. B. 1995. Common Murre Abundance, Phenology, and Productivity on the Barren Islands, Alaska: the *Exxon Valdez* Oil Spill and Long-Term Environmental Change. In: Exxon Valdez Oil Spill: Fate and Effects in Alaskan Waters, ASTM Special Publication #1219. Peter G. Wells, James N. Butler, and Jane S. Hughes, Eds., American Society for Testing and Materials, Philadelphia.

Boersma, P. D. & Parrish, J. K. Fork-tailed Storm-petrel growth: Internal versus external control. (In prep.)

Clark, R. B. 1984. Impact of oil pollution on seabirds. Environ. Pollut. (Ser. A) 33:1-22.

Diaz, H. F. & Markgraf, V. 1992. El Niño: Historical and Paleoclimatic Aspects of the Southern Oscillation. Cambridge University Press, New York. 476pp.

Dunnett, G. M. 1982. Oil Pollution and Seabird Populations. Philosophical Transactions of the Royal Society of London 297: 413-427.

Furness, R. W. 1987. Seabirds as monitors of the marine environment. ICBP Tech. Publ. 6:217-230.

Furness, R. W. & Barrett, R. T. 1991. Seabirds and fish declines. Natl. Geo. Res. & Explor. 7(1):82-95.

Gilbertson, M., Elliott, J. E. & Peakall, D. B. 1987. Seabirds as indicators of marine pollution. ICBP Tech. Publ. 6:231-248.

Graybill, M. R. & Hodder, J. 1985. Effects of the 1982-1983 El Nino on reproduction of six species of seabirds in Oregon. In: El Niño North: Niño Effects in the Eastern Subarctic Pacific Ocean. Wooster, W. S. & Fluharty, D. L. (eds.) WA Sea Grant, University of Washington, Seattle. pp:205-210.

Halley, D. J. & Harris, M. P. 1993. Intercolony movement and behaviour of immature Guillemots *Uria aalge*. Ibis 135:264-270.

Halpert, M. S. & Bell, G. D. 1993. The global climate of June-August 1991: Tropical Pacific warm episode conditions evolve; new base period means established. Journal of Climate 6:1434-1456.

Hatch, S. A. & Hatch, M. A. 1989. Attendance patterns of murres at breeding sites: implications for monitoring. J. Wildl. Manage. 53(2):483-493.

Hunt, G. L. 1987. Offshore Oil Development and Seabirds: The Present Status of Knowledge and Long-Term Research Needs. In: Long-Term Environmental Effects of Offshore Oil and Gas Development. Elsevier, New York. pp:539-586.

Manuwal, D. A. 1980. Breeding biology of seabirds on the Barren Islands, Alaska, 1976-1979. U.S.F.&W.S., Off. Biol. Serv., Anchorage, AK Unpubl. Rep. 195pp.

Massey, B. W., Bradley, D. W. & Atwood, J. L. 1992. Demography of a California least tern colony including effects of the 1982-1983 El Nino. Condor 94:976-983.

Nishimoto, M., Trapp, J., Williamson, D. and Hanson, K. 1986. The status of Fork-tailed Storm-petrels and other seabirds at St. Lazaria Island during the summer of 1985. USF&WS unpubl. rept., Homer, AK.

Nishimoto, M., Thounhurst, K., and Kirkhorn, S. 1987. The status of Fork-tailed Storm-petrels and other seabirds at East Amatuli Island during1986. USF&WS unpubl. rept., Homer, AK.

Nishimoto, M. and Beringer, B. 1988. Status of Fork-tailed Storm-petrels at East Amatuli Island during the summer of 1987. USF&WS unpubl. rept., Homer, AK.

Nishimoto, M. and O'Reilly, K. 1989. Status of Fork-tailed Storm-petrels at East Amatuli Island during the summer of 1988. USF&WS unpubl. rept., Homer, AK.

Nysewander, D. R., C. Dippel, G. V. Byrd, and E. P. Knudtson. 1993. "Effects of the T/V *Exxon Valdez* Oil Spill on Murres: A Perspective from Observations at Breeding Colonies." Exxon Valdez *Oil Spill Symposium Abstracts*, Anchorage, AK; 135-138.

Parrish, J. K. & Boersma, P. D. 1995. Muddy waters: Seabird mortality following the Exxon Valdez oil spill. Am. Sci. 83:112-115.

Piatt, J. F. 1990. The aggregative response of Common Murres and Atlantic puffins to schools of capelin. Studies Av. Biol. 14:36-51.

Piatt, J. F., Lensink, C. J., Butler, W., Kendziorek, M. & Nysewander, D. R. 1990. Immediate impact of the 'Exxon Valdez' oil spill on marine birds. Auk 107:387-397.

Ricklefs, R. E. 1979. Adaptation, constraint and compromise in avian postnatal development. Biol. Rev. 54:269-290.

Royer, T. C. 1989. Upper ocean temperature variability in the northeast Pacific ocean: Is it an indicator of global warming? J. Geophys. Res. 94:18,175-18,183.

Sharp, G. D. 1992. Fishery catch records, El Niño/Southern Oscillation and longer-term climate change as inferred from fish remains in marine sediments. In: El Nino: Historical and Paleoclimatic Aspects of the Southern Oscillation. (Diaz, H. F. & Markgraf, V. eds.). Cambridge University Press, New York. pp:379-418.

Springer A. M., Roseneau, D. G., Lloyd, D. S., McRoy, C. P. & Murphy, E. C. 1986. Seabird responses to fluctuating prey availability in the eastern Bering Sea. Mar. Ecol. Prog. Ser. 32:1-12.

Sydeman, W. J. 1993. Survivorship of Common Murres on Southeast Farallon Island, California. Ornis Scand. 24:135-141.

Sydeman, W. J. & Ainley, D. G. 1994. Marine birds in the California Current Ecosystem: Contributions to U.S. GLOBEC's goals. U.S. GLOBEC NEWS No. 7, September 1994.

Wanless, S., French, D. D., Harris, M. P. and Langslow, D. R. 1982 Detection of annual change in the numbers of cliff-nesting seabirds in Orkney 1976-1980. J. Anim. Ecol. 51: 785-795.

Wiens, J. A. 1995. "Recovery of seabirds following the Exxon Valdez oil spill: an overview," Exxon Valdez Oil Spill: Fate and Effects in Alaskan Waters, ASTM Special Publication #1219. Peter G. Wells, James N. Butler, and Jane S. Hughes, Eds., American Society for Testing and Materials, Philadelphia.

Wilson, U. W. 1991. Responses of three seabird species to El Niño events and other warm episodes on the Washington coast, 1979-1990. Condor 93:853-858.

Wooster, W. S. & Fluharty, D. L. 1985. El Nino North: Nino Effects in the Western Subarctic Pacific Ocean. Washington Seagrant Program, Seattle. 312pp.

Table 1 - Reproductive success for all pairs of Common Murres that could be followed within each time-lapse camera plot, East Amatuli Light Rock, Barren Islands, Alaska.

Camera-Year	Attendance (X ± SD)	Number of eggs	Number of relays	Number of chicks	Reproductive Success
C1 - 1991	57 ± 5.1	46	4	34	0.74-0.76
C1 - 1993	57 ± 9.6	41	1	34	0.76-0.89
C2 - 1993	58 ± 3.0	44	4	24	0.58-0.79
C3 - 1993	35 ± 5.0	19	-	17	0.79-0.89
C4 - 1993	62 ± 7.9	24	1	19	0.65-0.83
C1 - 1994	52 ± 3.7	39	0	36	0.90-0.92
C2 - 1994	59 ± 5.1	41	1	38	0.93

Table 2. Reproductive success for all marked burrows of Fork-tailed Storm-petrels within 6 study sites (A-E, Z). Status refers to whether the burrow was marked in a previous year (OLD) or newly marked that year (NEW). Within a year, old burrows (TOTAL), could be either not found (NNF), found but collapsed (COLL.), or occupied by at least one adult on one occasion (OCC.). Within the category occupied, the majority of the burrows had actively reproducing pairs (ACTIVE), indicated by the presence of an egg. Fledging was defined as chicks which fledged during our field season, or chicks in healthy condition at the end of the season.

1990

STATUS	AREA	TOTAL	NNF	COLL.	OCC.	ACTIVE	CHICKS	FLEDGED
OLD	A	143	1	1	67	66	17	5
	B	53	0	1	30	30	3	2
	C	29	0	0	13	13	2	0
	D	174	1	0	91	89	14	5
	E	122	2	0	56	56	15	7
	Z	30	0	0	17	17	6	4
NEW	A	14			14	14	6	1
	B	7			7	7	0	0
	C	0			0	0	0	0
	D	37			36	36	9	3
	E	62			60	60	26	7
	Z	1			1	1	0	0

1991

STATUS	AREA	TOTAL	NNF	COLL.	OCC.	ACTIVE	CHICKS	FLEDGED
OLD	A	152	-	-	51	31	8	4
	B	53	-	-	18	15	1	1
	C	29	-	-	11	11	2	1
	D	184	-	-	42	36	12	11
	E	130	-	-	26	21	3	2
	Z	35	-	-	11	9	2	1
NEW	A	12			12	12	3	1
	B	0			0	0	0	0
	C	0			0	0	0	0
	D	28			28	28	5	3
	E	47			47	47	27	19
	Z	1			1	1	0	0

1992

STATUS	AREA	TOTAL	NNF	COLL.	OCC.	ACTIVE	CHICKS	FLEDGED
OLD	A	180	6	6	72	68	28	18
	B	54	2	4	33	33	14	9
	C	29	0	7	12	11	5	2
	D	215	27	1	97	97	54	29
	E	177	28	7	74	74	32	14
	Z	37	4	3	16	16	11	3
NEW	A	10			8	7	3	2
	B	1			1	1	0	0
	C	0			0	0	0	0
	D	10			7	7	5	3
	E	8			4	4	3	1
	Z	1			1	1	1	0

1993

STATUS	AREA	TOTAL	NNF	COLL.	OCC.	ACTIVE	CHICKS	FLEDGED
OLD	A	188	18	2	70	67	29	21
	B	54	0	5	28	23	8	5
	C	29	0	0	10	9	3	2
	D	230	24	4	105	99	34	23
	E	196	33	6	60	56	28	15
	Z	37	3	0	17	16	5	4
NEW	A	1			1	1	1	1
	B	1			1	1	1	1
	C	0			0	0	0	0
	D	1			1	0	0	0
	E	29			29	28	12	8
	Z	0			0	0	0	0

1994

STATUS	AREA	TOTAL	NNF	COLL.	OCC.	ACTIVE	CHICKS	FLEDGED
OLD	A	176	8	8	68	63	48	45
	B	56	0	7	24	20	16	15
	C	29	0	2	10	8	6	5
	D	209	7	2	86	79	58	57
	E	200	6	1	83	74	57	51
	Z	34	0	2	10	8	6	6
NEW	A	6			6	5	4	4
	B	3			3	3	2	2
	C	0			0	0	0	0
	D	12			12	10	9	9
	E	28			28	25	17	17
	Z	2			2	2	1	1

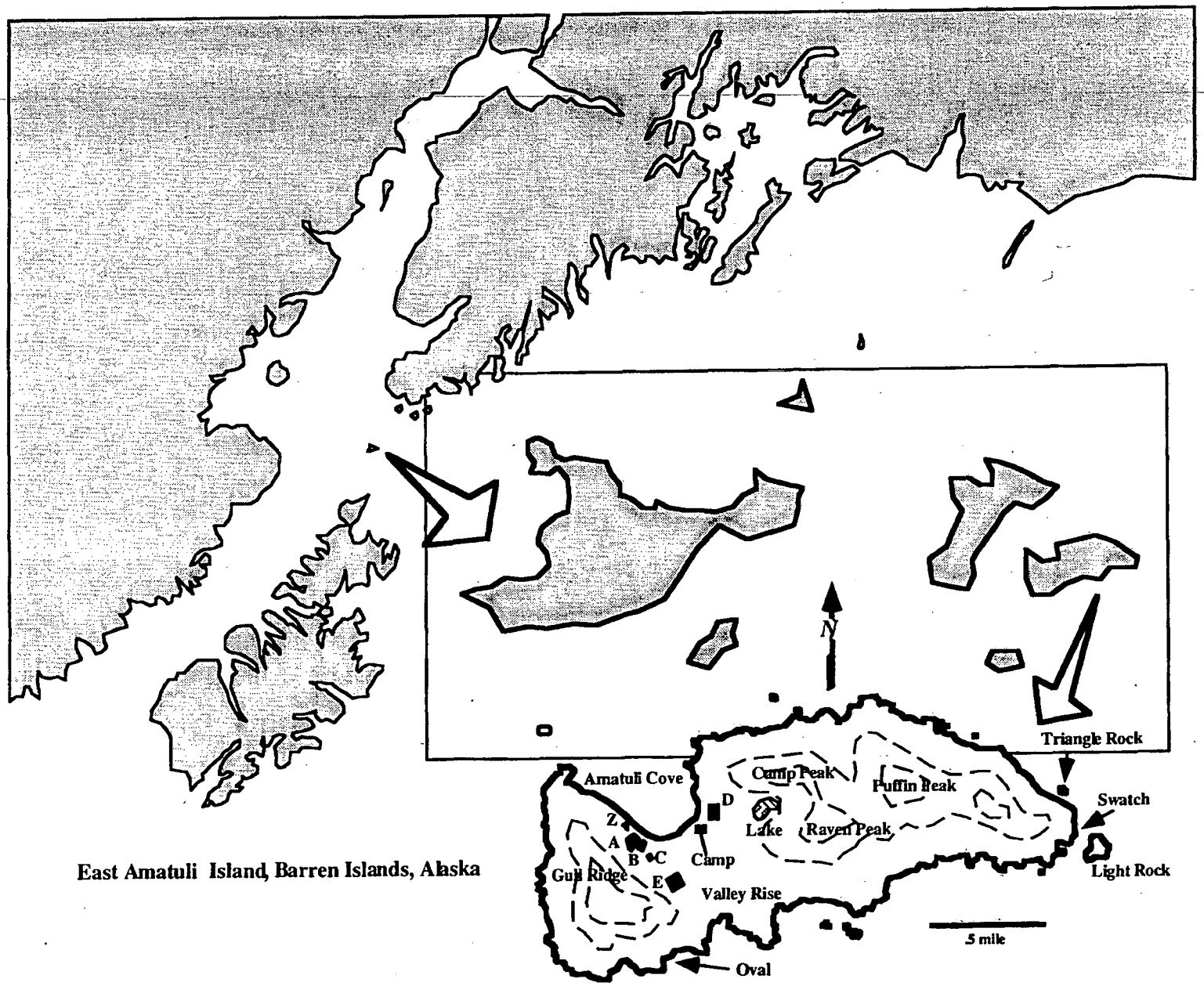

Figure 1. Topographic map of East Amatuli Island, Barren Islands, Alaska, showing the placement of six Fork-tailed Storm-petrel study areas with permanently marked burrows (A, B, C, D, E, Z), the Common Murre census areas (Oval, Swatch, Triangle Rock), and Light Rock - the site of Common Murre reproductive success assessment (5x5m plot; 35mm time-lapse camera plots). Inset is location of East Amatuli relative to the Barren Islands system.

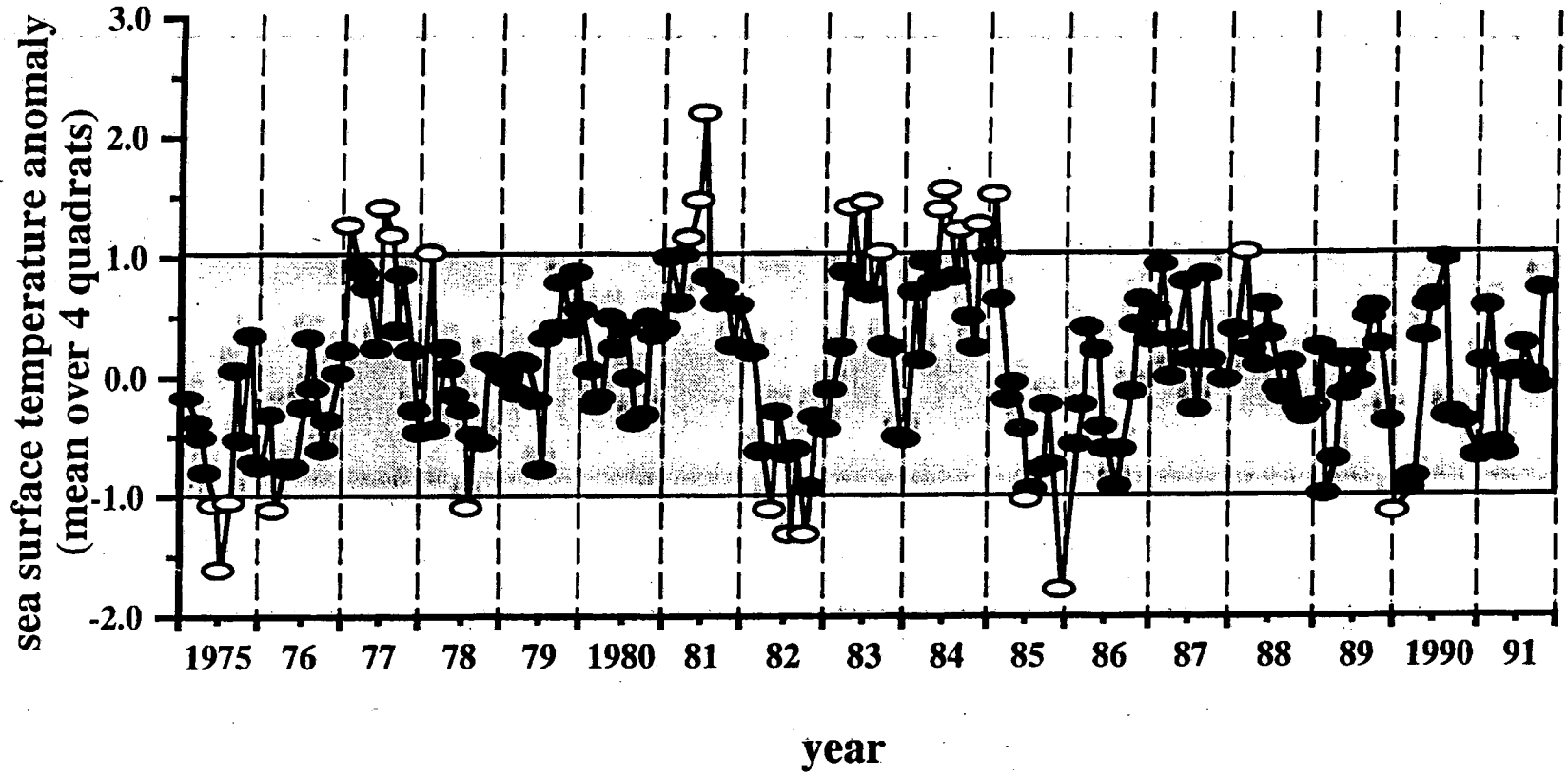

Figure 2. Sea surface temperature anomaly, by month, integrated over a 2° square centered on the Barren Islands (1975-1991). Temperatures greater or less than 1° are shown by open circles. All data from COADS.

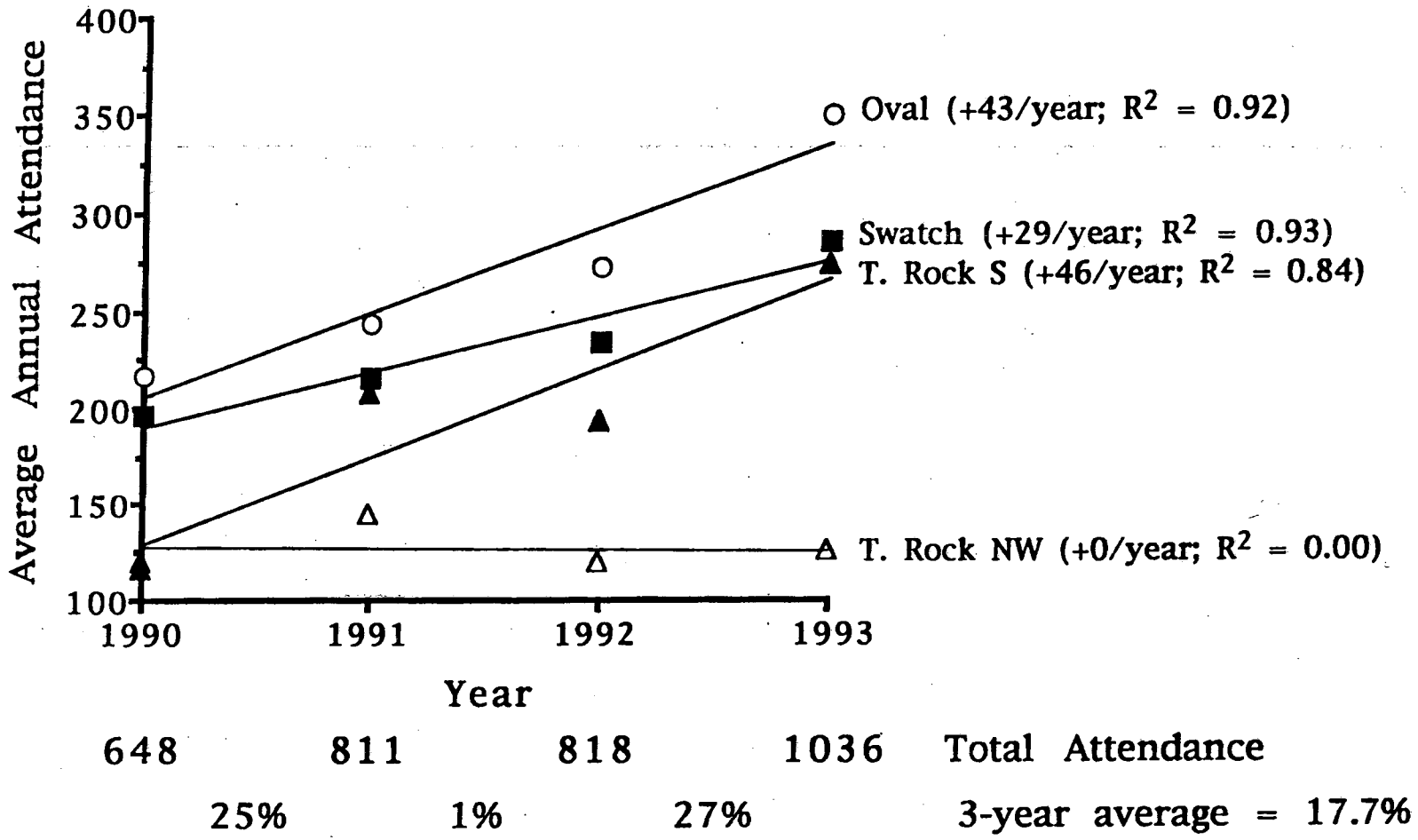

Figure 3. The average annual attendance of Common Murres at four multiple-count areas (Oval, Swatch, Triangle Rock South and Northwest, respectively). Lines are least-squares fit. Slopes are indicated as the average gain in attendance per year. R^2 values indicate slope fit. Total attendance summed over all four areas, and the corresponding percentage increase is indicated below each year. Percent increase is calculated as (1-(larger value/smaller value)) to correct for polarization.

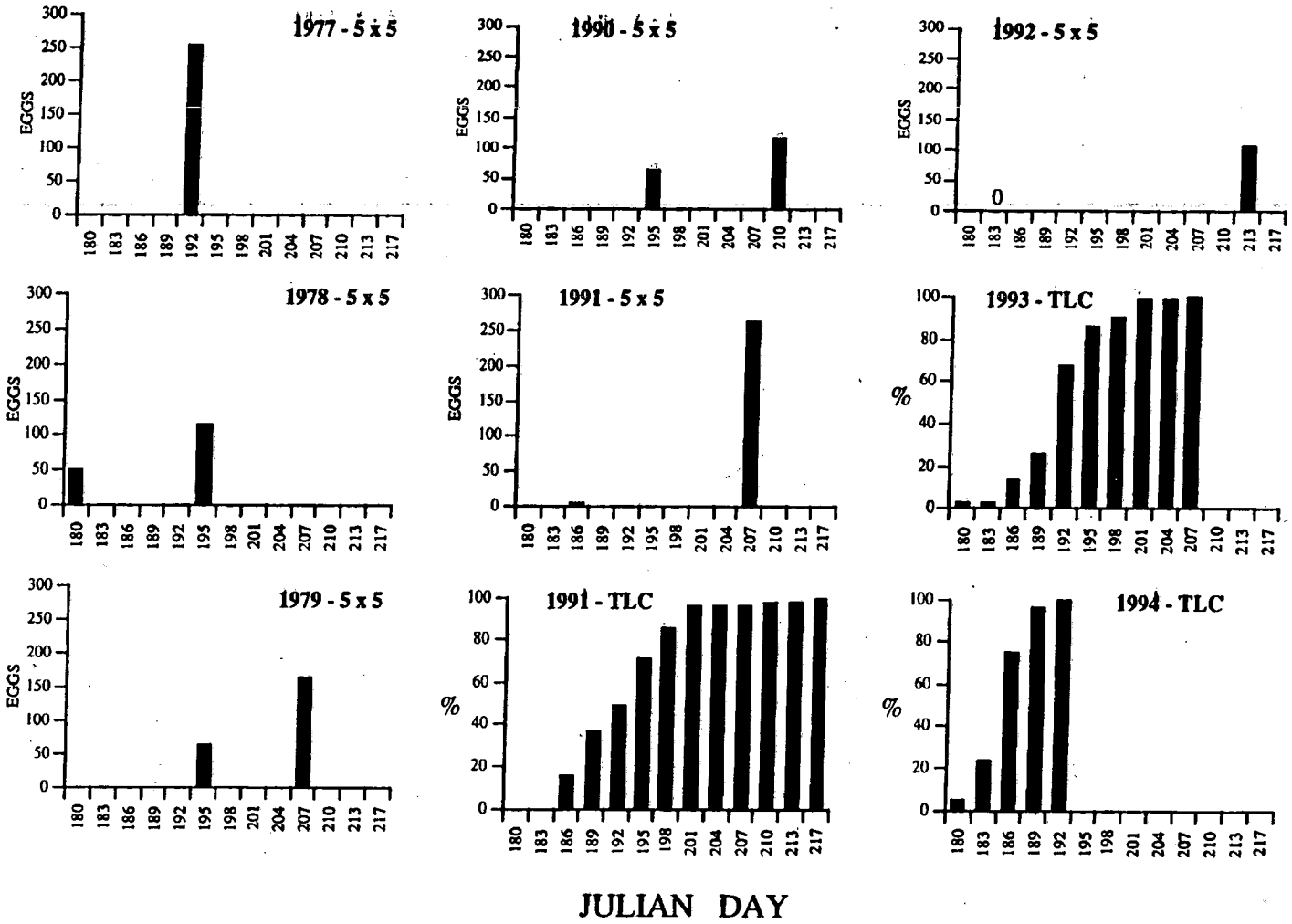

Figure 4. Phenology in Julian days, as assessed by the number or percentage of eggs laid, of Common Murres nesting on East Amatuli Light Rock from 1977 to 1994. 5x5 - the original plot set up by Manuwal and Boersma, which was visited 1-3 times each year (data are actual number of eggs on the plot); TLC - time-lapse camera #1 plot located above and west of 5x5 plot (data are percent of total eggs laid). A zero (0) indicates a visit was made but no eggs were present. TLC data are cut off when all eggs are laid (i.e. 100% is reached).

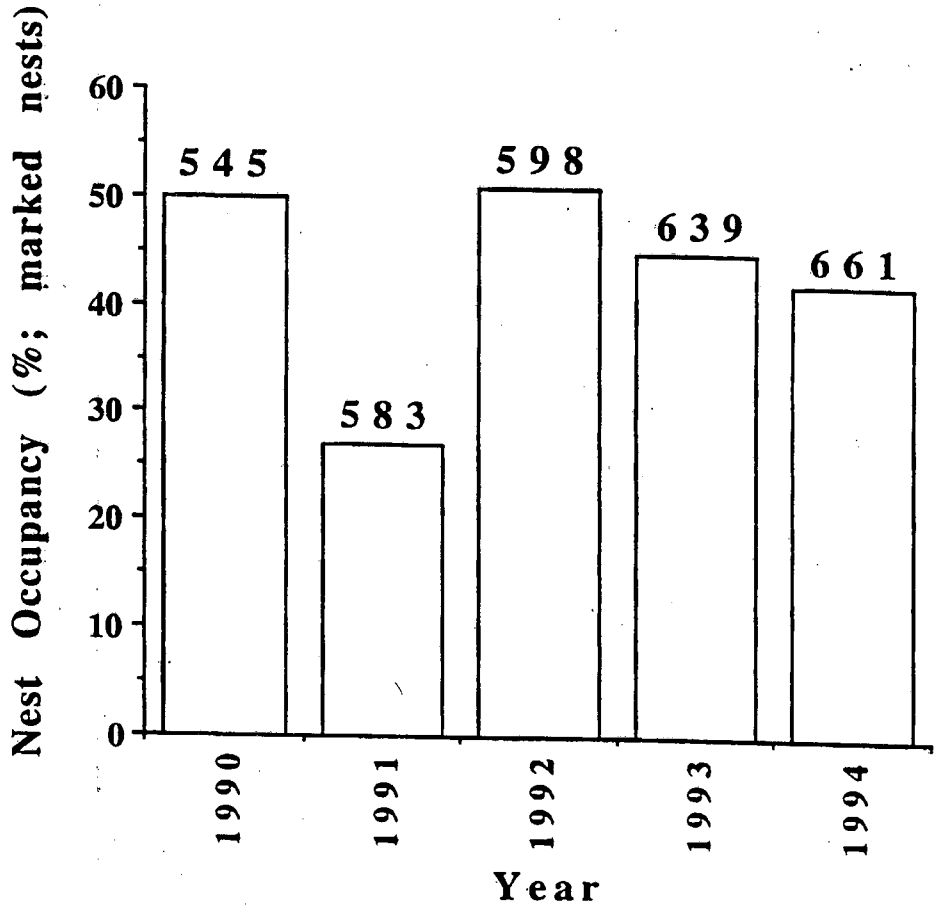

Figure 5. Nest occupancy in permanently marked burrows of Fork-tailed Storm-petrels, 1990-1994.

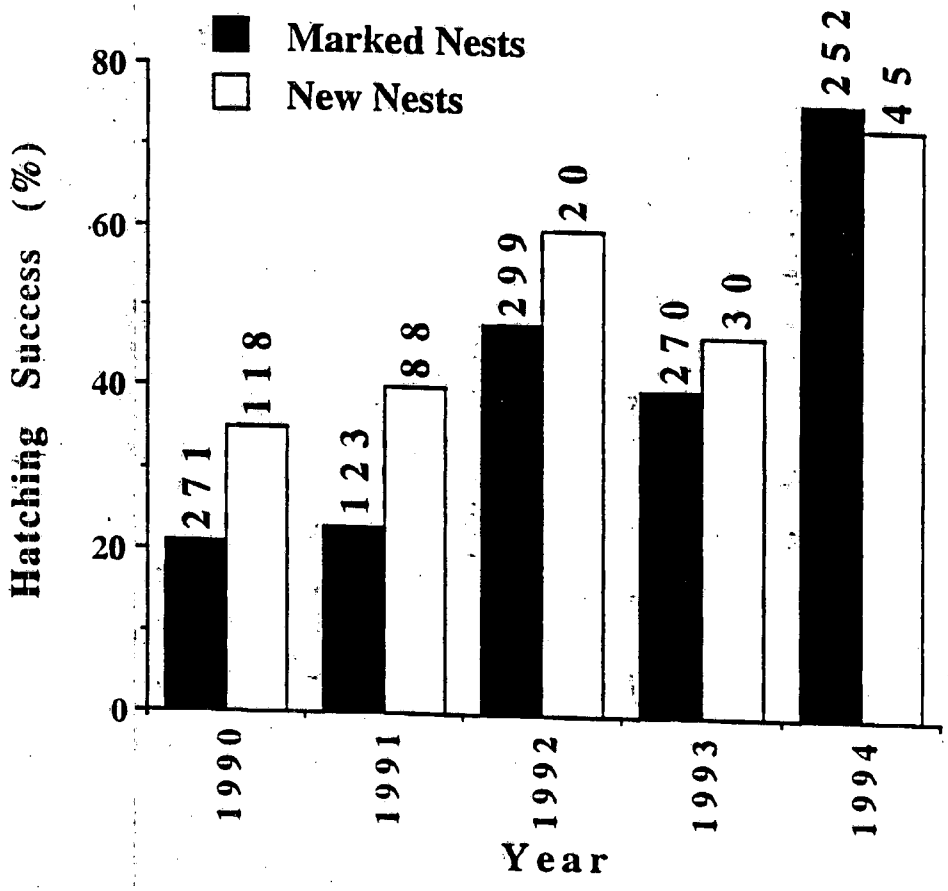

Figure 6. Hatching success of Fork-tailed Storm-petrels, 1990-1994. Permanently marked nests are filled bars, new nests, by year, are open bars. Numbers above each bar are sample sizes.

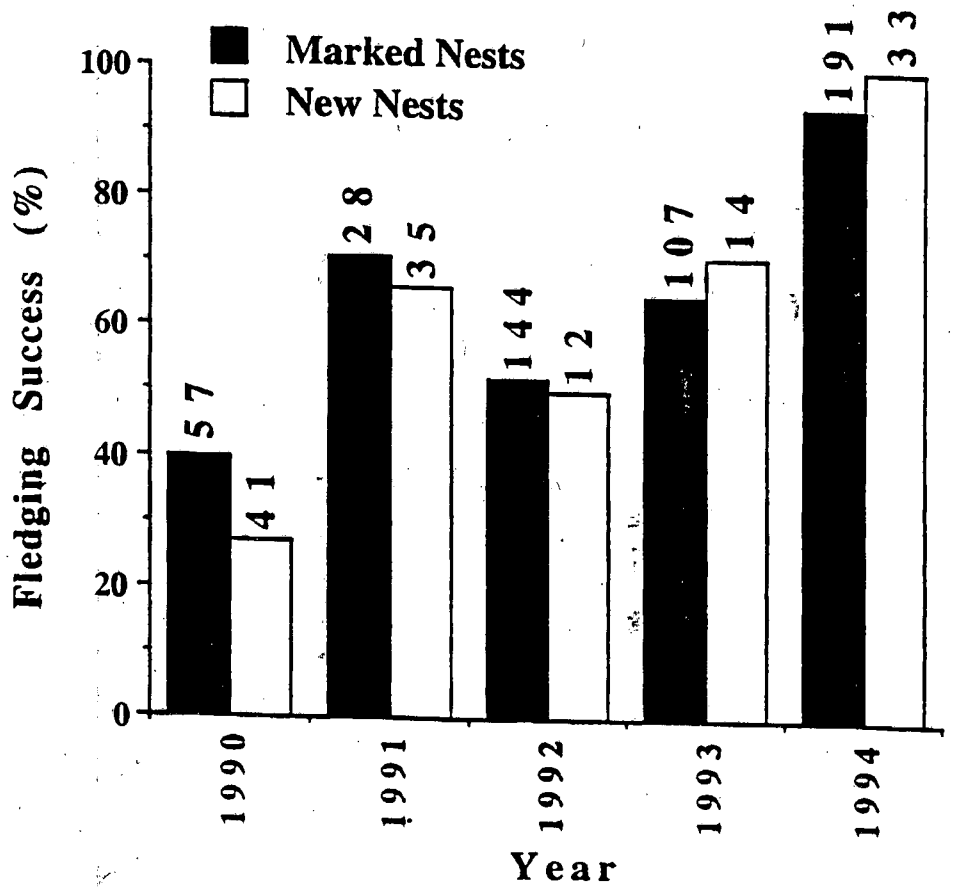

Figure 7. Fledging success of Fork-tailed Storm-petrels, 1990-1994. Permanently marked nests are filled bars, new nests, by year, are open bars. Numbers above each bar are sample sizes.

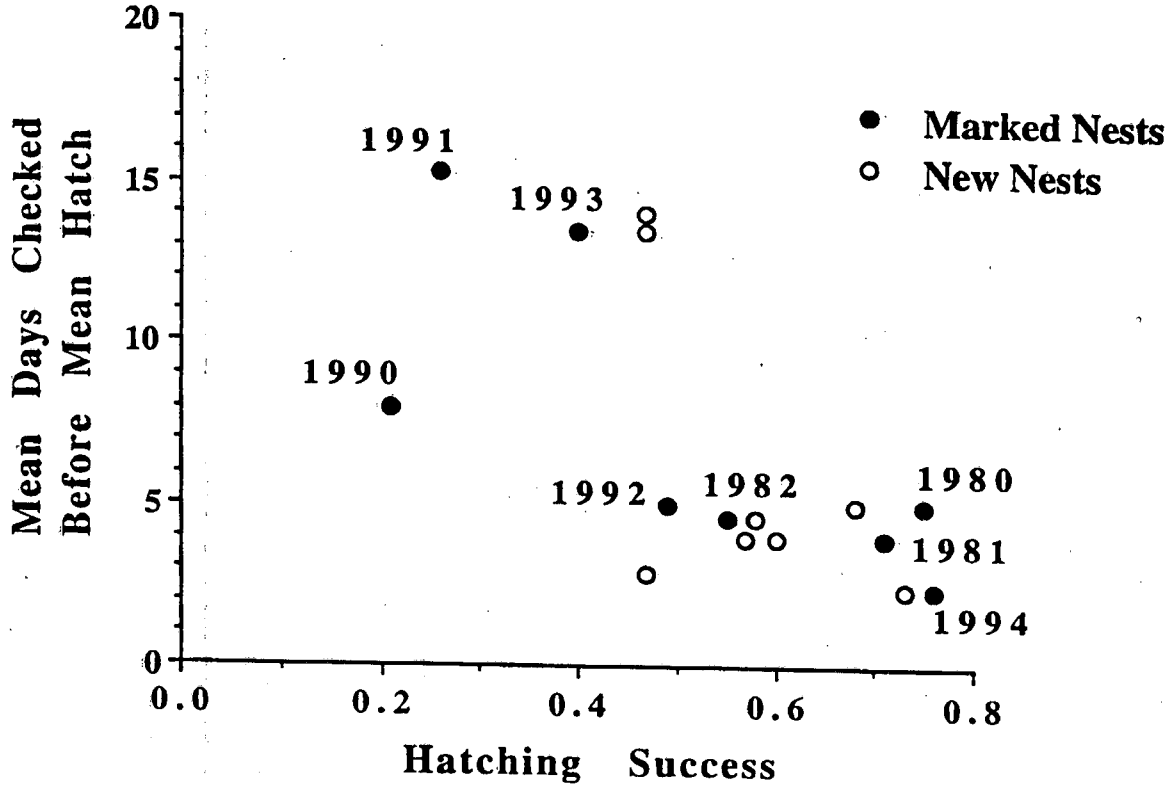

Figure 8. Hatching success of Fork-tailed Storm-petrels as a function of the average number of nest checks before mean hatch date, by year. Permanently marked nests are filled circles, new nests, by year, are open circles. Numbers above each filled circle are years.

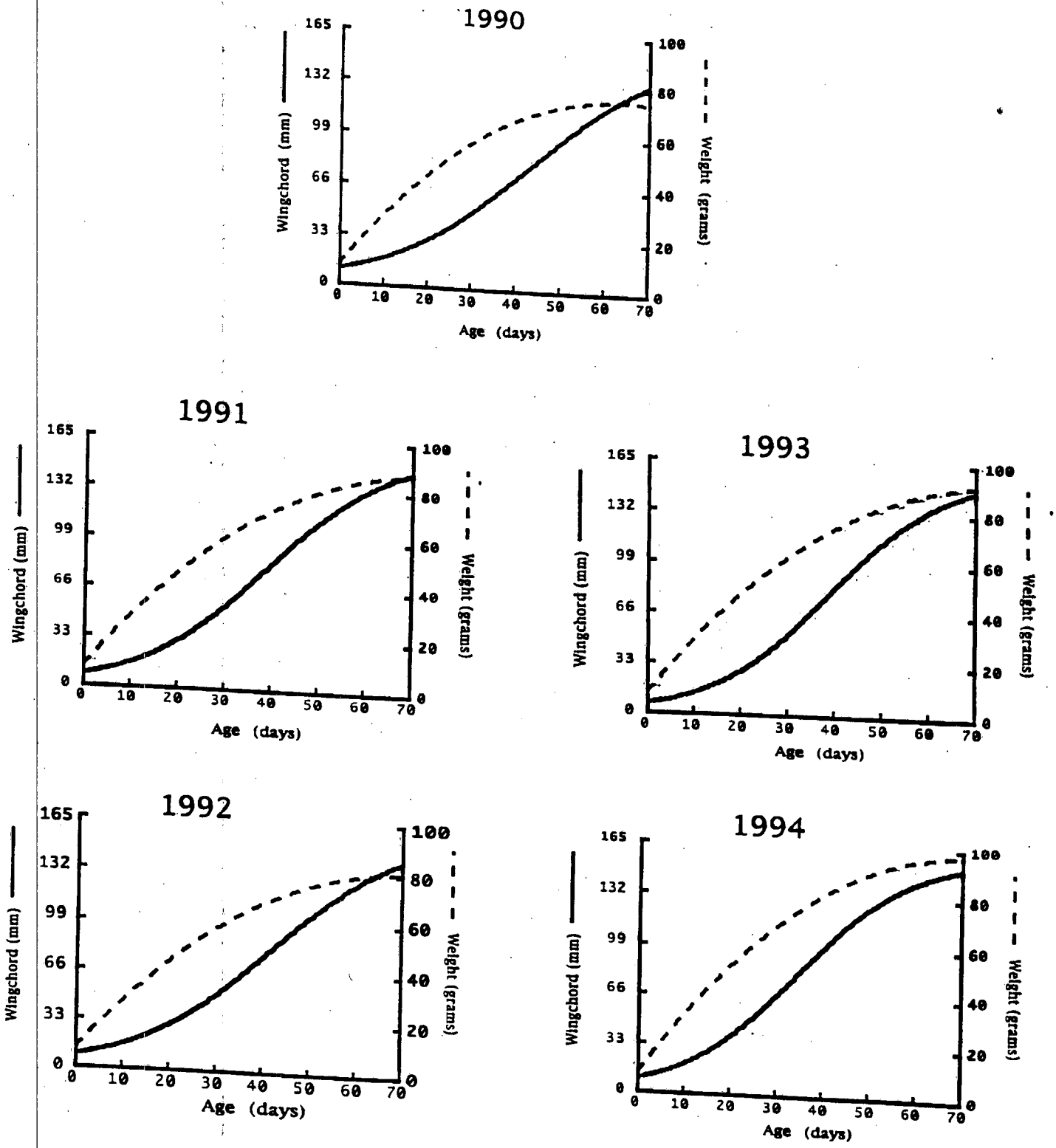

Figure 9 A-E. Wingchord growth (solid line) and weight gain (dashed line), averaged within age (in days) for Fork-tailed Storm-petrel chicks, 1990 - 1994.

OCS Study MMS 2001-040

Final Report
to
Minerals Management Service
Alaska OCS Region

Seasonal Movements and Pelagic Habitat Use of Murres Determined by Satellite Telemetry

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Seasonal Movements and Pelagic Habitat Use of Murres Determined by Satellite Telemetry

MMS Final Report

Study History: In 1994, the National Biological Service (now the Biological Resources Division of the U.S. Geological Survey) used in-house funds to conduct a feasibility study of satellite telemetry in common murres on Middleton Island, north-central Gulf of Alaska. Results of that effort formed the basis of a proposed 3-year study in lower Cook Inlet and the Chukchi Sea. In 1995, in-house funds and funds from the Exxon Valdez Oil Spill Restoration Project were used for the first large-scale deployment of satellite transmitters in murres and tufted puffins. Thirty transmitters were implanted into murres and 5 into puffins. In 1996, 16 transmitters were deployed in murres in the Chukchi Sea. The following account of work conducted at Cape Lisburne in 1996 is submitted as the final report for the Minerals Management Service.

Abstract: We implanted 16 satellite transmitters into common and thick-billed murres at Cape Lisburne Alaska to track foraging patterns and migration and to test the effects of signal transmission on mortality. During the breeding season, areas around the colony and east-northeast of the colony were the most heavily used locations. Murres in 1996 covered roughly the same area during the breeding season as in the previous year. All birds abandoned nesting attempts after implantation. We were able to track several birds after leaving the breeding area. These birds moved south through Bering Straight to an area near the Pribilof Islands. This pattern was similar to that seen in 1995 by both Cape Lisburne and Cape Thompson murres, and we suggest that this area may be an important wintering area for several Alaska murre colonies. Transmitters were active from 0-126 days, and location quality was somewhat better than in 1995. Because 8 transmitters failed after implantation, we were unable to determine whether signal transmission affected mortality.

After implantation, we compared subsequent presence at the colony, nesting status, and provisioning to a control group that underwent a simple surgical procedure. In the 10 days following implantation, we resighted 10 of 11 control birds at the colony and 6 of 16 implanted birds. Of the birds that did return, 7 of 10 control birds retained breeding status, while 0 of 6 implanted birds retained breeding status. We conclude that abdominal implantations alter murre nesting behavior.

We also analyzed body temperatures from 1995 to look at daily and seasonal variation. During the breeding season, no predictable circadian pattern occurred. In the winter, however, birds showed a lowered body temperature in the early morning hours and an increased body temperature during midafternoon. Seasonally, body temperature was higher from the breeding season through migration and lower during the winter months.

Key Words: Alaska, behavior, body temperature, Cape Lisburne, Chukchi Sea, circadian rhythm, common murre, distribution, foraging, habitat use, implantation, migration, nesting, PTT, satellite telemetry, satellite transmitter, seabird, seasonal movements, seasonal variation, thick-billed murre, *Uria aalge*, *Uria lomvia*.

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SEASONAL MOVEMENTS AND PELAGIC HABITAT USE OF MURRES DETERMINED BY SATELLITE TELEMETRY

ABSTRACT

We implanted 16 satellite transmitters into common and thick-billed murres at Cape Lisburne Alaska to track foraging patterns and migration and to test the effects of signal transmission on mortality. During the breeding season, areas around the colony and east-northeast of the colony were the most heavily used locations. Murres in 1996 covered roughly the same area during the breeding season as in the previous year. All birds abandoned nesting attempts after implantation. We were able to track several birds after leaving the breeding area. These birds moved south through Bering Straight to an area near the Pribilof Islands. This pattern was similar to that seen in 1995. Transmitters were active from 0-126 days, and location quality was somewhat better than in 1995. Because 6 transmitters completely failed soon after implantation, we were unable to determine whether signal transmission affected mortality.

Key Words: Alaska, Cape Lisburne, common murre, distribution, migration, satellite telemetry, seasonal movements, thick-billed murre, *Uria aalge*, *Uria lomvia*.

INTRODUCTION

Because of the potential for oil and gas development in the Chukchi Sea, murre populations in that area have been an important target of seabird monitoring efforts sponsored by the Minerals Management Service (MMS), Fish and Wildlife Service (FWS), and the Biological Resources Division (BRD) of the U.S. Geological Survey since 1976 (Springer et al. 1985, Fadely et al. 1989, Mendenhall et al. 1993a, b). To date, this monitoring has emphasized colony population size and breeding productivity. On an annual basis, however, seabirds spend most of their time at sea, and even in the breeding season, they are most vulnerable to potential pollution events while on the water. Similar to restoration management, risk assessment for murres requires a basic knowledge of foraging and migration patterns year-round.

Accurate assessments of murre natural history traits are difficult to obtain because of the distances the birds travel and the difficulty in tracking individuals on the open ocean. Previous to this study, data on traits such as foraging ranges have been estimated through ocean surveys (Nettleship and Gaston 1978, Bradstreet 1979, Gaston and Nettleship 1981, Schneider and Hunt 1984, and Bradstreet and Brown 1985) and calculation of activity times (Cairns et. al 1987). Outside of Hatch et al. (1996), few data are available on wintering populations and none that pertain to birds from known breeding areas. For this reason, this project was funded by BRD, in consultation with MMS, to improve our understanding of pelagic movements of murres and our ability to interpret variation in conventional measures of population health.

The availability of satellite transmitters small enough to be implanted in seabirds has made it possible to sample murre movements directly. These transmitters have generated many recent

studies into seabird foraging and migration (Jouventin and Weimerskirch 1990, Ancel et al. 1992, Davis and Miller 1992, Weimerskirch et al. 1993, Weimerskirch and Robertson 1994, Falk and Møller 1995, Petersen et al. 1995). In 1995, we implanted 30 murres with satellite transmitters at Cape Lisburne, Cape Thompson, and E. Amatuli Island, AK (Hatch et al. 1996). Results of that study revealed foraging patterns and migration routes for all three colonies. However, data from a single year can be misleading, as characteristics may vary from year to year. In 1996, we returned to Cape Lisburne and implanted 16 more murres with satellite transmitters. Our primary objective was to compare movements and distribution in 1996 to those in 1995 to determine whether variation in foraging areas and migration occurred between consecutive years. Our second objective was to test whether the transmitter signal was a factor in the previous year's mortality. In 1995, 40% of the birds in the study died within the first month of implantation. This figure is much higher than the yearly adult mortality rate of 7-21% (Birkhead and Hudson 1977). Between survivors and nonsurvivors, only one factor stood out as significantly different. Murres with PTTs that transmitted more frequently had significantly higher mortality. This suggests that the transmission of the signal may have affected survivorship. In 1996, we altered the programming of the transmitters to determine whether this actually occurred.

STUDY AREA

Cape Lisburne is on the Chukchi Sea about 60 km north of Point Hope on Alaska's northwest coast (Fig. 1). The area is the Pacific's northernmost murre colony and supports approximately 70,000 common murres (*Uria aalge*) and 130,000 thick-billed murres (*Uria lomvia*) (U.S. Fish and Wildlife Service, 1997). Black-legged kittiwakes (*Rissa tridactyla*) also nest in large numbers at Cape Lisburne. Other seabirds include pelagic cormorants (*Phalacrocorax pelagicus*), black guillemots (*Cepphus grylle*), glaucous gulls (*Larus hyperboreus*), and horned puffins (*Fratercula corniculata*). Cape Lisburne Long-range Radar Station is located approximately 3 km from the east end of the colony. The buildings of this station served as our base camp.

METHODS

From 2 August 1996 to 4 August 1996, we captured nesting murres with a light cable noose attached to a 9-m telescoping fiberglass pole. We took murres from lower ledges at the east end of the colony in areas that were accessible by foot from Cape Lisburne radar station. The birds were transported in burlap bags to the station, where we banded them with colored tarsus bands and Fish and Wildlife Service metal tarsus bands. The birds were anaesthetized, surgically sexed, and implanted. For a full description of surgical methods, see Hatch et al. (1996). Briefly, the transmitter was inserted into the air sac cavity through a vertical ventral incision. The antenna was drawn through a hole on the dorsal side so that it pointed upward when the bird was on the water. Birds were released 1-3 hours after surgery. All birds were away from the colony for 6.5-13.5 hours. We attempted to obtain 8 thick-billed murres and 8 common murres with an even sex ratio of each.

The PTTs weighed approximately 35 grams and were identical to those used in 1995 (see Hatch et al. 1996) except that rather than 2 small batteries, a single AA-sized battery was used. This made the base of the PTT slightly wider than the top. PTTs were constructed to meet the specifications of Service Argos, Inc. Argos computes locations by measuring the Doppler shift of the PTT signal transmitting to a moving satellite. For this reason the frequency of the transmitter must be within 4 kHz of 401.65 MHz. At the time of the study there were 2 active Argos receivers. Because batteries would wear out quickly if left on continuously, we programmed them to turn on at specific times during the day. In 1995, duty cycles were 6 hours on, 12 hours off (short cycle), and 6 hours on, 66 hours off (long cycle). As previously stated, significantly more short-cycle birds died than long-cycle birds in 1995. To test whether signal transmission affected survival, we increased the difference in duty cycles in 1996. Duty cycles were 8 hours on, 8 hours off (short cycle), and 6 hours on, 120 hours off (long cycle). After 40 days of operation (expected time at colony after implantation) the short-cycle PTTs switched to the long cycle.

Not all of the location data obtained were reliable. Information supplied by Argos included a coded index to the accuracy of each location. Location accuracy depends on the number of signals received and parameters internal to the Argos system (Fig. 2). This accuracy is expressed as a probability—two-thirds of the locations in a given class are expected to fall within the stated bounds. Thus, while a point assigned location class 3 probably lies within 150 m of true location, it may in fact be off by a larger, unknown amount. Conversely, a point receiving one of the poorer quality codes (0, A, B, or Z) may in fact be very accurate. To cull erroneous points, we relied on the redundancy of locations obtained close to each other in time as well as on reported signal strengths. For a full description of the criteria we used, see Hatch et al. (1996).

In addition to location, each message contained calibration indices for the bird's internal body temperature and the battery's voltage. We retrieved data every 3-4 days through Tymnet, Argos' online data distribution system. We also purchased tapes of cumulative data. Data were converted to Arc/Info coverages for analysis.

RESULTS

Data Quantity and Quality

Due to the small number of common murres at the colony, we captured more thick-billed murres than common murres (Table 1). Sex ratios were even for the common murres, but we captured more male than female thick-billed murres. Three birds died before implantation—one during surgery and two in transit. A fourth bird also exhibited severe stress and was released within 10 minutes of capture. Three of these birds had young (≤ 3-day-old) chicks. The fourth also had a chick, but the age was undetermined. All other birds survived surgery and were released in apparently healthy condition.

We received 1005 signals, 758 locations, and 535 usable locations (Table 2). Overall, we culled 29.4% of the locations received--28.1% during the breeding season, 34.4% post-breeding (table 3). These figures are similar to those during the breeding season in 1995 but higher than those during post-breeding season in 1995. The number of days in contact ranged from 0 to 126 (Table 4). Two transmitters gave 0 locations and 5 transmitters remained active beyond the normal breeding season. Of the 16 transmitters deployed, 7 birds outlived the PTT, 3 birds died, and the fates of 6 are unknown. Location quality was somewhat better than that in 1995. About 54% of the locations were of classes 3, 2, or 1 (Table 5) and were therefore expected to be accurate within 1000 m. This compares to 42% in 1995. Nearly 72% of the locations were based on 4 messages received during an overpass (class 0 or better). This compares to 66% in 1995. The additional 28% of locations were of quality A, B, or Z. Due to redundancy of points and our method of culling, however, these locations are probably more accurate than the category implies. Overall, though we obtained considerable information, data were more sparse than in 1995 due mainly to poorer battery performance and a higher number of transmitter failures.

Movement by Species and Year

All of the implanted murres abandoned breeding attempts after implantation, and most spent little time at the colony after release. In chapter 2, we present evidence that abandonments were caused primarily by implantation and not by capture and other handling. A few birds did return to the colony, but none appeared to commute on a regular basis. Murres tended to forage northeast to northwest of the colony (Fig 3). The areas around the colony and just northeast of the colony saw the highest use. A common pattern was for the birds to travel northeast before drifting north and away from the colony. Breeding-season distribution in 1996 was similar to that in 1995 (Fig 4). Birds in 1996 used the area just west of the colony somewhat less than in 1995, and did not drift as far north, but overall, the boundaries of distribution were remarkably similar. Figure 5 shows the minimum convex polygons for breeding-season locations from both years. Almost all of the outermost locations that form the polygons represent noncommuting murres that had abandoned nesting attempts. Still, the areas are very similar between years. The area of intersection constitutes 29,000 km^2 of mostly pelagic and some coastal habitat.

The area around Point Hope, which was important for Cape Thompson birds in 1995, was completely avoided by Lisburne murres in 1996, as in 1995. Although we have no knowledge of Cape Thompson murre movements in 1996, we suspect that the two colonies once again foraged in different areas during the summer months. As was true in 1995, no apparent differences were seen in the movements between males and females (Fig. 6). Some studies have suggested thick-billed murres forage farther from land than common murres (Swartz 1966, Drury et al. 1981, Gould et al. 1982). We were not able to verify this for commuting birds, but there appeared to be no difference in foraging distance between the species for individuals that abandoned nesting attempts (Fig. 7).

We were able to track 5 murres past the breeding season. Two were still in the vicinity of the colony on 10 and 19 October, respectively, when their transmitters stopped working (Figs. A.11 and A.14). Two left the area 1 and 5 September, respectively (Figs. A.2 and A.8), and moved south through Bering Straight (Fig. 8). The fifth murre had a PTT that failed (only 2 locations

received) but gave one location after breeding season (Fig. A.16). Migration was similar to that seen in 1995 (Fig. 9). No apparent staging areas were used, and final destination appeared to be an area near the Pribilof Islands.

Mortality and Transmitter Failure

The biggest single factor in the relatively low number of locations was transmitter failure. Of the 16 transmitters deployed, 8 failed within the first 2 weeks of deployment. Six failed completely, and 2 gave sporadic signals up to 3 months later. In addition to transmitter failure, battery life was shorter. The longest time in contact was 126 days in 1996 compared to 258 days in 1995.

As in 1995, we encountered murre mortality. Because of transmitter failure, the extent of this mortality was uncertain, and we were not able to clarify its cause. We were unable to track 6 of the birds past the 2-3 week window in which we observed most mortality in 1995. Of the 10 birds for which the fate is known, 3 died (30%), and 7 outlived their transmitters. Of the 3 birds that died, 1 had a short cycle transmitter and 2 had long-cycle transmitters (Table 4).

DISCUSSION

Data Quantity and Quality

In general, the new batteries did not perform as well as the batteries used in 1995. Due to the high internal heat of the bird, the batteries tend to discharge even when the transmitter is switched off. In order to counteract this discharge, a chemical coating covers the nodes during the off period. This chemical can, however, build up to such a level that the electrical current is unable to break it down, and the current is not able to flow. This process is known as passivation, and it caused the early cessation of many transmitters in 1995. To overcome this problem, we deployed a battery with larger surface area at the nodes. However, we also increased the off time for the long-cycle transmitters. The longer the PTT is switched off, the more likely passivation is to occur, and we believe the extended off period counteracted the improved battery design.

The high rate of transmitter failure probably was due also to the new battery type. In addition to the differences already discussed, this year's battery also contained a fuse which was not present in 1995. When examining a recovered 1995 transmitter, we noticed that the PTT case was slightly compressed. We hypothesize that high pressure due to water depths compresses the case, forcing internal parts in the PTT to touch each other, effectively shorting out the circuitry. Such a short would blow the battery fuse, and the transmitter would quit working even though the battery might still contain adequate charge. This compression presumably occurred both years, but because no fuse was present in 1995, the PTTs continued to transmit. Data from 1995, however, do indicate several sporadic transmitters.

Movements and Distribution

Some care must be given to the interpretation of the distribution charts for this year's data. First, this year's movements reflect only noncommuting murres or murres that made very few trips back to the colony. Second, because the sampling period between short and long cycle transmitters was so different, on maps that contain both, the majority of points are from a few birds with short-cycle transmitters. Therefore areas with dense clusters of points may look like higher-use areas but really only represent the movements of one or two birds that were sampled intensively. Looking at individual movements from the track lines in appendix 2 allows one to assess more accurately where most birds are foraging. Taking this into account, we conclude that the area just around the colony and just east-northeast of the colony were important locations. The area east-northeast of the colony seemed to be frequented by the birds just after release. From there they tended to drift northward or else returned to the colony and then drifted north. We speculate that this area is a common feeding area while the bird has ties to the colony. Once the decision is made to abandon the colony, other areas might prove more productive.

Although few transmitters lasted until migration, we received enough data to corroborate the migration patterns of 1995. The outer continental shelf around the Pribilofs has been studied intensively and has been shown to be a productive area (Woodby 1984) containing persistent fronts (Kinder et al. 1983, Schneider et al. 1990, Coyle et al. 1992) that tend to concentrate prey. This area may be extremely important for wintering murres from several colonies. We have learned that murres from both Cape Thompson and Cape Lisburne winter in the vicinity. It is not unreasonable to assume that murres from other colonies along the west coast of Alaska spend some of the winter months in this area. In addition, the Pribilof Islands themselves support a large number of breeding murres (the colony at St. George contains over a million murres), and it is likely that some of these birds also winter in the area. If this is true, the well-being of many seabird colonies along the coast of Alaska may depend on the health of a relatively small area of pelagic habitat.

Mortality and Transmitter Failure

In 1995, we proposed many possible factors involved in murre mortality (Hatch et al. 1996). Of those, most remain possible, but data from 1996 allowed us to rule out several. The possibilities we now consider unlikely are as follows: 1) Picric acid. Because we observed mortality again this year, and we did not use picric acid, we can probably rule out the effects of this dye. 2) Hypothermia. These transmitters have now been implanted successfully in spectacled eiders (Petersen et al.1995), common loons (K. Kino, pers. comm.), and harlequin ducks (S. Brodeur, pers. comm.). In addition, smaller conventional transmitters have been implanted with the same surgical technique in harlequin ducks (Dan Esler, pers. comm.) The success of implantations in these species suggest that hypothermia is not a likely problem, as murres should be at no greater risk than other birds living in cold-water environments. 3) Bulk of transmitter causing false sense of fullness. This hypothesis appears unlikely as harlequin ducks are smaller birds but show fewer problems. 4) Added weight impairing ability to fly. Although this remains a possibility, our data show that birds that die are often in the same areas as birds that live. This suggests that birds are not restricted in finding suitable feeding areas by potential flight problems. We do not

have enough data to completely rule out this hypothesis, however, and it is still possible that increased weight and density associated with transmitter implants affects diving ability.

Of all the species so far implanted, only murres and puffins have shown increased mortality. These birds are also the only deep-diving species that have been released immediately to the water after surgery. This suggests a problem related to the depths to which the birds dive. The possibility exists that high pressure on the unhealed incision compromises that incision, either causing pain during foraging or forcing water into the body cavity, thereby producing infection. The possible effect of the transmission on foraging behavior or physiology has not yet been confirmed and also remains a viable hypothesis. Of the 16 hypotheses we proposed in 1995, we now consider only 5 to be reasonable candidates (Table 6). Those 5 all relate to either diving depths or PTT transmission.

CONCLUSIONS

The results of this study, together with those from 1995, have shown satellite telemetry to be a relatively accurate, efficient, and cost-effective way to obtain data heretofore unavailable. We have also learned, however, that abdominal implantations, while effective in many species, are not the preferred method of attachment for murres and puffins. Since this study was conducted, small external satellite transmitters have become available, and methods are being developed to permanently attach external mounts to diving birds (S. Newman, pers. comm.). We believe these new methods may be the answer to attachment problems for external mounts. In addition, Argos has plans to launch a new, more sensitive receiver in 1997-1998. This receiver will increase data quantity and quality. The combination of increased accuracy, the development of smaller transmitters, and the development of new transmitter capabilities (e.g., time-depth recorders) all forecast a bright future for satellite telemetry in seabirds.

Ecological findings of the 1995 and 1996 studies are also encouraging. Previous to this study, movements of individual murres from a given colony were not well understood. We have established foraging ranges, migration routes, nursery areas, and wintering areas of birds from several colonies, as well as identifying several key habitats. We have shown the area around Perenosa Bay to be an important foraging area for birds from the Barren Islands. In the Chukchi Sea, we have learned that both the summer distribution of noncommuting murres and the nursery area for post-fledging chicks are extremely large. Finally, we have shown that areas around the Pribilof Islands are important wintering areas with possible ecological importance to many seabird colonies. Further evaluation of this area to determine its extent of use by murres from other colonies is desirable. A small number of PTTs should be deployed on murres from colonies in Kotzebue Sound, Norton Sound, St. Lawrence Island, St. Matthew Island, and Nunivak Island to determine whether these colonies all rely on the same wintering area.

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LITERATURE CITED

Ancel A., G.L. Kooyman, P.J. Ponganis, J-P Gendner, J. Lognon, X. Mestre, N. Huin, P.H. Thorson, P. Robisson, and Y. Le Maho. 1992. Emperor penguins foraging behaviour as a resource detector in winter and summer. Nature 360:336-339.

Birkhead, T. R. and P. J. Hudson. 1977. Population parameters for the common guillemot *Uria aalge*. Ornis Scand. 8:145-154.

Bradstreet, M. S. W. 1979. Thick-billed murres and black guillemots in the Barrow Strait area, N.W.T., during spring: distribution and habitat use. Can. J. Zool. 57:1789-1802.

Bradstreet, M. S. W., and R. G. B. Brown. 1985. Feeding ecology of the Atlantic Alcidae. Pp. 263-318 *in* The Atlantic Alcidae (D. N. Nettleship and T. R. Birkhead, Eds.) Academic Press. London.

Cairns, D. K., K. A. Bredin, and W. A. Montevecchi. 1987. Activity budgets and foraging ranges of breeding common murres. Auk 104:218-224.

Coyle, K.O., G.L. Hunt, Jr., M.B. Decker, T.J Weingartner. 1992. Murre foraging, epibenthic sound scattering and tidal advection over a shoal near St. George Island, Bering Sea. Mar. Ecol. Prog. Ser. 83:1-14.

Davis, L.S. and G.D. Miller. 1992. Satellite tracking of Adélie penguins. Polar Biol. 12:503-506.

Drury, W. H., C. Ramsdell, and J. B. French. 1981. Ecological studies in the Bering Strait region. U.S. Dep. Commer., NOAA OCSEAP Final Rep. 3:175-486.

Falk, K. and S. Møller. 1995. Satellite tracking of high-arctic northern fulmars. Polar Biol. 15:495-502.

Fadely, B. S., J. F. Piatt, S. A. Hatch, and D. G. Roseneau. 1989. Populations, productivity, and feeding habits of seabirds at Cape Thompson, Alaska. U.S. Fish and Wildlife Serv., Final Rep., OCS Study MMS 89-0014.

Gaston, A. J., and D. N. Nettleship. 1981. The thick-billed murres of Prince Leopold Island. Can. Wildl. Serv. Monogr. No. 6.

Gould, P. J., D. J. Forsel, and C. J. Lensink. 1982. Pelagic distribution and abundance of seabirds in the Gulf of Alaska and eastern Bering Sea. U.S. Dep. Int., Fish and Wildl. Serv., FWS/OBS-82/48. 294 pp.

Hatch S.A., P.M. Meyers, D.M. Mulcahy, and D.C. Douglas. 1996. Seasonal movements and pelagic habitat use of murres and puffins determined by satellite telemetry. *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Project 95021), National Biological Service, Anchorage, Alaska.

Jouventin, P. and H. Weimerskirch. 1990. Satellite tracking of wandering albatrosses. Nature 343:746-748.

Kinder, T.H., G.L. Hunt, Jr., D. Schneider, J.D. Schumacher. 1983. Correlations between seabirds and oceanic fronts around the Pribilof Islands, Alaska. Est., Coastal and Shelf Sci. 16:309-319.

Mendenhall, V. M., (ed.). 1993a. Monitoring of populations and productivity of seabirds at St. Matthew Island, Bluff, and Cape Thompson, Alaska, 1991. U.S. Fish and Wildlife Serv., Draft Rep., OCS Study MMS 91-00__.

Mendenhall, V. M., (ed.). 1993b. Monitoring of populations and productivity of seabirds at Cape Pierce, Bluff, and Cape Thompson, Alaska, 1990. U.S. Fish and Wildlife Serv., Final Rep., OCS Study MMS 92-0047.

Nettleship, D. N., and A. J. Gaston. 1978. Patterns of pelagic distribution of seabirds in western Lancaster Sound and Barrow Strait, N.W.T. Can. Wildl. Serv. Occ. Pap. No. 39.

Petersen, M.R., D.C. Douglas, and D.M. Mulcahy. 1995. Use of implanted satellite transmitters to locate spectacled eiders at-sea. Condor 97:276-278.

Schneider, D. and G. L. Hunt, Jr. 1984. A comparison of seabird diets and foraging distribution around the Pribilof Islands, Alaska. Pp. 86-95 *in* Marine birds: their feeding ecology and commercial fisheries relationships (D. N. Nettleship, G. A. Sanger, and P F. Springer, Eds.) Canadian Wildl. Serv., Ottawa.

Schneider, D., N.M. Harrison, and G.L. Hunt, Jr. 1990. Seabird diet at a front near the Pribilof Islands, Alaska. Stud. Avian Biol. 14:61-66.

Springer, A. M., E. C. Murphy, D. G. Roseneau, and M. I. Springer. 1985. Population status, reproductive ecology, and trophic relationships of seabirds in northwestern Alaska. U.S. Dep. Commer., NOAA OCSEAP Final Rep. 30:127-242.

Swartz, L. G. 1966. Sea-cliff birds. Pp. 611-678 *in* Environment of the Cape Thompson region, Alaska (N. J. Wilimovsky and J. N. Wolfe, Eds.). U.S. Atomic Energy Commission, Oak Ridge, Tennessee.

U.S. Fish and Wildlife Service. 1997. Alaska seabird colony catalog—computer database and colony status record archives. U.S. Fish and Wildlife Service, Migratory Bird Management, Anchorage AK.

Weimerskirch H., and G. Robertson. 1994. Satellite tracking of light-mantled sooty albatrosses. Polar Biol. 14:123-126.

Weimerskirch H., M Salamolard, F. Sarrazin, and P. Jouventin. 1993. Foraging strategy of wandering albatrosses through the breeding season: a study using satellite telemetry. Auk 110:325-342

Woodby, D.A. 1984. The April distribution of murres and prey patches in the southeastern Bering Sea. Limnol. Oceanogr. 29:181-188.

Table 1. Deployment of 16 satellite transmitters in common and thick-billed murres at Cape Lisburne, AK, August 1996.

	Number of Transmitters				
	Short Cycle		Long Cycle		
	Males	Females	Males	Females	Total
Common Murre	1	2	2	1	6
Thick-billed Murre	3	2	3	2	10
Total	4	4	5	3	16

Table 2. Summary of bird location data obtained through 31 December 1996.

	Breeding Season[a]	Postbreeding Season[b]	Total
Messages[c]	758	247	1005
Locations	595	163	758
Culled Locations	167	56	223
Useable Locations	428	107	535

[a]capture to first migrational movements (3 Aug-31 Aug)
[b]First migrational movements to last location received (1 Sep-31 Dec)
[c]Satellite overpasses with at least one signal received from a PTT

Table 3. Comparison of transmitter performance and data acquisition between 1995 and 1996.

	1995	1996
Murres Implanted	30	16
Average Battery Life[a]	116	81
Locations/bird[a]	102	87
Percent of Locations culled	22.1	29.4

[a]birds that outlived PTT and transmitters that did not fail early

Table 4. Details of satellite transmitter deployment by species, duty cycle, and performance in 1996.

Species	PTT	Sex	Program	Date Released[a]	Last Contact	Days in Contact	Total Locations	Useable Locations	Outcome
COMU	5851	F	Short	3 Aug	7 Dec	126	288	196	outlived PTT
COMU	5852	M	Short	3 Aug	8 Aug	5	6	6	PTT failed
TBMU	5853	F	Short	5 Aug	8 Aug	5	8	7	PTT failed
TBMU	5856	M	Long	4 Aug	No Signals	0	0	0	PTT failed
TBMU	7875	M	Long	4 Aug	4 Aug	1	17	4	died
TBMU	7876	M	Short	4 Aug	12 Aug	8	10	4	PTT failed
COMU	7879	F	Long	4 Aug	5 Nov	93	28	22	outlived PTT
TBMU	7880	M	Short	4 Aug	No Signals	0	0	0	PTT failed
COMU	7882	F	Short	5 Aug	5 Sep	31	29	24	outlived PTT
COMU	7884	M	Long	3 Aug	29 Oct	87	32	25	outlived PTT
TBMU	7887	F	Long	4 Aug	4 Aug	<1	6	4	died
COMU	7888	M	Long	3 Aug	10 Oct	68	58	49	outlived PTT
TBMU	7901	F	Long	5 Aug	21 Dec	138	2	2	PTT failed but indicated bird's survival through day 138
TBMU	7903	M	Long	5 Aug	23 Oct	79	8	6	PTT failed but indicated bird's survival through day 79
TBMU	7915	M	Short	5 Aug	24 Aug	19	229	165	died
TBMU	7917	F	Short	5 Aug	16 Aug	11	37	21	PTT failure

[a]Date is for Greenwich Mean Time

Table 5. Frequency distribution of data by Argos location classes.

	Before Culling		After Culling	
Argos Signal Quality Code	No. Locations	% of total	No. Locations	% of total
3	35	4.6	34	6.4
2	95	12.5	89	16.6
1	182	24.0	167	31.2
0	143	18.9	94	17.6
a	122	16.1	82	15.3
b	138	18.2	59	11.0
z	39	5.1	9	1.7
Not classified	4	0.5	1	0.2
Total	758	99.9	535	100

Table 6. Hypothesized causes of murre mortality associated with satellite transmitter implants.

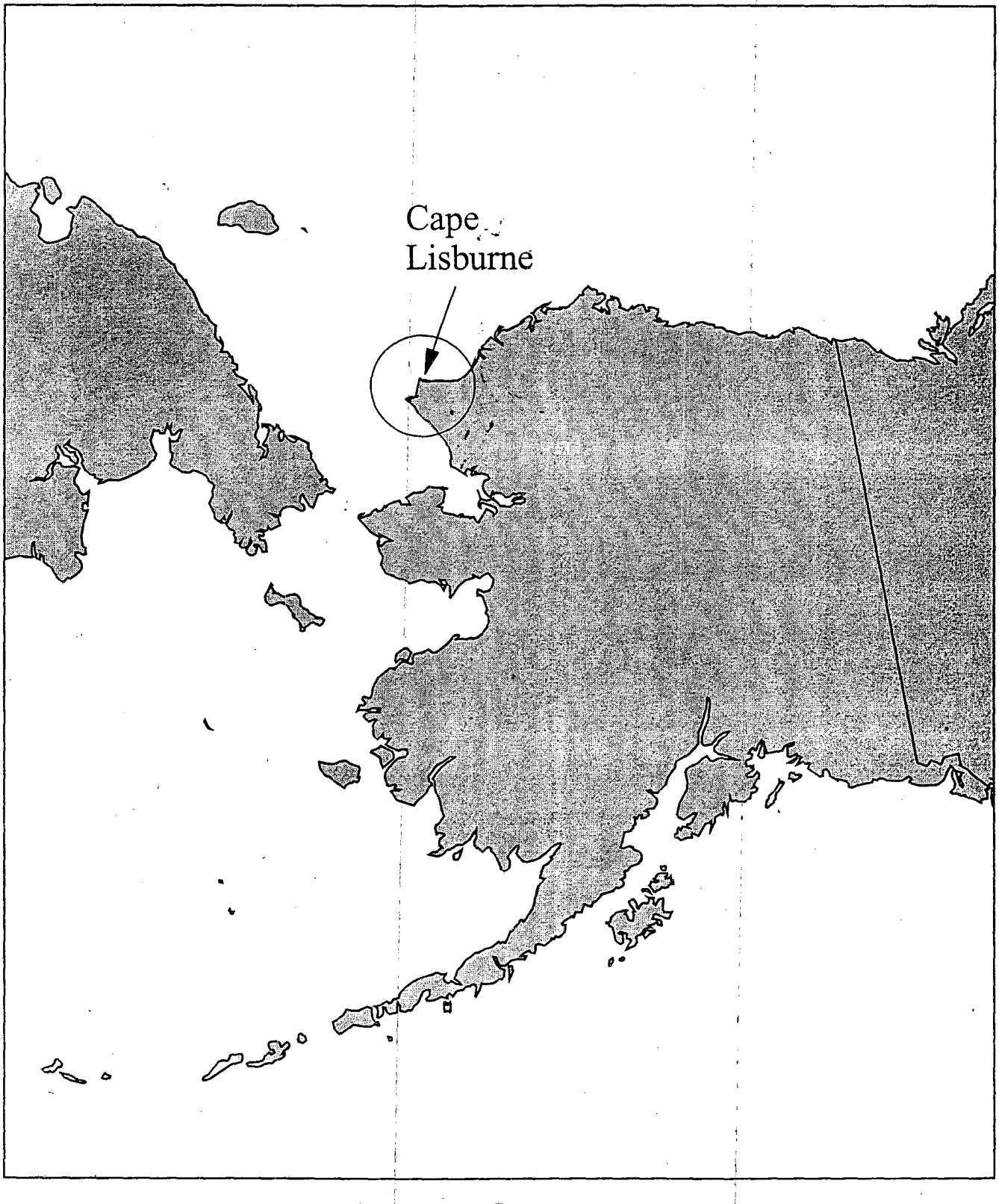
A. Depth-related

(1) Increased pressure due to diving causes discomfort or rupture of new incision, leading to chronic pain or infection
(2) Bulk—PTT introduces mechanical pressures on internal organs, especially at depth.

B. Transmission-related

(1) Transmission causes discomfort or disorientation (neurotransmitter release, heart arrhythmia, effects on magnetite in brain, radio frequency 'burns', other?)
(2) Transmission causes impairment of immune system (effects on bursa, T-cell production, effects on unhealed membranes)
(3) Prey detecting radio signals and avoiding predation

Figure 1. Study site location.



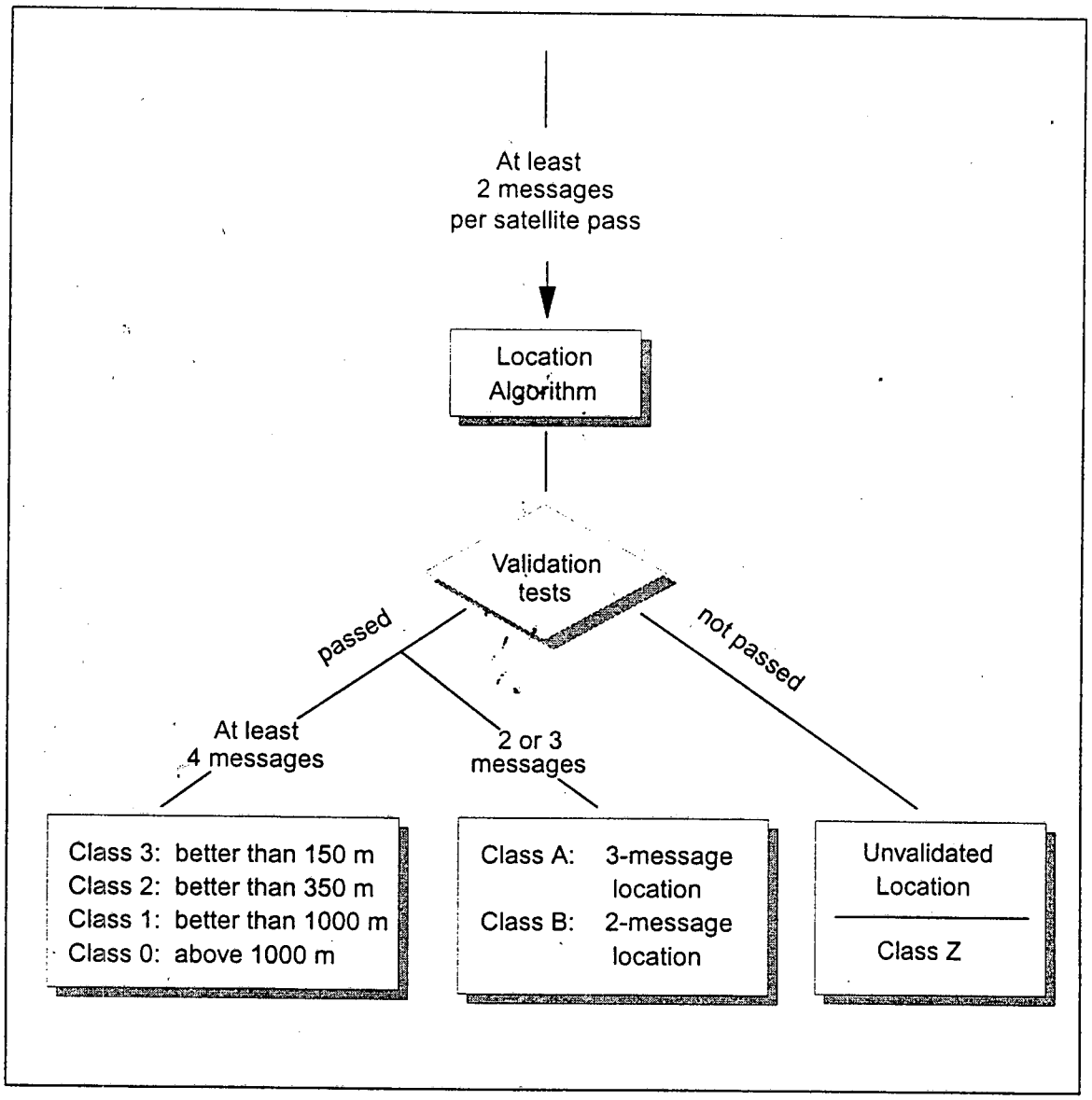


Figure 2. Location quality classes assigned by Argos. (Source: Argos, Inc. Newsletter, October, 1995.)

Figure 3. Distribution of Cape Lisburne murres during the breeding season, 1996.

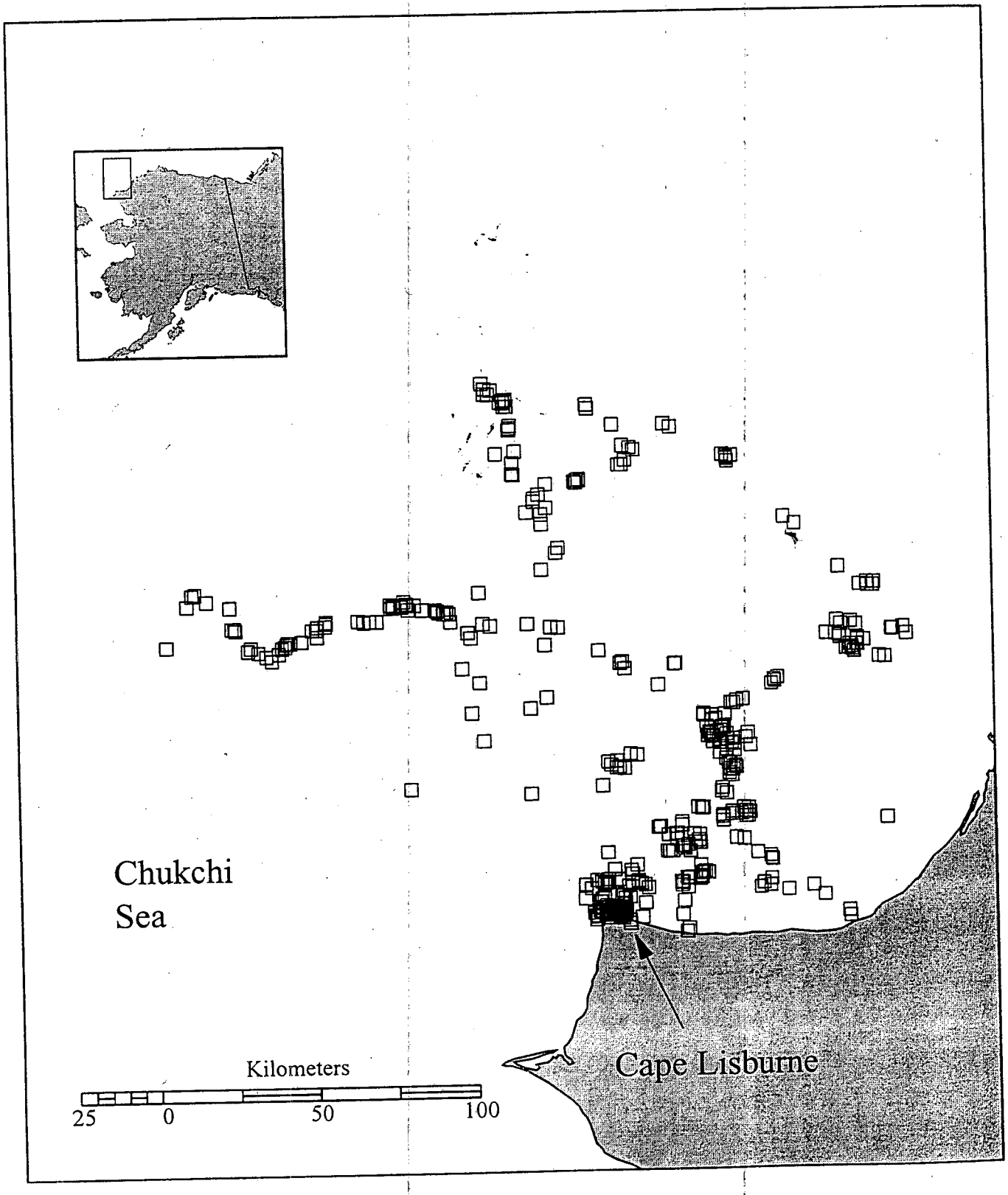


Figure 4. Distribution of Cape Lisburne murres during the breeding season by year. Squares represent 1996 distribution, and circles represent 1995 distribution.

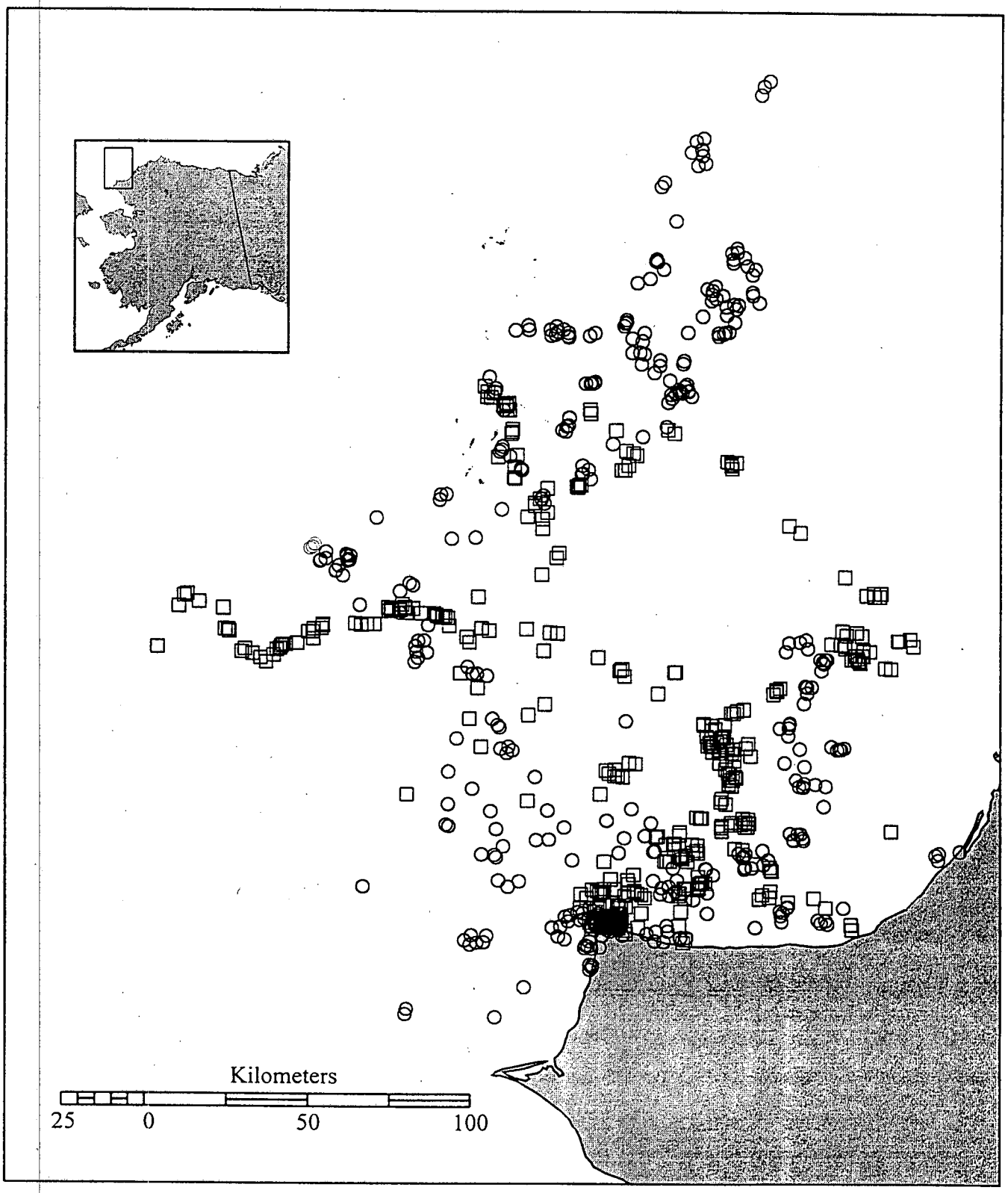


Figure 5. Minimum convex polygons for Cape Lisburne murres during the breeding season. These foraging areas mainly represent murres that had abandoned nesting and were no longer commuting to the colony.

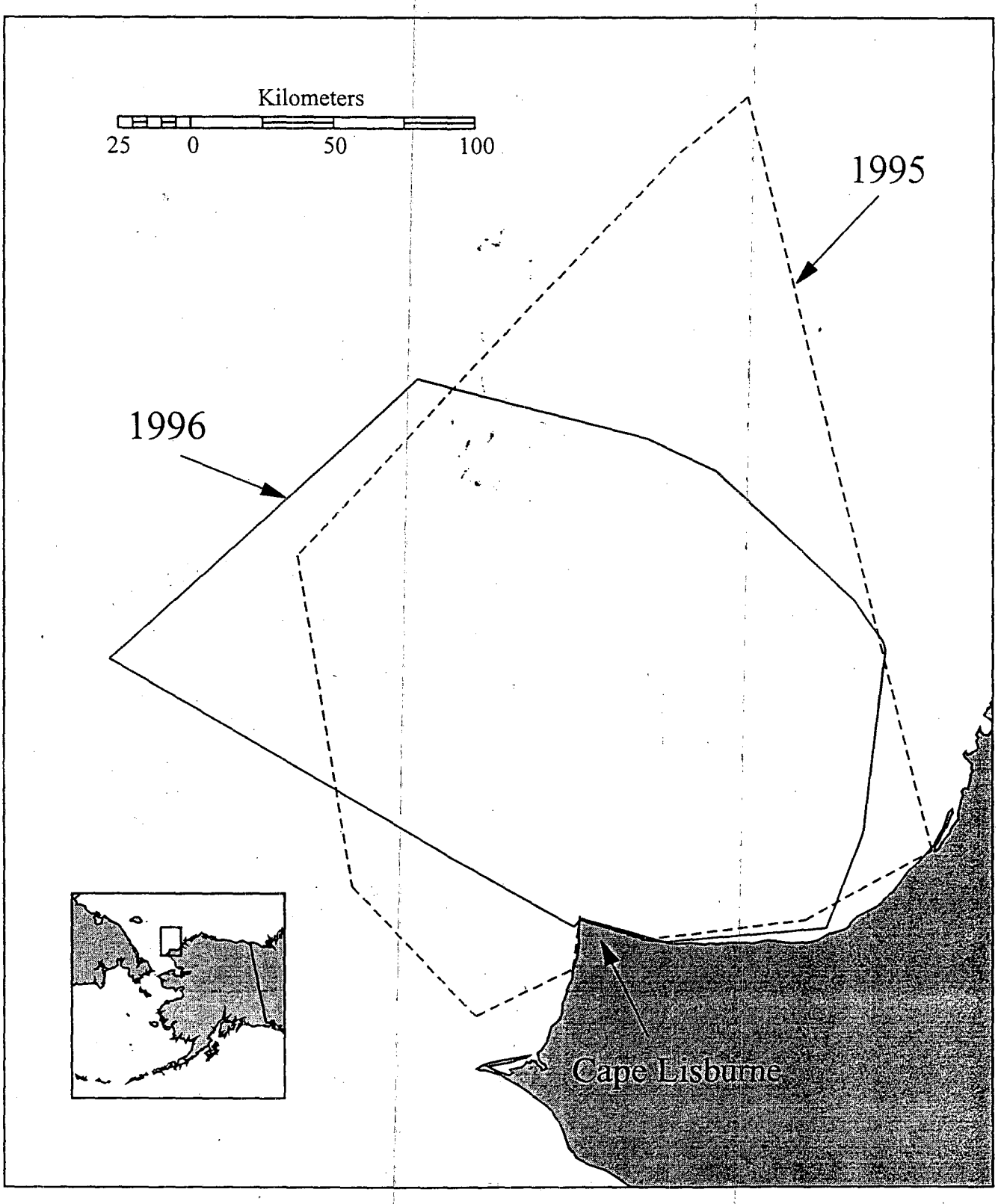


Figure 6. Distribution of Cape Lisburne murres during the breeding season by sex. Squares represent females and circles represent males.

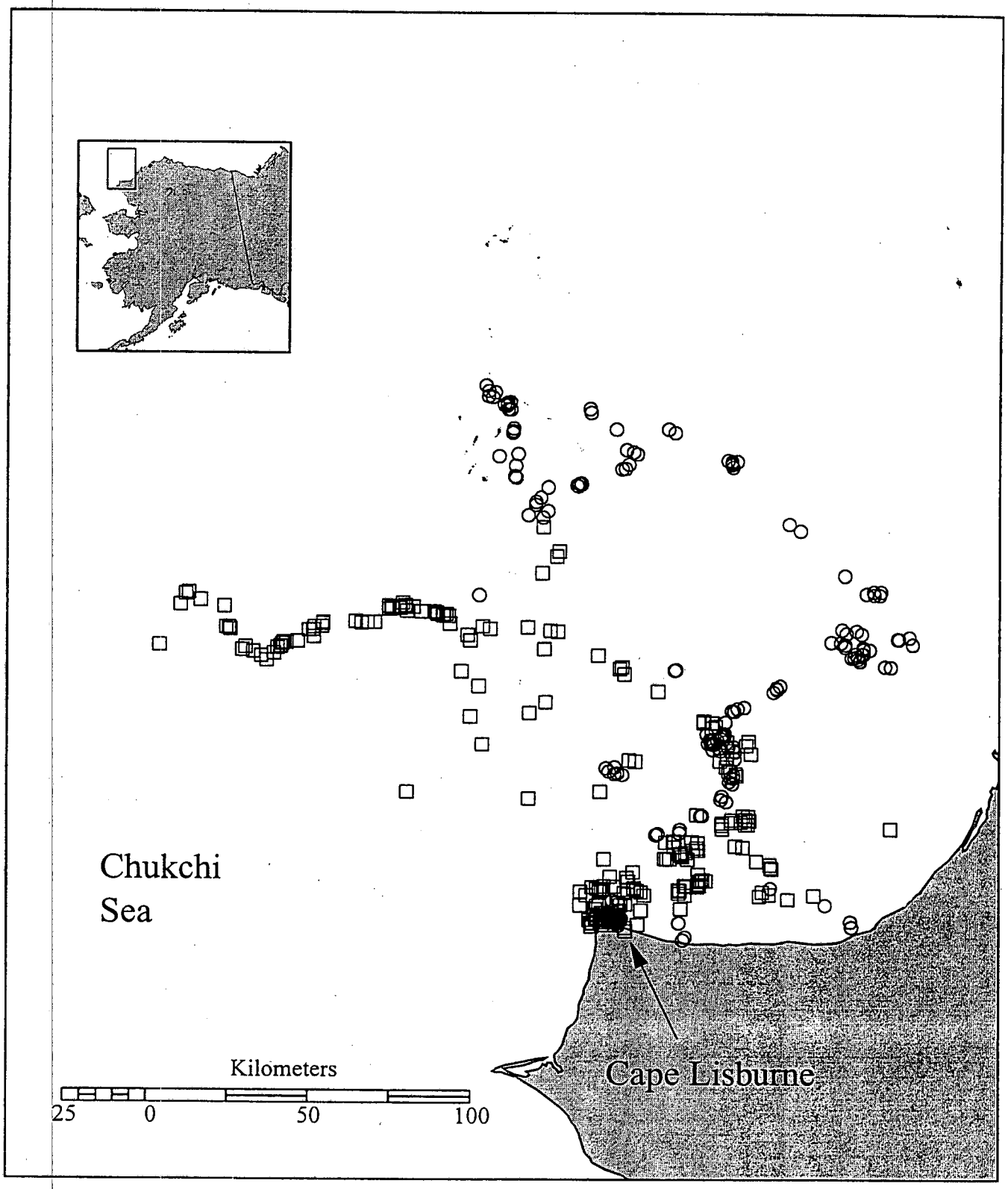


Figure 7. Distribution of Cape Lisburne murres during the breeding season by species. Squares represent common murres and circles represent thick-billed murres.

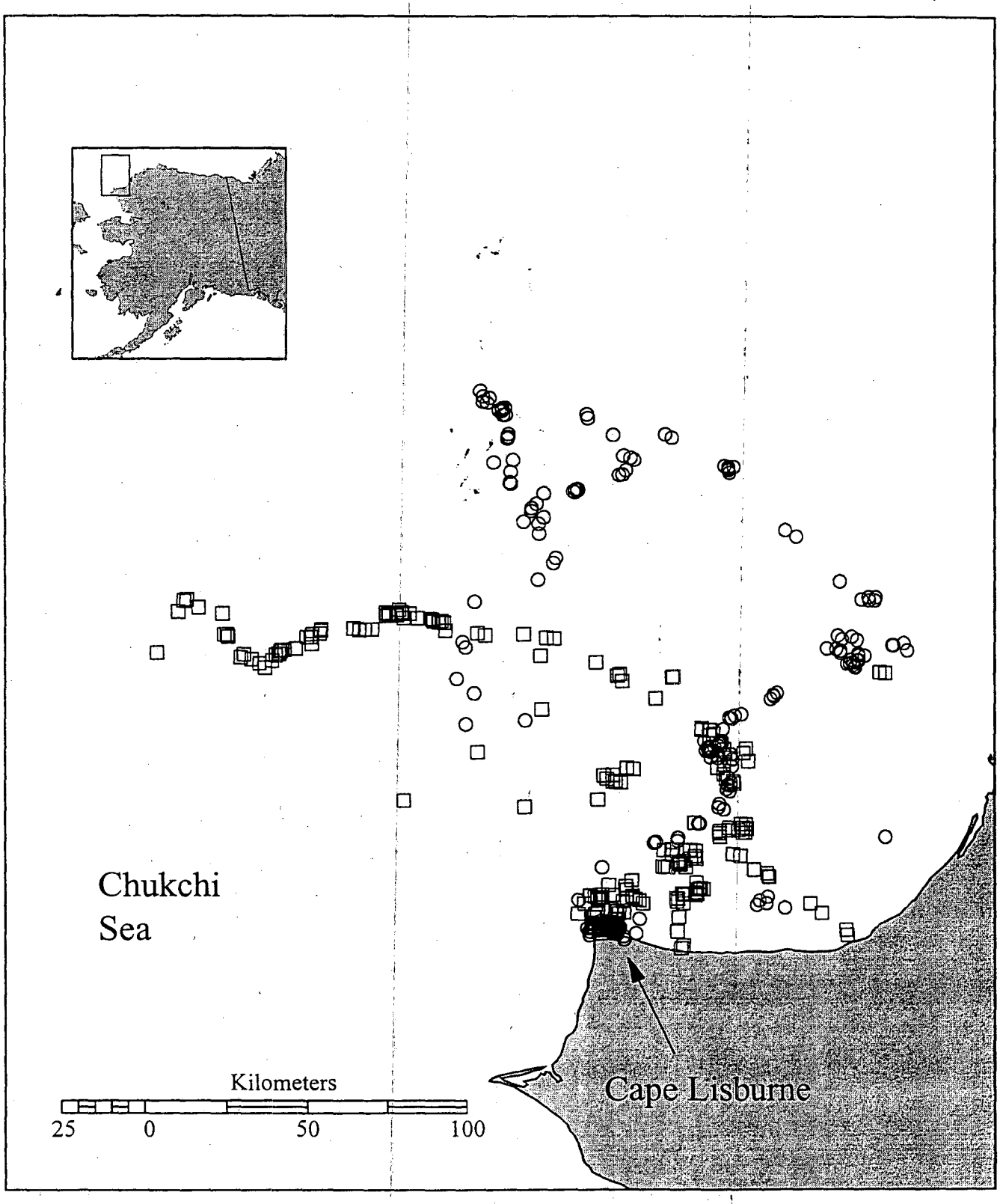


Figure 8. Migration of 3 murres from Cape Lisburne, AK, 1996.

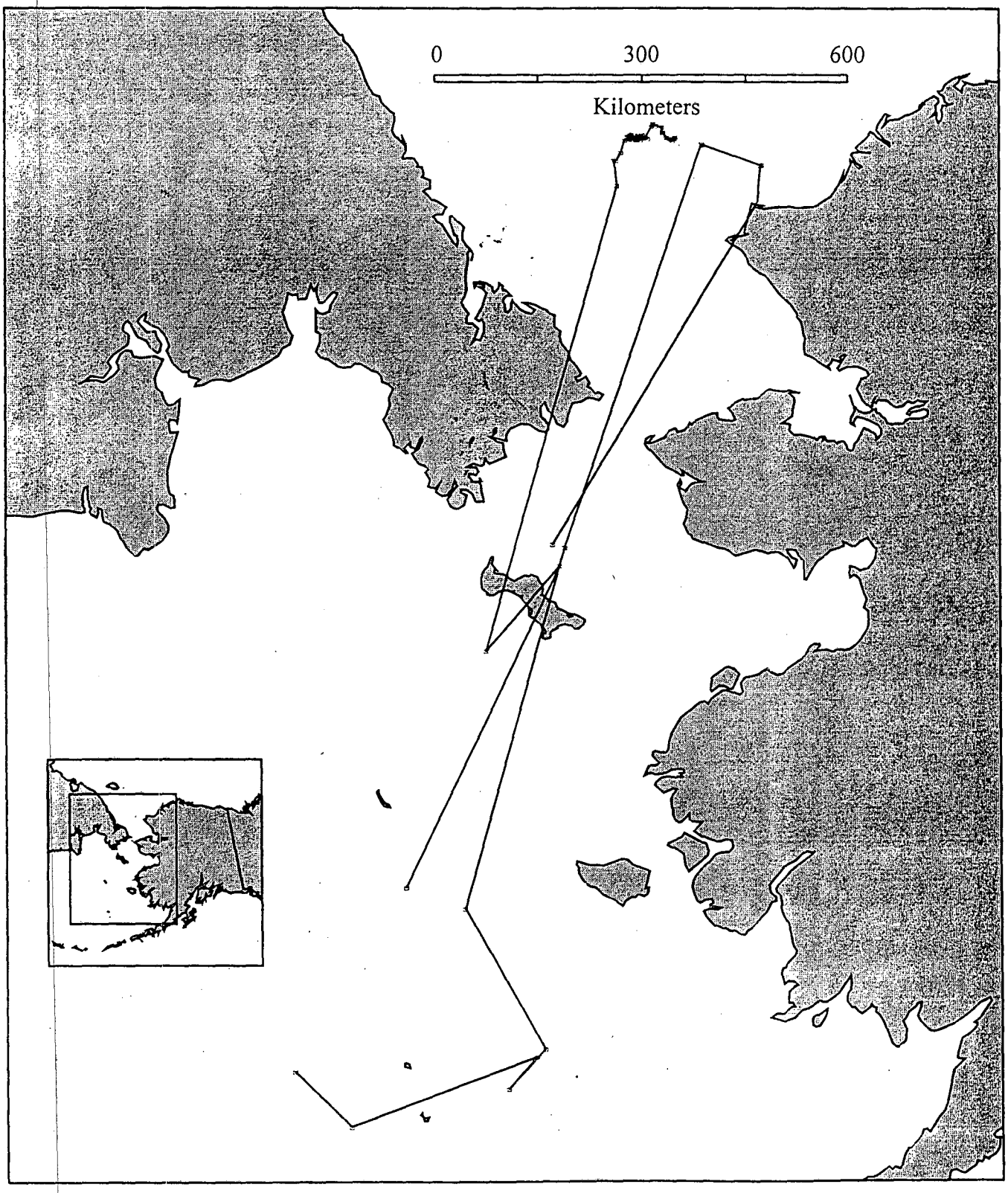
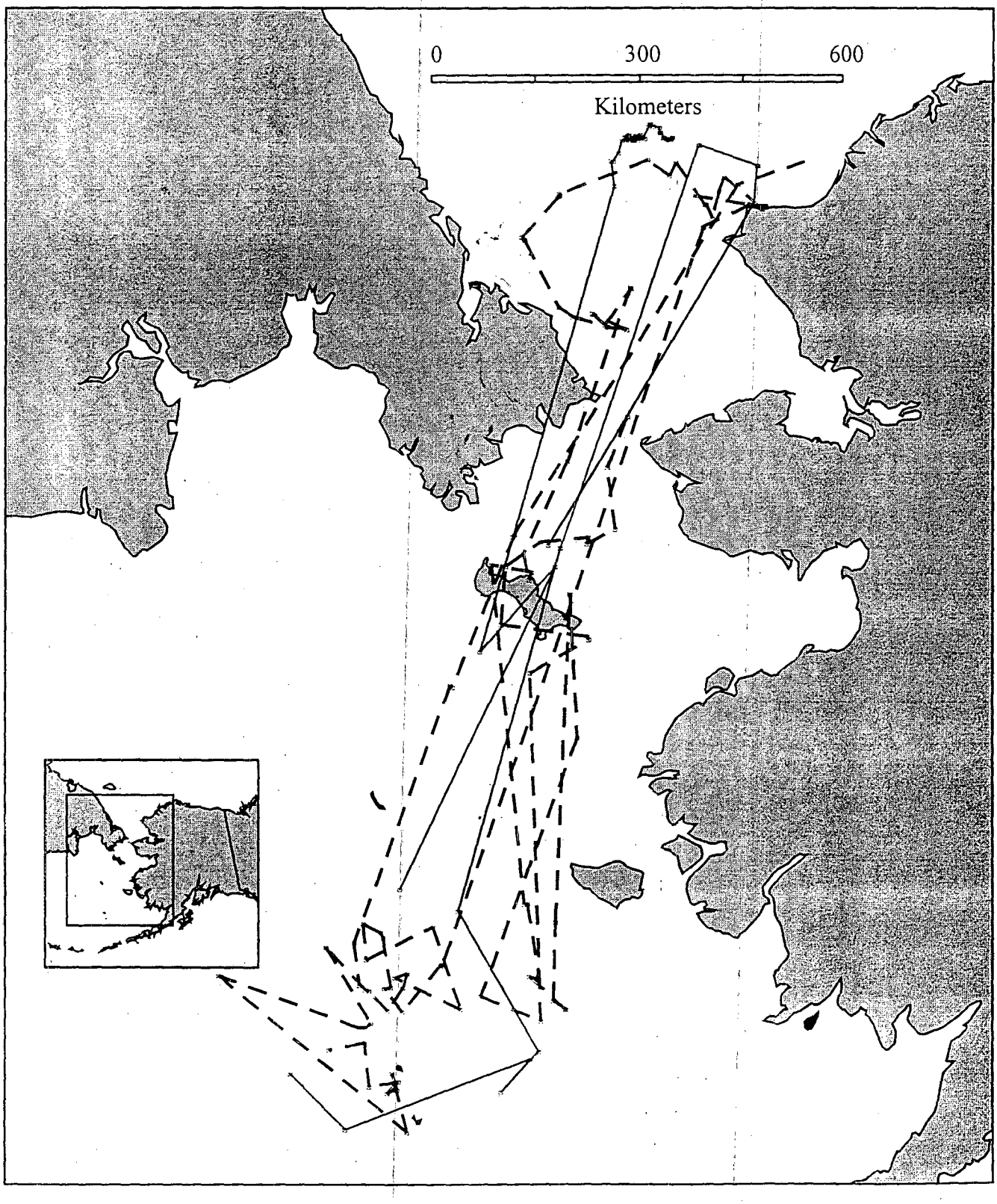


Figure 9. Migration of Cape Lisburne murres by year. Solid lines represent 1996 murres and dashed lines represent 1995 murres.



EFFECT OF IMPLANTED SATELLITE TRANSMITTERS ON THE NESTING BEHAVIOR OF MURRES

ABSTRACT

We implanted 6 Common Murres (*Uria aalge*) and 10 Thick-billed Murres (*Uria lomvia*) with satellite transmitters and compared subsequent presence at the colony, nesting status, and chick provisioning to a control group that underwent a minor surgical procedure. In the 10 days following implantation, we resighted 10 of 11 control birds at the colony and 6 of 16 implanted birds. Of the birds that returned, 7 of 10 control birds retained breeding status, while 0 of 6 implanted birds retained breeding status. We conclude that abdominal implantations alter murre nesting behavior.

Key Words: behavior, Common Murre, implantation, nesting, PTT, satellite telemetry, satellite transmitter, seabird, Thick-billed Murre, Uria aalge, Uria lomvia.

INTRODUCTION

The advent of satellite transmitters small enough for use on seabirds has generated many recent studies of seabird foraging and migration (Jouventin and Weimerskirch 1990, Ancel et al. 1992, Davis and Miller 1992, Weimerskirch et al. 1993, Weimerskirch and Robertson 1994, Falk and Møller 1995, Petersen et al. 1995, Hatch et al. 1996). Satellite telemetry offers a way to track individual animals anywhere in the world without the logistics involved in conventional VHF telemetry. Secure attachment of any device without causing behavioral changes, however, has been a persistent problem for biologists working with diving birds (Woakes and Butler 1975, Perry 1981, Wilson et al. 1986, Wanless et al. 1988 and 1989, Calvo and Furness 1992). Abdominal implantation (Korschgen et al. 1984) is an alternative to various externally mounted packages and has been used successfully in diving birds (Petersen et al. 1995, D. Esler Biological Resources Division-USGS, pers. comm.). Implantation results in no appreciable increase in the bird's surface area, does not compromise feathers, and leaves no chance of the bird losing the transmitter. However, no information is available on the behavioral effects of implantation. Interpretation of any telemetry study assumes that normal behavioral patterns are retained or that alterations in behavior can be adequately addressed. To assess possible changes in behavior, we implanted 16 murres with satellite transmitters and compared returns to the colony, nesting status, and returns with fish between implanted birds and control birds that underwent minor surgery.

STUDY AREA AND METHODS

Cape Lisburne is on the Chukchi Sea about 60 km north of Point Hope on Alaska's northwest coast. This area supports approximately 70,000 common murres (*Uria aalge*) and 130,000 thick-billed murres (*Uria lomvia*) (U.S. Fish and Wildlife Service, 1997) and is the northernmost

Pacific murre colony of its size. Black-legged kittiwakes (*Rissa tridactyla*) also nest there in large numbers. Other seabirds include pelagic cormorants (*Phalacrocorax pelagicus*), black guillemots (*Cepphus grylle*), glaucous gulls (*Larus hyperboreus*), and horned puffins (*Fratercula corniculata*).

Beginning 2 August 1996, we captured nesting murres with a light cable noose attached to a 9-m telescoping fiberglass pole. We took murres from lower ledges at the east end of the colony in areas that were accessible by foot from Cape Lisburne radar station. Capture areas consisted of 3 ledge complexes ≥0.5 km apart. The birds were transported in burlap bags to the station where we banded them with colored tarsus bands. To assign birds to the implant or control group, we chose a bird at random, anaesthetized it, and surgically sexed it using a rigid endoscope inserted through the last two ribs on the left side or through the implantation incision. Our primary goal was to obtain an even sex ratio for both species in the transmittered group. Upon sexing a bird, it was assigned to a group depending on the number of that sex and species already in the transmittered group. Because the first few birds were automatically assigned to the treatment group, control birds averaged longer times in the holding bins than implanted birds.

Experimental birds were sexed and implanted (Korschgen et al. 1984, Hatch et al. 1996), and control birds were sexed and allowed to recover from anesthesia. All surgery was performed by a veterinarian experienced in implantation techniques. Birds were released 1-3 hours after surgery. Processing time from capture to release was from 6.5-13.5 hours. The transmitters we used were 35-gram platform transmitting terminals (PTTs) described by Hatch et al. (1996).

Beginning the day following surgery, we performed spot checks for presence of banded and transmittered birds. Each day from 5 August-14 August 1996, we conducted one 6-hour focal observation of a capture area, alternating areas each day. During the course of the study, we covered all hours of adequate daylight (0600 to 2400 ADT) at each capture area. We recorded arrival and departure times, nesting status, and returns with fish. Observations were done with binoculars and a spotting scope from a point that was out of the normal flight path of the birds. After each observation period, we performed spot checks of the other capture areas. Proportions were analyzed with 2-tailed Fisher's exact tests, and differences between means were analyzed with 2-tailed Student's t-tests.

A bird was considered definitely nesting if we observed it taking over or leaving a nest, or bringing fish to a nestling. A bird was considered probably nesting if it was attending a nesting bird (e.g., standing very close, placing its bill where the chick would be) but was not actually seen taking over brooding.

RESULTS

We captured 31 murres, 16 of which we implanted (Table 7). Thirteen birds were incubating, 9 were attending chicks, and 9 were nesting but we could not determine nesting stage. Four of the birds exhibited severe stress—3 died and 1 was released 10 minutes after capture—and were

excluded from the study. Three of these stressed birds, and possibly the fourth, had newly hatched (≤ 3 day-old) chicks.

Neither weight ($t = 0.70$, $P = 0.49$, df = 25) nor wing length ($t = 1.24$, $P = 0.22$, df = 25) were significantly different between the treatment and control group. Handling time was longer for the control birds (mean ± SD = 11.0 ± 2.3 hours) than for the implanted birds (8.9 ± 1.9 hours) ($t = -2.52$, $P = 0.02$, df = 25). We resighted significantly more ($P = 0.015$) control birds (10 of 11) than transmittered birds (6 of 16). Of the resighted birds, we tended to see individuals from the control group more often (3.1 ± 1.8 sightings/bird) than individuals from the implanted group (2.0 ± 1.5 sightings/bird), but the difference was not significant ($t = -1.25$, $P = 0.23$, df = 14).

Of the 10 control birds resighted, 4 definitely remained nesting and 3 additional birds probably remained nesting. Two control birds either lost or abandoned their nests, 1 control bird was not resighted either because it brooded continuously or it did not return to the colony, and nesting status could not be determined for another. Of the 6 transmittered birds resighted, none remained nesting; significantly fewer ($P = 0.011$) than birds in the control group when we included birds probably nesting. The proportion was not significantly different ($P = 0.23$) when we included only birds definitely nesting. We observed only 4 instances of birds returning with fish. All of these were in the control group.

Subsequent telemetry signals (unpubl. data) indicated that 3 of the 16 implanted birds died, 7 lived, and 6 had transmitters that failed prematurely. The fates of these latter 6 are unknown. Of the 7 that remained in contact, 4 were resighted during observations. Of the 9 that died or disappeared, 2 were resighted during observations. These proportions were not significantly different ($P = 0.30$) from each other.

DISCUSSION

The largest difference between groups was the likelihood that birds would return to their former ledges--91% of control birds were resighted, compared to 38% of the transmittered birds. We may have underestimated the proportion of control birds returning, however, because tarsus bands were difficult to observe when the bird was brooding. Two of the control birds may have remained on the nest during entire observation periods and therefore were not recorded as present. We are reasonably certain that we did not miss any transmittered birds in this way, as antennae were clearly visible. Elimination of this potential bias could only increase the differences we observed, and therefore, not affect our conclusions.

Colony abandonment by so many of the implanted birds was unexpected. Although the proportion of resighted birds within groups was not significantly different between those that subsequently died or disappeared, power of our test was low ($\beta = 0.29$). Given that at least 3 individuals died within the observation period, the general health of the bird after surgery must be considered the most likely explanation for both colony abandonment and disruption of breeding by those birds that did return.

Of the murres that did return to the colony, fewer implanted birds than control birds remained nesting. Considering that control birds were removed from the nest for an even longer period of time than implanted birds, we cannot attribute nesting failure to time off the nest. Changes were likely due to the implantation procedure or to the transmitter itself. Hatch et al. (1996) stated that 25% of murres from Cape Lisburne and Cape Thompson probably remained nesting after implantation in 1995. Productivity in 1995 was higher than in 1996 (D.G. Roseneau, U.S. Fish and Wildlife Service, pers. comm.), however, and 1996 may have been a more stressful year.

Murres are probably the deepest diving alcid (Piatt and Nettleship 1985), and alcids in general have higher wing loads than other flying seabirds (Pennycuick 1987). Either of these factors (i.e., pressure on a new incision due to diving, or increased wing load) may have affected bird behavior. Smaller transmitters would help in both regards.

Other seabirds may be better adapted than murres, both physically and behaviorally, for implantation. Spectacled Eiders, *Somateria fischeri*, (Petersen et al. 1995), are larger (≥ 1000 g verses 896 ± 69 g) and remain inland several weeks after implantation, thus giving birds time to recuperate before the stresses of diving in a marine environment. Harlequin Ducks (*Histrionicus histrionicus*) have been successfully implanted with VHF transmitters (D. Esler, Biological Resources Division-USGS, pers. comm.), but the devices are smaller and the depths these birds reach are probably much shallower. The effects of abdominal implantation may vary among species and may also depend on transmitter design. Therefore we suggest this method be assessed species-by-species. In the case of murres, we conclude that nesting behavior of implanted murres differs significantly from nesting behavior of non-implanted murres. Data received after abdominal implantation must be interpreted with this in mind.

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LITERATURE CITED

Ancel A., G.L. Kooyman, P.J. Ponganis, J.-P. Gendner, J. Lognon, X. Mestre, N. Huin, P.H. Thorson, P. Robisson, and Y. Le Maho. 1992. Emperor Penguins foraging behaviour as a resource detector in winter and summer. Nature 360:336-339.

Calvo, B., and R.W. Furness. 1992. A review of the use and the effects of marks and devices on birds. Ringing Migr. 13:129-151.

Davis, L.S. and G.D. Miller. 1992. Satellite tracking of Adélie Penguins. Polar Biol. 12:503-506.

Falk, K. and S. Møller. 1995. Satellite tracking of high-arctic Northern Fulmars. Polar Biol. 15:495-502.

Hatch S.A., P.M. Meyers, D.M. Mulcahy, and D.C. Douglas. 1996. Seasonal movements and pelagic habitat use of murres and puffins determined by satellite telemetry. *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Project 95021), National Biological Service, Anchorage, Alaska.

Jouventin, P. and H. Weimerskirch. 1990. Satellite tracking of Wandering Albatrosses. Nature 343:746-748.

Korschgen, C. E., S. J. Maxson, and V. B. Kuechle. 1984. Evaluation of implanted radio transmitters in ducks. J. Wildl. Manage. 48:982-987.

Perry, M.C. 1981. Abnormal behavior of Canvasbacks equipped with radio transmitters. J. Wildl. Manage. 45:786-789.

Pennycuick, C.J. 1987. Flight of seabirds, p. 43-62. *In* J.P. Croxall (ed.), Seabirds: feeding ecology and role in marine ecosystems. Cambridge Univ. Press.

Petersen, M.R., D.C. Douglas, and D.M. Mulcahy. 1995. Use of implanted satellite transmitters to locate Spectacled Eiders at-sea. Condor 97:276-278.

Piatt, J.F. and D.N. Nettleship. 1985. Diving depths of four alcids. Auk 102:293-297.

U.S. Fish and Wildlife Service. 1997. Alaska seabird colony catalog—computer database and colony status record archives. U.S. Fish and Wildlife Service, Migratory Bird Management, Anchorage AK.

Wanless, S., M.P. Harris, and J.A. Morris. 1988. The effect of radio transmitters on the behavior of Common Murres and razorbills during chick rearing. Condor 90:816-823.

Wanless, S., M.P. Harris, and J.A. Morris. 1989. Behavior of alcids with tail-mounted radio transmitters. Colonial Waterbirds 12:158-163.

Weimerskirch H., and G. Robertson. 1994. Satellite tracking of light-mantled Sooty Albatrosses. Polar Biol. 14:123-126.

Weimerskirch H., M. Salamolard, F. Sarrazin, and P. Jouventin. 1993. Foraging strategy of Wandering Albatrosses through the breeding season: a study using satellite telemetry. Auk 110:325-342

Wilson, R.P., W.S. Grant, and D.C. Duffy. 1986. Recording devices on free-ranging marine animals: does measurement affect foraging performance? Ecology 67:1091-1093.

Woakes, A.J., and P.J. Butler. 1975. An implantable transmitter for monitoring heart rate and respiratory frequency in diving ducks. Biotelem. 2:153-160.

Table 7. Nesting stage at time of capture, treatment, and post-operative behavior of Common and Thick-billed Murres captured at Cape Lisburne, August 1996.

Bird	Treatment	Species[a]	Sex	Nesting Stage	Processing time (hrs)	Total Resightings	Remained Nesting?
1	Implant	COMU	F	?[b]	8	0	No
2	Implant	COMU	M	?[b]	7	2	No
3	Implant	TBMU	F	Egg	7.5	0	No
4	Implant	TBMU	M	Egg	8	0	No
5	Implant	TBMU	M	Egg	8	0	No
6	Implant	TBMU	M	Chick	7.5	0	No
7	Implant	COMU	F	?[b]	10.5	5	No
8	Implant	TBMU	M	Egg	10.5	0	No
9	Implant	COMU	F	Egg	11	1	No
10	Implant	COMU	M	Egg	7	1	No
11	Implant	TBMU	F	Egg	10.5	0	No
12	Implant	COMU	M	Egg	6.5	1	No
13	Implant	TBMU	F	Chick	7	0	No
14	Implant	TBMU	M	?[b]	11.5	0	No
15	Implant	TBMU	M	Egg	11.5	2	No
16	Implant	TBMU	F	Egg	11	0	No
17	Control	COMU	M	Egg	8	6	?[b]
18	Control	COMU	M	?[b]	8	5	Yes
19	Control	COMU	M	?[b]	7.5	5	Yes
20	Control	TBMU	?[b]	?[b]	10	4	No
21	Control	TBMU	M	Chick	11	2	No
22	Control	TBMU	F	Egg	13.5	1	Yes
23	Control	TBMU	M	Egg	11.5	1	Yes
24	Control	TBMU	M	Chick	13	0	No
25	Control	TBMU	F	Chick	12.5	2	Yes
26	Control	TBMU	F	?[b]	12	3	Yes
27	Control	TBMU	F	Chick	13.5	2	Yes
28	—	TBMU	M	?[b]	—	—	Died in surgery
29	—	TBMU	—	Chick	—	—	Released
30	—	TBMU	—	Chick	—	—	Died in transit
31	—	TBMU	—	Chick	—	—	Died in transit

[a]COMU=Common Murre; TBMU=Thick-billed Murre
[b]?=Unknown

DAILY AND SEASONAL TEMPERATURE VARIATION IN FREE-RANGING MURRES

ABSTRACT

We implanted 20 common and thick-billed murres with satellite transmitters containing temperature sensors and looked at daily and seasonal changes in body temperature. During the breeding season, no predictable circadian pattern occurred. In the winter, however, birds showed a lowered body temperature in the early morning hours and an increased body temperature in mid-afternoon. Seasonally, body temperature was higher during the breeding season through migration and lower during the winter months.

Key Words: Alaska, body temperature, Cape Lisburne, circadian rhythm, common murre, seabird, seasonal variation, thick-billed murre, *Uria aalge*, *Uria lomvia*

INTRODUCTION

Seasonal and circadian rhythms occur in many birds and mammals. Body temperatures in particular have been shown to vary as much as 3.0-4.5 C daily in birds (Binkley et al. 1971, Heldmaeir 1991), and 0.5-1 C in mammals (Aschoff 1982). Body temperatures for many seabirds have been documented (McNab 1966, Warham 1971, Iversen and Krog 1972, Johnson and West 1975, Barrett 1984, Platania et al. 1986), and daily cycles have been described (Irving 1955, Howell and Bartholomew 1961, Bartholomew 1966, Cooper 1979). But data on murre temperature cycles are few, and no studies have tracked seasonal temperature changes of individuals in the wild. As body temperature can be closely correlated to metabolism (McNab 1966, Gavrilov 1985) knowledge of how temperature changes from season to season may be important in understanding murre energetics and climatic stress. In 1995, we implanted 20 murres with satellite transmitters that contained temperature sensors. We were able to sample murre body temperatures over the course of months and record daily cycles and seasonal changes.

STUDY AREA AND METHODS

Cape Lisburne and Cape Thompson are north and south, respectively of Point Hope on Alaska's northwest coast. Cape Lisburne supports approximately 70,000 common murres (*Uria aalge*) and approximately 130,000 thick-billed murres (*Uria lomvia*) (U.S. Fish and Wildlife Service 1997) and is the northernmost Pacific murre colony. Cape Thompson supports approximately 390,000 murres. Black-legged kittiwakes (*Rissa tridactyla*) are also present in high numbers at both sites. Other seabirds include pelagic cormorants (*Phalacrocorax pelagicus*), black guillemots (*Cepphus grylle*), glaucous gulls (*Larus hyperboreus*), and horned puffins (*Fratercula corniculata*).

From 2-6 August 1995, we captured nesting murres with a light cable noose attached to a 9-m telescoping fiberglass pole. We took murres from lower ledges accessible from the ground or a ladder. The birds were transported in burlap bags to a base camp where they were banded, anaesthetized, surgically sexed, and implanted with transmitters (Korschgen et al. 1984, Hatch et al. 1996). Birds were released 2-6 hours after surgery. The transmitters we used were 35-gram platform transmitting terminals—PTTs (see Hatch et al. 1996). Each transmitter varied slightly in its absolute temperature reading. To calibrate each transmitter, we recorded ambient temperature before implantation and allowed the PTT to transmit this information to a satellite. Calibration information was not recorded by the satellite, however, so reported temperature values may not be absolute. However, individual temperature sensors were accurate to within 0.33 C, and we were able to look at relative temperature changes over time in individual birds.

Eight of the transmitters were programmed to transmit for 6 hours and rest for 12 hours (short cycle). This pattern sampled a different 6-hour segment of the day for each cycle. Twelve of the transmitters were programmed to transmit for 6 hours and rest for 66 hours (long cycle). This pattern should sample the same time period everyday. However, there was significant drift in the internal clock that resulted in coverage throughout the 24-hour clock over the course of weeks. The short-cycle transmitters switched to long-cycle after 30 days of operation.

For seasonal analysis, we averaged daily temperatures for each individual and plotted daily means over time. For daily analysis, we divided the 24-hour clock into 4-hour segments and averaged temperatures for each time segment. Southwick (1980) found that in White Crowned Sparrows (*Zonotrichia leucophrys gambelii*), daily body temperatures varied more in winter than summer. Therefore, we compared data before and after the autumnal equinox (20 September). Because daily sampling times varied among individuals, we compared means between seasons by averaging mean temperatures of the 4-hour time periods and comparing overall seasonal means with a paired t-test.

RESULTS

In general, average daily body temperature increased after implantation, remained high until late September, and declined after that (e.g., Fig. 10). Of 9 birds for which we obtained adequate data, 8 showed an autumn decline in average body temperature similar to that seen in figure 10. Of these 8, 7 appeared to have a plateau of higher temperatures from about mid-August to mid-September or early October. This effect occurred regardless of whether the bird remained nesting after implantation and regardless of sex and species (i.e., of these 7 birds, 3 were commuting birds and 4 abandoned the colony; 3 were female and 4 were male, 3 were thick-billed murres and 4 were common murres). Average temperature after 20 September (38.5 C) was 0.6 C lower than average temperature before that time ($P = 0.001$, $t = 2.3$, $df = 8$).

On a daily basis, temperature fluctuation (difference between high and low averages for 4-hour time periods) averaged 0.41 C before 20 Sep. and 0.65 C after 20 Sep. ($P = 0.005$, $t = -3.8$, $df = 8$). Before the autumnal equinox, birds showed no association of high temperature with time of day. Of the 4-hour time periods, neither high temperatures ($P < 0.75$, $\chi^2 = 3.67$, $df = 5$) nor low

temperatures ($P < 0.90$, $\chi^2 = 2.34$, df = 5) were distributed differently than expected at random. However, after the autumnal equinox, the average high temperature was found in the period of 15:00-18:59 AST in 6 of 9 birds ($P < 0.005$, $\chi^2 = 18.33$, df = 5). The average low temperature was found in the period of 3:00-6:59 AST for 7 of 9 birds ($P < 0.001$, $\chi^2 = 25.0$, df = 5). A typical example is illustrated in Figure 11.

DISCUSSION

This study has shown that both seasonal and daily variation exists in the body temperature of free ranging murres. Although this variation is small, it appears to be fairly consistent and predictable among individuals. The increase in body temperature after release may have, in some cases, been related to increased activity (Barret 1984, Boyd and Sladen 1971, Howell and Bartholomew 1962) due to chick provisioning. Hatching occurred just after implantation and chicks began to fledge around 1 September. This corresponds reasonably well with the plateau of higher temperature, given that the males then escort the chicks out to sea and provisioning continues after fledging. The fact that the plateau lasts until mid-September or early October even in birds that abandoned nesting suggests that this increased temperature may be more a seasonal adaptation, possibly cued by photoperiod (Heldmaier 1991), than a function of activity.

The change in body temperature throughout the day was fairly small when compared to smaller birds (Welty 1982), but there was a slight drop during the early morning hours in winter. The most interesting feature of daily temperature profiles was that no definable pattern emerged during the fall, yet a noticeable pattern occurred during the winter. This may occur for several reasons. First, as stated, activity can affect body temperature, and activity patterns may be less defined during the breeding season. During and leading up to this time, little darkness occurs at the latitude of Cape Thompson and Cape Lisburne, and activity is not restricted to certain times of the day. Also, murre activity while chick provisioning can vary according to fish availability (Burger and Piatt 1990) and may be less influenced by time of day than presence of prey. Finally, the effects of photoperiod on thermoregulation (Heldmaier 1991) may play a role in regulating body temperature apart from activity.

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LITERATURE CITED

Aschoff, J. 1982. The circadian rhythm of body temperature as a function of body size, p. 173-188. *In* C.R. Taylor (ed.), A companion to animal physiology. Cambridge University Press.

Barrett, R.T. 1984. Adult body temperatures and the development of endothermy in the Puffin *Fratercula arctica*, Razorbill, *Alca torda*, and Guillemot *Uria aalge*. Fauna Norveg. Ser. C. Cinclus 7:119-123.

Bartholomew, G.A. 1966. The role of behavior in the temperature regulation of the Masked Booby. Condor 68:523-535.

Boyd, J.C. and W.J.L. Sladen. 1971. Telemetry studies of the internal body temperatures of Adelie and Emperor Penguins at Cape Crozier, Ross Island, Antarctica. Auk 88:366-380.

Burger, A.E., and J.F. Piatt. 1990. Flexible time budgets in breeding common murres: buffers against variable prey abundance. Stud. Avian Biol. 14:71-83.

Cooper, J. 1979. Diel body temperature, posture and activity in a hand-reared juvenile Cape Gannet *Sula capensis*. Ibis 121:509-512.

Gavrilov, V.M. 1985. Seasonal and circadian changes of thermoregulation in passerine and non-passerine birds: which is more important? Proc. Int. Ornithol. Congr. 18:1254-1277.

Hatch S.A., P.M. Meyers, D.M. Mulcahy, and D.C. Douglas. 1996. Seasonal movements and pelagic habitat use of murres and puffins determined by satellite telemetry.

Heldmaier, G. 1991. Pineal involvement in avian thermoregulation. In B.D. Bell, R.O. Cossee, J.E.C. Flux, B.D. Heather, R.A. Hitchmough, C.J.R. Robertson, and M.J. Williams (eds.) Acta Congressus Internationalis Ornithologici. 4:2042-2051.

Howell, T.R. and G.A. Bartholomew. 1961. Temperature regulation in Laysan and Black-footed Albatrosses. Condor 63:185-197.

Howell, T.R. and G.A. Bartholomew. 1962. Temperature regulation in the Red-tailed Tropic Bird and the Red-footed Booby. Condor 64:6-18.

Irving, L. 1955. Nocturnal decline in the temperature of birds in cold weather. Condor 57:362-365.

Iversen, J.A. and J. Krog. 1972. Body temperatures in active and resting charadriiforme birds (murres, puffins and auklets) at different ambient temperatures. Norweg. J. Zool. 20:145-146.

Johnson, S.R. and G.C. West. Growth and development of heat regulation in nestlings, and metabolism of adult Common and Thick-billed Murres. Ornis. Scand. 6:109-115.

Korschgen, C.E., S.J. Maxson, and V.B. Kuechle. 1984. Evaluation of implanted radio transmitters in ducks. J. Wildl. Manage. 48:982-987.

McNab, B.K. 1966. An analysis of the body temperatures of birds. Condor 68:47-55.

Southwick, E.E. 1980. Seasonal thermoregulatory adjustments in White-crowned Sparrows. Auk 97:76-85.

Platania, S.P., G.S. Grant, and D.S. Lee. 1986. Core temperatures of non-nesting western Atlantic seabirds. Brimleyana 12:13-18.

U.S. Fish and Wildlife Service. 1997. Alaska seabird colony catalog—computer database and colony status record archives. U.S. Fish and Wildlife Service, Migratory Bird Management, Anchorage AK.

Warham, J. 1971. Body temperatures of petrels. Condor 73:214-219.

Welty, J.C. 1982. The Life of Birds. Third Edition. CBS College Publishing. Philadelphia.

Figure 10. Body temperature of a female common murre from Cape Thompson, AK, 1995.

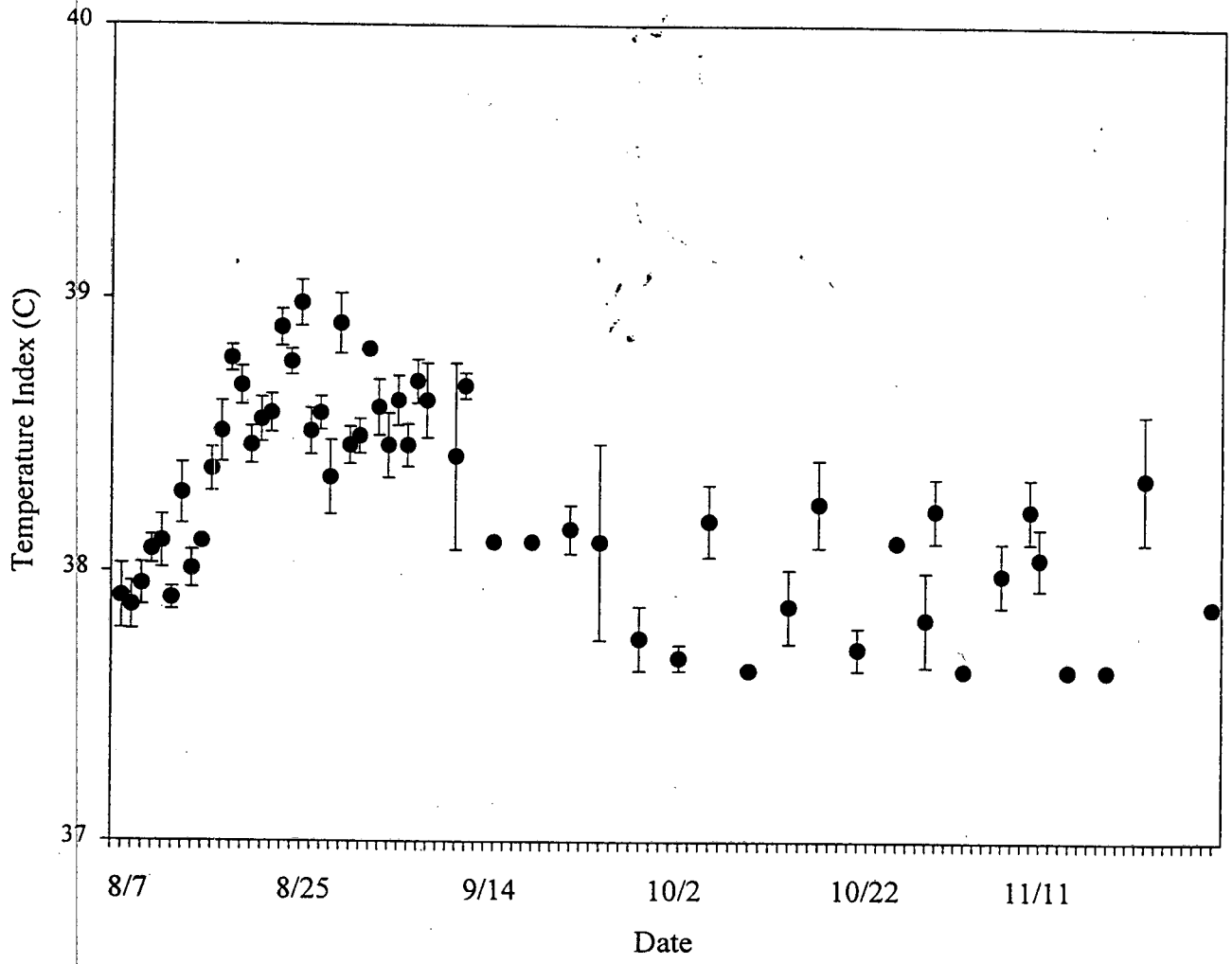
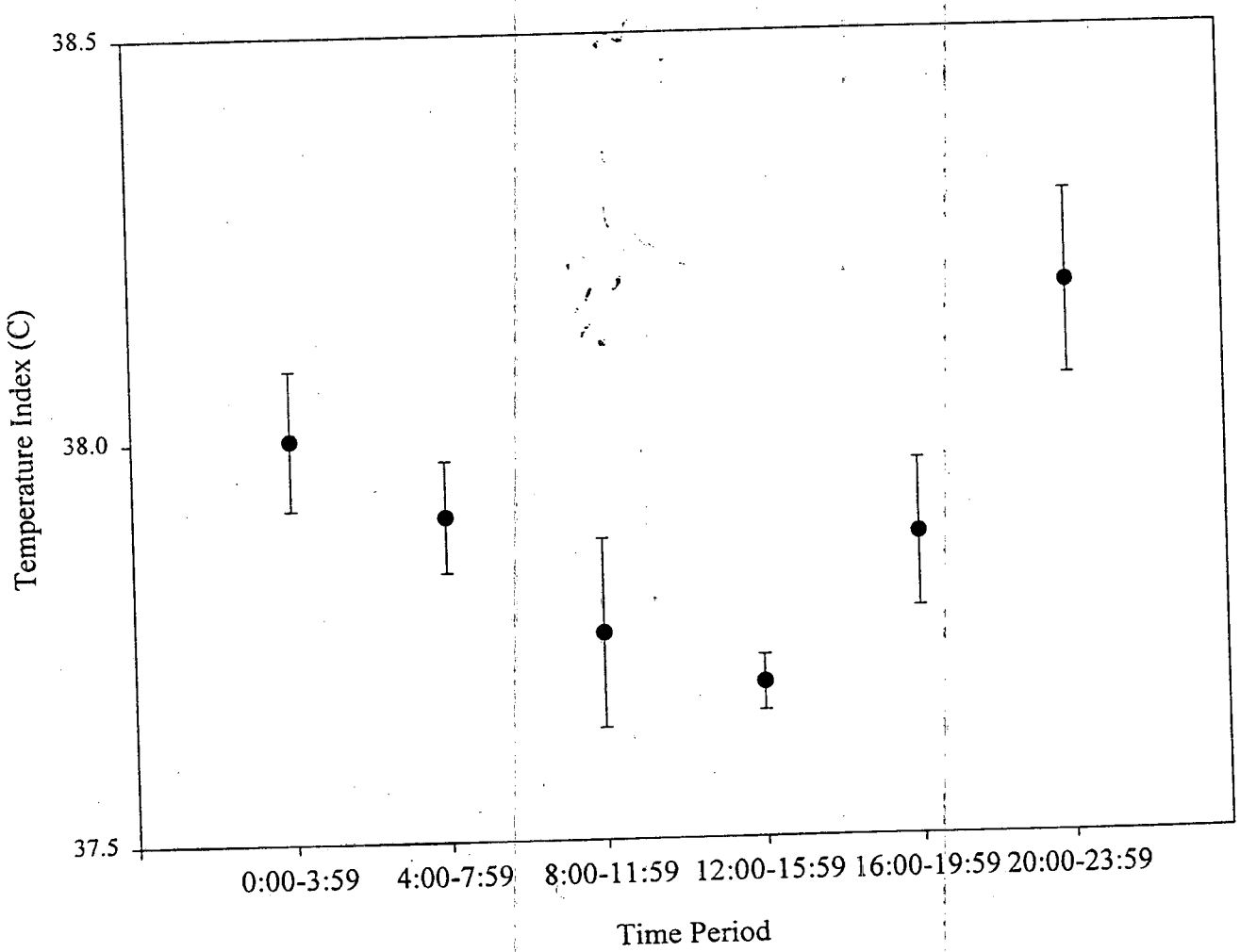


Figure 11. Daily temperature cycle in winter of a female common murre from Cape Lisburne, AK, 1995.



APPENDIX 1

Track lines showing breeding-season and postbreeding-season movements of each individual included in the study, 3 Aug - 31 Dec 1996

Figure A.1. Track lines of female common murre 5851 from Cape Lisburne, AK, 1996. Short-cycle transmitter. In contact for 126 days.

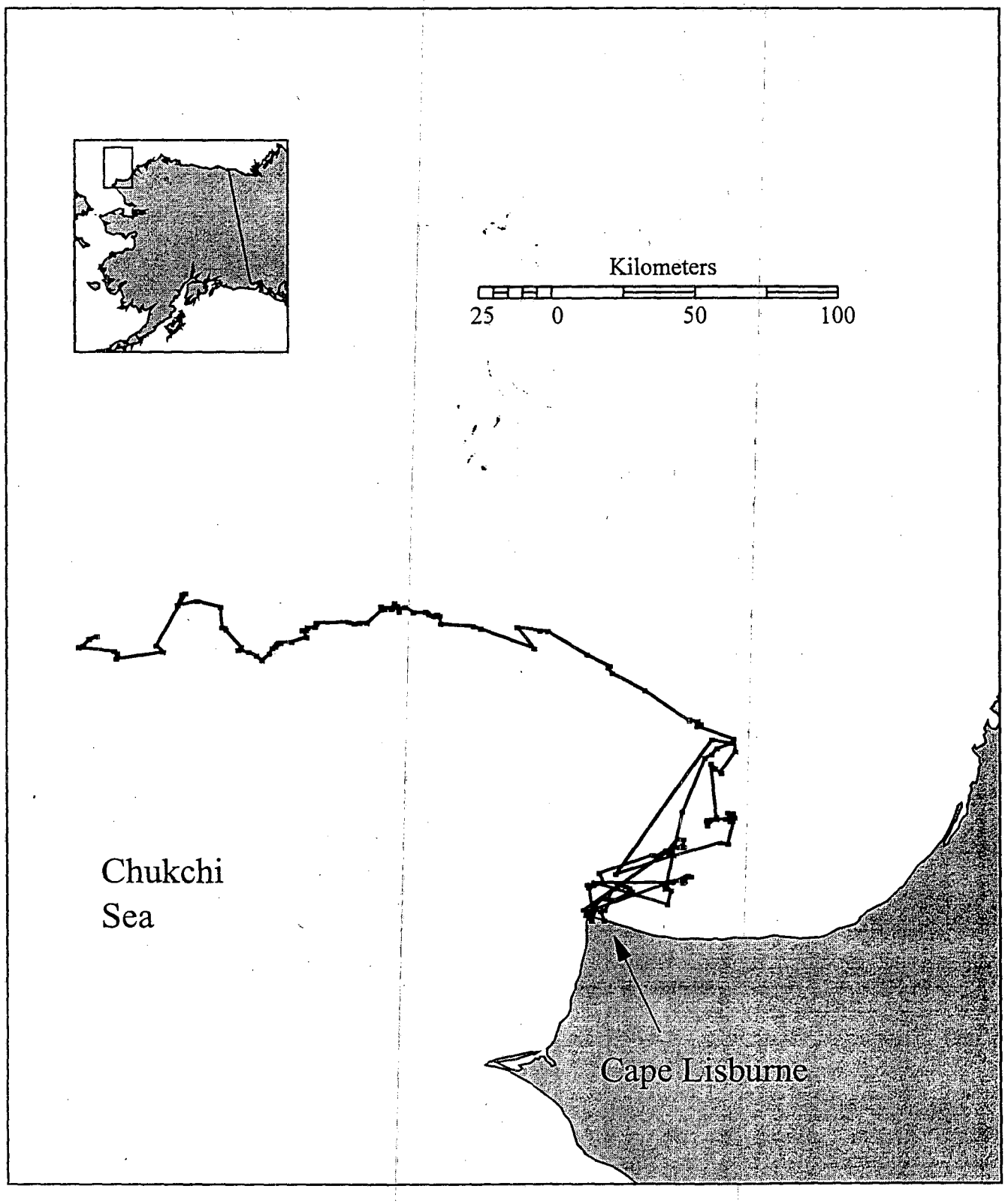


Figure A.2. Post-breeding-season movements of female common murre 5851.

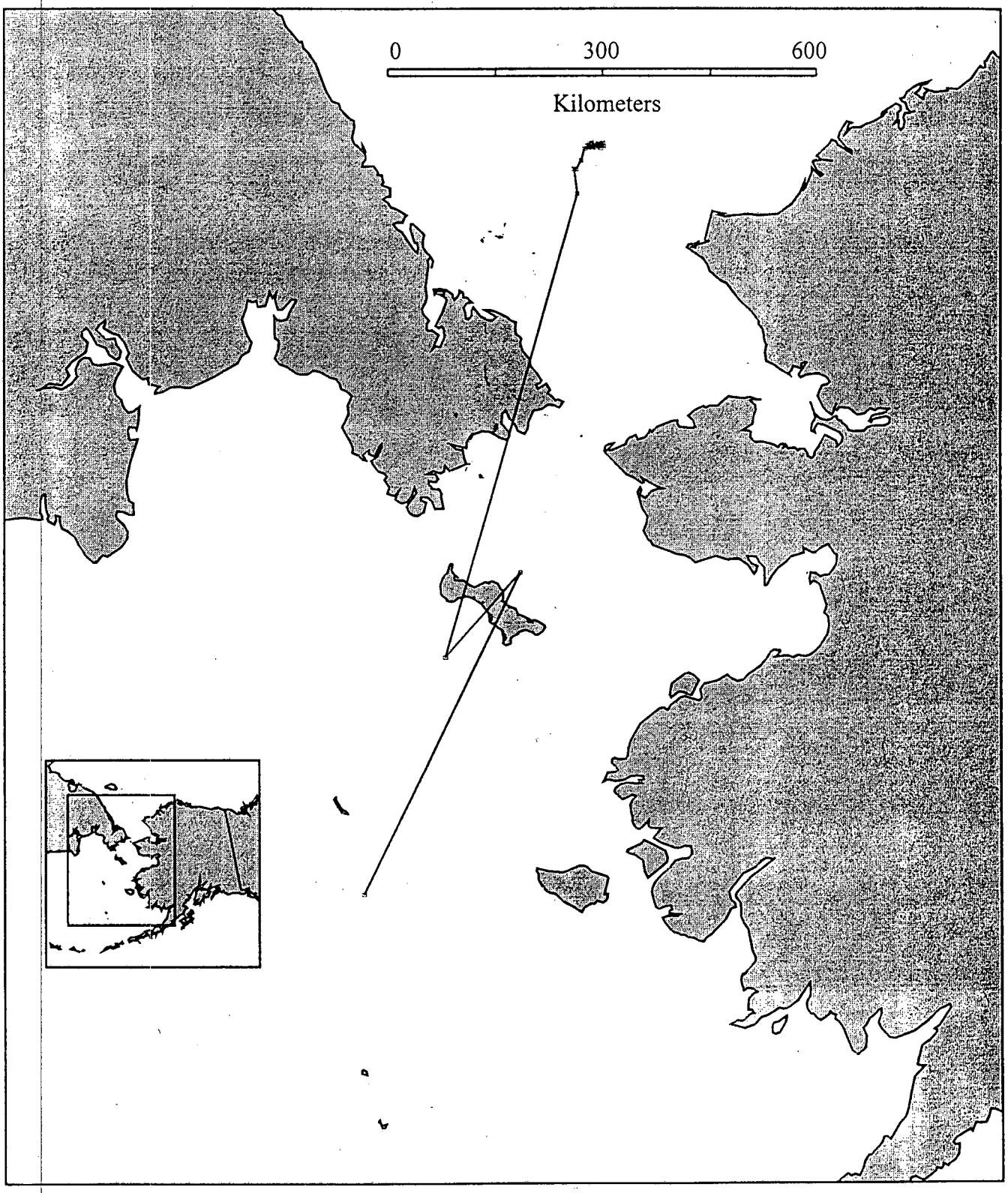


Figure A.3. Track lines of male common murre 5852 from Cape Lisburne, AK, 1996. Short-cycle transmitter. In contact 5 days.

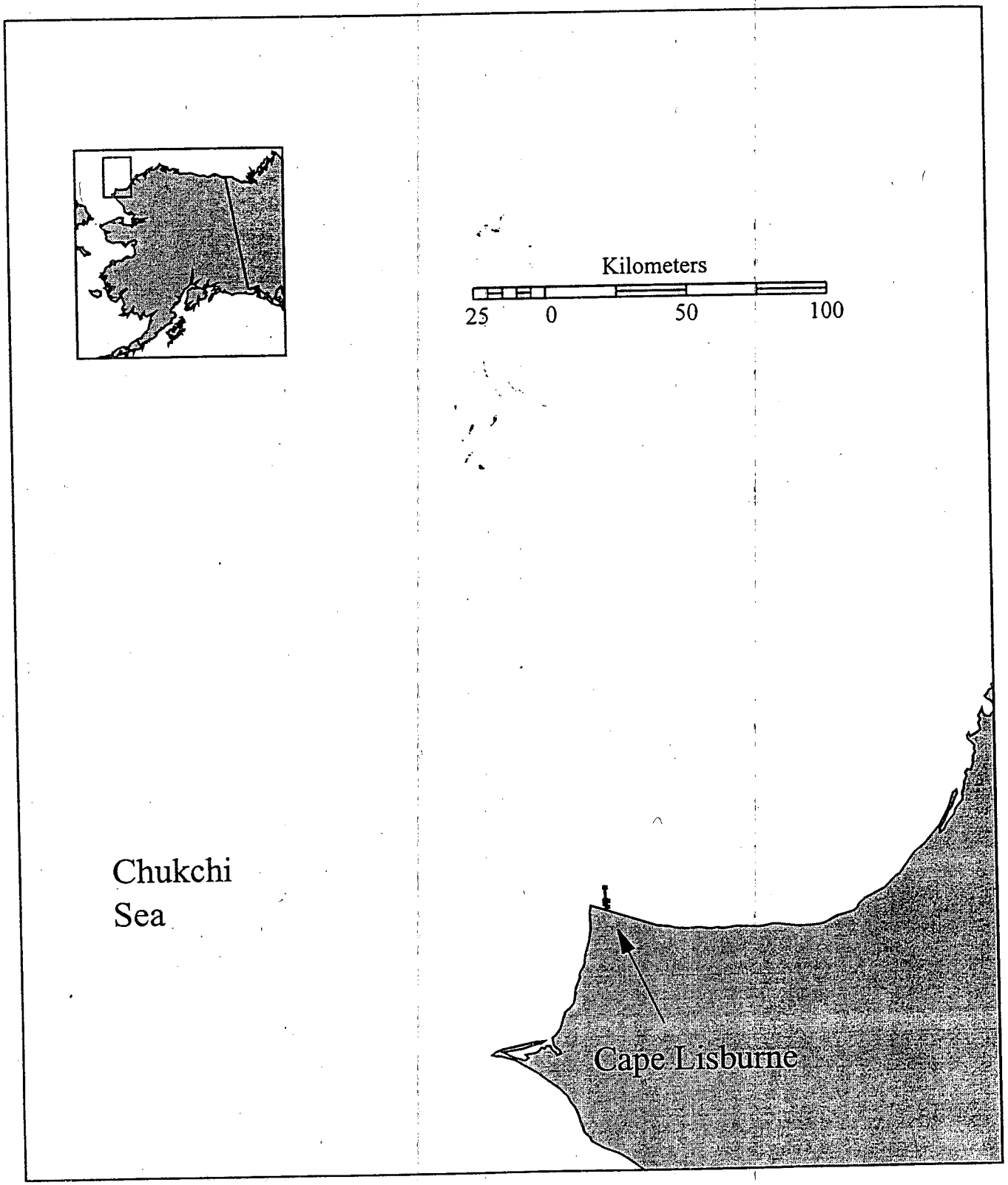


Figure A.4. Track lines of female thick-billed murre 5853 from Cape Lisburne, AK, 1996. Short-cycle transmitter. In contact 5 days.

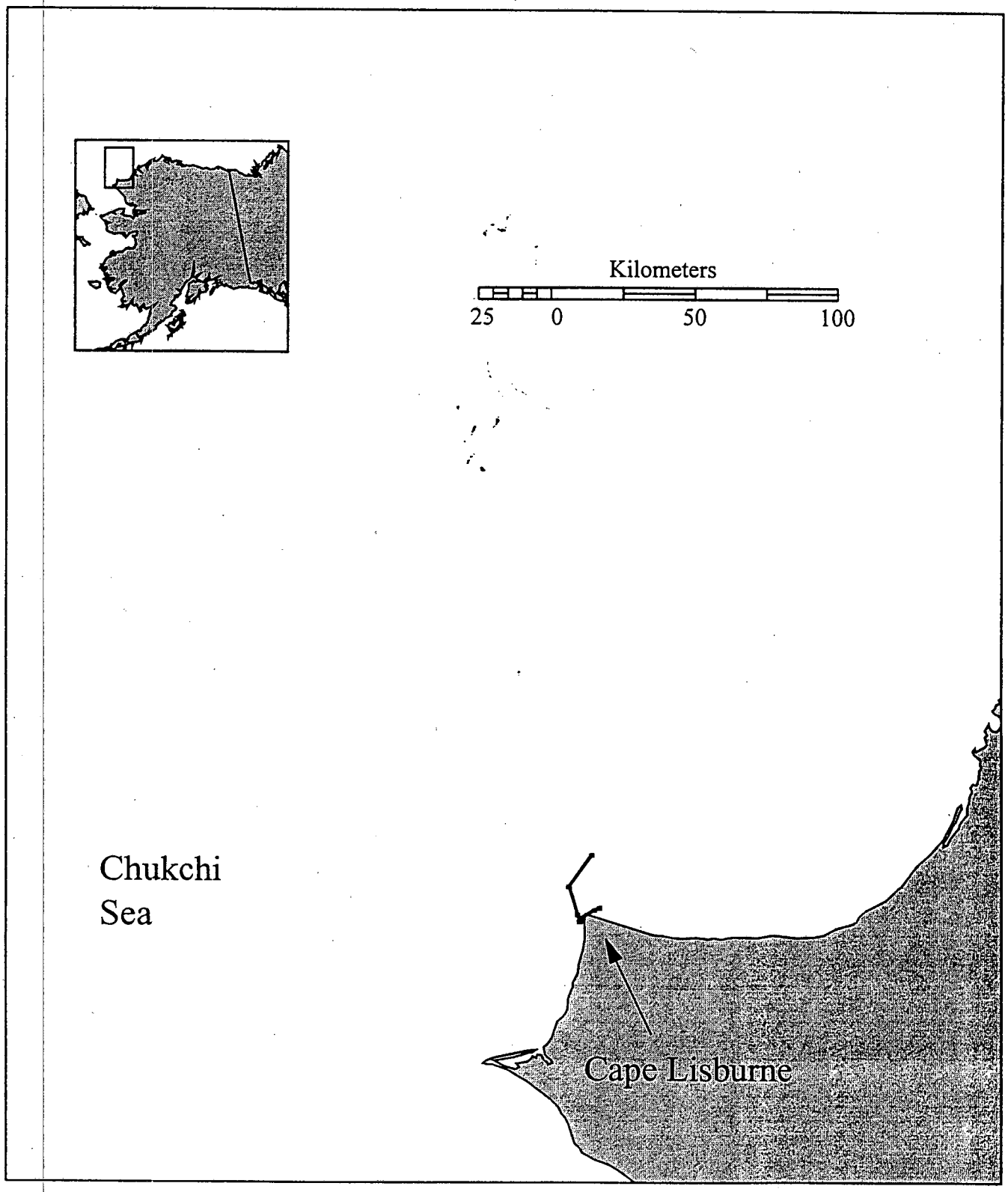


Figure A.5. Track lines of male thick-billed murre 7875 from Cape Lisburne, AK, 1996. Long-cycle transmitter. In contact 1 day.

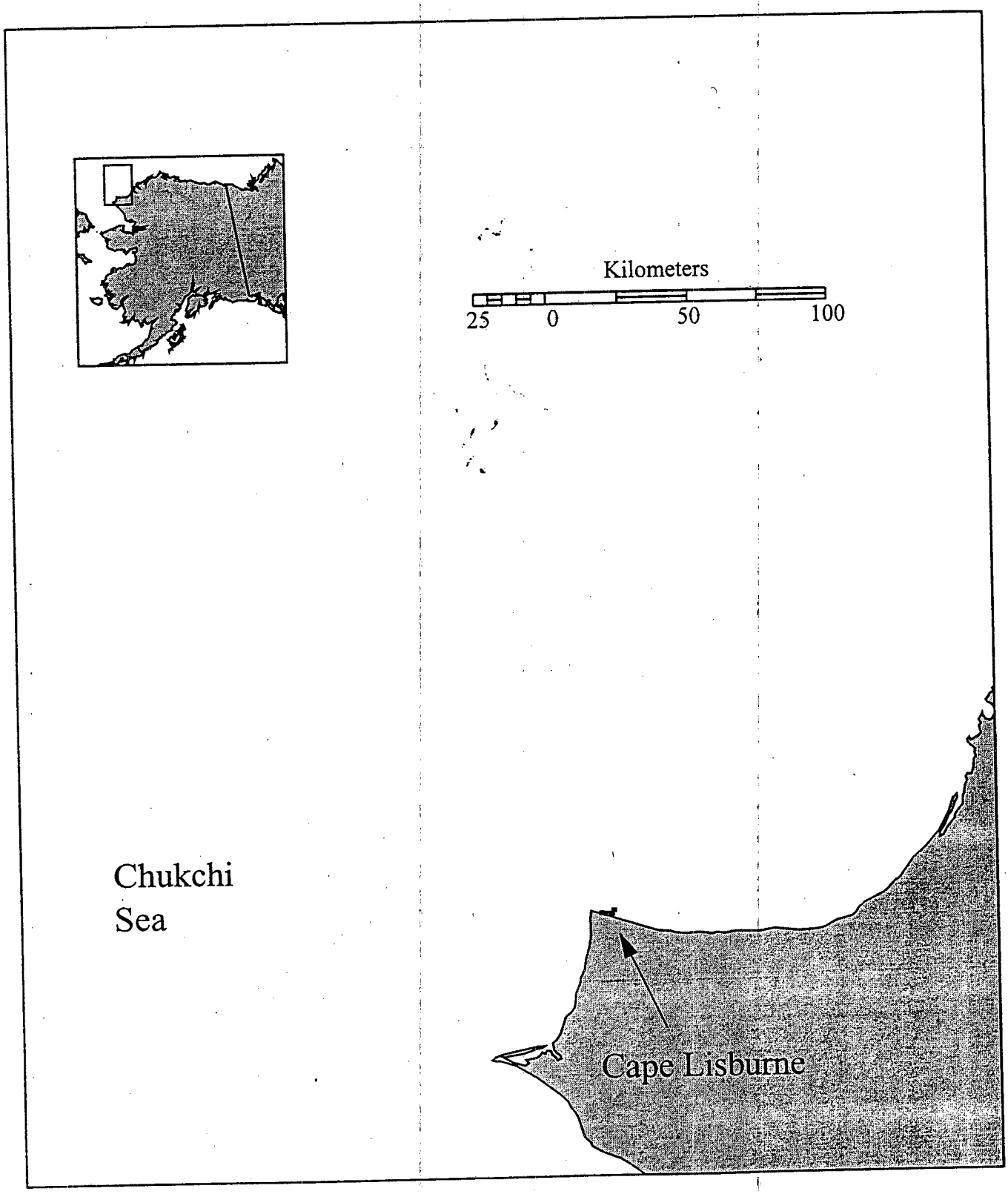


Figure A.6. Track lines of male thick-billed murre 7876 from Cape Lisburne, AK, 1996. Short-cycle transmitter. In contact 8 days.

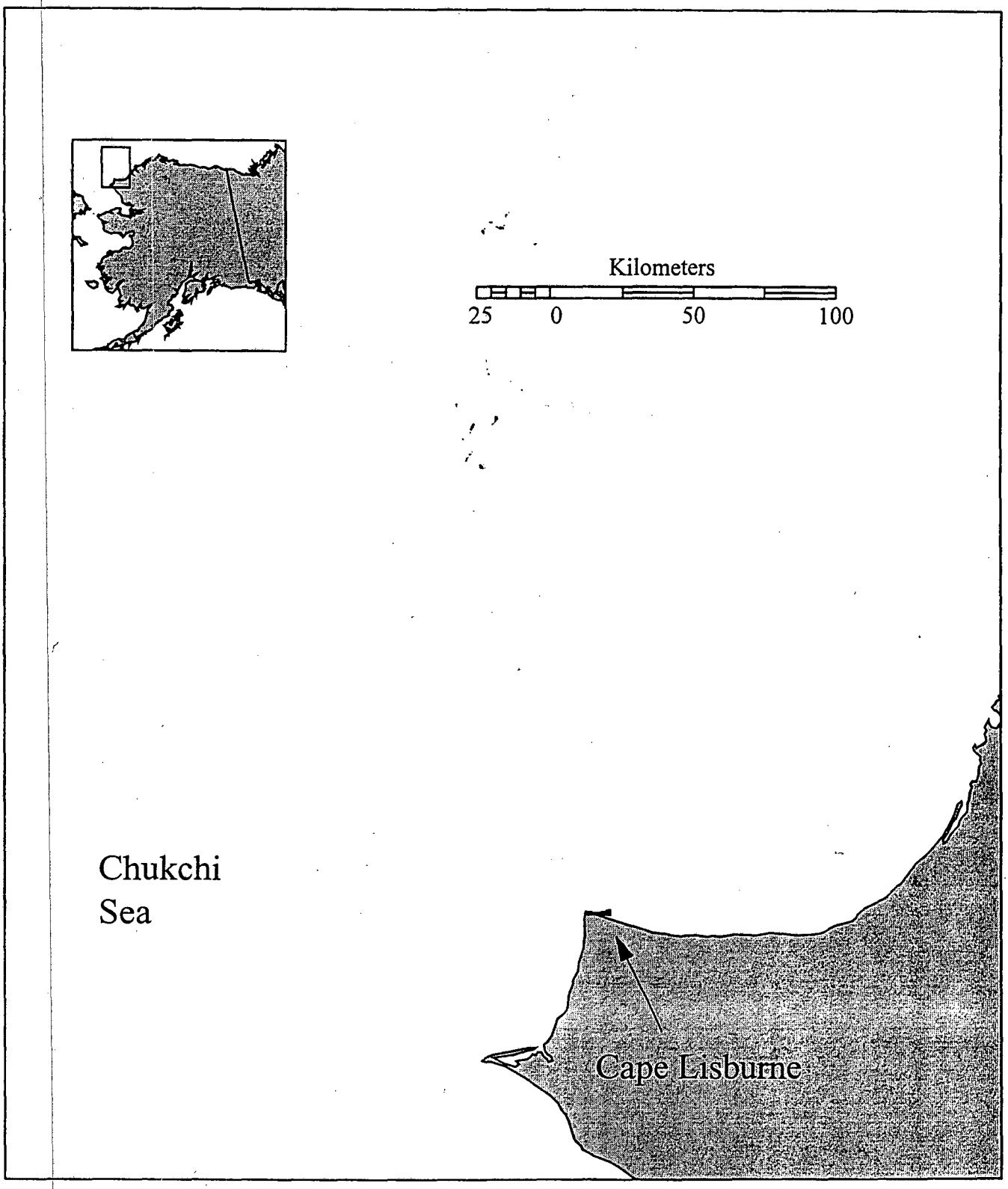


Figure A.7. Track lines of female common murre 7879 from Cape Lisburne, AK, 1996. Long-cycle transmitter. In contact 41 days.

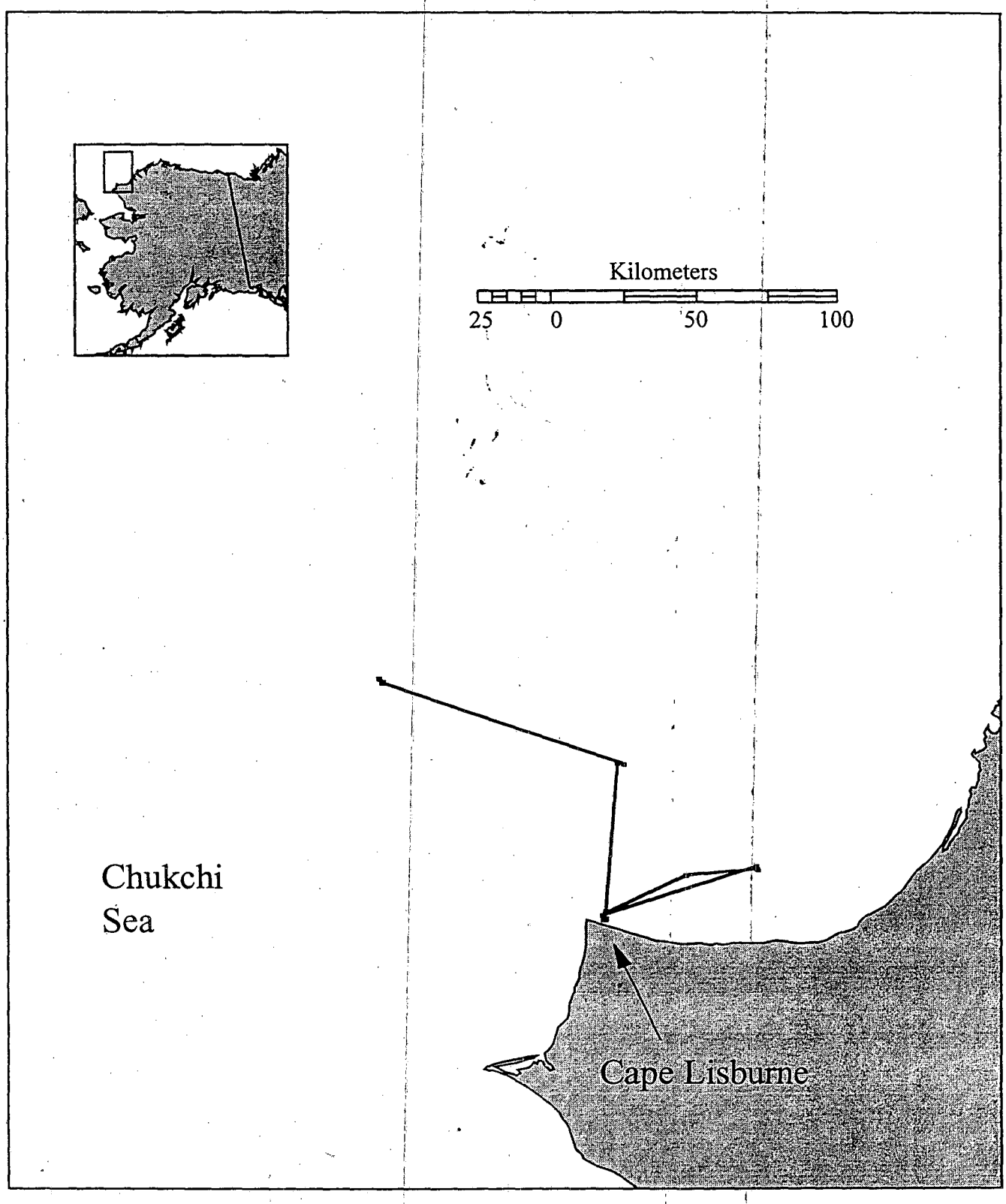


Figure A.8. Post-breeding-season movements of female common murre 7879 from Cape Lisburne, AK, 1996.

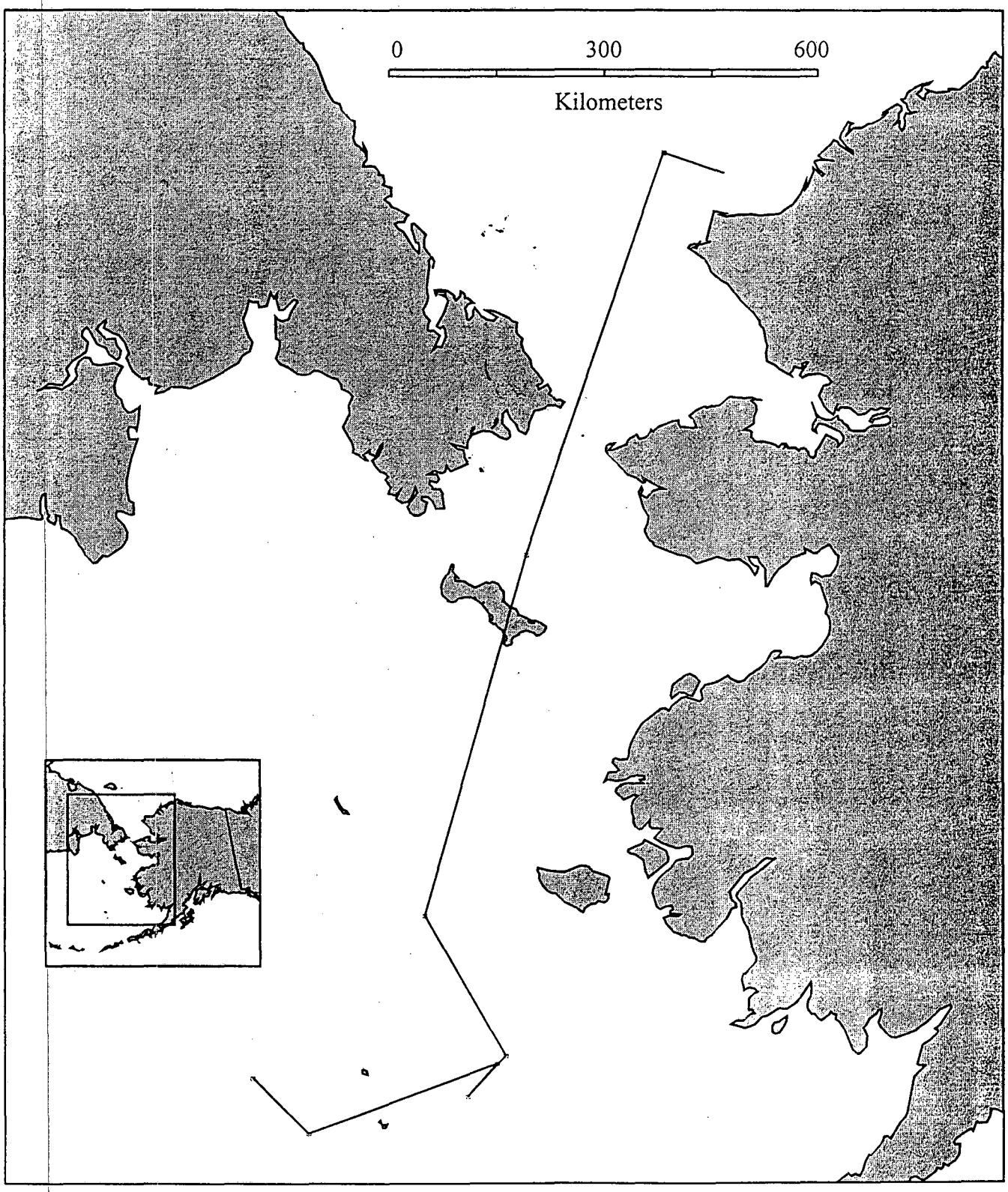


Figure A.9. Track lines of female common murre 7882 from Cape Lisburne, AK, 1996. Short-cycle transmitter. In contact 31 days.

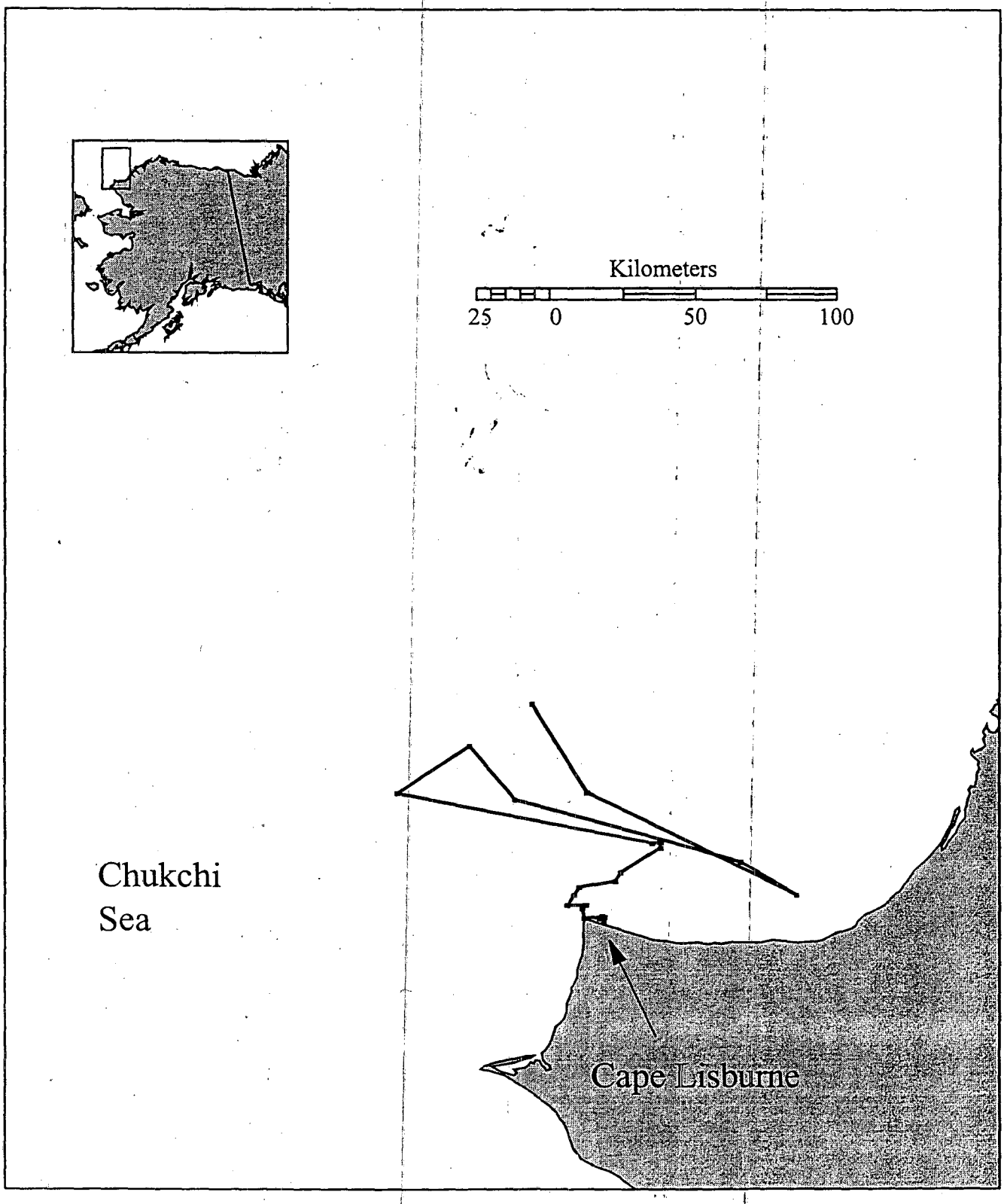


Figure A.10. Track lines of male common murre 7884 from Cape Lisburne, AK, 1996. Long-cycle transmitter. In contact 87 days.

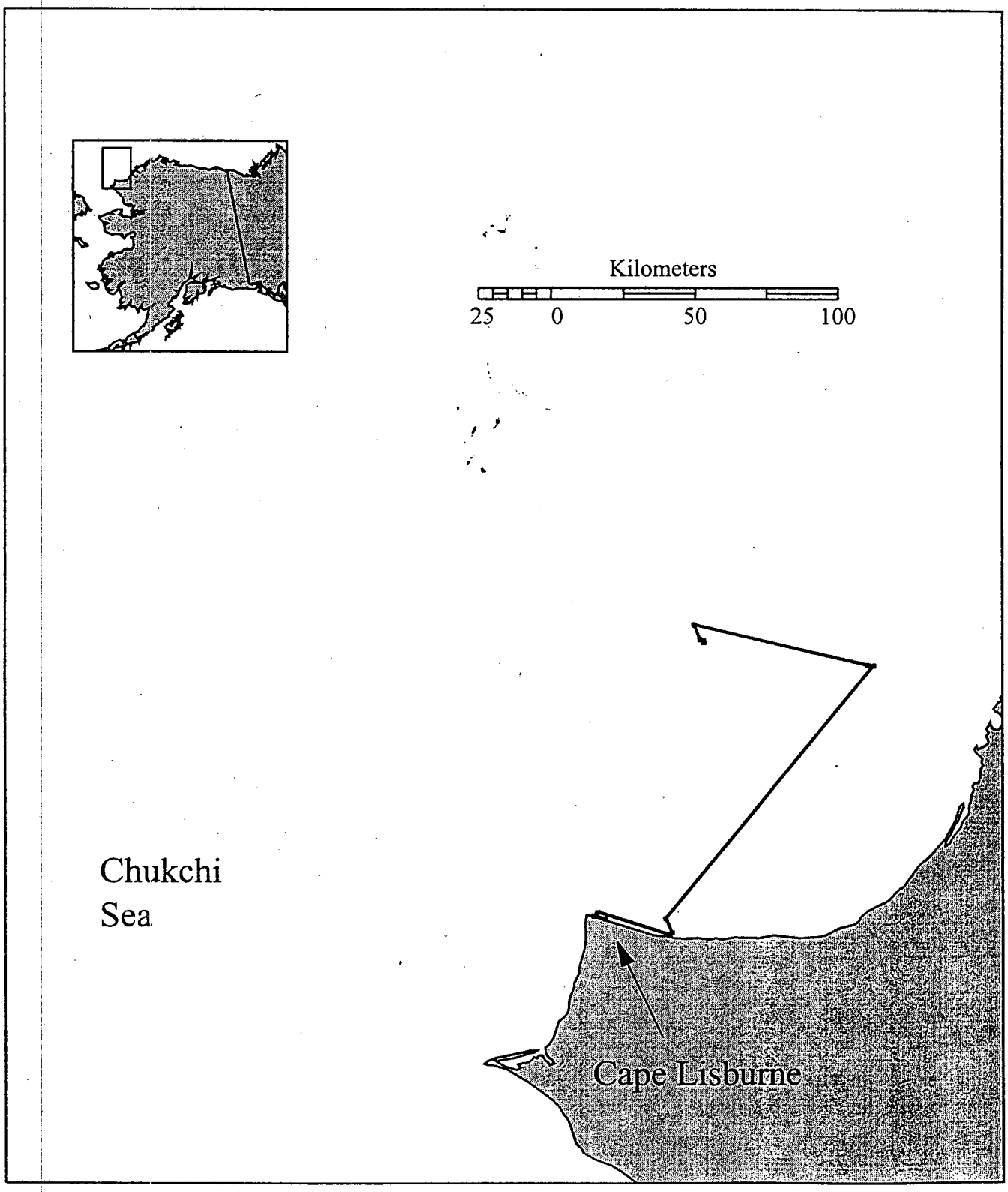


Figure A.11. Post-breeding-season movements of male common murre 7884.

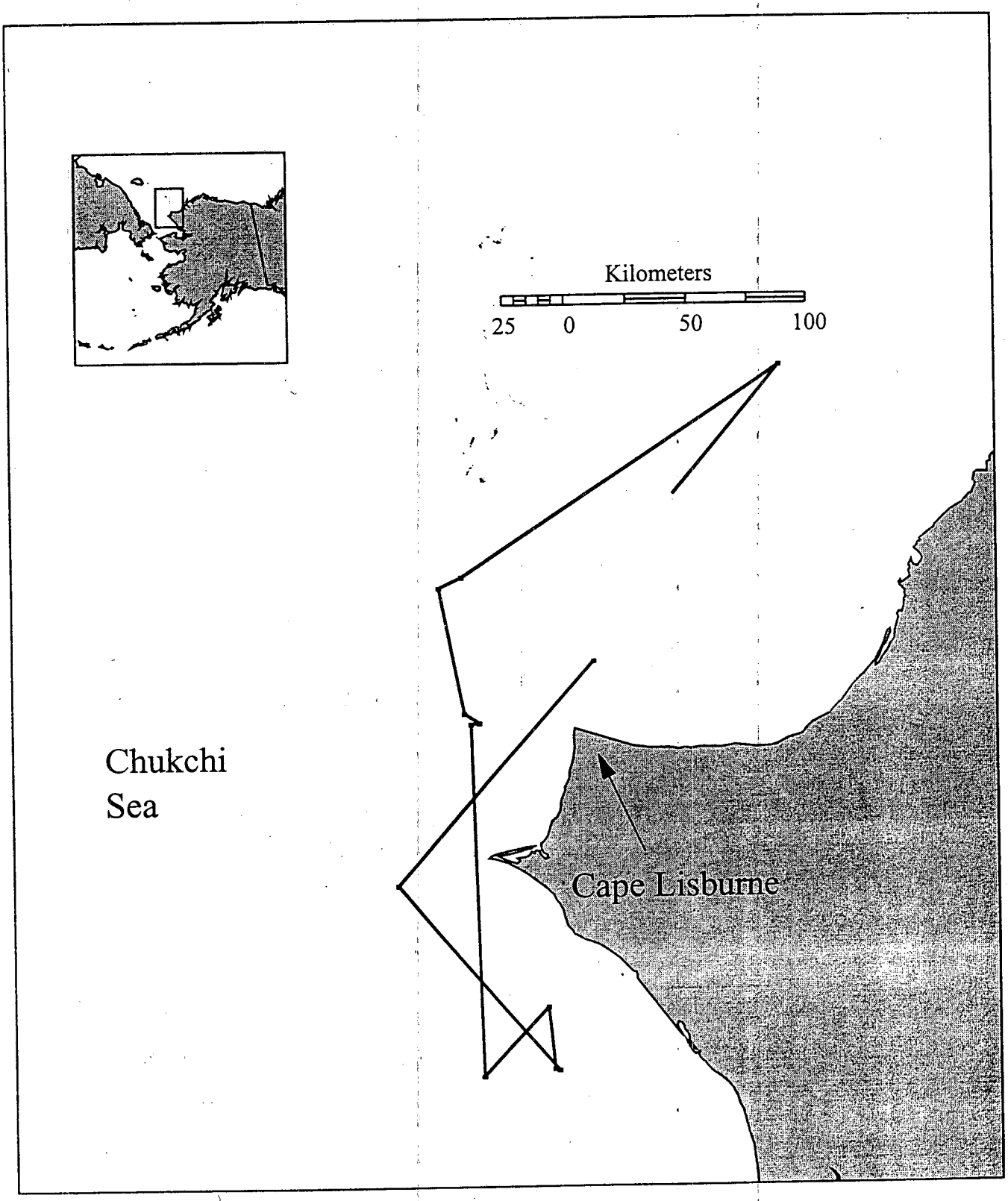


Figure A.12. Track lines of female thick-billed murre 7887 from Cape Lisburne, AK, 1996. Long-cycle transmitter. In contact 1 day.

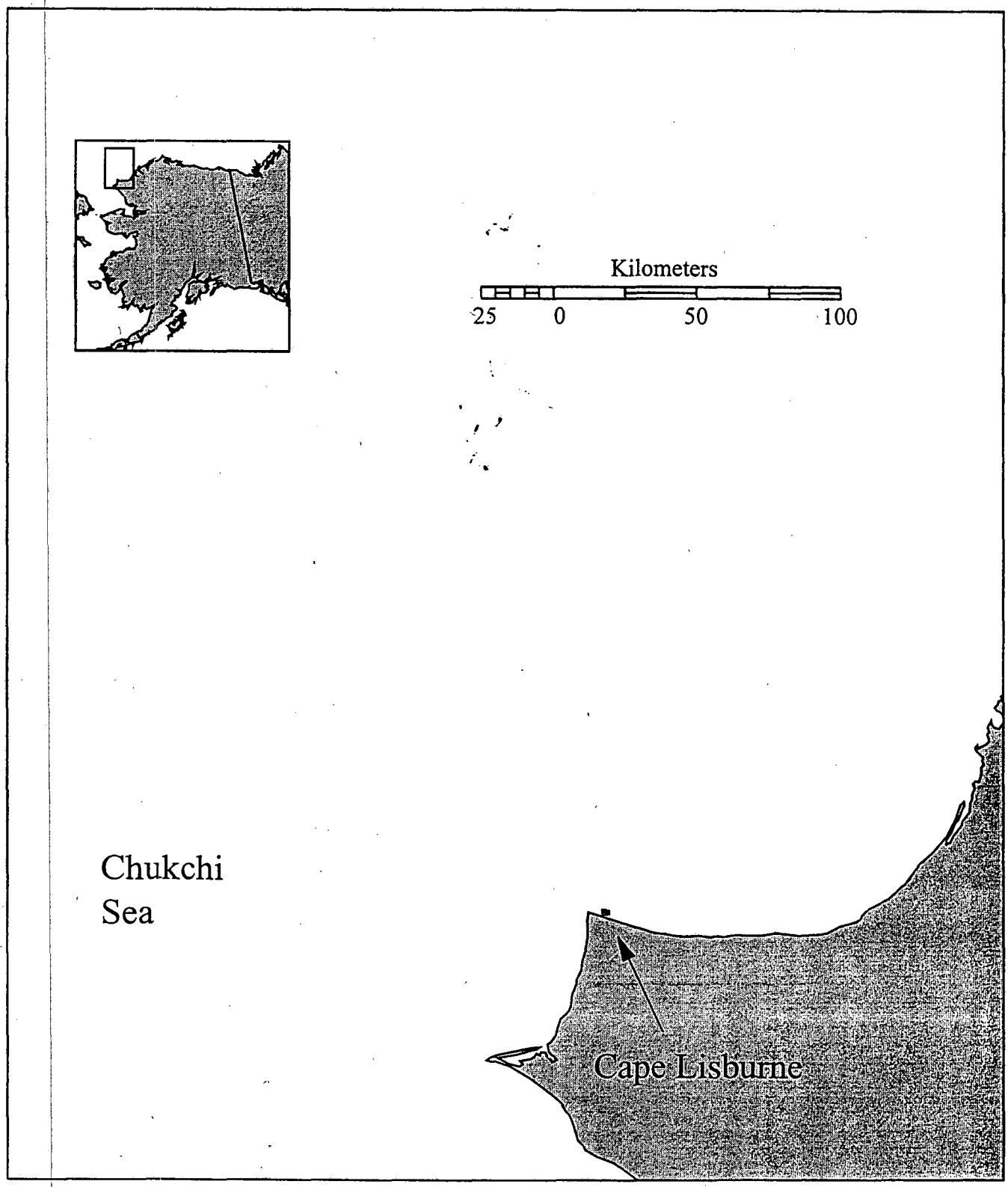


Figure A.13. Track lines of male common murre 7888 from Cape Lisburne, AK, 1996. Long-cycle transmitter. In contact 68 days.

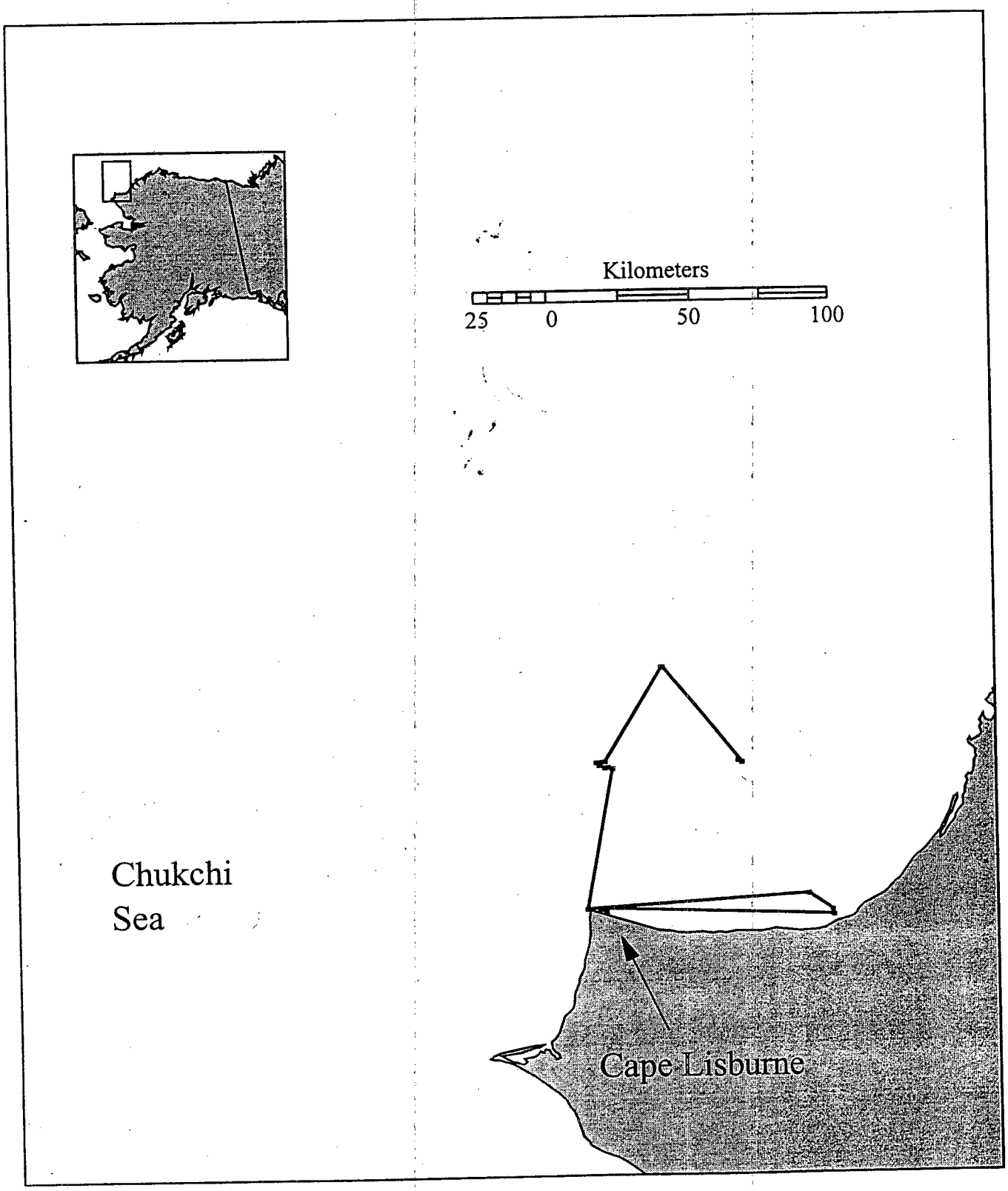


Figure A.14. Post-breeding-season movements of male common murre 7888.

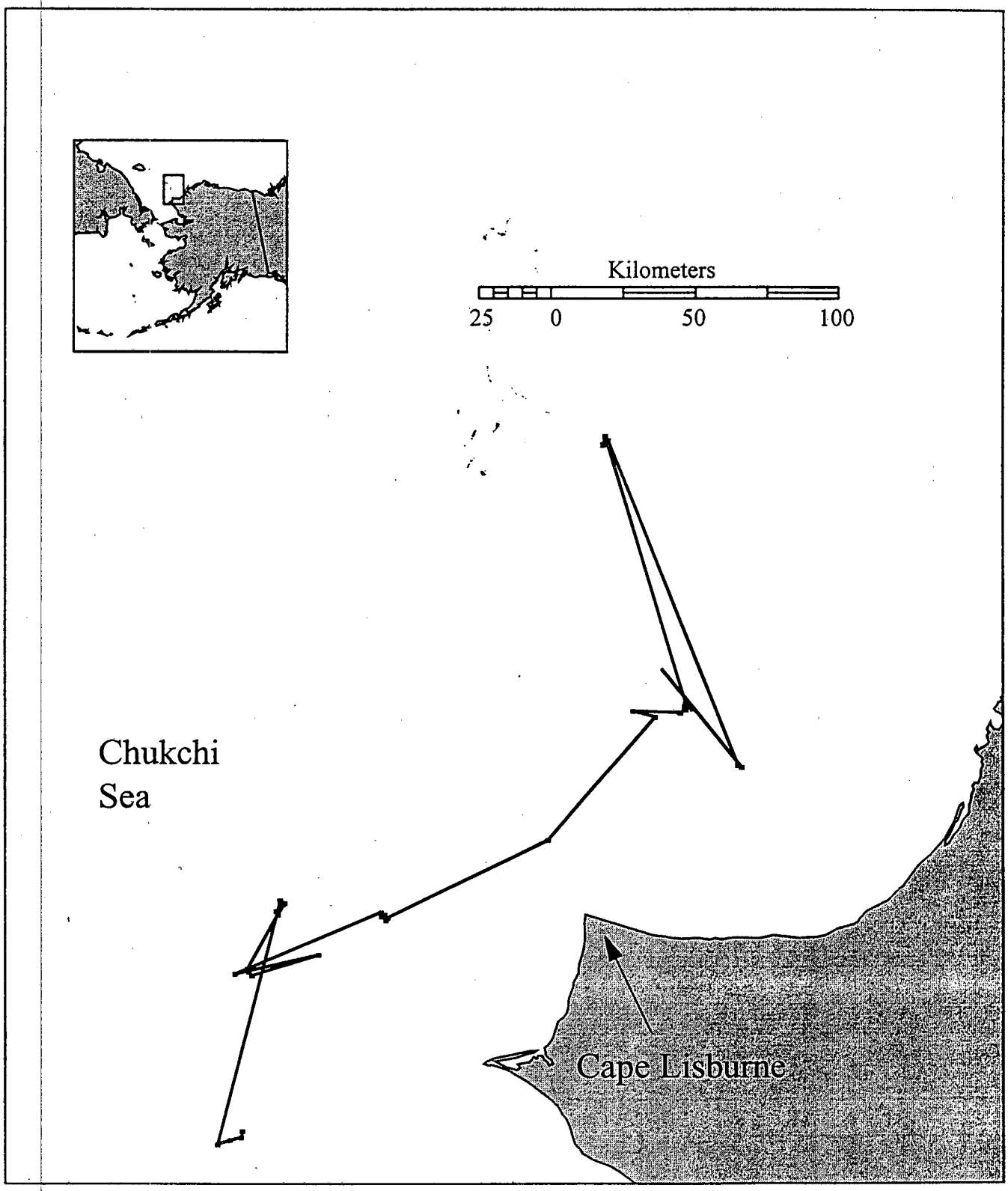


Figure A.15. Location of female thick-billed murre 7901 from Cape Lisburne, AK, 1996. Long-cycle transmitter. In contact 14 days.

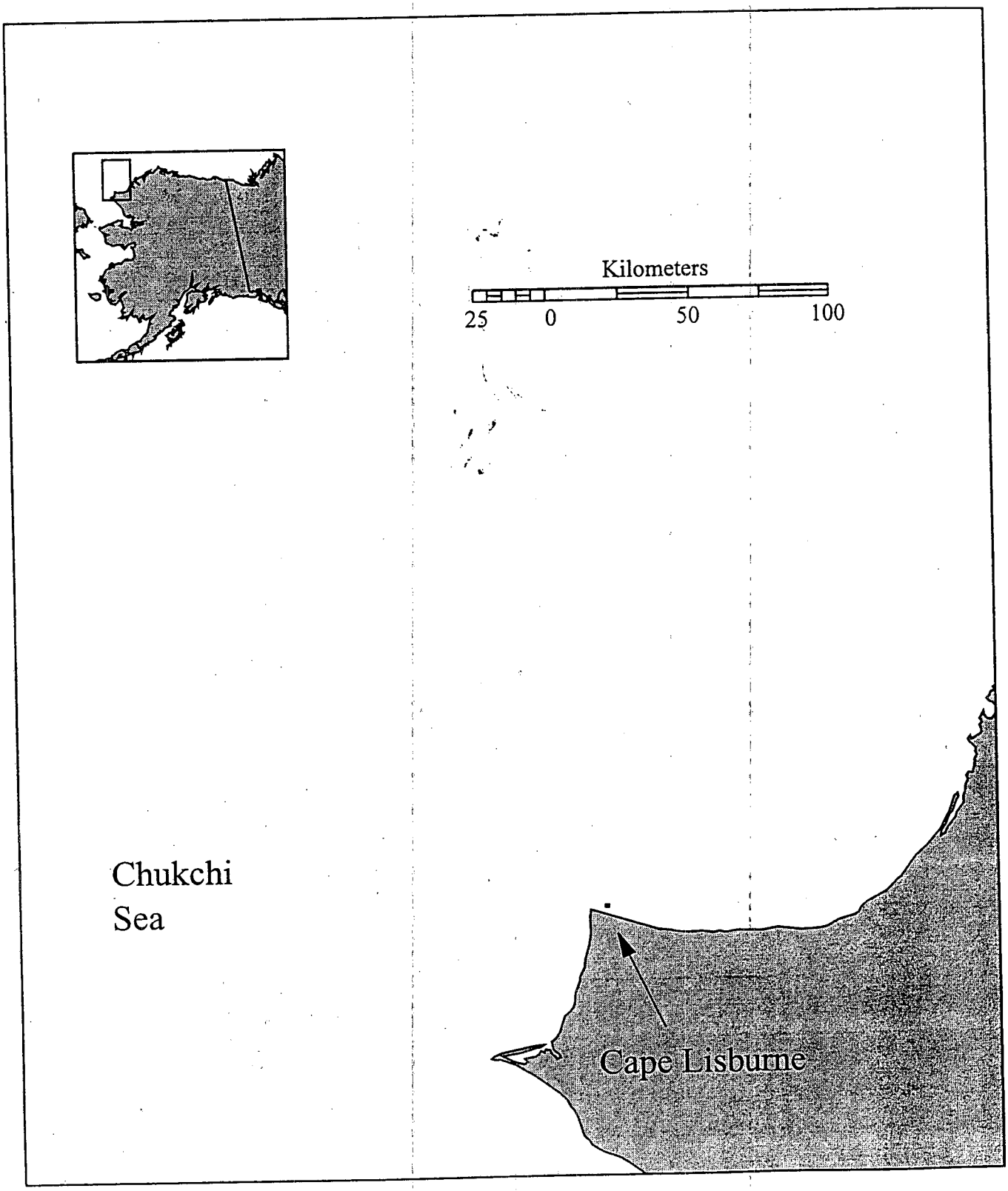


Figure A.16. Post-breeding-season movements of female thick-billed murre 7901 from Cape Lisburne, AK, 1996.

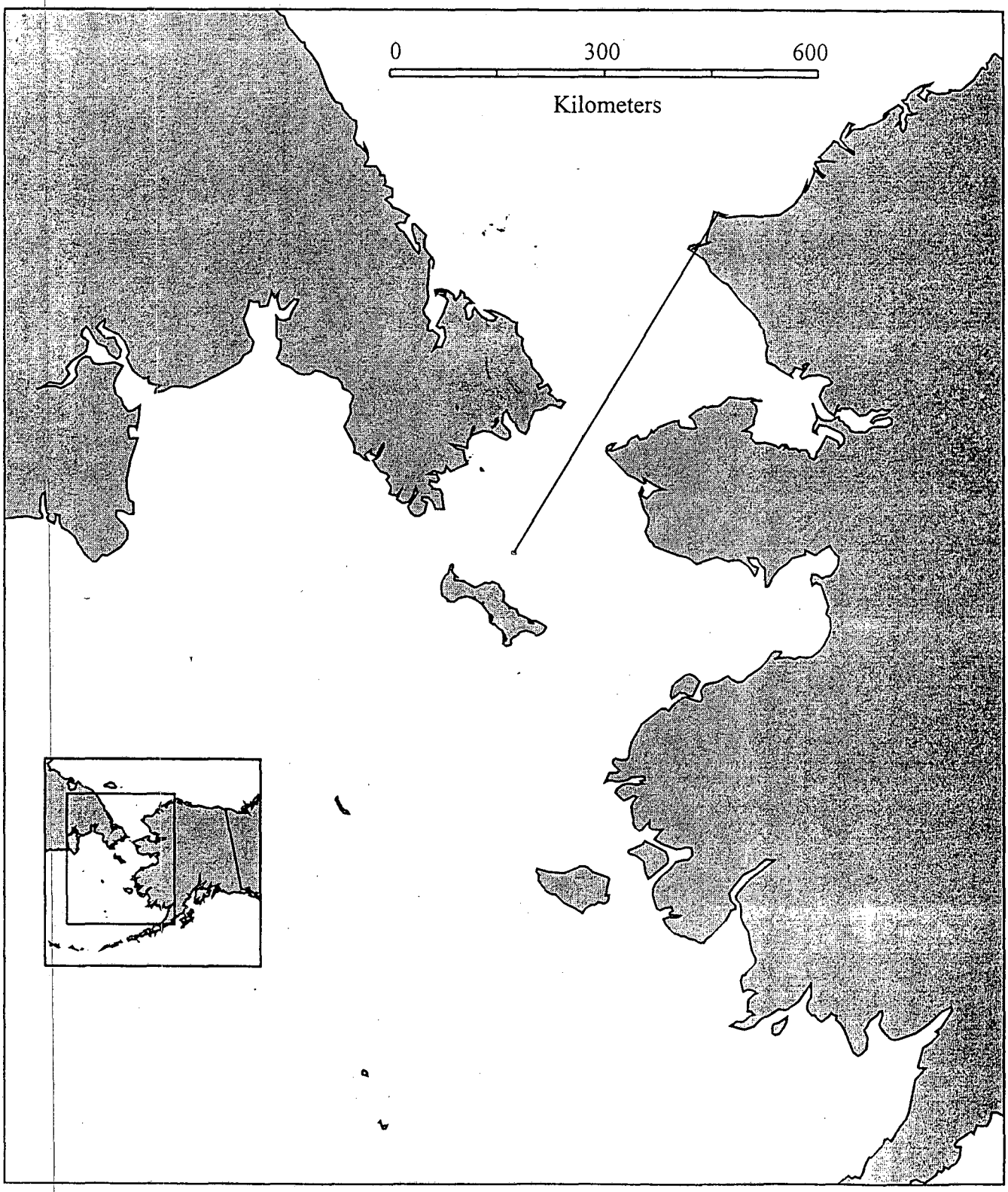


Figure A.17. Track lines of male thick-billed murre 7903 from Cape Lisburne, AK, 1996. Long-cycle transmitter. In contact 74 days.

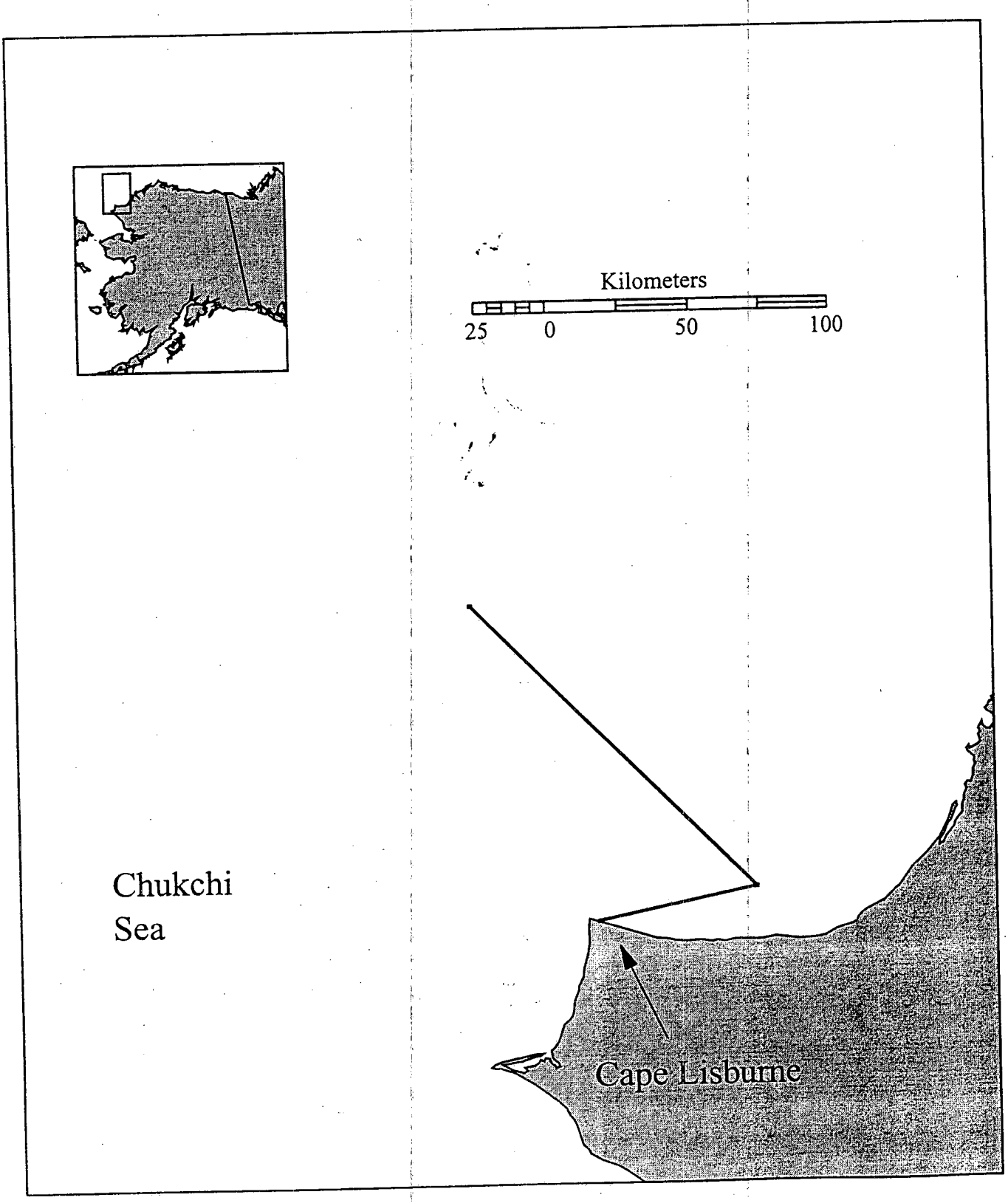


Figure A.18. Track lines of male thick-billed murre 7915 from Cape Lisburne, AK, 1996. Short-cycle transmitter. In contact 18 days.

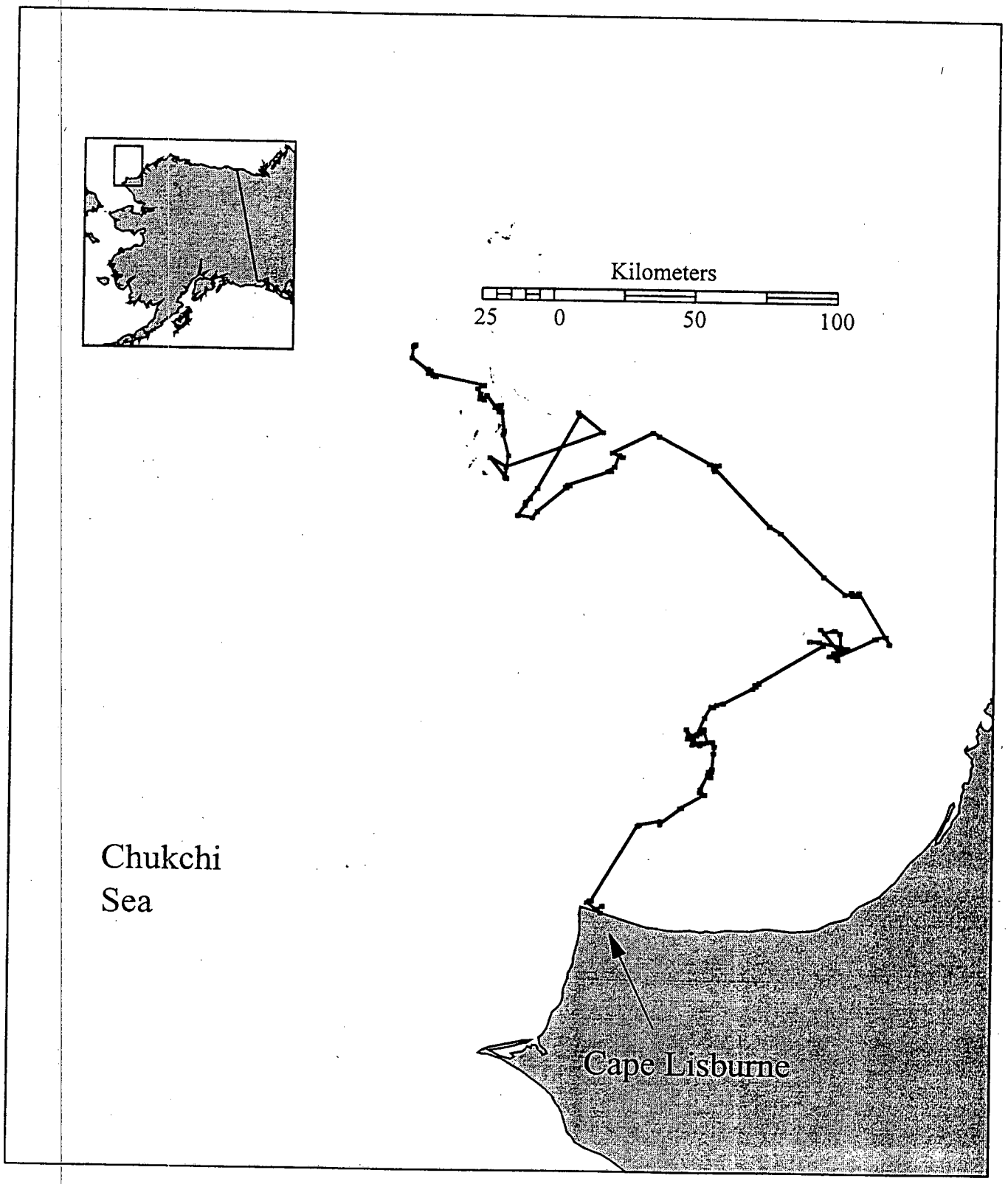
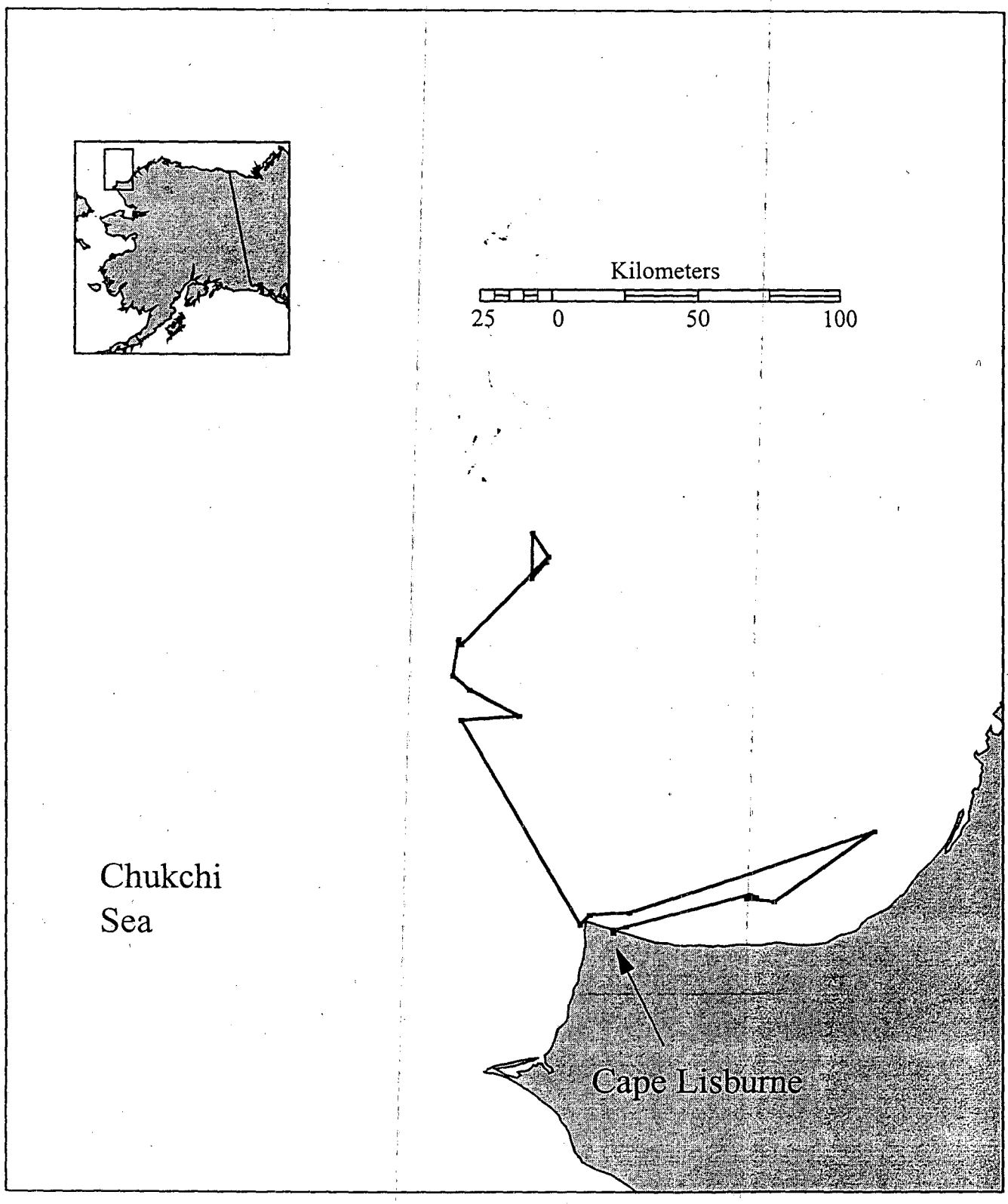



Figure A.19. Track lines of female thick-billed murre 7917 from Cape Lisburne, AK, 1996. Short-cycle transmitter. In contact 11 days.