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

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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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## 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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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.

| Argos Signal Quality Code | Before Culling | | After Culling | |
|---|---|---|---|---|
| | 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.

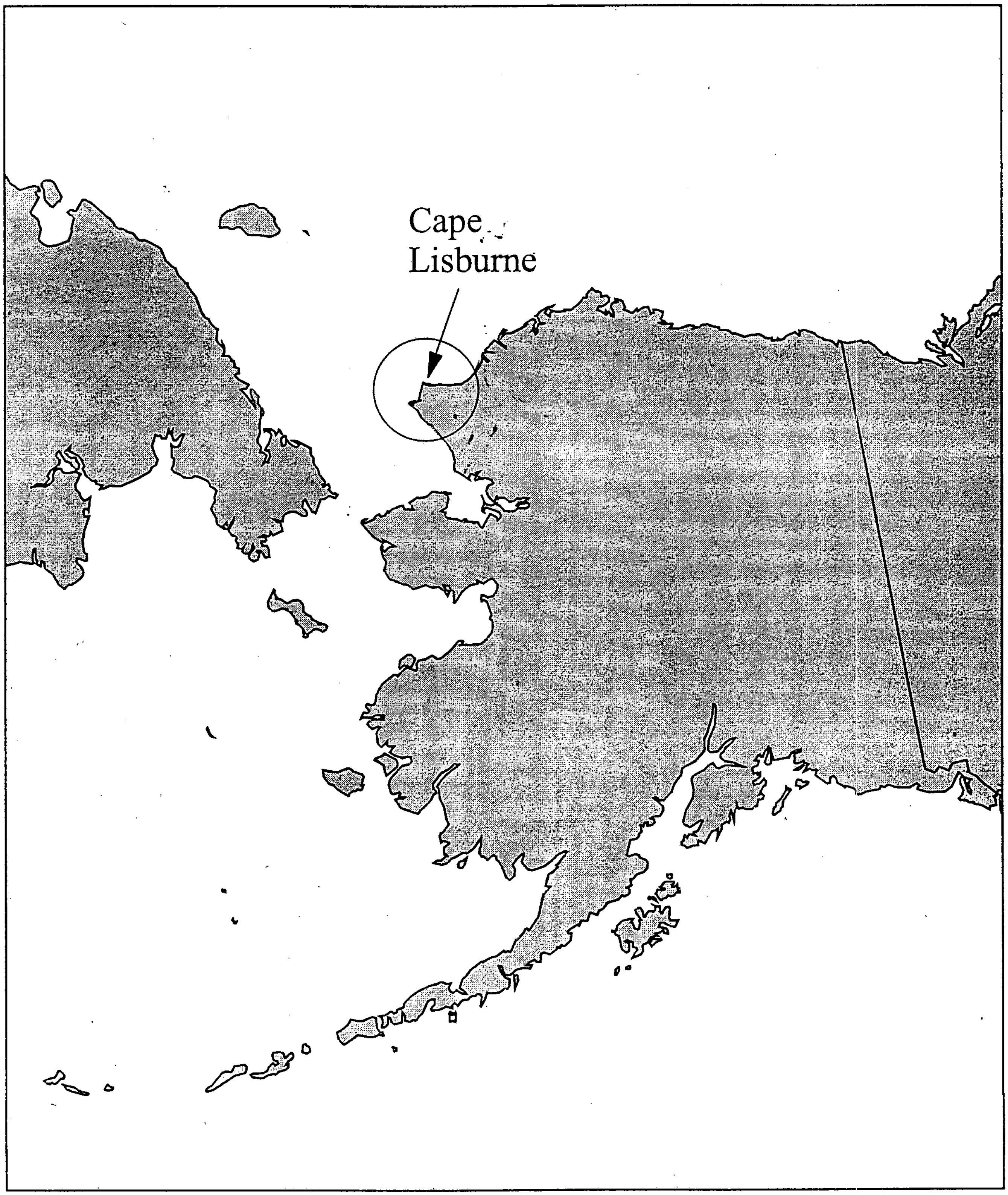
A. Depth-related

(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.



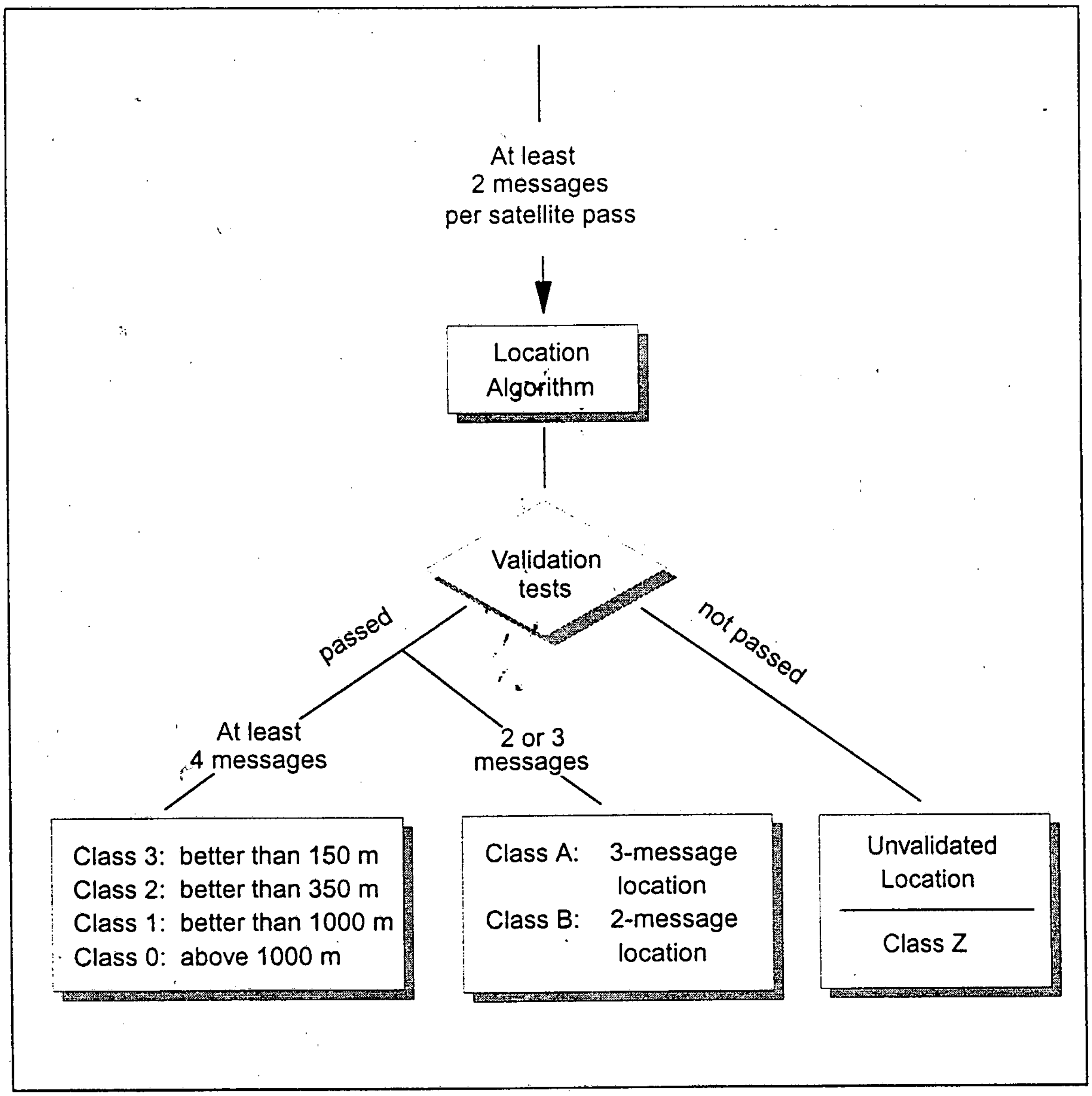



Figure 2. Location quality classes assigned by Argos. (Source: Argos, Inc. Newsletter, October, 1995.)

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

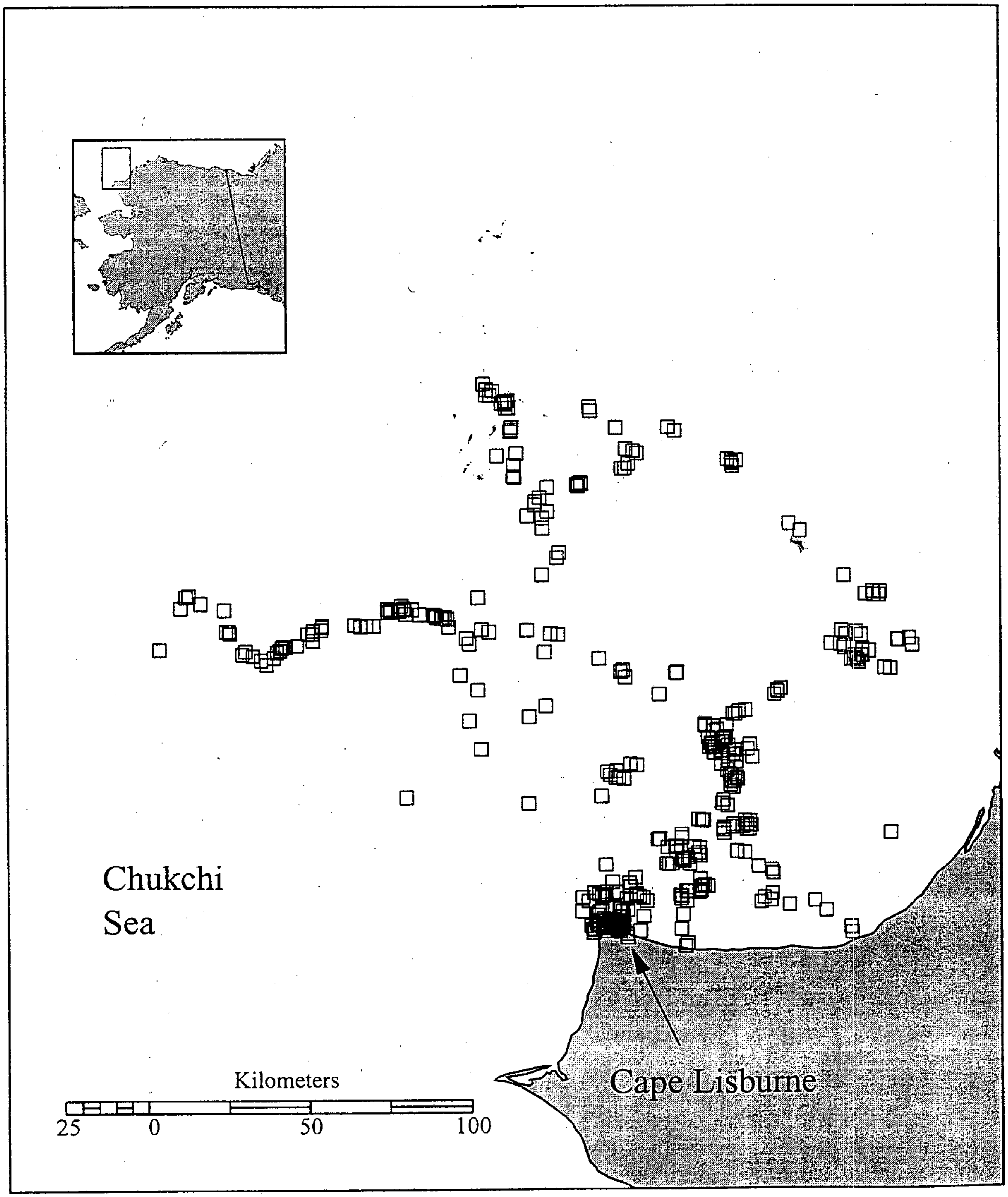


Figure 4. Distribution of Cape Lisburne murres during the breeding season by year. Squares represent 1996 distribution, and circles represent 1995 distribution.

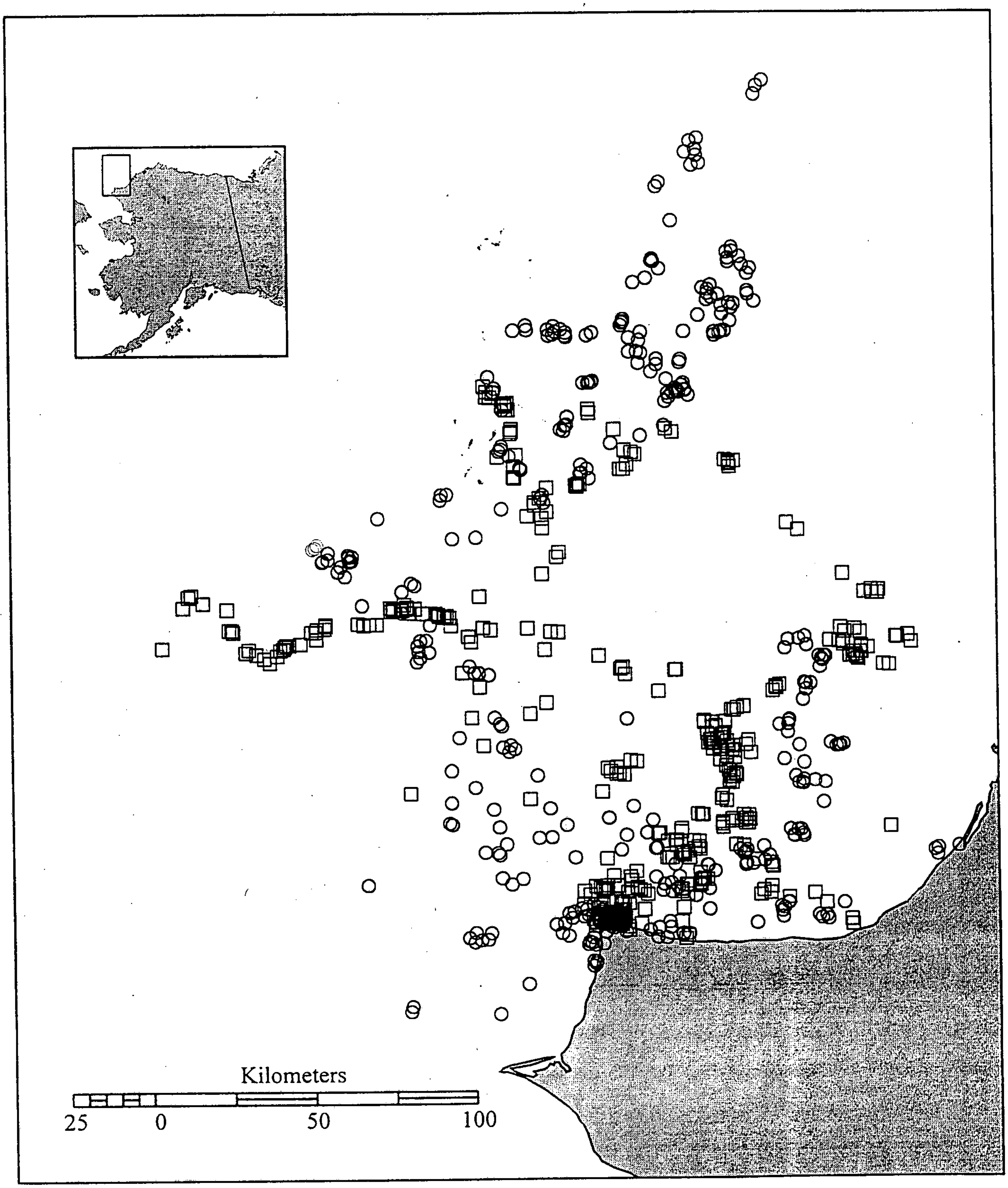


Figure 5. Minimum convex polygons for Cape Lisburne murres during the breeding season. These foraging areas mainly represent murres that had abandoned nesting and were no longer commuting to the colony.

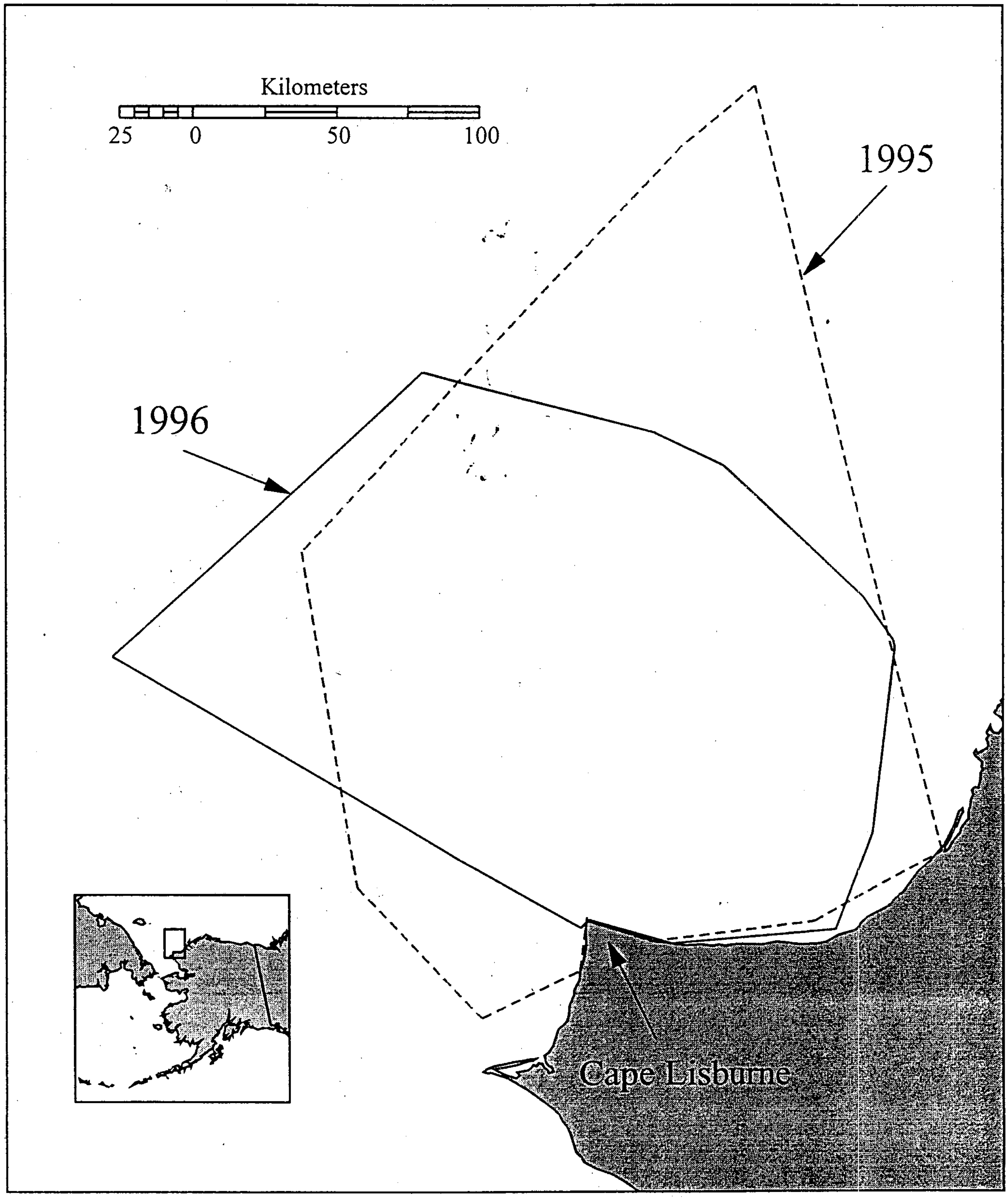


Figure 6. Distribution of Cape Lisburne murres during the breeding season by sex. Squares represent females and circles represent males.

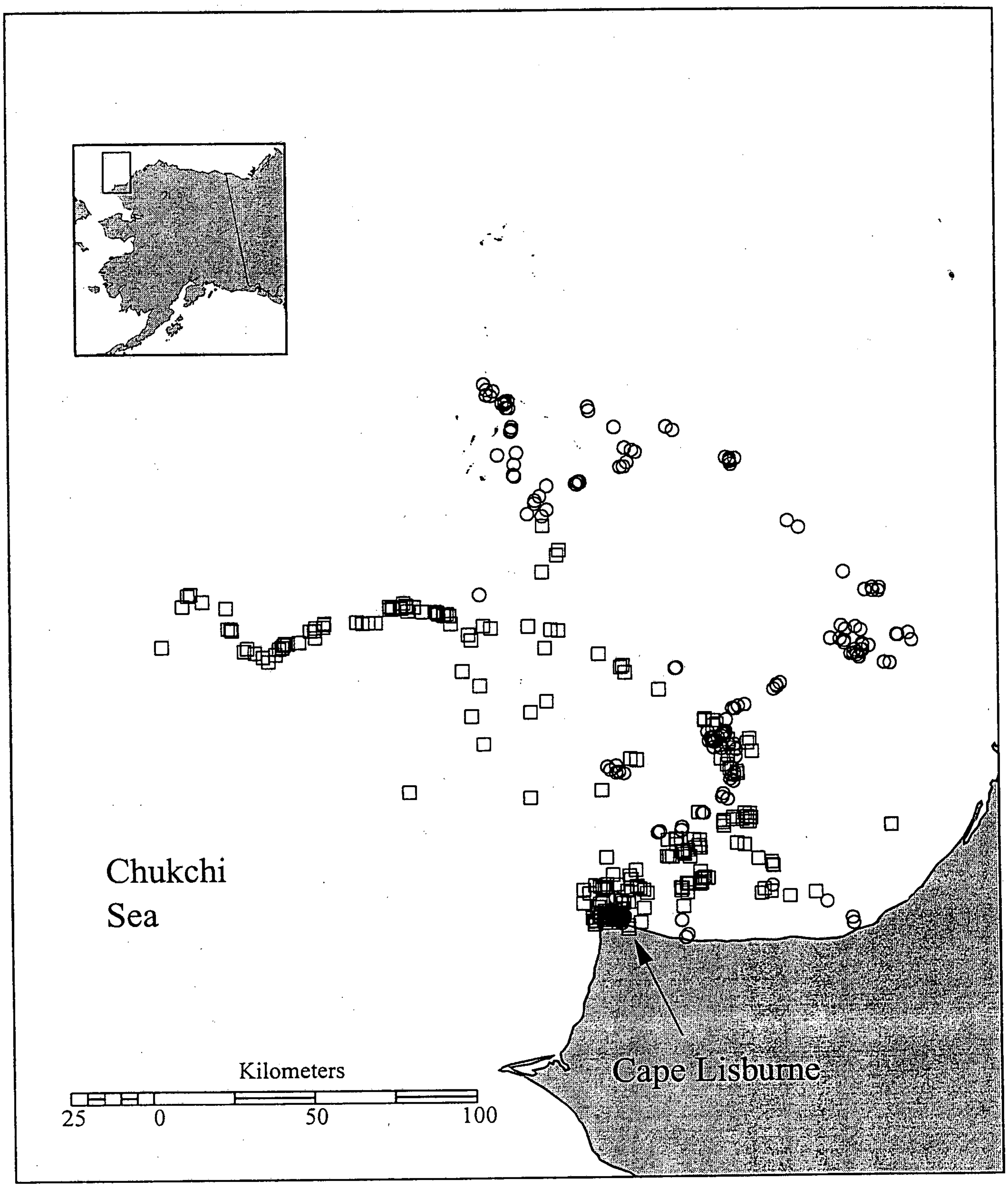


Figure 7. Distribution of Cape Lisburne murres during the breeding season by species. Squares represent common murres and circles represent thick-billed murres.

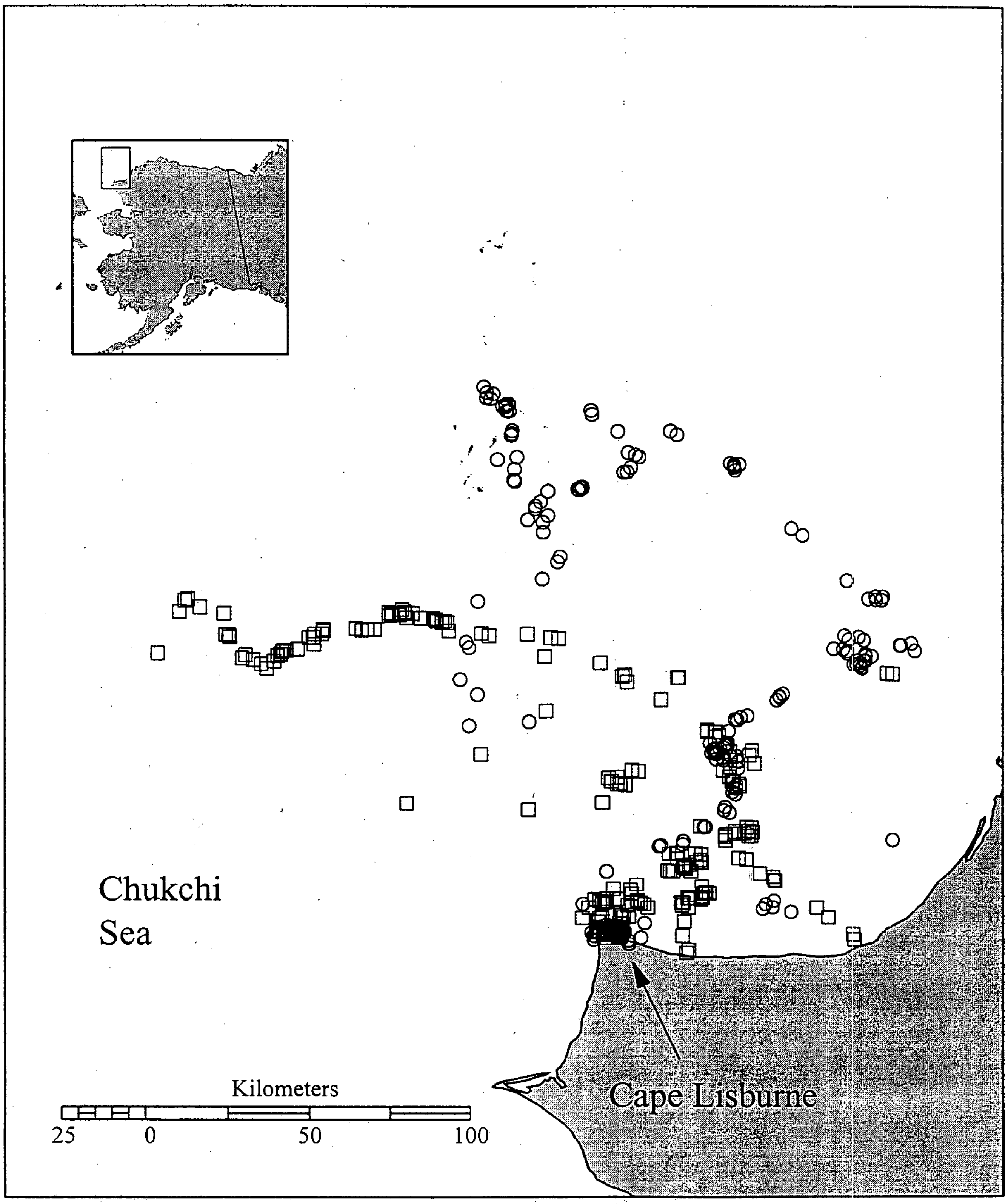


Figure 8. Migration of 3 murres from Cape Lisburne, AK, 1996.

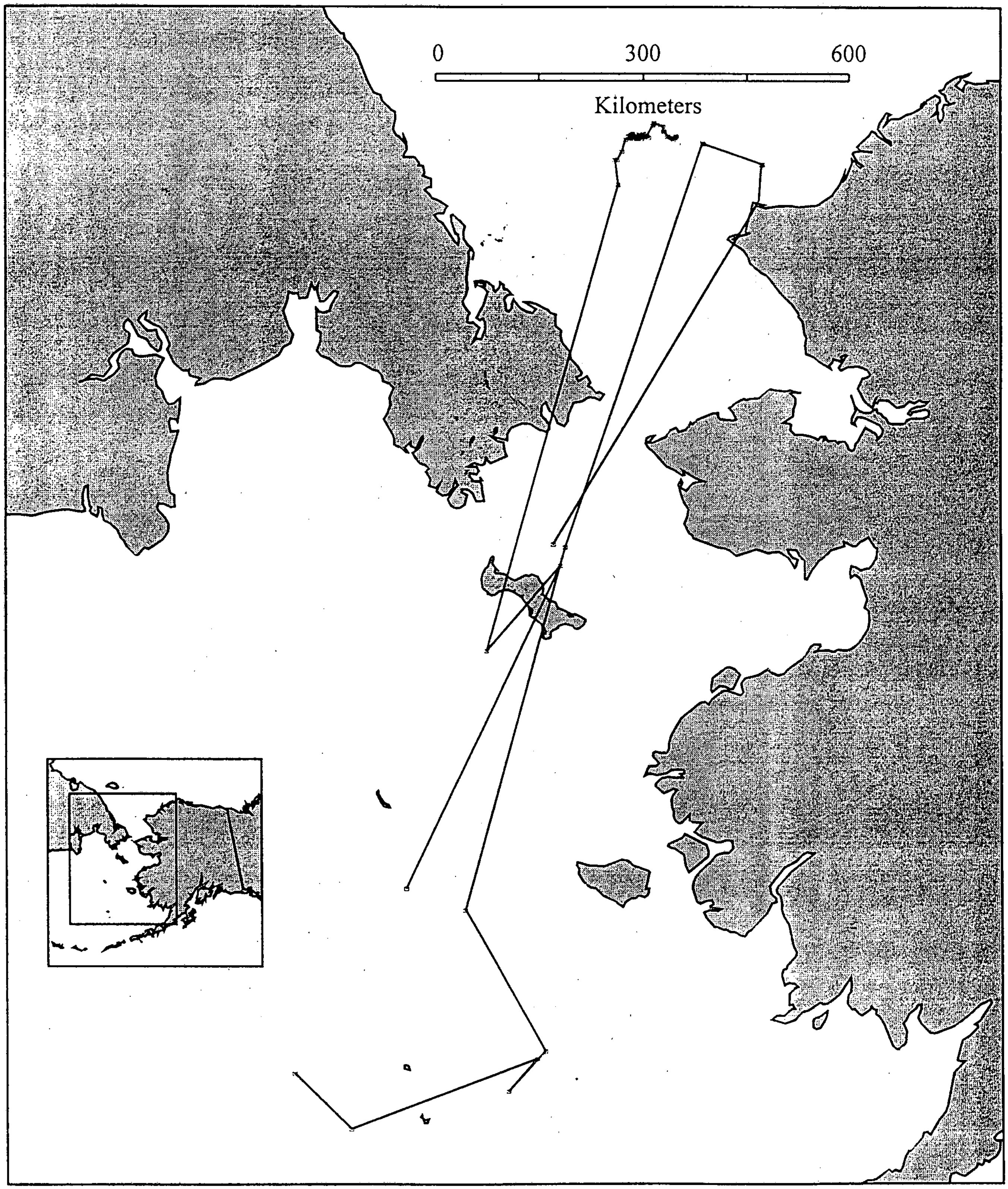
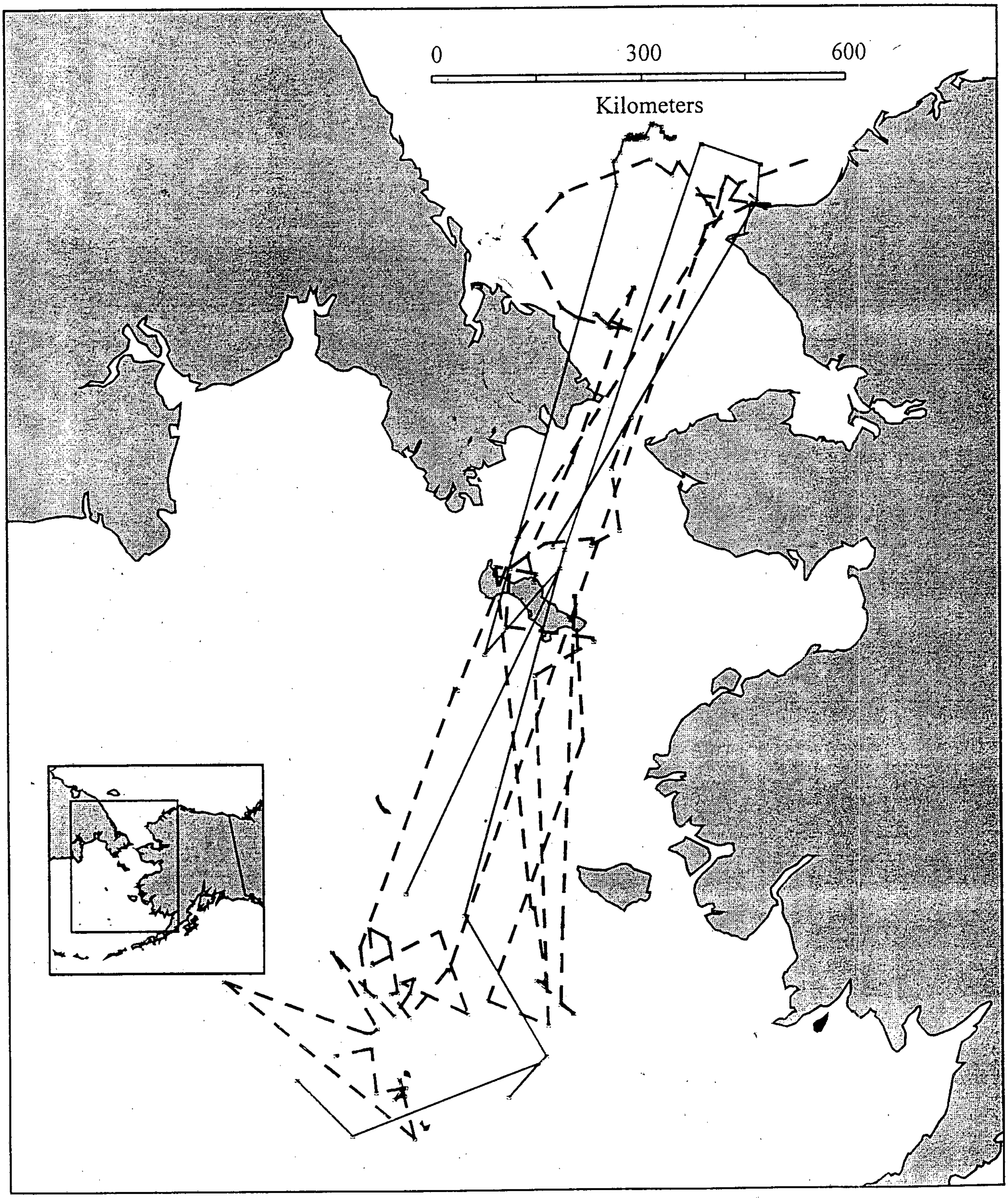


Figure 9. Migration of Cape Lisburne murres by year. Solid lines represent 1996 murres and dashed lines represent 1995 murres.



# 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 ($\geq$ 1000 g verses 896 $\pm$ 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.

## ACKNOWLEDGMENTS

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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.

## ACKNOWLEDGMENTS

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

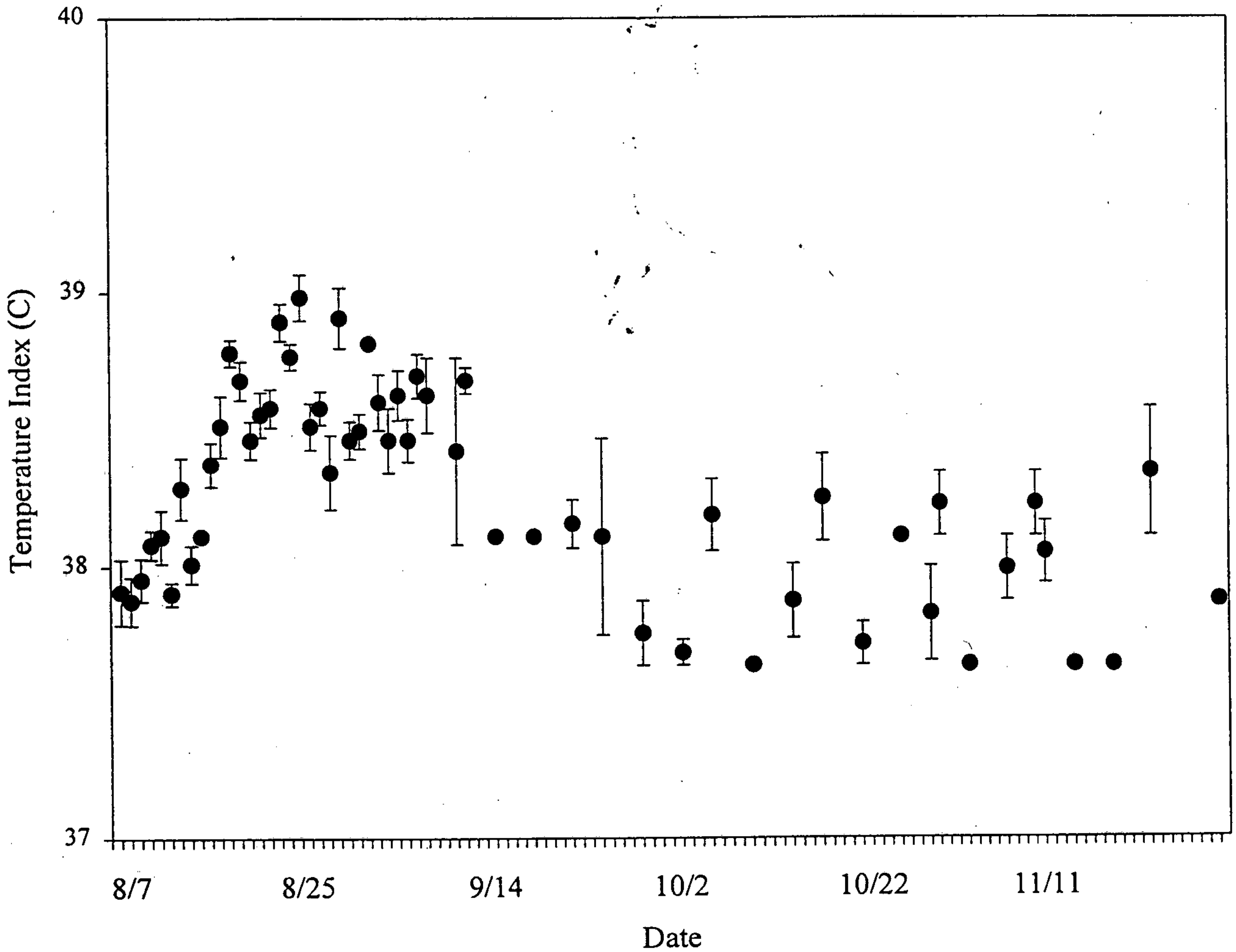
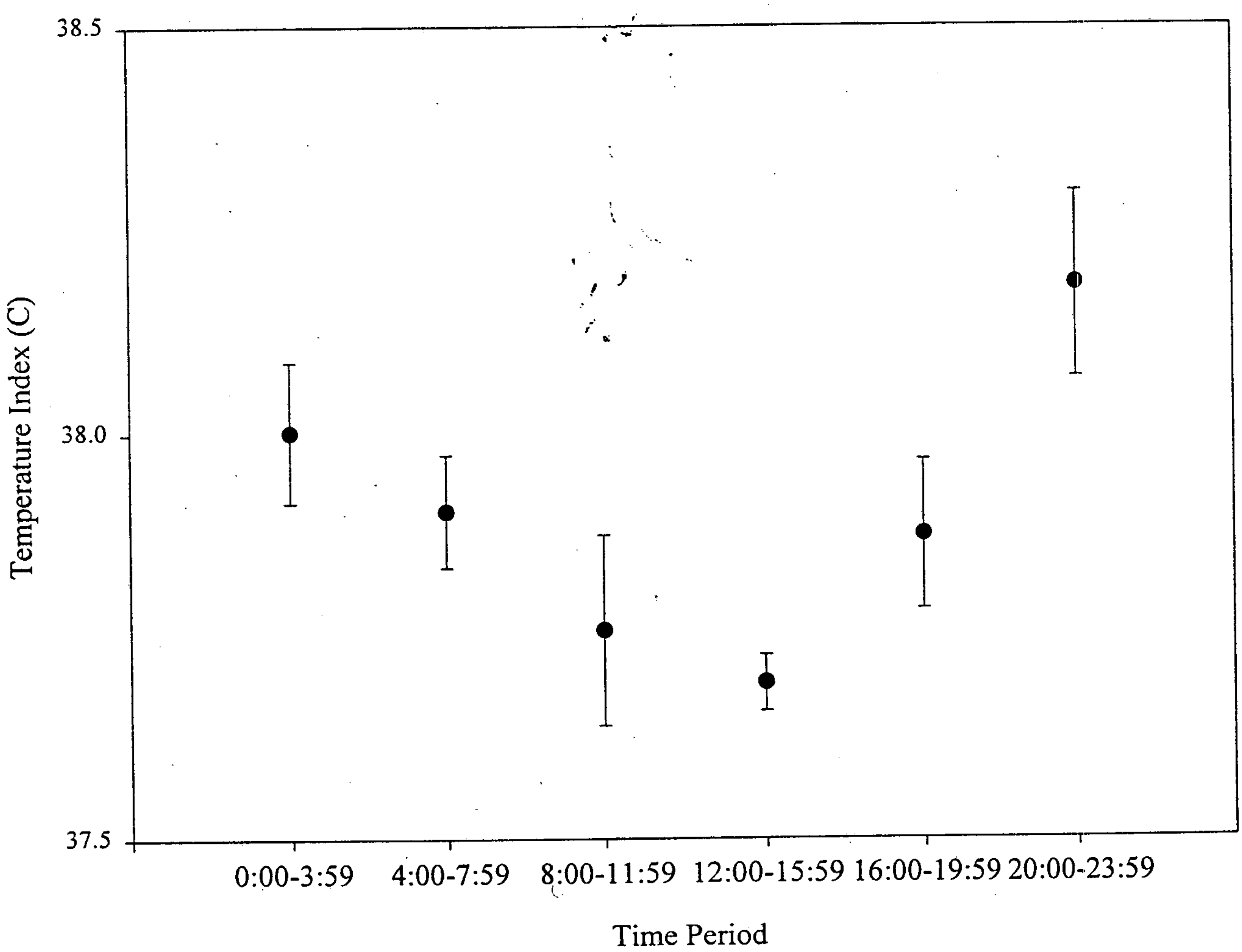


Figure 11. Daily temperature cycle in winter of a female common murre from Cape Lisburne, AK, 1995.



# 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.

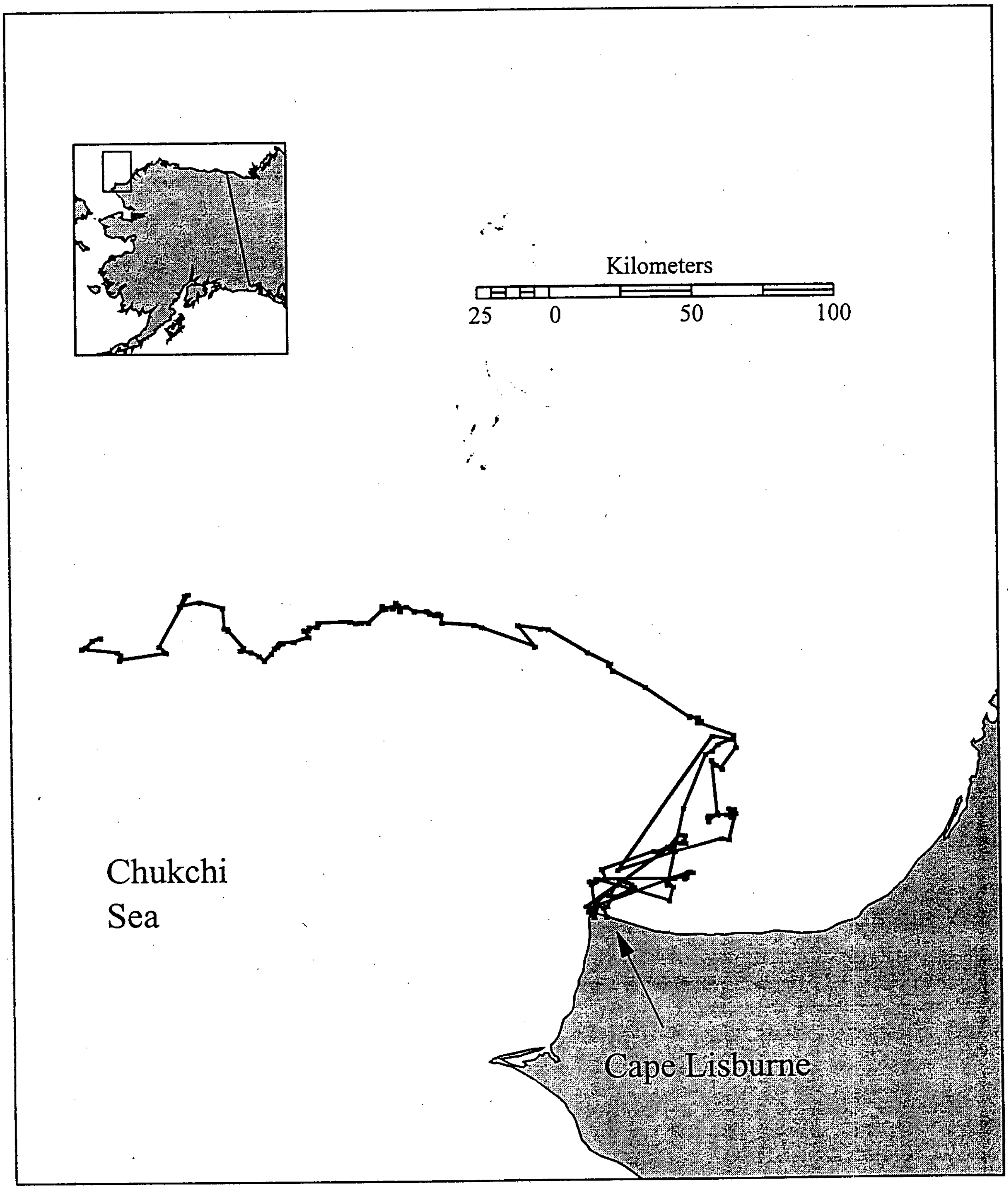


Figure A.2. Post-breeding-season movements of female common murre 5851.

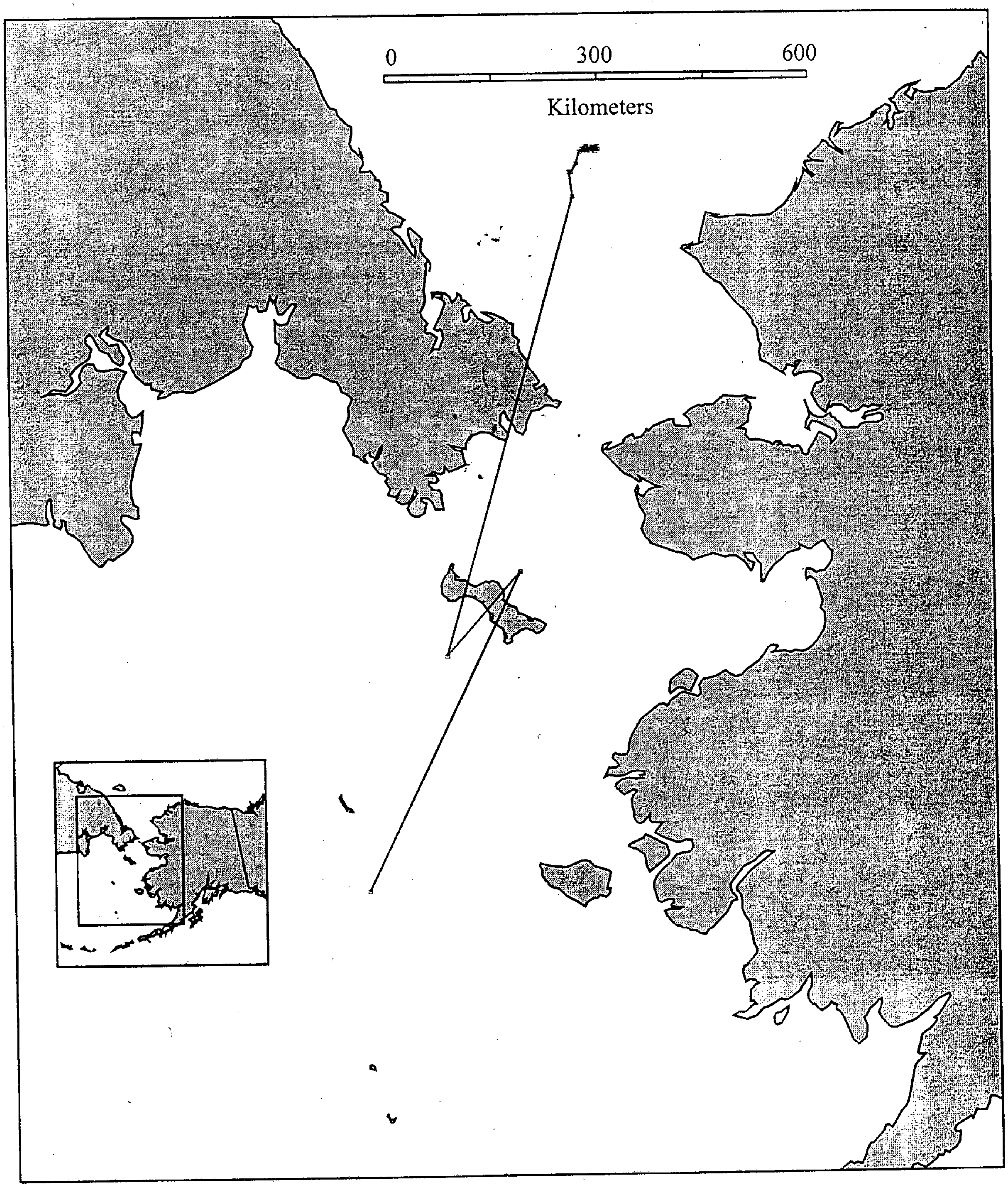


Figure A.3. Track lines of male common murre 5852 from Cape Lisburne, AK, 1996. Short-cycle transmitter. In contact 5 days.

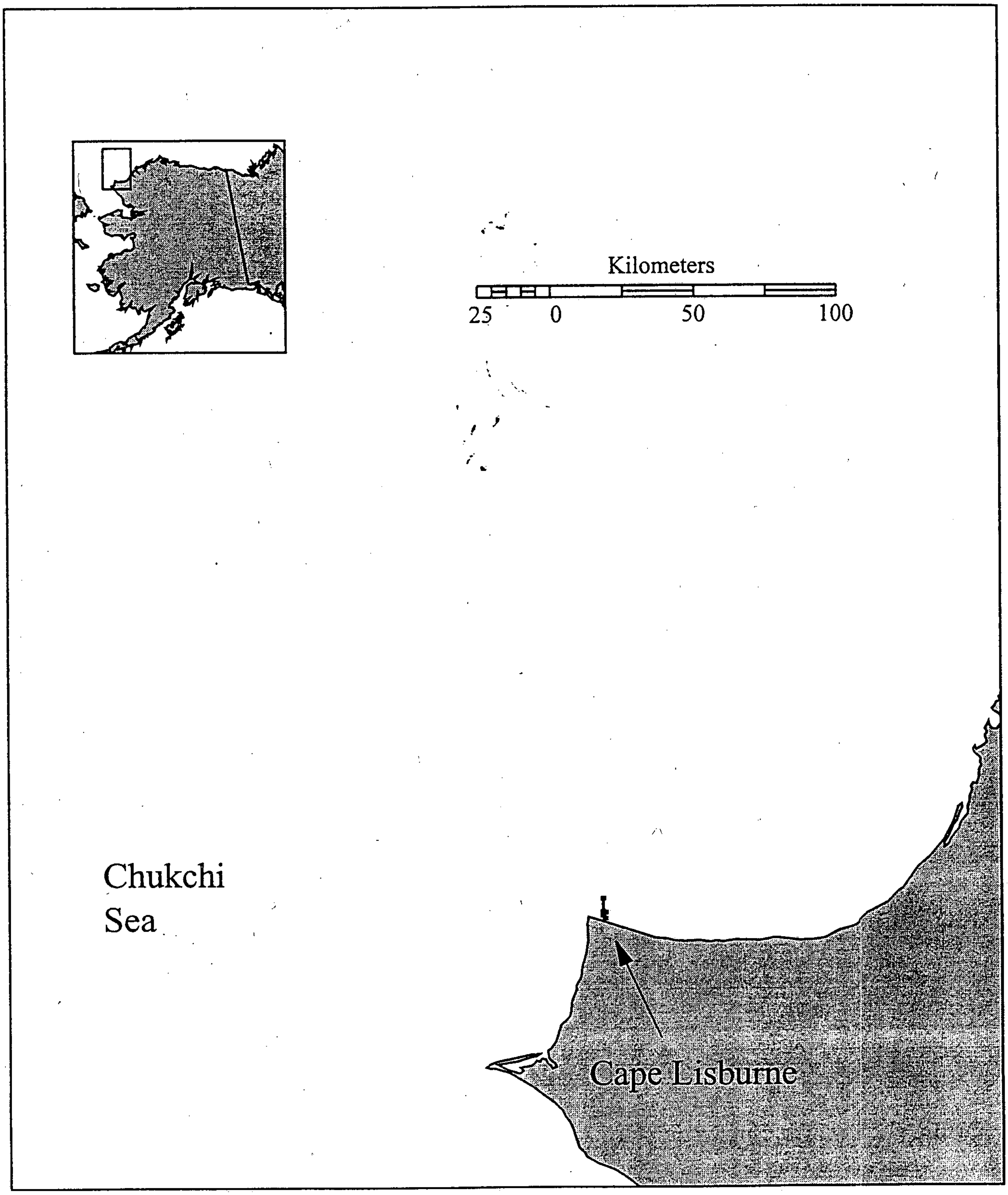


Figure A.4. Track lines of female thick-billed murre 5853 from Cape Lisburne, AK, 1996. Short-cycle transmitter. In contact 5 days.

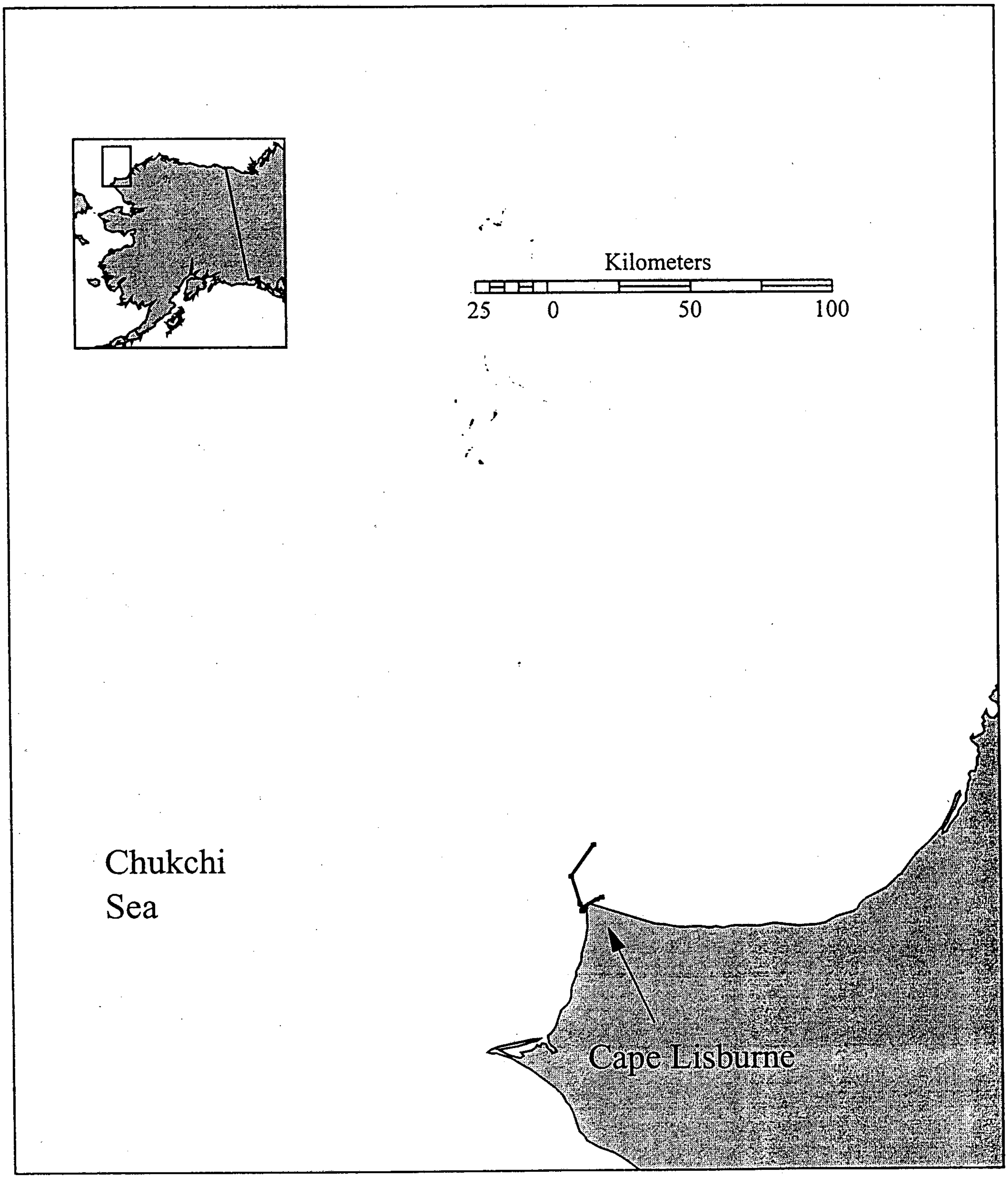


Figure A.5. Track lines of male thick-billed murre 7875 from Cape Lisburne, AK, 1996. Long-cycle transmitter. In contact 1 day.

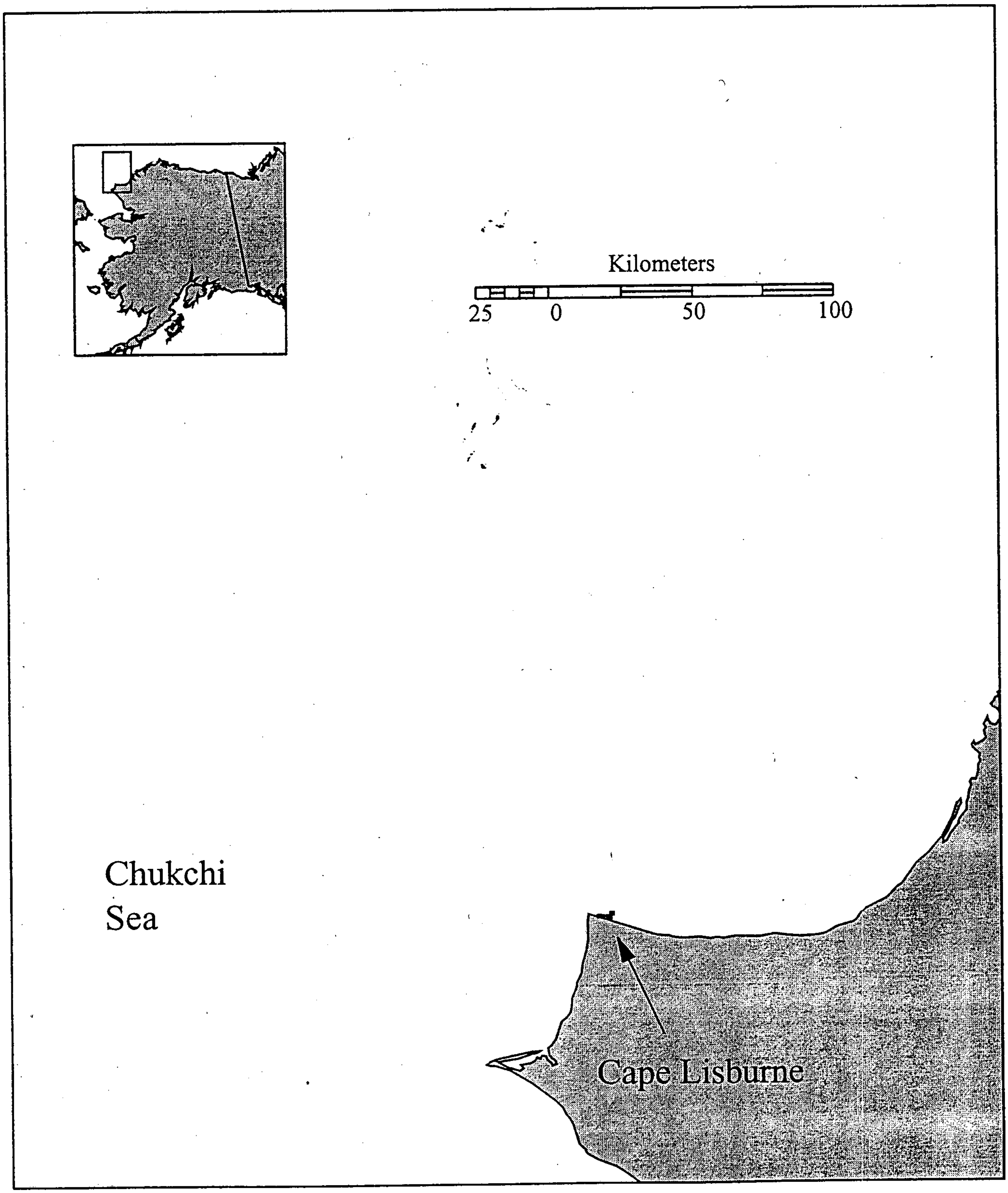


Figure A.6. Track lines of male thick-billed murre 7876 from Cape Lisburne, AK, 1996. Short-cycle transmitter. In contact 8 days.

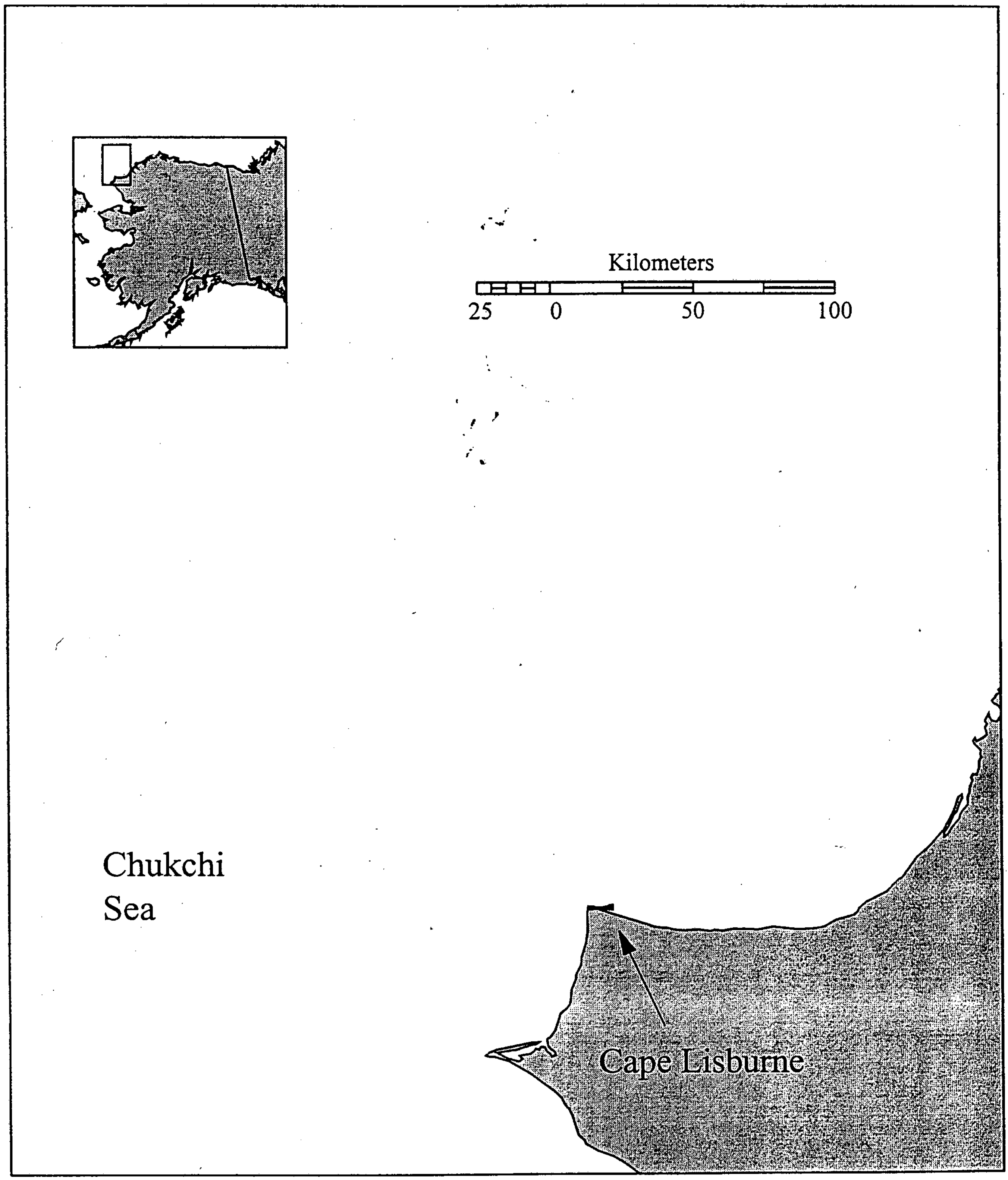


Figure A.7. Track lines of female common murre 7879 from Cape Lisburne, AK, 1996. Long-cycle transmitter. In contact 41 days.

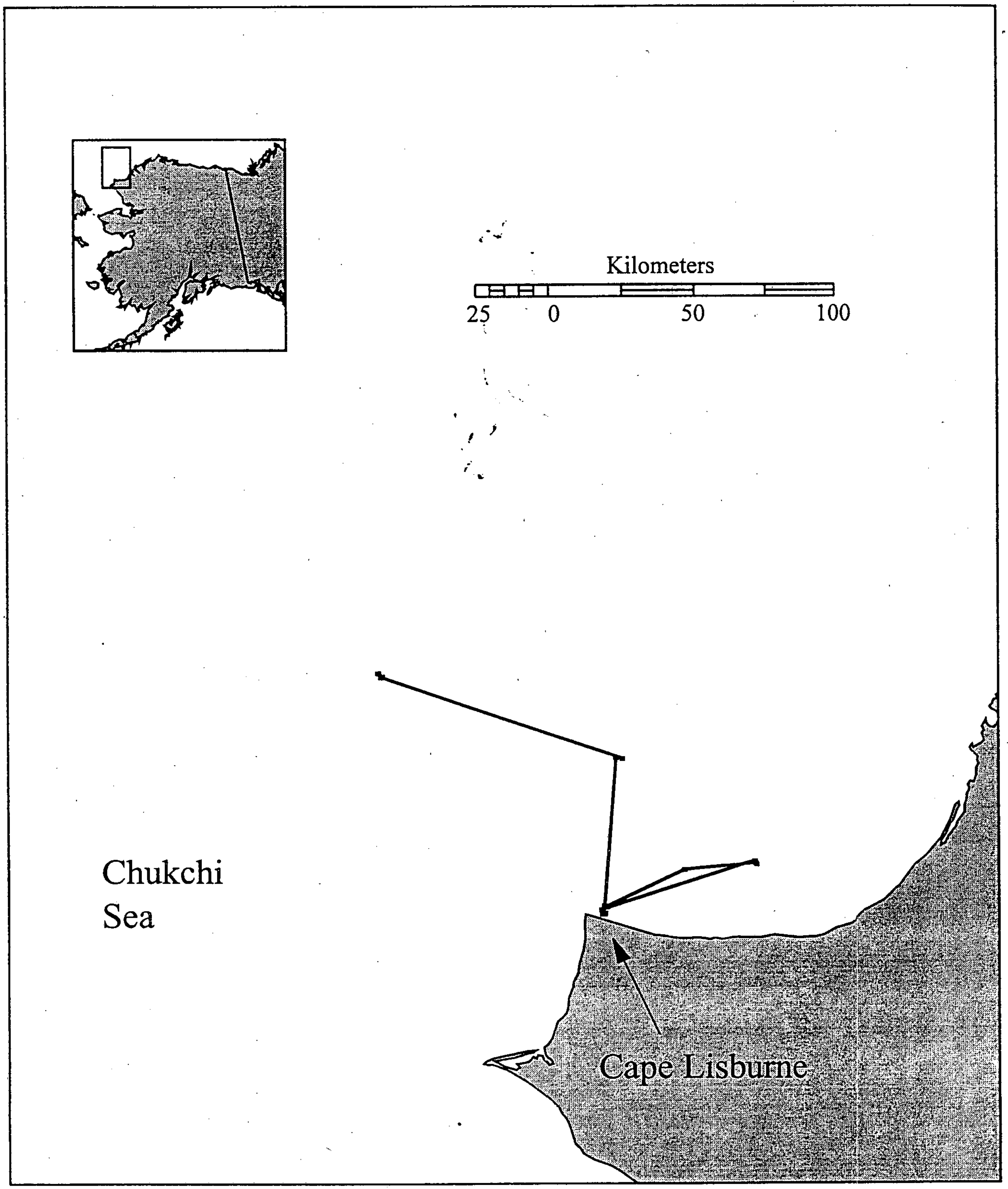


Figure A.8. Post-breeding-season movements of female common murre 7879 from Cape Lisburne, AK, 1996.

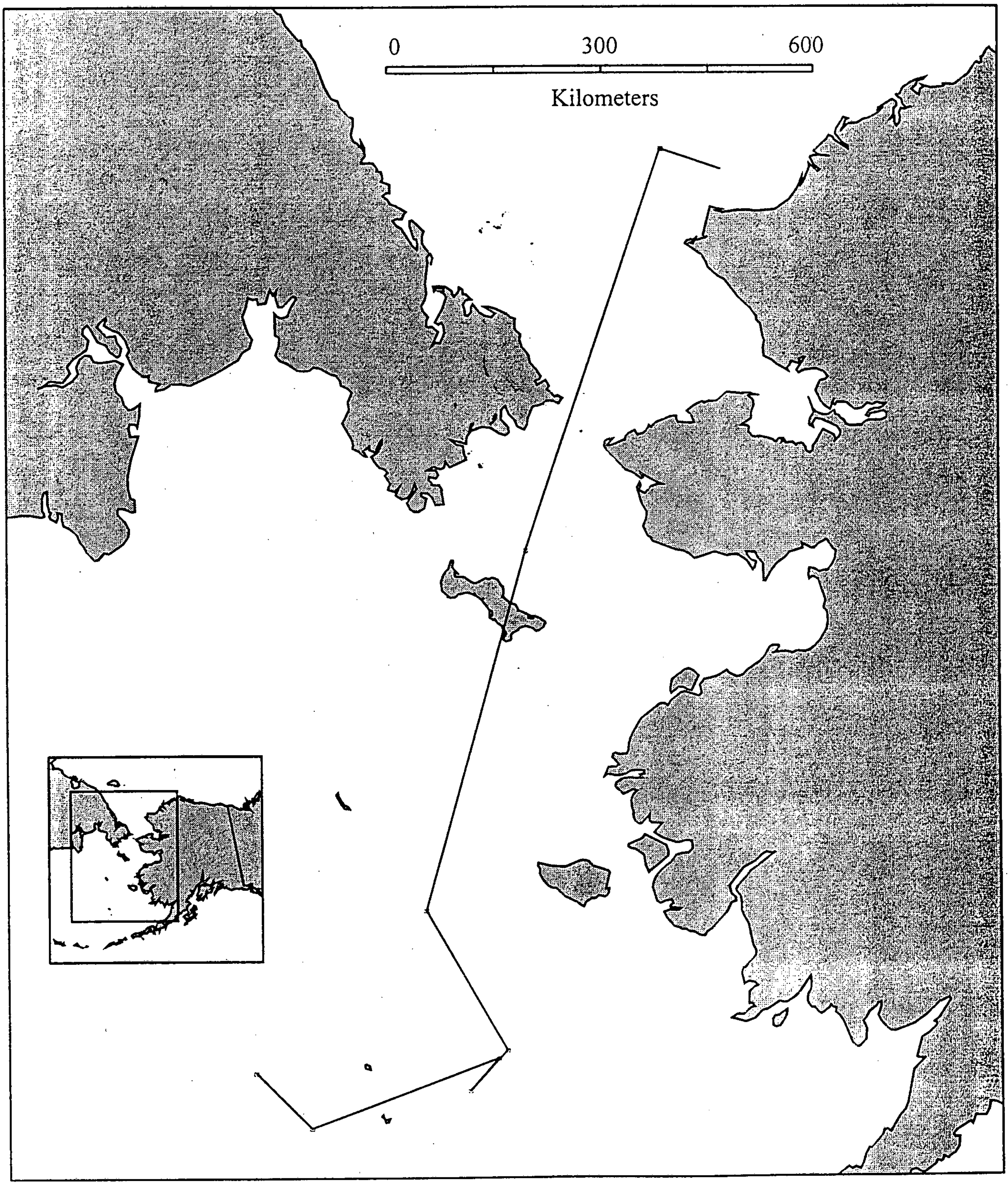


Figure A.9. Track lines of female common murre 7882 from Cape Lisburne, AK, 1996. Short-cycle transmitter. In contact 31 days.

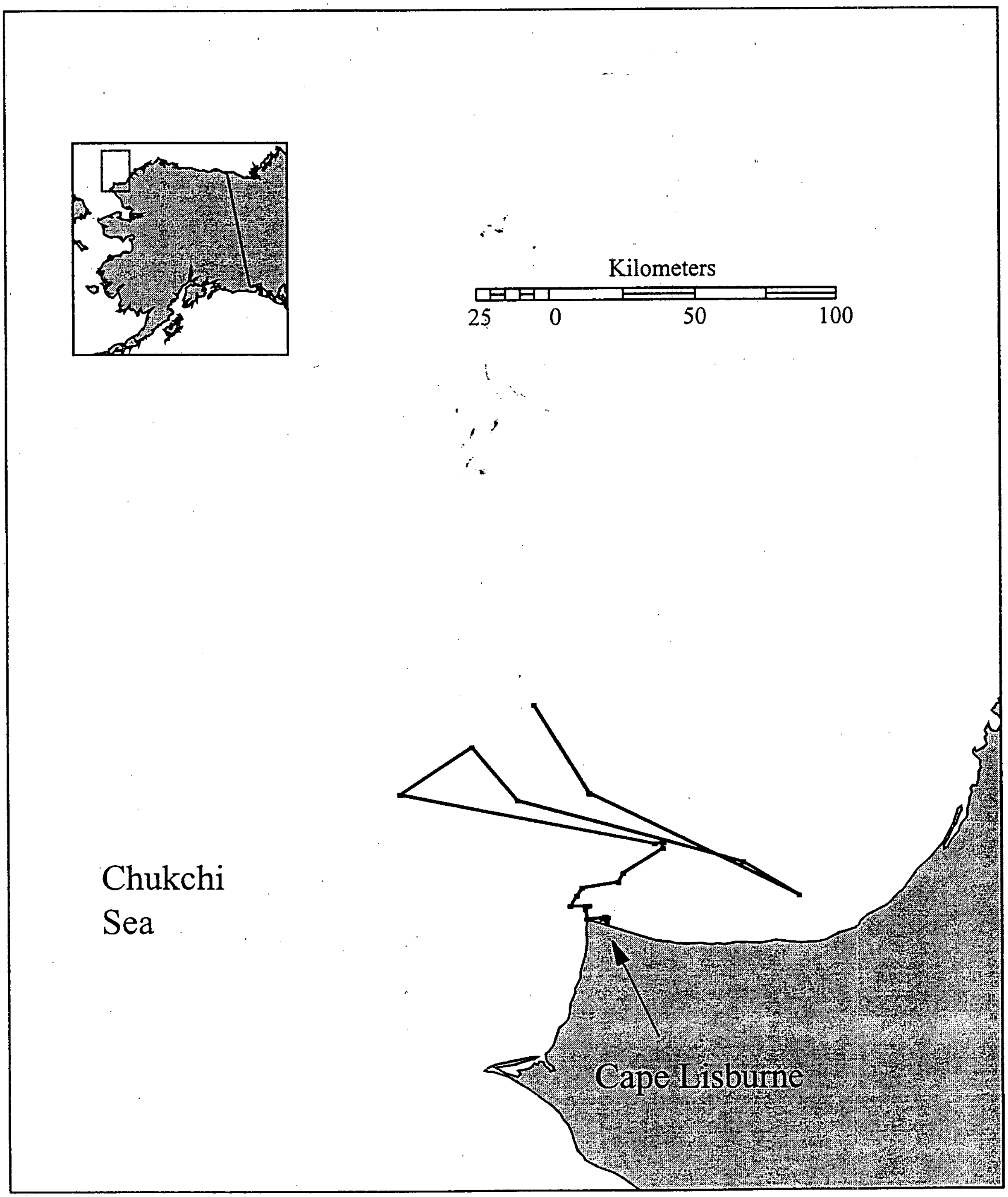


Figure A.10. Track lines of male common murre 7884 from Cape Lisburne, AK, 1996. Long-cycle transmitter. In contact 87 days.

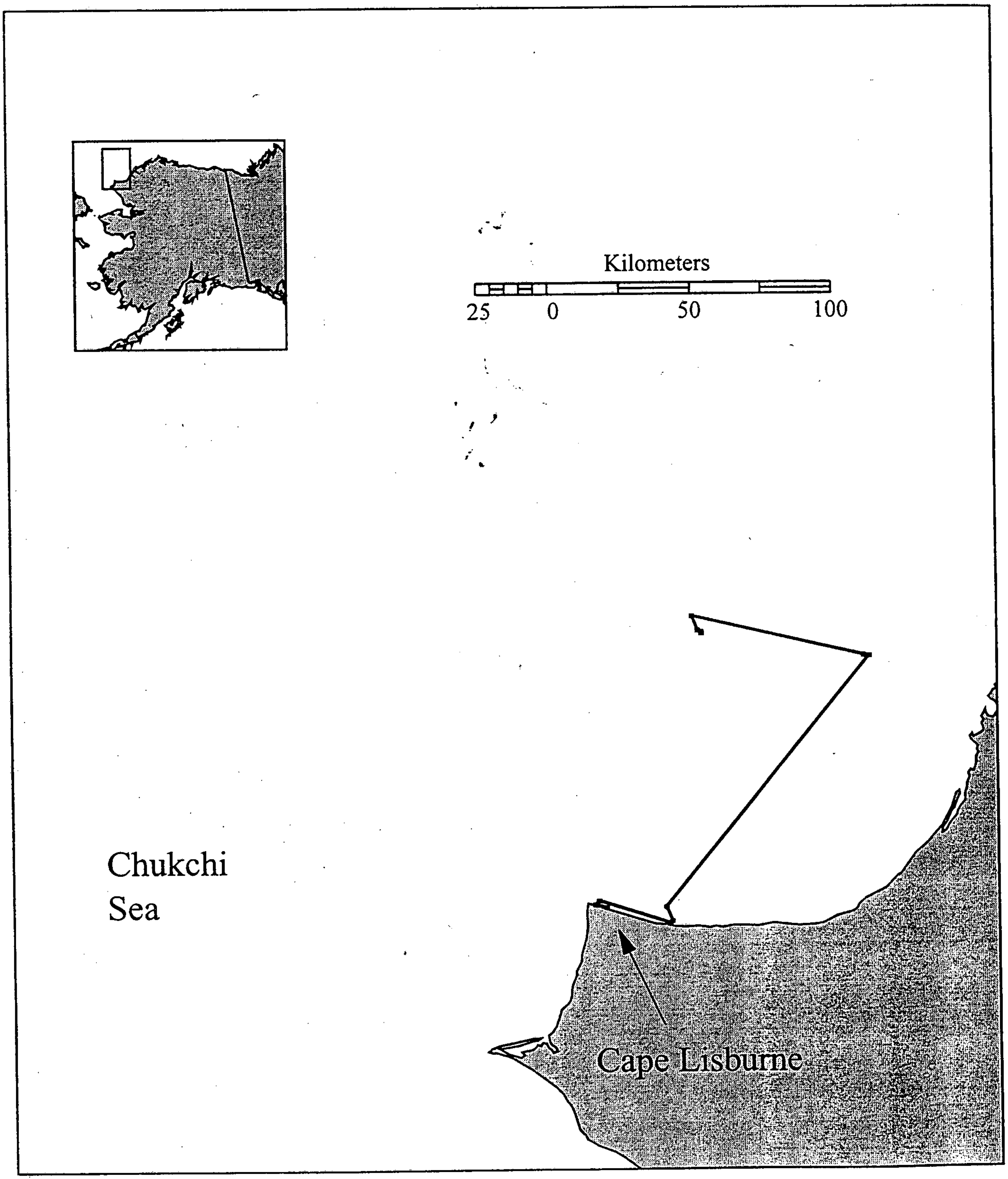


Figure A.11. Post-breeding-season movements of male common murre 7884.

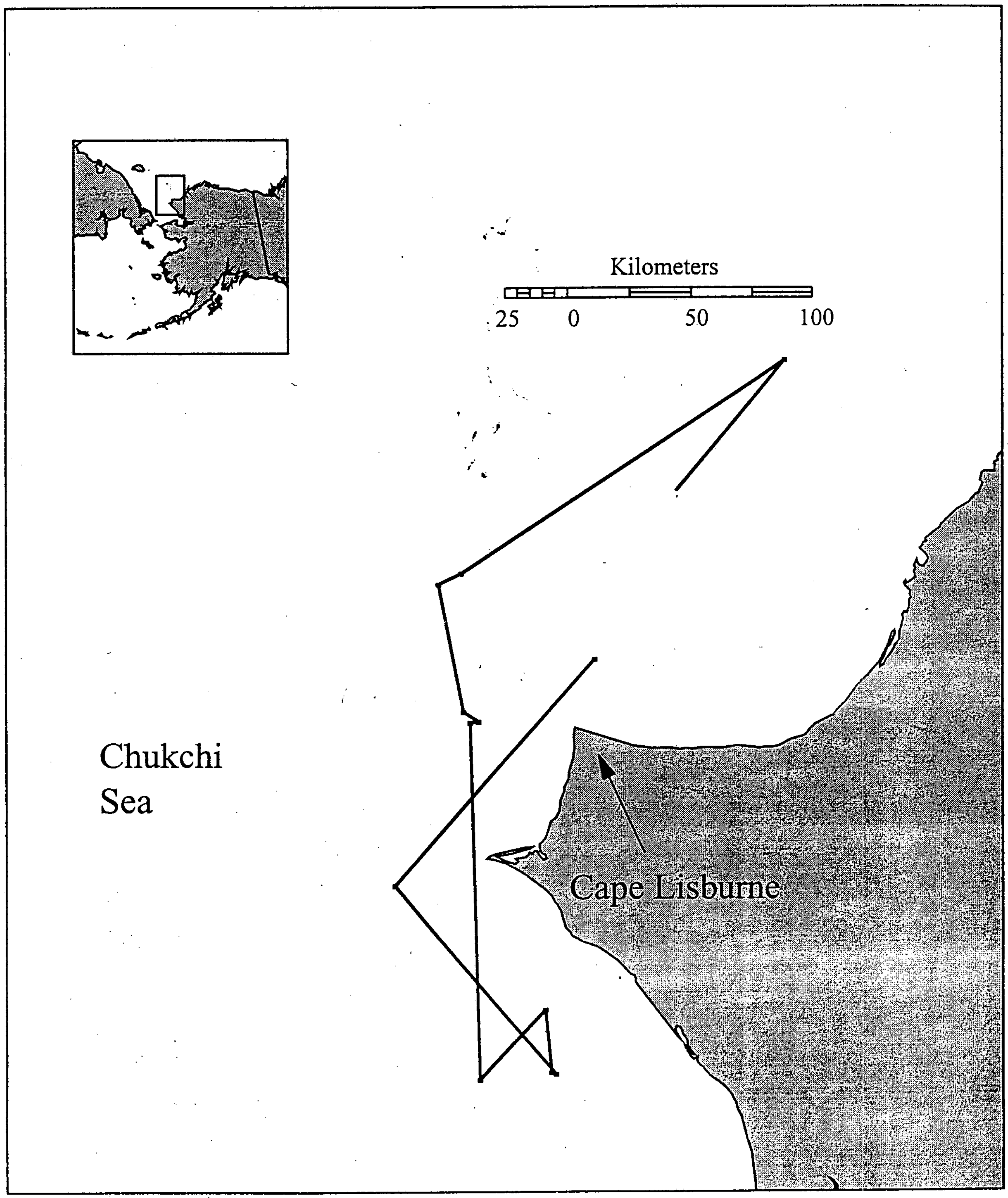


Figure A.12. Track lines of female thick-billed murre 7887 from Cape Lisburne, AK, 1996. Long-cycle transmitter. In contact 1 day.

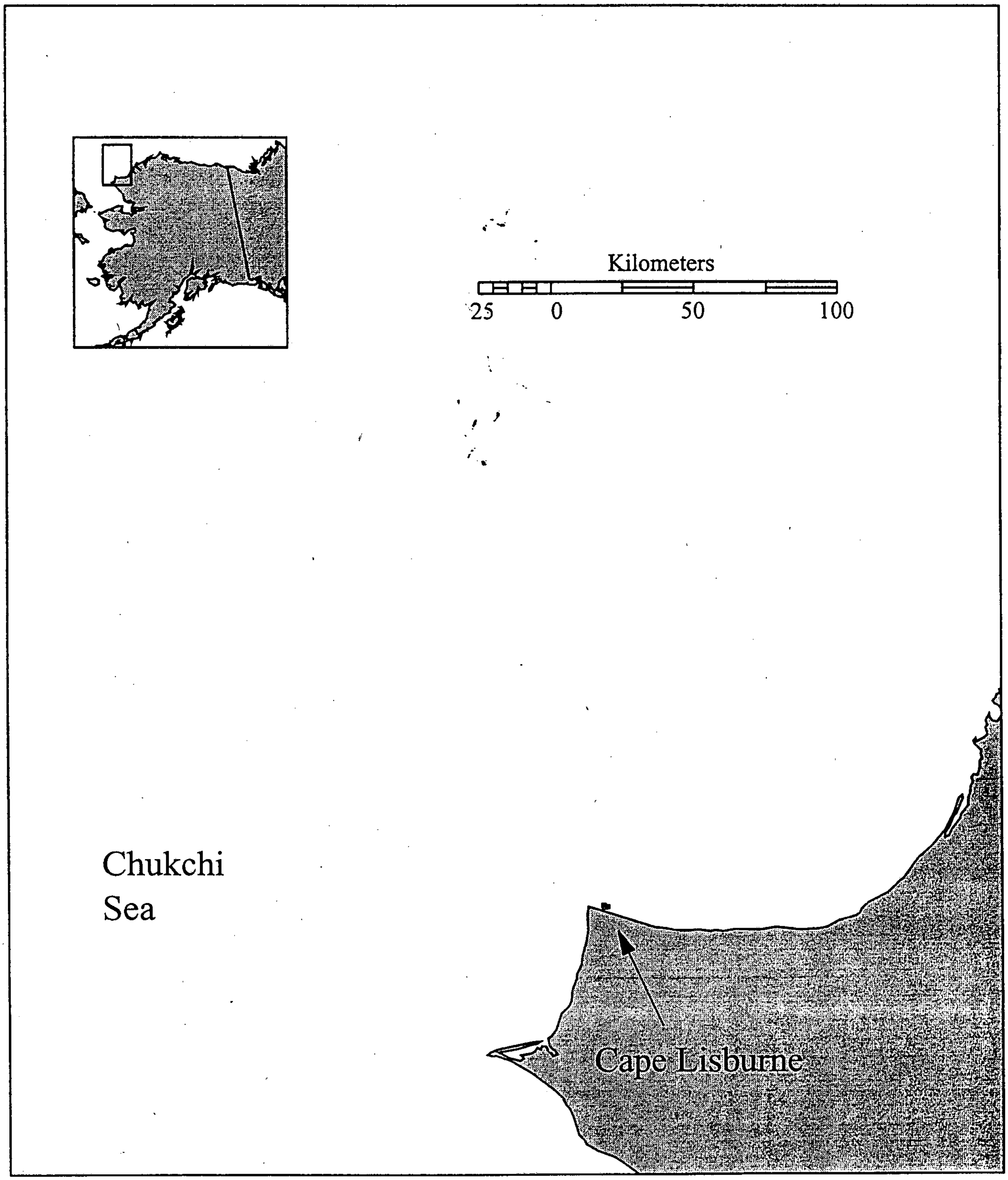


Figure A.13. Track lines of male common murre 7888 from Cape Lisburne, AK, 1996. Long-cycle transmitter. In contact 68 days.

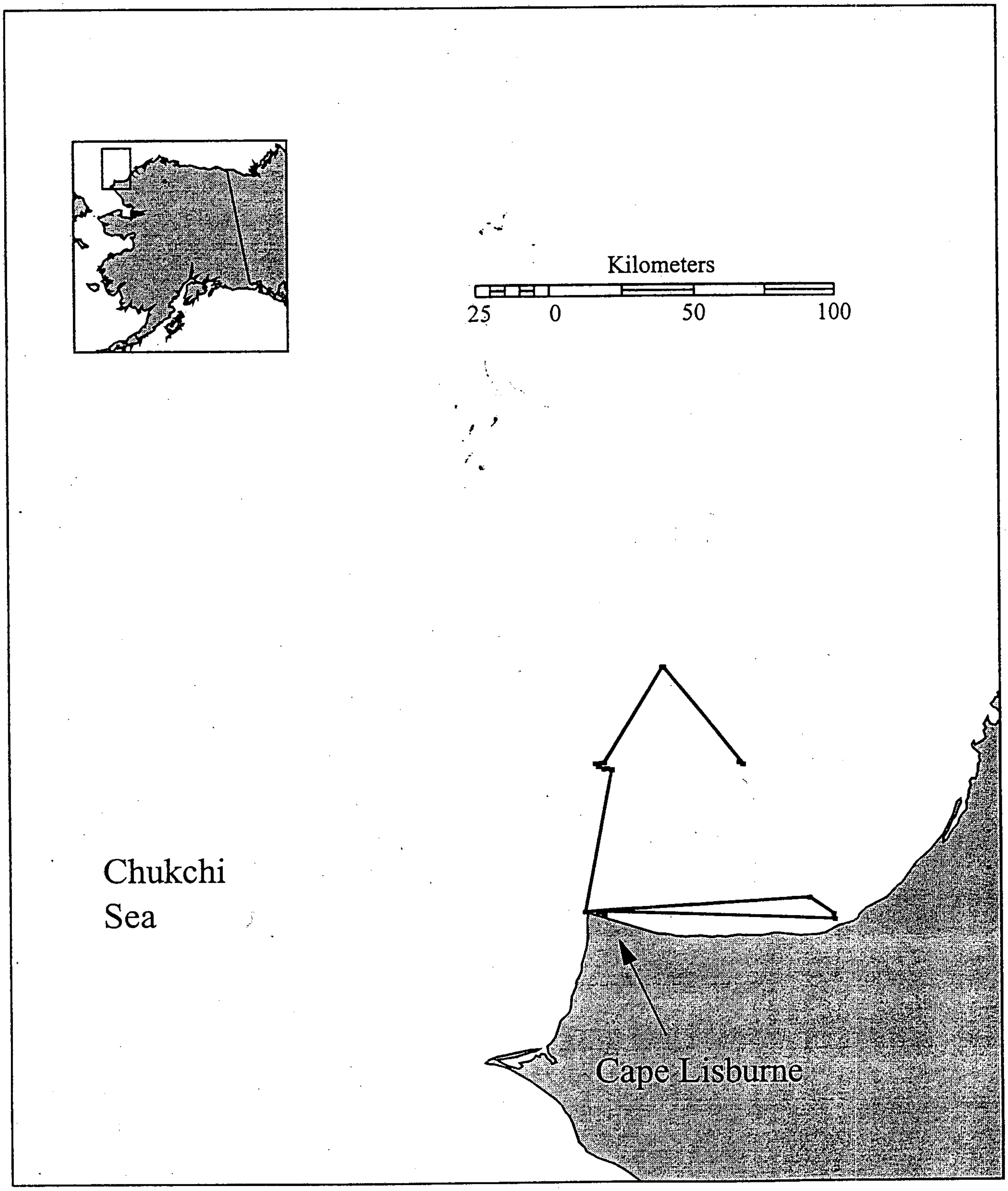


Figure A.14. Post-breeding-season movements of male common murre 7888.

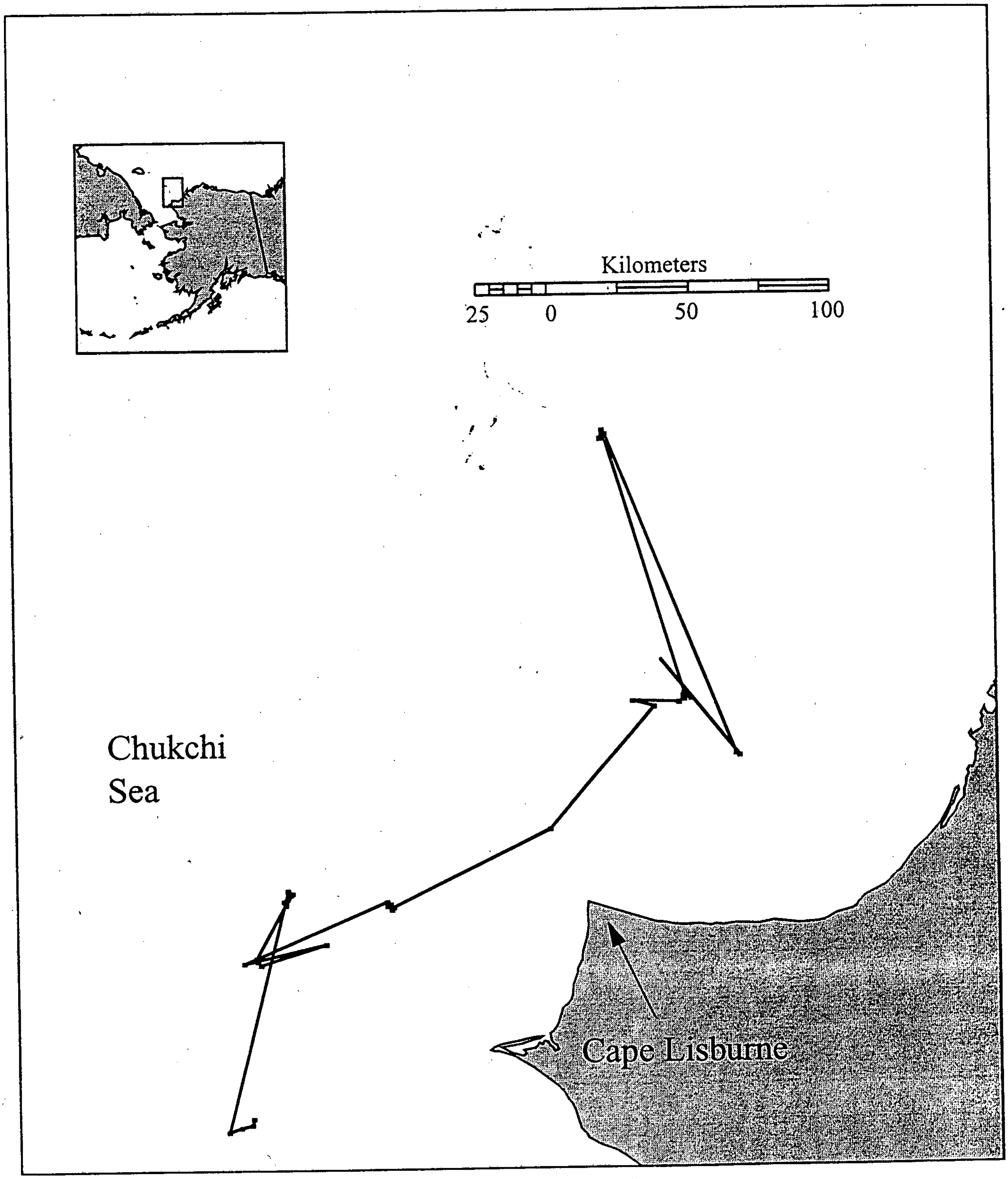


Figure A.15. Location of female thick-billed murre 7901 from Cape Lisburne, AK, 1996. Long-cycle transmitter. In contact 14 days.

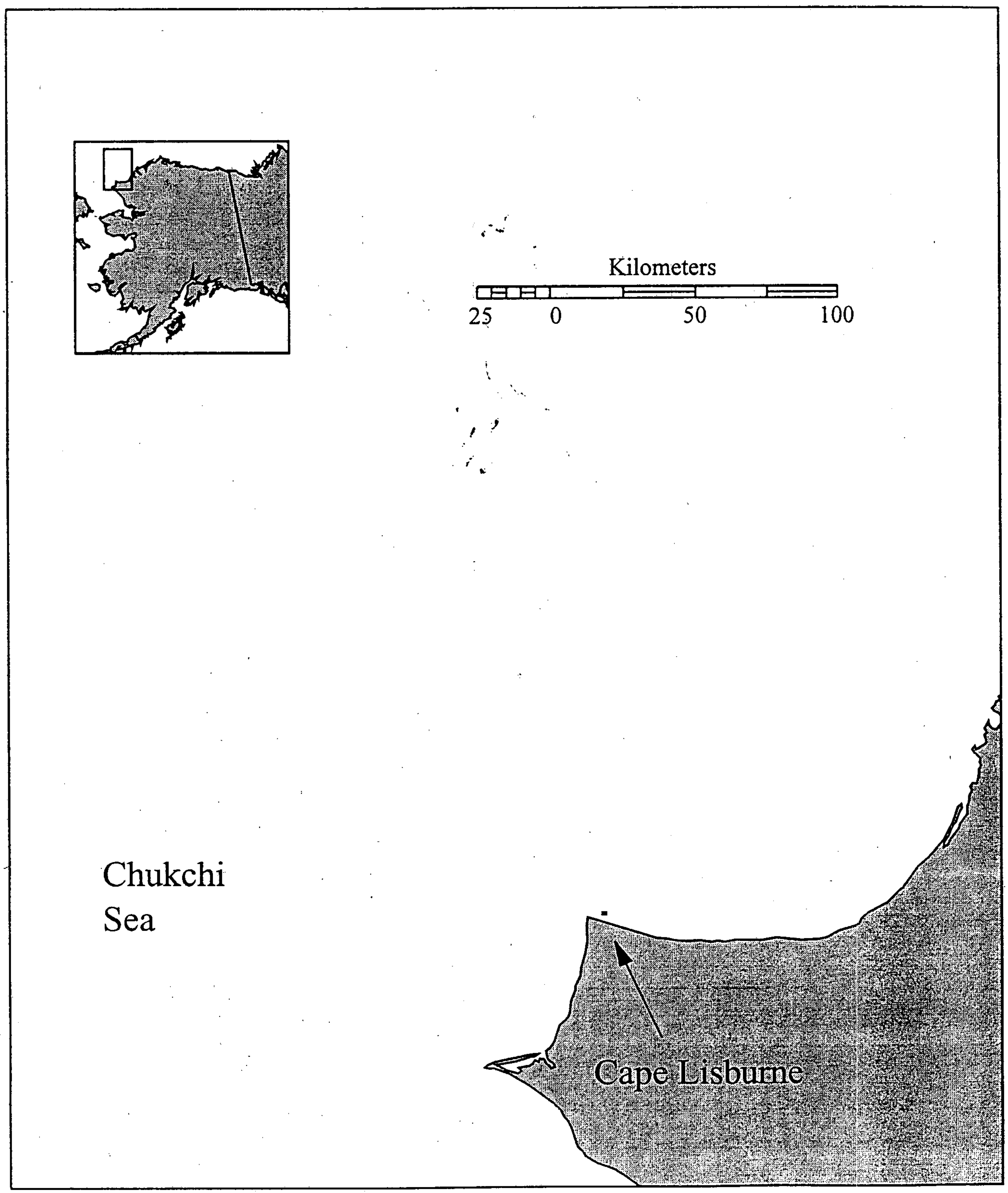


Figure A.16. Post-breeding-season movements of female thick-billed murre 7901 from Cape Lisburne, AK, 1996.

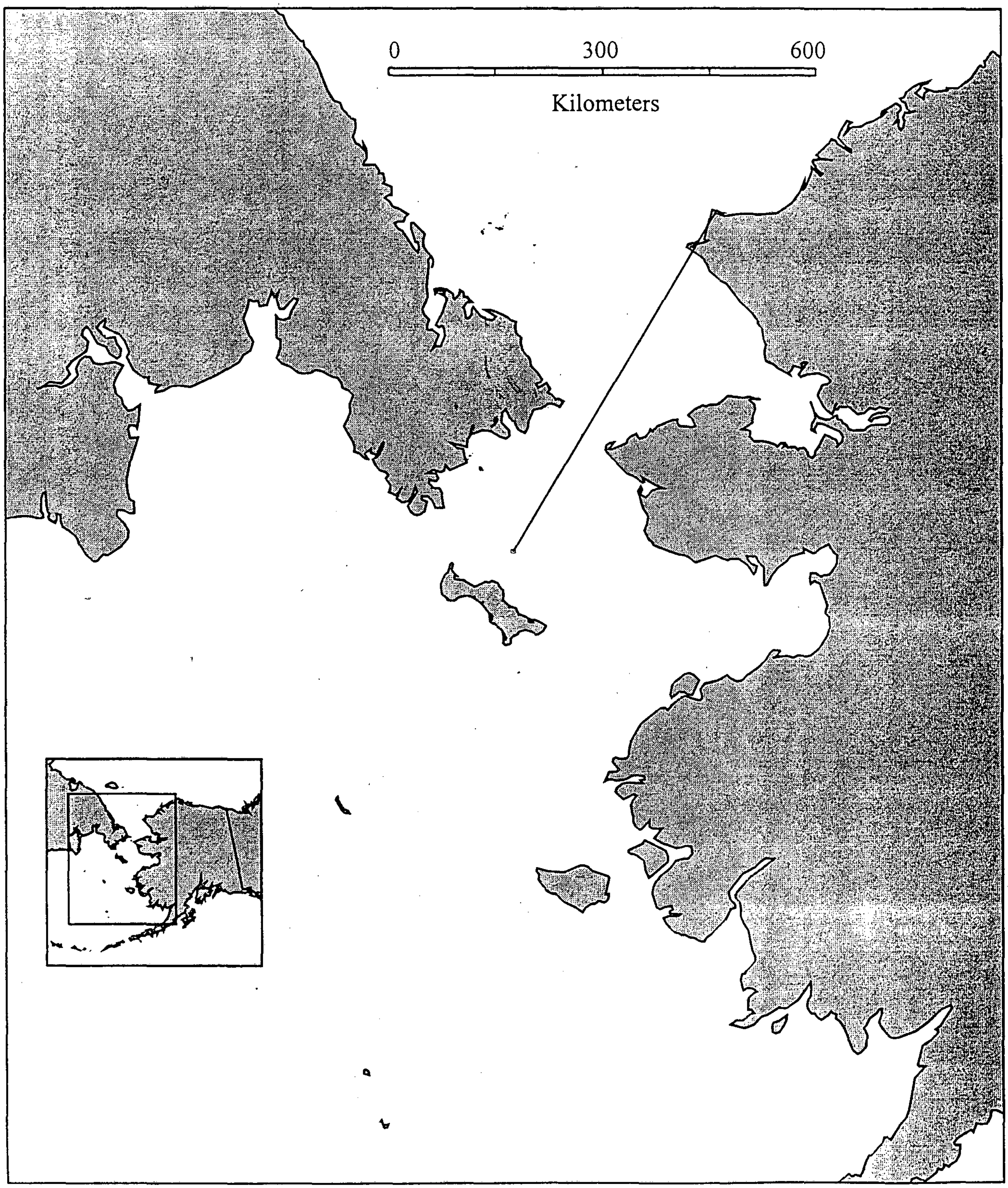


Figure A.17. Track lines of male thick-billed murre 7903 from Cape Lisburne, AK, 1996. Long-cycle transmitter. In contact 74 days.

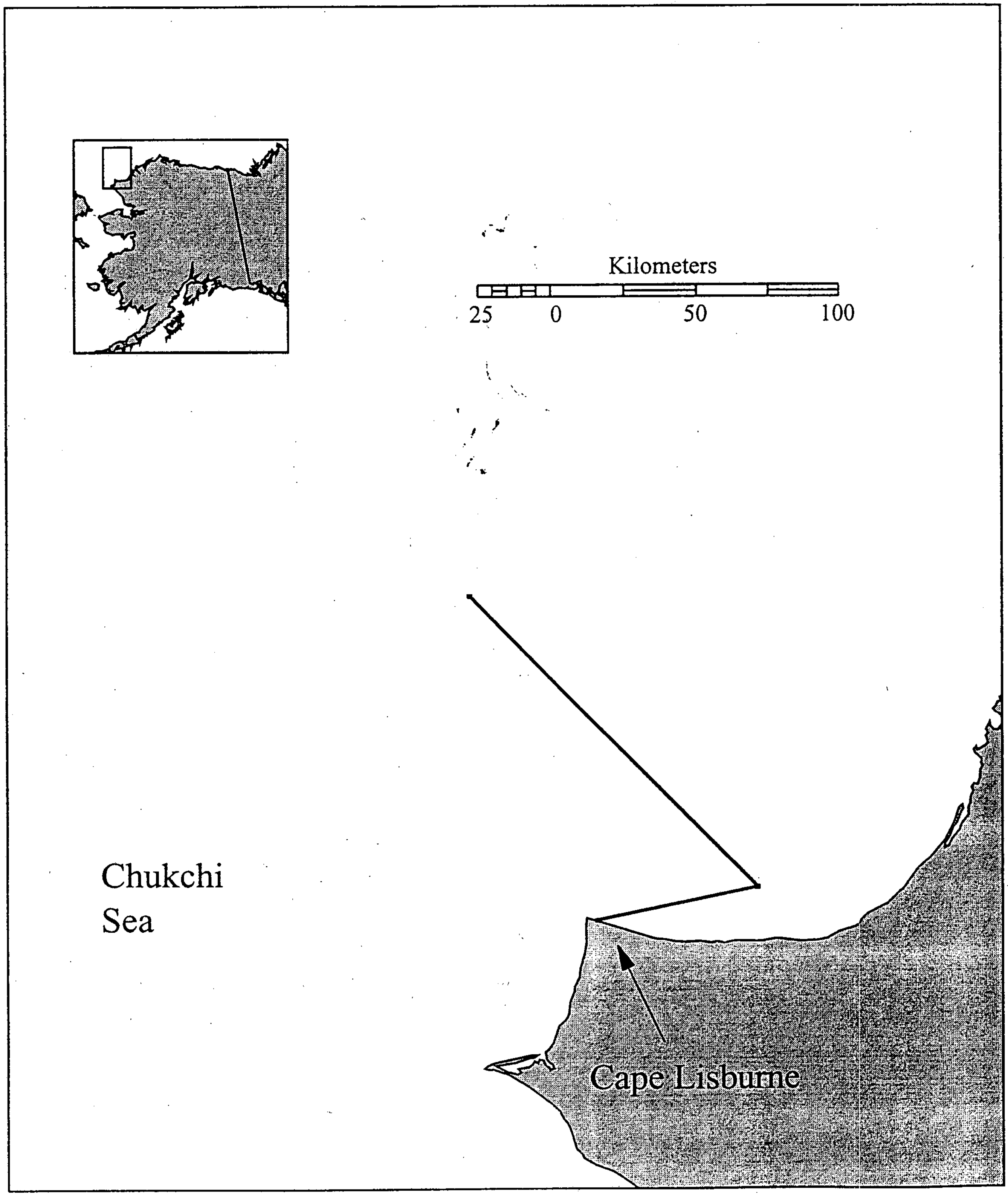


Figure A.18. Track lines of male thick-billed murre 7915 from Cape Lisburne, AK, 1996. Short-cycle transmitter. In contact 18 days.

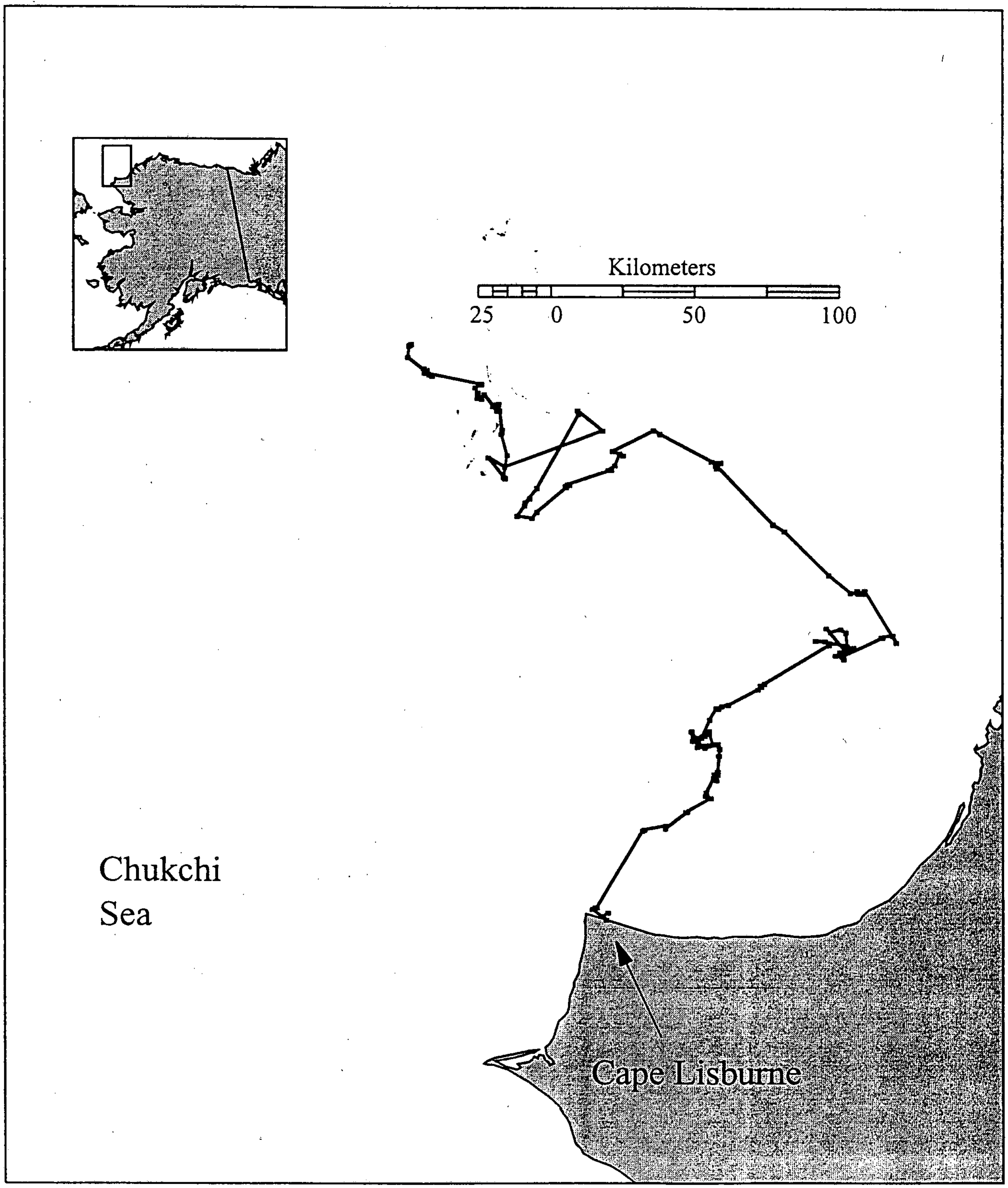


Figure A.19. Track lines of female thick-billed murre 7917 from Cape Lisburne, AK, 1996. Short-cycle transmitter. In contact 11 days.