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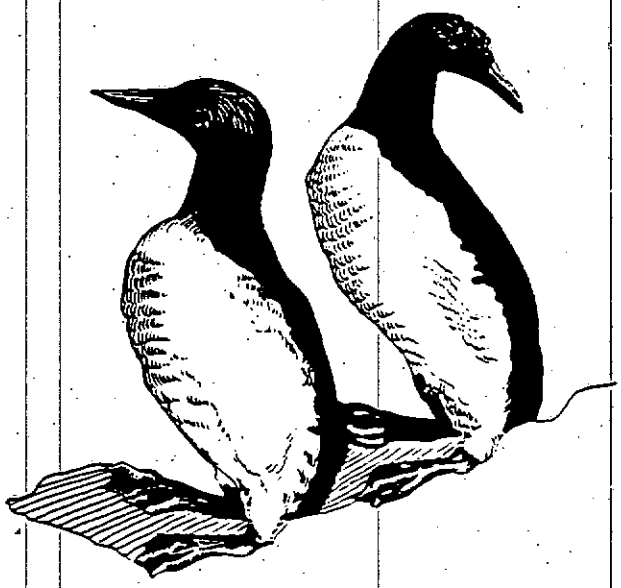
Monitoring Seabird Populations in Areas of Oil and Gas Development on the Alaskan Continental Shelf:

ESTIMATES OF MARINE BIRD AND SEA OTTER ABUNDANCE IN LOWER COOK INLET, ALASKA DURING SUMMER 1993 AND WINTER 1994

Final Report



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EXECUTIVE SUMMARY

We conducted surveys of marine birds and sea otters (*Enhydra lutris*) in Lower Cook Inlet, Alaska during June 1993 (summer) and February-March 1994 (winter). During summer 1993, we used small boats to survey 411 transects randomly-placed throughout the Inlet and recorded 56 bird and 6 mammal species. We estimated the overall summer population of birds (± 95% CI) as 798,042 ± 195,555 individuals. During summer 1993, population estimates were 37,333 ± 13,586; 254,975 ± 168,684; and 505,733 ± 97,995 marine birds in the shoreline (≤0.1 nautical mile (nm) of shore), coastal (>0.1 nm and ≤3 nm of shore), and pelagic (>3 nm from shore) strata, respectively. Total bird density within the Inlet was 57.9 marine birds/km^2. Densities by stratum were 152.9 birds/km^2 in the shoreline, 71.6 birds/km^2 in the coastal, and 50.7 birds/km^2 in the pelagic strata.

Alcid (Family Alcidae, 38.1%) was the most common species group during summer 1993, and the majority of these were murres (*Uria* spp., 21.2% of total). The second most common species group was tubenose (Order Procellariiformes, 35%), consisting of shearwaters and fulmars (*Puffinus* spp. and *Fulmarus glacialis*, 20.7% of total) and storm-petrels (*Oceanodroma* spp., 14.3% of total).

Marine birds were distributed throughout the Inlet during summer 1993, although the highest estimates of birds were near breeding colonies. Large numbers of pelagic species, such as shearwaters and murres, were found in the eastern half of the Inlet from Kachemak Bay south.

During winter 1994, we limited our survey area to the eastern portion of Lower Cook Inlet. We observed 43 bird and 4 marine mammal species. We estimated that the wintering bird population was 122,946 ± 25,804 birds. We divided the winter study area into three strata: shoreline (≤0.1 nm of shore), bay (>0.1 nm and east of 152°04' W longitude), and pelagic (between 152°04' W and 152°28' W longitude). We estimated that 14,611 ± 2,792; 75,310 ± 21,069; and 33,025 ± 14,634 birds were in the shoreline, coastal, and pelagic strata, respectively. Total density in the study area was 33.6 birds/km^2 during winter 1994. We calculated densities of 214.2 birds/km^2 in the shoreline stratum, 61.7 birds/km^2 in the coastal, and 13.9 birds/km^2 in the pelagic strata.

Waterfowl (Family Anatidae, 46.0% of total) was the most common species group during winter 1994 with a population estimate of 56,607 ± 19,985 birds. Most of these were scoters (*Melanitta* spp., 23.9% of total). We estimated that 40,271 ± 12,810 alcids (32.8%) were in the Inlet during our winter survey. The alcid species group consisted of murres (20.7% of total), *Brachyramphus* murrelets (marbled and Kittlitz's murrelets, *B. marmoratus* and *brevirostris*; 9.5% of total), and pigeon guillemots (*Cepphus columba*, 2.4% of total).

Marine birds were distributed in low numbers throughout the study area during winter 1994. Most birds were found in the protected bays and fjords along the southern shore of Kachemak Bay.

During winter 1994, we also conducted an aerial shoreline survey of western Lower Cook Inlet and Kachemak Bay. Along the western shoreline, we counted a

total of 1,486 marine birds within a 0.1 nm zone, an area comparable to our small boat surveys, and 4,807 marine birds within a 0.2 nm zone, an area similar to that used by previous surveys (Erikson 1977, Arneson 1980). Most birds in both zones on the west side were waterfowl (83%, 0.1 nm zone; 93%, 0.2 nm zone). In Kachemak Bay, we counted 7,092 marine birds within the 0.1 nm zone and 15,775 birds in the 0.2 nm zone. In Kachemak Bay, most birds were either waterfowl (51%, 0.1 nm zone; 41% 0.2 nm zone) or alcids (34%, 0.1 nm zone; 46%, 0.2 nm zone) in both zones.

We estimated that 5,914 $\pm$ 3,094 sea otters were in Lower Cook Inlet during summer 1993. Of these, 520 $\pm$ 534; 2,855 $\pm$ 2,014; and 2539 $\pm$ 2,287 sea otters were in the shoreline, coastal, and pelagic strata, respectively. During winter 1994, we estimated that 1,104 $\pm$ 592 otters were present in the eastern portion of Lower Cook Inlet. Of these, 172 $\pm$ 107 otters were in the shoreline stratum, 933 $\pm$ 583 otters were in the bay stratum, and no otters were recorded in the pelagic stratum.

We also sighted other marine mammals including harbor porpoise (*Phocoena phocoena*, summer only), Dall's porpoise (*Phocoenoides dalli*), minke whale (*Balaenoptera acutorostrata*, summer only), Steller sea lion (*Eumetopias jubatus*), and harbor seal (*Phoca vitulina*).

INTRODUCTION

Lower Cook Inlet is an important area for many marine and coastal birds (Erikson 1977, Arneson 1980, Piatt 1993), but no estimate of the abundance of these species has been determined for 15 years. In 1976, a year-long survey of Kachemak Bay and Lower Cook Inlet was conducted in response to potential petroleum development in the area (Trasky et al. 1977). Eleven different environmental studies were undertaken, including studies of coastal morphology (Hayes et al. 1977), circulation (Burbank 1977), distribution of king crab (*Paralithodes camtschatica*, Haynes 1977) and shrimp (*Pandalus* spp. and *Pandalopsis dispar*, Crow 1977), and distribution and abundance of marine birds (Erikson 1977). Data from additional marine bird surveys conducted in 1977-78 were combined with data from Erikson (1977) in a comprehensive report on the coastal migratory bird habitat of Alaska (Arneson 1980). Both Erikson (1977) and Arneson (1980) determined seasonal densities and distribution of marine birds in Lower Cook Inlet and identified important habitats for these species. Although they provided baseline data on the area, these studies (Erikson 1977, Arneson 1980) were not designed to provide population estimates.

In July 1992, Piatt (1993) conducted a shipboard survey to determine the abundance of marine birds within a 50 km radius of the Barren Islands, located in the mouth of Lower Cook Inlet. Piatt's (1993) study area was further south in the rich waters surrounding the Barren Islands, so data from Piatt (1993) were not comparable with this study.

Seabirds are vulnerable to a variety of human-related sources of mortality, such as entanglement in fishing gear (DeGange and Day 1991) and adverse effects from oil development (King and Sanger 1979). Oil and gas extraction and shipment have been conducted in and around Lower Cook Inlet for over 30 years, raising concern about possible effects on marine species. The Minerals Management Service Cook Inlet Planning Area is expected to be leased in 1996 (J. Hubbard, Minerals Management Service, pers. commun.). To assess potential effects from additional leases, it is necessary to obtain baseline data of the area. Thus, the Minerals Management Service, the National Biological Service, and the U.S. Fish and Wildlife Service funded a study to determine seasonal marine bird and sea otter distribution and abundance within Lower Cook Inlet.

In June (summer) 1993, the U.S. Fish and Wildlife Service, Migratory Bird Management conducted a shipboard survey of Lower Cook Inlet, and in February-March (winter) 1994, we conducted a combined small boat and shipboard survey of the eastern portion of the Inlet and an aerial survey of the western and Kachemak Bay shorelines. Data from these surveys will provide baseline data useful for monitoring changes in bird abundance over time.

OBJECTIVES

The overall purpose of this study was to obtain baseline data on the abundance and distribution of marine bird and sea otter populations in Lower Cook Inlet during summer and winter. Our primary objectives were to:

(1) develop population estimates, with 95% confidence intervals, of marine birds and sea otters in Lower Cook Inlet during summer 1993 and winter 1994;

(2) examine marine bird and sea otter distributions within Lower Cook Inlet and map these in a geographical information system; and,

(3) determine the relative abundance and densities of marine bird species groups within the Inlet during summer 1993 and winter 1994 and compare these data with data from previous surveys of Lower Cook Inlet (Erikson 1977, Arneson 1980) and Prince William Sound (Klosiewski and Laing 1994, Agler et al. 1994a,d).

METHODS

Study Area

Lower Cook Inlet is a large embayment off the northwestern edge of the Gulf of Alaska (Fig. 1). Our summer 1993 study area included all water within Lower Cook Inlet and land within 0.07 nm (100 m) of shore. The southern boundary of the study area was defined by a line from Cape Douglas on the Alaska Peninsula to Point Adam on the Kenai Peninsula. The northern boundary was a line from Harriet Point on the Alaska Peninsula to the southwestern end of Kalgin Island then extending to Cape Kasilof on the Kenai Peninsula (Fig. 1). The study area for the winter 1994 boat survey (Fig. 2) included eastern Lower Cook Inlet from Ninilchik south (60°02' N latitude) to approximately 20 miles north of the Barren Islands (59°04' N latitude). The western boundary of the study area was the 152°28' W longitude line. During February 1994, we also conducted an aerial survey of the shoreline of the western side of Lower Cook Inlet and Kachemak Bay. The aerial survey of the western shoreline extended from Cape Douglas north to and including Tuxedni Bay, and Kachemak Bay was surveyed from Bluff Point to Seldovia Point (Fig. 3).

Lower Cook Inlet is a physically diverse area, containing a wide variety of avian habitats. The southeastern portion of the Inlet and the southern shore of Kachemak Bay are made up of sheltered rocky bays and deep fjords. These waters are generally ice-free in winter and provide important year-round habitat for marine birds (Erikson 1977, Arneson 1980). The north side of Kachemak Bay and the coastline along the northeastern side of the Inlet consists mostly of sand beaches and shallow mudflats with steep cliffs. Two major rivers, the Kenai and Kasilof, enter Lower Cook Inlet south of the town of Kenai, adding to the turbidity of the upper Inlet and lowering salinities in this area (Burbank 1977). Several relatively shallow bays, with extensive tidal flats, are located on the western side of the Inlet. For example, Kamishak Bay, in the southwestern portion of the Inlet, has extensive tidal flats and coastal floodplains.

Lower Cook Inlet is surrounded by large mountains, the Aleutian Range on the west and the Kenai Mountains on the east. This funnels winds up and down the Inlet. predominantly southwest in spring and summer, and northeast in fall and winter (Hayes et al. 1977). Many of the bays on the west side, Kamishak Bay in particular, frequently have localized, strong westerly winds due to air masses from Bristol Bay moving through the mountain passes. The Kenai Mountains block moist air from the Gulf of Alaska, resulting in a relatively low annual precipitation rate of 14-22 inches along the northeastern side of Lower Cook Inlet (Hayes et al. 1977). Precipitation is higher on the northwestern side of the Inlet (Iniskin Bay, mean = 73.2 in) due to funneling of moist southerly winds into areas such as Kamishak Bay (Wagner et al. 1969). In winter, ice floes from Upper Cook Inlet are frequently found as far south as Ninilchik, and the shallow bays off of Kamishak Bay may freeze over. Strong northerly winds during the fall, winter, and spring concentrate sea ice in the western and southwestern portions of the Inlet.

Marine waters within Lower Cook Inlet range from high salinity, low turbidity waters in the southeastern portion of the Inlet, caused by an influx of water from the Alaska Coastal Current (Fig. 4), to relatively low salinity, turbid waters in the northern and western portions of the study area (Erikson 1977). Waters within Cook Inlet are also subject to a large tidal range ($\pm$8 m, Hayes 1977) that generates strong currents. Current velocities of 3.5 m/sec are common, and during spring tides, velocities may exceed 7 m/sec (Horrer 1967). The turbulence created by these swift tidal currents causes Lower Cook Inlet to be fairly well-mixed with little stratification. Stratification may develop seasonally due to high river discharge during the warmer months. The tidal currents and fresh water influx create a counterclockwise circulation pattern within Lower Cook Inlet (Fig. 4).

Survey Methodology

Survey methodology was similar to other surveys conducted in Prince William Sound (Irons et al. 1988a,b; Agler et al. 1994a,d; Klosiewski and Laing 1994) and Southeast Alaska (Agler et al. 1995) allowing comparison among coastal areas within the Gulf of Alaska ecosystem.

Two observers surveyed a sampling window 0.07 nm (100 m) on either side, ahead of, and above the vessel (Klosiewski and Laing 1994). Observers estimated the distance after practicing with objects at a known distance. In winter 1994, we installed radars on each boat, and we used these to maintain a distance of 0.07 nm (100 m) from shore. When surveying shoreline transects, observers also recorded sightings on land within 0.07 nm (100 m) of shore. Observers sampled continuously and used binoculars to aid in species identification. All birds within the survey window were counted, and behavior (ie.- flying, sitting, or following) was recorded for each sighting. Prior to beginning each transect, observers recorded environmental data, including weather conditions, wind speed and direction, water and air temperature, amount of ice, and tidal cycle.

We surveyed during all phases of the tidal cycle. This may affect the species and numbers observed but was unavoidable due to the logistics of covering such a

large area. Many of the bays and shoreline areas in Lower Cook Inlet were shallow. and mudflats extended far offshore during low tide. We usually surveyed transects in these areas at high tide. If a mudflat was exposed, the edge was considered the shore, and transects were run from pre-determined latitudes and longitudes along this edge.

During the summer survey (Agler et al. 1994b), most transects were surveyed when wave height was $\leq$1 ft, and we did not sample when wave height was >2 ft. During the winter survey, we encountered extreme weather conditions (Agler et al. 1994c). We surveyed the pelagic stratum in seas ranging from 2-6 ft., which undoubtedly affected our ability to sight some birds. The surveys of shoreline and bay transects were usually conducted in $\leq$3 ft. seas. We were unable to complete some transects because of ice encountered in the northern portion and bad weather in the southern portion of our study area (Fig. 2).

To calculate population estimates, we assumed that all birds and mammals on transects were counted; however, it was likely that some unknown percentage of birds and mammals was not counted.

Design of Summer Boat Survey

We surveyed Lower Cook Inlet from 7-23 June 1993, a total of 15 days within a 17-day period. We surveyed 411 transects, using three 25-foot (7.5 m) fiberglass boats traveling at speeds of 5-10 nm/hr (9-14 km/hr).

To determine the locations of our transects, we first divided all waters within Lower Cook Inlet into two strata: shoreline and offshore. We then generated a 2-minute latitude by 4-minute longitude grid for the study area with the Atlas Geographical Information System (Strategic Mapping 1992) to separate the starting locations of our transects (Fig. 5). At the latitude of the study area, the 1,096 blocks of the grid were approximately 2 nm^2 (3.7 km^2).

Shoreline Stratum.--The shoreline stratum was defined as all waters within 0.1 nm (200 m) of land and contained a total area of 244.11 km^2 (Table 1). Before selecting transects, we excluded areas of the shoreline stratum that were too shallow (<0.5 ft, 15 cm) for our boats. We then placed a 0.1 nm (200 m) wide strip (buffer) along the shoreline and divided this buffer into segments with the 2 nm^2 grid (Fig. 6). Segments <0.5 nm (0.9 km) were merged with adjacent ones. We randomly chose 30% of these segments for a total of 86 shoreline transects (Fig. 7). The mean length of transects within the shoreline stratum was 2.3 nm (4.3 km), ranging from 0.6 nm (1.2 km) to 4.9 nm (9.0 km). We surveyed 30% of the total area of this stratum.

Offshore Stratum.--We used the blocks of the grid to determine the starting points of our transects. Before randomly selecting the offshore blocks, we examined each block that intersected either land or the boundaries of the study area to determine whether the block was large enough to contain a transect $\geq$0.5 nm (0.9 km). If a block was too small, it was merged with an adjacent block. If a merged block was randomly chosen, the transect extended across both blocks (Fig. 7).

When possible, we oriented our transects north to south to run parallel with the strong tidal currents of Lower Cook Inlet. Thus, we chose the northeastern corner of a

block as the starting point for a transect and extended it to the southeastern corner of the block. If a block intersected land, the transect was drawn perpendicular to the land, thus a few transects were oriented east to west along the northern edge of the block (Fig. 7). Sometimes adjacent blocks were chosen, resulting in the appearance of one long transect (Fig. 7). We stopped between transects to collect environmental data and maintain separation between our sampling units.

We randomly chose 30% (327) of the blocks available in the offshore stratum. In the field, we found that we were unable to survey two selected transects, so we surveyed a total of 325 offshore transects.

The offshore stratum was post-stratified into two strata: coastal and pelagic. The coastal stratum was a 3 nm (5.6 km) zone outside of the 0.1 nm (200 m) shoreline stratum (Fig. 6). We classified transects with ≥50% of their length within the 3 nm (5.6 km) zone as coastal stratum, and transects with <50% of their length within the 3 nm (5.6 km) zone as pelagic stratum. We surveyed 112 transects in the coastal and 213 transects in the pelagic strata. Transects within the coastal stratum averaged 1.8 nm (3.3 km) in length, and we surveyed 2% of the area of this stratum. Transects within the pelagic stratum averaged 2.0 nm (3.7 km) in length, and we surveyed 1.6% of the area of this stratum (Table 1).

Design of Winter Surveys

Winter Boat Survey

During winter 1994, we reduced our study area within Lower Cook Inlet (Fig. 2). We divided this area into three strata: shoreline, bay, and pelagic. We surveyed the shoreline and bay strata on 10 days from 6 February-5 March 1994 using two or three 25-foot (7.5 m) fiberglass boats, and we surveyed the pelagic stratum on seven days from 8 February-10 March 1994 using a 73-foot (22.3 m) charter vessel. Due to gale force winds and extreme cold temperatures, we were unable to survey all transects within the time available. The harbor in Homer was frozen for approximately two weeks, and even when the winds subsided, we were able to leave the harbor only when a larger boat broke a path through the sea ice.

To determine the locations of our transects, we used methods similar to those described for the summer survey. We first divided all waters within eastern Lower Cook Inlet into three strata: shoreline, bay, and pelagic, then we constructed a 2-minute latitude by 4-minute longitude grid over the study area to separate the starting locations of the transects.

Shoreline Stratum.--The shoreline stratum was defined as all waters within 0.1 nm (200 m) of land and contained a total area of 68.21 km^2 (Table 1). For the winter 1994 survey, we randomly chose 50% of the available transects for a total of 37 shoreline transects (Fig. 8). The mean length of transects within the shoreline stratum was 2.4 nm (4.4 km), and we surveyed 52% of the total area of this stratum.

Bay Stratum.--The bay stratum contained all waters >0.1 nm (200 m) from land, east of 152°04' W longitude and south of 59°46' N latitude, essentially Kachemak Bay (Fig. 2). We surveyed 61 transects in the bay stratum (Fig. 8), averaging 1.7 nm (3.1 km) in length (Fig. 8). We surveyed 3.1% of the area of this stratum.

Pelagic Stratum.--The pelagic stratum consisted of all waters between 152°28' W and 152°04' W longitude and north of 59°46' N latitude (Anchor Point). In this stratum, we surveyed from a 73-foot (22.3 m) vessel, which traveled at 10 nm/hr (14 km/hr). We surveyed nine lines extending from the southern boundary of the study area north to 60°02' N (Fig. 8). The lines ranged in length from 14.9-56.0 nm (27.6-103.8 km) and were spaced four degrees of longitude apart, approximately 2 nm (3.7 km). We subdivided these lines into 2 nm (3.7 km) segments similar to the bay transects and randomly selected 50% (85 transects) of these segments for use in our population estimates (Fig. 8). These segments averaged 2.0 nm (3.7 km) in length, and we surveyed 2.7% of the area of this stratum (Table 1).

Surveys Comparing Large and Small Boats.--In the past, many pelagic surveys of marine birds were conducted from large ships (Gould et al. 1982, Tasker et al. 1984, Haney 1985, Gould and Forsell 1989). Large ships were usually relatively slow-moving, and the preferred method was to survey long, straight lines rather than numerous, short ones. Using a large vessel for our winter pelagic survey allowed us to compare the differences in population estimates calculated from a few long lines surveyed in their entirety with estimates derived from numerous, short transects, as in our summer 1993 survey.

To compare the differences between long lines and short transects, we surveyed nine long lines and randomly-selected 2 nm (3.7 km) segments from within these lines. We used a Monte-Carlo simulation to randomly-select 50% of the segments (without replacement) 1,000 times. For each run, we calculated the coefficient of variation (CV) of the population estimate. We compared these values with those calculated for the lines by determining how often (%) the CV of the segments was lower than the CV of the lines. Surveying only 50% of all possible segments would require less effort than surveying long lines. To compare population estimates calculated by both methods using a similar amount of effort, we determined population estimates using 50% of the segments, then we simulated a larger sample size (equal effort) by increasing the sample size in the variance.

Winter Aerial Shoreline Survey

To determine abundance of marine birds on the western side of Lower Cook Inlet during winter, we re-surveyed Erikson's (1977) aerial shoreline transects on 9 and 16 February 1994 (Fig. 3). Ameson (1980) combined Erikson's (1977) transects into 17 units, 14.8-76.3 nm (27-141.3 km) in length, with boundaries easily detected from the air. We surveyed 11 of these 17 units. Eight were surveyed completely, but three of the units (3, 5, and 8) were partially surveyed. Surveys were conducted using a Cessna 206 flying at speeds of 90-100 nm/hr (167-185 km/hr) at an elevation of 200 ft (61 m). To compare our counts with previous surveys (Erikson 1977, Ameson 1980), we counted birds in a 0.2 nm (400 m) wide zone. Two observers recorded all birds within 0.1 nm (200 m) on each side of the aircraft. Starting and ending times were recorded for each sampling unit.

To compare data from the aerial shoreline survey with our boat survey, we also conducted an aerial survey of Kachemak Bay on 17 February 1994 (Fig. 3).

Observers on aerial surveys generally miss more birds than observers on boats (Conant et al. 1988). Small, dark birds are especially difficult to see at the high speeds traveled by most aircraft. We compared the aerial shoreline survey with our boat survey of the shoreline of Kachemak Bay to develop correction factors to enable us to compare our data with previous surveys (Erikson 1977, Arneson 1980). We calculated correction factors by dividing the boat estimate by the aerial counts for each area. We only calculated correction factors for species observed on both surveys. Thus, we could not obtain correction factors for species difficult to see from the air, such as *Brachyramphus* murrelets, which were not seen within the 0.1 nm (200 m) aerial survey zone. We then used the correction factors to calculate corrected counts for the 0.1 nm (200 m) western shoreline and the combined shoreline survey zones and for the total (0.2 nm) counts from all three areas (western, Kachemak Bay, and combined shorelines).

Statistical Analysis

Grouping of Data.--Birds that were difficult to classify by species were analyzed by species group (Table 2). For example, short-tailed and sooty shearwaters (*Puffinus tenuirostris* and *P. griseus*) were grouped as shearwaters (*Puffinus* spp.). Gulls (*Larus* and *Rissa* spp.), shorebirds (Families Charadriidae and Scolopacidae), puffins (*Fratercula* spp.), and waterfowl were analyzed both by individual species and by the four groups. During shoreline surveys, we observed several species that are not ordinarily classified as marine birds. Of these, we analyzed only the data for bald eagles (*Haliaeetus leucocephalus*) and northwestern crows (*Corvus caurinus*), species common along the Alaskan shoreline.

Population Estimates.--We used a ratio estimator to estimate population sizes and variances (Cochran 1977). The population estimate of each species or species group was calculated for each stratum using the formula:

$$\hat{Y} = X \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} x_i},$$

where:

$\hat{Y}$ = *population estimate for a stratum.*
X = *total area of the stratum.*
y_i = *number of birds counted on the ith transect.*
x_i = *area of ith transect.*

The areas for each stratum are listed in Table 1. Estimated variances for the population estimates were calculated as follows:

$$\hat{v}(\hat{Y}_R) = \frac{X^2}{\bar{x}^2} \cdot \frac{\Sigma y_i^2 + \hat{R}^2 \Sigma x_i^2 - 2\hat{R} \Sigma x_i y_i}{n(n-1)}$$

where:

$\hat{v}(\hat{Y}_R)$ = *estimated variance of* $\hat{Y}_R$.
n = *number of transects sampled in the stratum.*
$\bar{x}$ = *mean area of all transects sampled in the stratum.*

$$\hat{R} = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} x_i}$$

Data from each stratum were treated as a simple random sample to estimate the population for that stratum. We calculated population estimates for each species and for all birds by adding the estimates from the three strata. We calculated 95% confidence intervals for these estimates by adding the variances.

Densities of Marine Birds.--To compare our results with previous surveys of Lower Cook Inlet (Erikson 1977, Arneson 1980) and with similar surveys of Prince William Sound in July 1993 (Agler et al. 1994a) and March 1994 (Agler et al. 1994d), we calculated bird densities (birds/km^2). Densities were determined by dividing our population estimates by the area of each stratum.

Relative Abundance of Marine Birds.--We compared relative abundance of species in Lower Cook Inlet with that from Prince William Sound. To determine relative abundance, we determined the total population of marine birds and calculated the proportion of birds belonging to each major species group for both areas.

Species Distribution.--We mapped our sightings with a geographical information system (Strategic Mapping 1992). This system allowed us to overlay the distribution of two species.

Comparison with Prince William Sound.--To compare the results of our Lower Cook Inlet survey with a similar region, we used the results of Prince William Sound surveys conducted in July 1993 (Agler et al. 1994a) and March 1994 (Agler et al. 1994d). To minimize between year variation, we compared surveys conducted during different months of the same year (ie.--June and July) rather than two surveys conducted in the same month but two or three years apart.

Bird distribution by month may be affected by breeding phenologies of various species. We examined the differences between June and July by comparing surveys of Prince William Sound conducted during June and July 1990. To determine the proportion of difference, we divided the June population estimates by the July population estimates (Klosiewski and Laing 1994, K. Laing, U.S. Fish and Wildlife Service, unpubl. data). Scoters, *Brachyramphus* murrelets, and murres showed notable differences between months. The population estimates of scoters and *Brachyramphus* murrelets were higher during July. The murre estimate was lower in July, but overall, the murre population estimates tended to be highly variable among years.

The shoreline strata of both Lower Cook Inlet and Prince William Sound were defined using the same criteria, but the coastal and pelagic strata were defined differently. Thus, we compared the differences between the shoreline strata of the two areas directly, but to compare the coastal and pelagic strata, we combined them into one offshore stratum.

Improvement of the Survey.--Precision can be improved by increasing sample size and using stratification to minimize variances within strata (Pojar et al. 1995). In a multi-species survey, such as this one, it is often impossible to stratify in the most appropriate manner for each species. Prior to the June 1993 survey, we divided Lower Cook Inlet into two strata: shoreline ($\leq$0.1 nm from shore) and offshore (>0.1 nm from shore). We then post-stratified by dividing the offshore stratum into a coastal ($\leq$3 nm of shore) and a pelagic strata (>3 nm of shore), and we used this design to calculate the population estimates presented here (Table 3). This design provided fairly good CV's for some species but not for all. To make recommendations for future surveys, we examined several other stratifications to determine whether the precision of the estimates would be improved by re-stratification of future surveys (Table 3).

When we examined the distribution maps from the June 1993 survey, we found that the highest counts of birds were on transects in the east and southeast portions of the Inlet. To re-stratify, we altered the original stratification (shoreline and offshore strata) by dividing the Inlet into east and west strata, which gave us four strata (Fig. 9). We then added a coastal stratum to this design, resulting in six strata (Fig. 10). Because there were fewer birds in the northern part of Lower Cook Inlet, we divided the Inlet at Anchor Point and placed Kamishak and Kachemak Bays into separate strata, resulting in seven strata (Fig. 11). Because many birds were near

colonies during the summer breeding season, we also examined three re-stratifications based upon distance (5, 10, and 15 km) from colonies of >500 birds (USFWS 1995, Figs. 12-14). Because of our initial results, we examined precision by increasing the size of the coastal stratum to 5 nm (Fig. 15).

Estimates may also be improved by increasing effort where the majority of the species are found and reducing effort in areas of low density (Cochran 1977). Thus, if we re-stratify in future surveys, we would also re-allocate effort to improve precision. To simulate this, we distributed transects among strata by two methods. First, we re-allocated transects by the percentage of the total marine birds found in each stratum. We also determined which species contributed most to the variance of the marine bird estimate by calculating population estimates without various species or species groups. Common murres (*Uria aalge*) contributed the most to the variance, so in the second method, we allocated transects by the percentage of murres in each stratum. The resulting sample sizes of transects (n) were used in the variance calculations for each stratum.

To compare among stratifications, we calculated the CV's of species and species groups with population estimates >500 birds then ranked the CV's by stratification designs. We then summed all ranks for each stratification and calculated a mean rank for each stratification.

Survey Frequency.--There are two major reasons to continue to conduct surveys: (1) to determine effects of an environmental perturbation, such as an oil spill; and, (2) to determine long-term trends in population abundance. Klosiewski and Laing (1994) examined the first possibility, which we will discuss later. To examine how often surveys should occur to determine long-term trends in abundance, we conducted a power analysis to calculate our ability to detect trends (Gerrodette 1987, eq. 20). We approximated power for different combinations of CV (0.2, 0.3, 0.4, and 0.5) and confidence level (α = 0.05, 0.10, 0.15, and 0.20).

RESULTS

Summer Boat Survey

We observed 56 bird (Appendix A) and 6 marine mammal (Appendices B and C) species in Lower Cook Inlet during June 1993.

Marine Birds

Population Estimates of Marine Birds.--We estimated that 798,042 $\pm$ 195,555 marine birds were in Lower Cook Inlet during June 1993 (Table 4). Of these, 37,333 $\pm$ 13,586 birds were in the shoreline stratum, 254,975 $\pm$ 168,684 birds were in the coastal stratum, and 505,733 $\pm$ 97,995 birds were in the pelagic stratum (Table 5). Common murre was the most abundant species (168,446 $\pm$ 135,747 birds) followed by fork-tailed storm-petrel (*Oceanodroma furcata*; 113,804 $\pm$ 60,101 birds; Appendix A). Population estimates of individual species and/or major species groups are listed in Table 4 and Appendix A.

Densities of Marine Birds.--During summer 1993, we estimated that density was 57.9 birds/km^2 (Table 6). The highest densities occurred in the shoreline stratum (152.9 birds/km^2) followed by the coastal (71.6 birds/km^2) and pelagic strata (56.7 birds/km^2, Table 6). The highest overall density was estimated for alcids (22.1 birds/km^2) followed by tubenoses (20.3 birds/km^2). However, the species group with the highest density varied among strata (Table 6). The highest density of alcids occurred in the coastal stratum (29.3 birds/km^2). In the shoreline stratum, gulls (89.6 birds/km^2) had the highest density, much higher than the 13.1 birds/km^2 estimated for alcids. In the pelagic stratum, tubenoses had the highest density (26.2 birds/km^2).

Relative Abundance of Marine Birds.--We found that the most common species group (Table 7) during summer 1993 was alcids (38.1%), consisting of murres (21.2% of total), puffins (8.4% of total), and *Brachyramphus* murrelets (7.3% of total). The second most common species group was tubenoses (35.0%), consisting of shearwaters and fulmars (20.7% of total) and storm-petrels (14.3% of total). Gulls (16.2% of total) was the third most common species group. When we examined these data by stratum, we found that the most common species group in the shoreline stratum was gulls (58.6%). Alcids (41.0%), consisting of mostly of murres (32.7% of total), was the most common species group in the coastal stratum, and tubenoses (51.8%), consisting of shearwaters and fulmars (29.3% of total) and storm-petrels (22.5% of total), was the most common group in the pelagic stratum.

Species Distribution.--Overall, marine birds were seen throughout the Inlet (Fig. 16). The transects with the highest counts of birds were located near shore, and most of these were near breeding colonies. Two transects were near a large colony at Chisik Island, and two other transects were on either side of a large colony in Kachemak Bay.

Tubenoses were sighted throughout the pelagic waters, but they were most abundant in the eastern portion of the study area, primarily the southeastern corner (Fig. 17). Shearwaters were common throughout the pelagic waters, but most sightings were in the eastern part of the study area (Fig. 18). Scattered sightings of northern fulmars (*Fulmarus glacialis*) were recorded throughout the eastern portion, but most sightings were along the southeastern border of the study area (Fig. 18). Distribution of storm-petrels was similar to that of fulmars (Fig. 19). Sightings of storm-petrels were most common along a line corresponding to one of the large tide rips found in the Inlet (Fig. 4, Burbank 1977).

Cormorants (*Phalacrocorax* spp.) were usually sighted along the shoreline and were most often seen near small colonies in Kamishak and Kachemak Bays (Fig. 20). Waterfowl were also usually distributed along the shoreline, and the largest estimates were from the western side of the Inlet (Fig. 21).

Although gulls (mostly black-legged kittiwakes, *Rissa tridactyla*, and glaucous-winged gulls, *Larus glaucescens*) occurred in small numbers throughout the Inlet, counts were largest on transects near colonies (Fig. 22). Terns (*Sterna* spp.) were only sighted in the northern end of the study area and within Kachemak Bay (Fig. 23).

Several of these sightings were of Aleutian terns (*S. aleutica*), which rarely nest in Kachemak Bay (G. West, pers. commun.).

Overall, alcids were distributed throughout the Inlet, but most were observed in the eastern part of the study area (Fig. 24). Murres were scattered throughout the area with high numbers observed at the mouth of Kachemak Bay and in the southeastern corner of the Inlet (Fig. 25). Numerous *Brachyramphus* murrelets were observed near the mouth of Kachemak Bay, but small numbers were sighted throughout the Inlet (Fig. 26). Horned (*Fratercula corniculata*) and tufted puffins (*F. cirrhata*) were mostly sighted in the eastern portion of the Inlet (Fig. 27), a distribution similar to that observed for murres (Fig. 25) and shearwaters (Fig. 19). The largest counts of horned puffins were located near Anchor Point at the mouth of Kachemak Bay; whereas, the largest numbers of tufted puffins were observed in the southeastern corner of the Inlet near a large tufted puffin breeding colony. Pigeon guillemots were usually observed along the shoreline, but a few observations occurred in pelagic waters near Anchor Point (Fig. 28).

Sea Otters

Population Estimates of Sea Otters.--From our summer 1993 survey, we estimated that 5,914 $\pm$ 3,094 sea otters were in Lower Cook Inlet (Appendix B). We estimated that 520 $\pm$ 534 otters were in the shoreline stratum, 2,855 $\pm$ 2,014 otters were in the coastal stratum, and 2,539 $\pm$ 2,287 otters were in the pelagic stratum.

Densities of Sea Otters.--We estimated a density of 0.4 otters/km^2 during summer 1993. Density was highest in the shoreline stratum (2.1 otters/km^2) followed by the coastal (0.8 otters/km^2) and pelagic strata (0.3 otters/km^2). In the combined offshore stratum, we estimated a density of 0.4 otters/km^2.

Species Distribution.--Most sea otters (Fig. 29) were observed within 8 nm (14.8 km) of land and along the southern edge of Kachemak Bay, although a few sightings occurred in the more exposed sections of Kamishak Bay. There was one observation of two otters in the middle of the Inlet, approximately 31 km from land.

Winter Boat Survey

During our February-March 1994 survey, we observed a total of 43 species of birds (Appendix A) and 4 species of marine mammals (Appendices B and C).

Marine Birds

Population Estimates of Marine Birds.--We estimated that 122,946 $\pm$ 25,804 marine birds were in the eastern portion of Lower Cook Inlet during winter 1994 (Table 4). Estimates for the shoreline, bay, and pelagic strata were 14,611 $\pm$ 2,792; 75,310 $\pm$ 21,069; and 33,025 $\pm$ 14,634 birds, respectively (Table 8). Waterfowl was the most common species group with a population estimate of 56,607 $\pm$ 19,985 birds. Most of these were scoters (29,408 $\pm$ 11,281 birds). The second most common group was alcids with a population estimate of 40,271 $\pm$ 12,810 birds. Most alcids (63%) were murres, but 29% of the alcids consisted of *Brachyramphus* murrelets (Table 4).

Densities of Marine Birds.--During winter 1994, density was estimated as 33.6 birds/km^2 in the eastern portion of Lower Cook Inlet (Table 9). Densities were 214.2, 61.7, and 13.9 birds/km^2 in the shoreline, bay, and pelagic strata, respectively. Waterfowl had the highest density (15.5 birds/km^2) of any species group followed by alcids (11.0 birds/km^2). Waterfowl had the highest densities in the shoreline (132.5 birds/km^2) and pelagic strata (7.0 birds/km^2), but alcids had a similar density in the bay stratum (alcids, 25.7 birds/km^2; waterfowl, 25.3 birds/km^2).

Relative Abundance of Marine Birds.--The most common species group (Table 10) observed in eastern Lower Cook Inlet during winter 1994 was waterfowl (46.0%), consisting of scoters (23.9% of total), oldsquaws (*Clangula hyemalis*, 9.0% of total), eiders (*Somateria* spp. and *Polysticta stelleri*, 4.7% of total), and goldeneyes (*Bucephala clangula* and *B. islandica*, 3.0% of total). The second most common species group was alcids (32.8%), consisting of murres (20.7% of total), *Brachyramphus* murrelets (9.5% of total), and pigeon guillemots (2.4% of total). The gull species group was the third most common (13.1%).

Species Distribution.--Marine birds were distributed in limited numbers throughout the study area during winter 1994 (Fig. 30), although most birds were concentrated within protected bays and fjords on the southern shore of Kachemak Bay.

Loons (*Gavia* spp., Fig. 31) and grebes (*Podiceps* spp., Fig. 32) were most common along the southern shore of Kachemak Bay. Unlike most species groups, cormorants were found throughout the winter study area (Fig. 33), and they were as common along the northwestern shore of Kachemak Bay as along its southern, more protected side. A number of cormorants were also observed on several of the pelagic transects, including transects in the center of the Inlet.

Most waterfowl were sighted along the southern side of Kachemak Bay (Fig. 34). Steller's eiders (*Polysticta stelleri*, Fig. 35) were found in the protected waters of Kachemak Bay, near Seldovia and Homer; whereas, common eiders (*Somateria mollissima*, Fig. 35) were observed in the open area off of Anchor Point, and one transect in the pelagic stratum had a count of >50 common eiders. Harlequin ducks (*Histrionicus histrionicus*, Fig. 36) and goldeneyes (Fig. 37) were most common along the protected coastline of southern Kachemak Bay. Oldsquaws were frequently observed in the protected waters of Kachemak Bay, but a number of individuals were also sighted on the pelagic surveys north of Anchor Point (Fig. 38). Scoters were sighted on both sides of Kachemak Bay. Several large groups were observed near Anchor Point and Homer and within the protected bays and fjords of the southern shore (Fig. 39).

Although gulls (mostly glaucous-winged gulls) were observed in small numbers on 61.2% of the pelagic transects, the largest numbers of gulls were observed on the mudflats east of Homer (Fig. 40).

Although alcids were also observed throughout the study area, most sightings were located within 8 nm (15 km) of Homer (Fig. 41). The largest counts of murres occurred along the southern shore of Kachemak Bay (Fig. 42), and most *Brachyramphus* murrelets were observed west of Homer (Fig. 43). The distribution of

pigeon guillemots (Fig. 44) during the winter appeared to be more pelagic than during summer 1993 (Fig. 28). Highest densities of guillemots during the winter were in the bay stratum (Table 9); whereas, highest summer densities were in the shoreline stratum (Table 6).

Surveys Comparing Large and Small Boat Methods.--When we calculated population estimates for the pelagic stratum using nine long lines and compared them with 85 randomly-chosen, short segments, we found that the estimates and 95% confidence intervals were similar (Table 11). Using the data from the long lines, we determined that there was a total of 25,484 $\pm$ 17,727 birds in the pelagic stratum. When we calculated the estimate from the short segments, we estimated that 33,025 $\pm$ 14,634 birds were in the pelagic stratum. Some species groups (Table 11), such as murres, had almost identical estimates (5,417 $\pm$ 1,988 birds, lines; 5,391 $\pm$ 1,845 birds, segments).

From a Monte-Carlo simulation, we found that the CV of the estimate of total marine birds calculated from the segments was lower than that calculated from the lines 100% of the time (Table 12). When estimates were calculated from segments, seven species groups had lower CV's >85% of the time. When estimates were calculated from lines, eight species groups had lower CV's >65% of the time. When we simulated equal effort, we found that 11 of the 15 species groups had lower CV's >90% of the time and 13 of the groups had lower CV's >50% of the time when estimates were calculated from short segments instead of long lines (Table 13).

Sea Otters

Population Estimates of Sea Otters.--During winter 1994, we estimated that 1,104 $\pm$ 592 sea otters were in the eastern portion of Lower Cook Inlet (Appendix B). We estimated that there were 172 $\pm$ 107 otters in the shoreline stratum, 933 $\pm$ 583 otters in the bay stratum, and no otters were recorded in the pelagic stratum.

Densities of Sea Otters.--We estimated that the overall density of sea otters in our study area was 0.3 otters/km^2. The highest densities (2.5 otters/km^2) were found in the shoreline stratum; whereas, the bay stratum had a density of only 0.8 otters/km^2. In the combined offshore stratum, density was 0.3 otters/km^2.

Species Distribution.--Although a few otters were observed off of Anchor Point near the mouth of Kachemak Bay, most were seen in protected, ice-free waters along the southern shore of Kachemak Bay (Fig. 45).

Winter Aerial Shoreline Survey

Marine Birds

Number of Birds Observed.--During the winter 1994 aerial shoreline survey of the western side of Lower Cook Inlet, we counted a total of 1,486 marine birds within the 0.1 nm (200 m) zone comparable to the shoreline stratum used in our small boat surveys (Table 14). Eighty-three percent (83%) of these birds were waterfowl. Oldsquaws were the most commonly sighted species (35% of waterfowl); whereas, harlequin ducks, Steller's eiders, and scoters were found in approximately equal

proportions (14, 16, and 17% of waterfowl, respectively). No alcids were counted within the 0.1 nm (200 m) zone. In the 0.2 nm (400 m) zone, we counted 4,807 marine birds (Table 13 and Appendix D). Waterfowl made up 93% of these birds.

We also surveyed three shoreline sections in Kachemak Bay originally surveyed by Arneson (1980). During this aerial survey, we counted 7,092 marine birds within the 0.1 nm (200 m) zone (Table 14). These birds consisted of waterfowl (51.5%) and alcids (34.1%). Most of the waterfowl were mergansers (32.9%) and scoters (27.5%); all of the alcids were murres. Within the 0.2 nm (400 m) zone of Kachemak Bay (Appendix D), we counted 15,775 marine birds (Table 14). Alcids (7,310 birds) outnumbered waterfowl (6,525 birds).

When we combined counts, we tallied 8,578 marine birds in the 0.1 nm (200 m) zone and 20,852 birds in the 0.2 nm (400 m) zone (Table 13). These birds consisted mostly of waterfowl and alcids.

Densities of Marine Birds.--The highest bird densities on the western aerial shoreline survey were waterfowl (9.8 birds/km^2, 0.1 nm zone; 18.0 birds/km^2, 0.2 nm zone). No alcids were sighted in the 0.1 nm (200 m) zone, and only two murres were seen within the 0.2 nm (400 m) zone. Highest waterfowl densities (47 birds/km^2) were observed along the Iniskin Peninsula, and these were all sea ducks (Table 15).

In the 0.1 nm (200 m) zone in Kachemak Bay, the highest density was recorded for waterfowl (62.2 birds/km^2). In the 0.2 nm (400 m) zone, the waterfowl density remained similar (60.0 birds/km^2) to the 0.1 nm zone; whereas, the density of alcids increased from 41.3 birds/km^2 in the 0.1 nm (200 m) zone to 67.2 birds/km^2 in the 0.2 nm (400 m) zone.

Correction Factors.--We combined data from the 0.1 nm (200 m) aerial survey zone with data from the small boat shoreline survey of Kachemak Bay to develop correction factors (Table 16). Correction factors ranged from 0.4 for eiders to 21.3 for buffleheads (*Bucephala albeola*). We could not calculate a correction factor for *Brachyramphus* murrelets, because this species group was not sighted within the 0.1 nm (200 m) aerial survey zone. Correction factors >1 indicated that the small boat surveys estimated a greater number of birds in Kachemak Bay than the aerial shoreline survey counted, while corrections factors <1 indicated that densities from the aerial shoreline survey were greater. Most species or species groups (71%) had correction factors >1.

Sea Otters

During the aerial shoreline survey of the western side of Lower Cook Inlet, we counted 68 sea otters in the 0.1 nm (200 m) zone (Table 13). Estimated density within this zone was 0.5 otters/km^2. In the 0.2 nm (400 m) zone, 186 sea otters were counted, with a density of 0.8 otters/km^2.

In Kachemak Bay, 72 sea otters were counted in the 0.1 nm (200 m) zone, with a density of 0.5 otters/km^2. In the 0.2 nm (400 m) zone, 283 sea otters were counted, and density was 2.6 otters/km^2.

Comparison with Prince William Sound

Densities of marine birds from a similar survey of Prince William Sound during July 1993 (Table 17) and March 1994 (Table 18) were calculated for comparisons with those in Lower Cook Inlet (Tables 6 and 9). Density of total marine birds in Prince William Sound during July 1993 was 41.3 birds/km^2. We found that the species group with the highest total density during summer 1993 was alcids (21.0 birds/km^2), mostly *Brachyramphus* murrelets (17.8 birds/km^2). The summer density in the shoreline stratum was 148.7 birds/km^2, and the density estimated for the offshore stratum was 30.5 birds/km^2. During winter 1994, the total marine bird density within Prince William Sound was 35.7 birds/km^2. The species group with the highest total density was waterfowl (14.8 birds/km^2). During the winter, the density of birds in the shoreline stratum was 190.1 birds/km^2, and the bird density within the offshore stratum was 20.2 birds/km^2.

Relative abundances were also calculated (Tables 19 and 20). Alcids had the highest relative abundance during summer 1993 (50.8%), and most alcids were *Brachyramphus* murrelets (42.9% of total). During winter 1994, the relative abundance of alcids declined to 28%; whereas, the relative abundance of waterfowl increase to 41.3%. Gulls were the second most abundant species group during the summer (31.4%) but dropped to third during the winter (20.4%).

Improvement of the Survey

We found that mean CV's of the various re-stratifications ranged from 0.46-0.49; whereas, the mean CV from the original stratification with no re-allocation of effort was 0.38 (Table 21). Although the original stratification design had the best mean CV, it ranked highest (worst, Table 22). When we simulated re-allocation of transects based on bird abundance as we did for the other stratifications, the rank of the original stratification design tied for the best ranking with the east-west re-stratification including shoreline, coastal, and pelagic strata (Fig. 10).

When we allocated transects by the species having the largest effect on the variance (common murre), mean CV's ranged from 0.38-1.97 (Table 23). Both original stratifications had the lowest mean CV's and held the top two ranks (Tables 23 and 24). By comparing the mean CV's for the groups in each re-stratification (Tables 21 and 23), we found that transect allocation based on common murre distribution resulted in higher CV's.

Survey Frequency

To determine optimum survey frequency, we conducted a power analysis to estimate the probability of detecting trends in abundance using linear regression from a given number of samples (Gerrodette 1987). If all other parameters are equal, we found that power is determined by the number of surveys conducted in a given period of time (Figs. 46-47). Thus, biannual surveys would reveal trends in population abundance earlier than surveys conducted every third year. To provide an accurate recommendation of survey frequency, we should know how long monitoring will persist.

For biannual surveys with CV = 0.3 and α = 0.10, power to detect an average annual change of 10% would be 49% over 10 years (5 surveys), >99% over 20 years (10 surveys), and >99% over 30 years (15 surveys, Table 25). If surveys are conducted every third year, power to detect the same 10% annual trend would be 32% over 10 years (4 surveys), 74% over 20 years (7 surveys), and >99% over 30 years (10 surveys). Biannual surveys conducted over 30 years would have 88% probability of detecting a trend when the average rate of change is only 5% (Table 26), but surveys conducted every third year for the same time period would only have a 45% chance of detecting such a trend.

Power is affected by CV. When we compared CV's for two different rates of change (Tables 24 and 25), we found that when the CV was high (0.5) the power of biannual surveys to detect an average annual change of 10% was low (16% over 10 years, 57% over 20 years, and 96% over 30 years). When the CV was low, power increased to 49% over 10 years and >99% for both 20 and 30 years of surveys. If surveys were conducted every third year and the CV was 0.5, power to detect a 10% annual trend would only be 12% over 10 years, 29% over 20 years, and 57% over 30 years, but when the CV was reduced to 0.2, power increased to 32% over 10 years, 74% over 20 years, and >99% over 30 years. Thus, decreasing the CV, would increase our ability to detect trends.

DISCUSSION

The results of these surveys represent the first estimates of marine bird abundance calculated for Lower Cook Inlet in 15 years. Developing these estimates was a vital step in our understanding of the significance of this area to the marine bird populations of Alaska. For example, our summer estimate of marine birds in Lower Cook Inlet was over twice the estimate calculated for Prince William Sound in July 1993 (Agler et al. 1994a), demonstrating the importance of Lower Cook Inlet within the Gulf of Alaska ecosystem for breeding and non-breeding marine birds and sea otters during both summer and winter.

During summer, most birds were distributed along the shoreline and on the eastern side of Lower Cook Inlet. Birds frequented the area where the Alaska Coastal Current enters the Inlet (Burbank 1977, see Fig. 4), bringing in nutrient-rich waters and causing upwelling and increased mixing. In winter, birds concentrated in protected, ice-free bays, especially those along the southern shore of Kachemak Bay. Any environmental alteration of these areas, such as an oil spill, could greatly affect the marine bird and sea otter populations of the Inlet.

The estimates presented here are based on a new technique, differing from previous surveys used to estimate seabird abundance. We used small, fast boats to survey a large number of short, widely-distributed, randomly-selected transects, a method developed in Prince William Sound, Alaska (Klosiewski and Laing 1994). Most previous studies used one large vessel to survey long, systematically-placed lines in pelagic waters (Tasker et al. 1984, Gould and Forsell 1989). Our study area covered both shoreline and pelagic habitats. Small boats allow greater

maneuverability in shallow waters, increasing our ability to survey shoreline habitats. where many breeding and non-breeding birds congregate. Pennington and Vølstad (1994) examined survey data on marine fishes and found that reducing the size of the sampling unit, then using the time saved to sample more locations, yielded more precise estimates of population parameters. The speed of the small boats reduced travel time between transects allowing us to sample a large number of short transects. thus, increasing the precision of our estimates.

As with all sampling methods, there are biases that might affect our estimates. We counted birds continuously along each transect, a controversial technique discussed by several authors sampling from larger vessels (Tasker et al. 1984, Haney 1985, Gaston et al. 1987, Gould and Forsell 1989, Spear et al. 1992, van Franeker 1994). Continuous sampling of birds flying across transects causes an overestimate of the abundance of some species by measuring bird flux instead of density (van Franeker 1994). To minimize the problem of counting birds flying across transects, we used a small survey window, two-thirds of the width and only one-third the length previously counted forward of the vessel. Recently developed methods, using "snapshot" counts (Gould and Forsell 1989, van Franeker 1994) to limit the number of flying birds recorded, may reduce this problem. If "snapshot" counts are employed in future surveys, the two methods should first be used simultaneously to develop correction factors to allow comparisons among years.

We assumed that we counted all birds and mammals on the transects; however, it was likely that some unknown percentage of birds and mammals was missed, causing us to underestimate population abundance. For instance, we might not see a bird leave the transect because of the boat's approach. Udevitz et al. (1995) conducted a pilot study of the sightability of sea otters from similar small boat surveys in Prince William Sound. They found that observers on boats only counted 70% of the otters seen from land. Due to small sample size, Udevitz et al. (1995) advised against application of their results to other studies (Udevitz et al. 1995), so we have chosen to remain conservative and have not corrected our sea otter estimates upward. For most bird species, studies of this type have not been done, so we have no correction factors for our estimates.

Comparison between Summer 1993 and Winter 1994 Surveys

Total density of marine birds decreased by 43% from summer to winter. This large decline between seasons occurred mostly in the offshore stratum, reflecting changes in the species composition from summer to winter. The density of tubenoses decreased by 42% in the offshore stratum, thus, summer birds, such as the shearwaters, which breed in the southern hemisphere during our winter months, departed and were replaced by over-wintering birds. Densities of tubenoses, gulls, and alcids decreased; whereas, densities of waterfowl increased three-fold during the winter, indicating that the Inlet was an important wintering site for waterfowl. Densities of gulls and alcids decreased by approximately 50% from summer to winter. For gulls, the decrease was due to a 100% reduction in the density of black-legged kittiwakes, and for alcids, the decrease was due to a 46% decrease in murres. Some species

(jaegers, terns, and puffins, summer; grebes, winter) were observed in only one season, emphasizing the significance of Lower Cook Inlet as year-round habitat.

Differences observed in densities between seasons were also true by stratum. The shoreline stratum was important for gulls during the summer, probably because of the colonies located in this stratum. The offshore stratum was an important site for tubenoses during the summer, providing important feeding habitat for these mostly non-breeding birds (Piatt 1993). The shoreline stratum was the preferred habitat for waterfowl during both seasons, and waterfowl was the most abundant group observed in both shoreline and offshore strata during the winter, adding support to the significance of Lower Cook Inlet as critical habitat for wintering waterfowl. The importance of Lower Cook Inlet as year-round habitat for some species was emphasized by the similarity of the relative abundance of alcids in the offshore stratum during summer and winter.

Evidently, sea otters remained within the Inlet year-round, because their densities were similar in both winter and summer. Although sea otters can feed in water depths of $\leq$80 m (Schneider 1976) and thus could be found anywhere in Lower Cook Inlet, our observations showed that sea otters preferred the shallower waters of the shoreline stratum, especially the protected bays and fjords in Kachemak Bay (Fig. 29).

Comparison with Previous Surveys

During summer 1993, we estimated a density within the shoreline stratum (152.9 birds/km^2) similar to Arneson's (1980; 130 birds/km^2) density from aerial surveys of Lower Cook Inlet during 1976-78. However, our density estimate for the pelagic stratum was twice that estimated by Arneson (1980; 26 birds/km^2). Both surveys found that sea ducks represented the highest proportion of birds in the shoreline stratum of the eastern portion of Lower Cook Inlet during winter, but our density estimates were 4.5 times greater than those estimated by Arneson (1980, 47 birds/km^2).

We do not believe the bird populations of Lower Cook Inlet have increased markedly in the 15 years between surveys. Recent counts of colonies within Lower Cook Inlet indicated that numbers of breeding pairs of black-legged kittiwakes and common murres have decreased since 1976 (Slater et al. 1995). Marine bird populations in nearby Prince William Sound also have decreased in the last 20 years (Klosiewski and Laing 1994). Thus, it is likely that the bird populations of Lower Cook Inlet have either remained stable or decreased as well.

The differences in densities observed between our survey and Arneson's (1980) were probably due to methodology. Arneson (1980) conducted mostly aerial surveys of Lower Cook Inlet. Aerial surveys tend to underestimate population size (Conant et al. 1988). We also found this to be true when we compared our small boat shoreline survey with our aerial survey of Kachemak Bay during winter 1994. Our results indicated that observers on the aerial survey counted only 70% of the birds. Thus, Arneson (1980) probably underestimated population abundance.

Sea otter populations were nearly eliminated from Lower Cook Inlet in the early 1900's (Schneider 1976). Only a few otters persisted in the Augustine Island area. In the last 25 years, the otter population has expanded northward around the Kenai Peninsula and eastward from Kamishak Bay to include Kachemak Bay (Schneider 1976). DeGange et al. (1990) conducted an aerial survey after the *Exxon Valdez* oil spill in 1989 and reported densities of 1 otter/km^2 along the southern shoreline of Kamishak Bay. We calculated similar densities from our winter aerial shoreline survey, indicating that the sea otter population of Kamishak Bay has remained fairly stable over the last four years.

The densities we estimated for sea otters in Kachemak Bay during summer 1993 and winter 1994 were higher than previous surveys (Schneider 1976, DeGange 1990), indicating that the otter population of Kachemak Bay has increased over time. Observers on an aerial survey of Kachemak Bay in 1976 counted 75 otters in Port Graham and only 6 otters east of and including Seldovia (Schneider 1976). DeGange et al. (1990) reported densities of <1-2 sea otters/km^2 east of and including Seldovia.

Schneider (1976) hypothesized that otters in Kachemak Bay were a non-breeding population. During our surveys, pups were commonly seen along the southern shore of Kachemak Bay, indicating that breeding now occurs in this area. Our sighting of a pair of otters in the middle of Lower Cook Inlet during summer 1993 supports Schneider's (1976) hypothesis that sea otters may move between Kamishak and Kachemak Bays.

Winter Aerial Shoreline Survey

Our estimates of bird density from the combined eastern and western aerial shoreline surveys of Lower Cook Inlet during winter 1994 were 180% higher than Arneson's (1980). This difference was likely due to differences in areas covered during the two surveys, especially in the eastern portion of the Inlet. Arneson (1980) covered 17 shoreline sections, but we were only able to survey 11 of these. On the eastern side, we only surveyed the three sections in Kachemak Bay where Arneson (1980) found birds to be most abundant. By surveying areas with the highest numbers of birds, our densities for the eastern portion of the Inlet may be artificially high. Our estimate for the western shoreline (19.3 birds/km^2) was similar to Arneson's (1980) estimate of 16.0 birds/km^2.

Kachemak Bay appears to be more important for wintering birds than Kamishak Bay on the western side of the Inlet. Arneson (1980) also noted a marked difference in densities between the eastern and western sides of Lower Cook Inlet. Arneson's (1980) eastern section had a density of 47 birds/km^2; whereas, the western side only had a density of 16 birds/km^2 (Arneson 1980). Kachemak Bay is more protected than Kamishak Bay from winter winds and tends to be free of ice.

Comparison of our estimates of abundance from the small boat shoreline survey with counts from the aerial survey of Kachemak Bay demonstrated that the densities calculated from aerial surveys generally underestimate bird abundance (Table 14). Observers on the aerial survey completely missed some of the smaller species, such as *Brachyramphus* murrelets. Conant et al. (1988) also found that

aerial observers underestimated waterfowl abundance. Correction factors developed for species that were sighted in both Kachemak Bay surveys varied overall by 140% of the estimate (Table 16). The differences among species support the importance of developing correction factors for each species. Observers on the aerial survey underestimated the number of birds by 30%. For some species, such as eiders and murres, counts from the aerial survey were higher than estimates from the boat survey, but this may be due to differences in counting techniques between surveys. The winter 1994 aerial survey observers counted all members of a large flock, especially in small bays; whereas, observers on the small boat survey counted only those birds within the survey window.

Surveys Comparing Large and Small Boat Methods

When sampling a species with an aggregated distribution, a large sample unit is less precise than smaller units (Green 1979, Pennington and Vølstad 1994). Because of the aggregated distribution of most seabird species, population estimates calculated from long lines surveyed by a large vessel should have larger confidence intervals than numerous, short segments for the same amount of effort. Thus, the similarity between our winter estimates from long lines and short segments for some species (ie.--scoters, murres) was not expected. For aggregated species such as waterfowl, we calculated better CV's from the short segments than from the long lines. Evidently, other species such as murrelets had a more uniform distribution than expected, because the CV's from their population estimates were lower from the long lines. Our maps of winter bird distribution (Figs. 23-37) corroborate these findings.

The similarity between results of the two methods supports the validity of using small, fast boats for this type of marine bird survey. With good weather, small boats would obtain similar results as a large vessel with less effort. Small boats only needed to sample 50% of the area sampled by a large vessel to obtain comparable estimates. When we simulated equal effort, we found that most estimates based on data from segments had lower CV's. This was to be expected because the sample size of the segments was larger.

Comparison with Prince William Sound

Summer Boat Survey.--Our summer 1993 estimate of marine birds in the Inlet (798,042 $\pm$ 195,555) was over twice the estimate calculated for a similar survey of Prince William Sound during July 1993 (371,327 $\pm$ 58,189 birds, Agler et al. 1994a). Because of the difference in size between the two areas (Lower Cook Inlet was 1.5 times larger), comparing densities between areas is more meaningful. Our summer 1993 total density estimate from Lower Cook Inlet (57.9 $\pm$ 14.2 birds/km^2) was 28.7% higher than the density estimated for Prince William Sound (41.3 $\pm$ 6.5 birds/km^2). Prince William Sound has long been considered an important area for marine birds (Agler et al. 1994a,d; Klosiewski and Laing 1994), yet our results indicate that Lower Cook Inlet is equally, if not, more important for marine birds during both summer and winter.

Most of the differences between Lower Cook Inlet and Prince William Sound during summer 1993 occurred in the offshore stratum. The estimated density of the offshore stratum of Lower Cook Inlet (Table 6) was 45.7% higher than that calculated for Prince William Sound (Table 17); whereas, the density in the shoreline stratum of Lower Cook Inlet (Table 6) was only 2.7% greater than the estimated density of Prince William Sound (Table 17). Species composition also differed between the two areas (Tables 7 and 18). Although the most common birds observed in both areas during summer were alcids, most of the alcids in Lower Cook Inlet were murres. In Prince William Sound, the most abundant alcid was *Brachyramphus* murrelets. In Lower Cook Inlet, the second most common species group was tubenoses (35%), but in Prince William Sound, the second most common group was gulls (31.4%).

We suggest that these differences in overall abundance of marine birds and in the relative species composition between the two areas were due to differences in the topography and oceanography of the two areas. Although the two areas were sampled at approximately the same time of year (Lower Cook Inlet, June; Prince William Sound, July), it is possible that breeding cycles may have influenced the estimates. We compared estimates from surveys done in June and July 1990 in Prince William Sound and found that the estimate of total marine birds was 30% higher in July. Thus, our estimates of marine bird abundance in Lower Cook Inlet are conservative because Lower Cook Inlet was sampled in June, but Prince William Sound was sampled in July.

The two areas differ in topography and overall structure. Prince William Sound (Fig. 48), with its convoluted coastline of bays and fjords, has more shoreline (9.1% of total area) than Lower Cook Inlet (1.8% of total area, Table 1). Overall, the waters of Lower Cook Inlet are shallower than Prince William Sound, and several of the bays on the west side of the Inlet are very shallow, averaging <20 m in depth (Hayes et al. 1977). Southern Prince William Sound is protected by two large islands (Hinchinbrook and Montague Islands). Oceanic water from the Gulf of Alaska enters the Sound through one small entrance between the islands (Fig. 48); whereas, Lower Cook Inlet is fairly open to the Gulf of Alaska (Fig. 4).

Lower Cook Inlet is considered "a well-mixed estuary" (Burbank 1977). The large tidal ranges, seasonally variable amounts of fresh water runoff, and presence of strong winds, which funnel down the long axis of the Inlet, create a fairly complex circulation pattern within the Inlet. Oceanic water from the Alaska Coastal Current (Fig. 4) enters the Inlet in its southeastern corner, causing upwelling northwest of the Chugach Islands. This northward intrusion of seawater is deflected west near Anchor Point by the strong, southward flow of turbid, low salinity water from the Upper Inlet, creating a counterclockwise gyre in the central part of the Inlet (Fig. 4). This large gyre generates two smaller gyres in the mouth of Kachemak Bay (Fig. 4). Lower Cook Inlet has several large tide rips, which act as frontal zones, separating the more dense seawater from the less dense southward flowing turbid waters.

Marine bird distribution in Lower Cook Inlet appeared to be related to the presence of both the seawater intrusion from the Gulf of Alaska and the tide rips. Shearwaters, fulmars, and puffins were most abundant in the southeastern corner,

where the oceanic water from the Alaska Coastal Current entered the Inlet. Sightings of storm-petrels were most common along the tide rips, and *Brachyramphus* murrelet abundance was highest near the small gyres in Kachemak Bay. Presumably, marine birds inhabiting Lower Cook Inlet during summer are feeding and exploiting areas near frontal zones, such as the Alaska Coastal Current, increasing the probability that they will find productive areas.

Winter Boat Survey.--During winter 1994, we only surveyed a portion of Lower Cook Inlet; whereas, we surveyed all of Prince William Sound. The abundance estimate for Lower Cook Inlet (Table 4) was correspondingly lower than the Prince William Sound estimate for March 1994 (320,470 $\pm$ 62,640 birds; Agler et al. 1994d). The total density of marine birds in Prince William Sound (Table 18) was only slightly higher than the density in Lower Cook Inlet (Table 9), indicating a similar level of use by wintering marine birds. In both areas, the highest densities were estimated within the shoreline stratum, demonstrating the importance of this stratum for wintering marine birds.

The most common birds observed in both areas during winter were waterfowl, but the species composition of this group differed between the two areas (Tables 10 and 20). In Lower Cook Inlet, waterfowl consisted mostly of scoters (23.9% of total); whereas, in Prince William Sound, goldeneyes were the most abundant waterfowl (16.5% of total). In both areas, the second most common species group was alcids. Murres made up a higher proportion of the alcids in Lower Cook Inlet; whereas, in Prince William Sound, *Brachyramphus* murrelets were the most abundant alcid. In both areas, gulls were the next most abundant species group. We suggest that the differences in species composition were due to differences in habitat. Lower Cook Inlet has more open water; whereas, Prince William Sound has more protected bays and fjords. Smaller birds, such as goldeneyes and murrelets, prefer the more protected habitats of Prince William Sound over the exposed waters of Lower Cook Inlet.

The densities of sea otters within Lower Cook Inlet were lower than those estimated for Prince William Sound during both winter and summer. This difference was to be expected. Sea otters seemed to prefer the shoreline habitat in both areas, and Prince William Sound has more shoreline than Lower Cook Inlet. Also, sea otters have only recently recolonized Lower Cook Inlet (National Marine Fisheries Service 1988), and their populations appear to be increasing in the Inlet.

Improvement of the Survey

Increased stratification reduced the size of each stratum, reducing the sample size within each stratum (Kraft et al. 1995). This reduced precision within the re-stratification designs. Thus, we simulated re-allocation of transects based on abundance of marine birds in each stratum, and this improved the precision of the estimates. Re-allocation of samples resulted in a tie between the ranks of the original stratification (re-allocated) and the east-west stratification design with a shoreline, a coastal, and a pelagic stratum (Fig. 10).

Kraft et al. (1995) found that although stratification generally increased precision, it usually increased cost. The highest abundances of marine birds were observed in the eastern portion of Lower Cook Inlet, thus, in future surveys a higher proportion of the transects should be allocated to this stratum. This should actually reduce costs, because transects on the western side of the Inlet are more difficult to survey due to distance from support facilities. Thus, using the east-west stratification design would allow us to reduce costs yet maintain precision.

We also examined allocation of samples based upon the species with the highest variability (common murre), and we found that either original stratification design (re-allocated or not re-allocated) had the best mean CV in that instance. Overall, mean CV's were much higher using this method to allocate samples, and we do not advise incorporating this technique into future surveys. We recommend re-allocating samples in future surveys into the east-west stratification design to reduce costs.

Survey Frequency

We suggest two major reasons to conduct future surveys: (1) to examine the effects of an environmental perturbation; and, (2) to determine long-term trends in abundance. Klosiewski and Laing (1994) conducted Monte-Carlo simulations to examine the lack of power associated with performing tests using the few data points available within Prince William Sound to assess injury to marine birds from the *Exxon Valdez* oil spill. When they generated data for a sampling regime that only included two years of pre- and one year of post-perturbation data, estimated power was low, regardless of the proportion of the population affected. This sampling regime gave a 20-40% chance of detecting a 50% decline for *Brachyramphus* murrelets, the species group estimated with the highest precision. Estimated power increased substantially with five years of pre- and one year of post-perturbation data (Klosiewski and Laing 1994). This sampling regime provided a 60-100% chance of detecting a 50% decline for *Brachyramphus* murrelets. These results supported the importance of regular monitoring, which would increase the likelihood of having a larger number of samples from a disturbed area (Klosiewski and Laing 1994).

This is an important consideration for Lower Cook Inlet. Fifteen years separated the only surveys (Ameson 1980) that have been conducted to estimate marine bird densities of the area, and these surveys were not directly comparable because of different methodologies. If an environmental perturbation were to occur in Lower Cook Inlet today, we would have little power to detect declines for most species, unless the decline was severe (>50%, Klosiewski and Laing 1994). Klosiewski and Laing (1994) found that five years of pre-perturbation data would substantially increase the chance of detecting a change in population abundance. If it is important to know effects of an environmental perturbation in Lower Cook Inlet, an area with a great deal of oil development and transport, we need more data on the population abundance of marine birds of the area. Thus, we need to conduct more surveys and soon; otherwise, we will be unable to determine any injury to this important resource within Alaska.

Statistical tests commonly use a small α level (≤ 0.05) to minimize probability of a Type I error. This reduces the probability of reporting a trend when none exists. However, power, the ability to detect a trend when it does exist, is inversely related to α. For example, if we have a CV of 0.3 and we increase the α level to ≤ 0.10, we increase our power to detect a trend by 11-52%. If a population may be declining, the benefits of increased power to detect a trend may outweigh the risks of lowering the confidence level. Thus, we recommend using a higher α level such as ≥ 0.10.

Continued monitoring of Lower Cook Inlet would allow us to examine trends in population abundance over time. Klosiewski and Laing (1994) demonstrated that the populations of some marine birds declined between 1972-73 and 1989-91. This may also have occurred in Lower Cook Inlet. Regular monitoring of Lower Cook Inlet would provide the data necessary to examine this hypothesis. From the results of our power analysis, we recommend that surveys be conducted every 2-5 years. The power analysis demonstrated that survey frequency would markedly increase our ability to detect trends in abundance. Models of seabird population growth predict most species increase no more than 12% per year (Nur and Ainley 1992). Thus, surveys should occur every other year over a 20-year period or every third year within a 30-year period to achieve maximum power to detect an annual rate of change of 10%. Models of seabird population growth predict most species increase no more than 12% per year (Nur and Ainley 1992).

CONCLUSIONS

Surveying randomly-selected transects allowed us to estimate the abundance of marine birds in Lower Cook Inlet during summer 1993 and winter 1994. We found that Lower Cook Inlet provides important habitat for large numbers of marine birds in the Gulf of Alaska during both summer and winter. This information is vital for determining short- and long-term changes in the abundance of marine birds in the area. Similar data from Prince William Sound has been used to determine changes in abundance of marine birds over time (Klosiewski and Laing 1994).

Because similar methods were used in both studies, we made comparisons between Lower Cook Inlet and Prince William Sound and developed hypotheses regarding the underlying ecology of the marine bird populations of coastal areas of the Gulf of Alaska. As the *Exxon Valdez* oil spill demonstrated, oil spills are not limited to one geographic location but move with the currents and wind.

We recommend that surveys be conducted more frequently to increase the likelihood of detecting population changes in the event of an environmental perturbation. At the present time, we do not have enough data to detect population changes due to an environmental perturbation. We recommend surveying a portion of Lower Cook Inlet (ie.--Kachemak Bay and the southeastern corner) every year for five years to examine annual variability in the marine bird populations of the Inlet. Abbreviated surveys, such as these, would also improve survey techniques. We also recommend conducting surveys of Lower Cook Inlet every 2-5 years to increase the baseline data available. Increased monitoring of Lower Cook Inlet would permit analysis of trends in population abundance. Marine bird populations in Prince William

Sound have declined since 1972-73 (Klosiewski and Laing 1994). This may have occurred in Lower Cook Inlet but can not be detected due to insufficient data.

In conjunction with these surveys, we also recommend investigation into: (1) comparisons between aerial and boat survey techniques; (2) differences between surveys with short, randomly-selected transects and those with long, systematic lines; (3) differences between the present method, in which we count all birds continuously on each transect and the relatively new "snapshot" counts; (4) effects of tide and time of day on bird distribution and abundance; (5) correlations of species distribution with habitat; and (6) comparisons of Lower Cook Inlet with other regions in the state.

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Table 1. Area (km^2) of strata used on boat surveys of Lower Cook Inlet during summer 1993 and winter 1994 to estimate population abundance of marine birds. Includes area of strata from a similar survey of Prince William Sound during July 1993 (Agler et al. 1994a).

	Lower Cook Inlet						Prince William Sound	
	Summer			Winter				
Stratum	Area	% of Total	No. of Transects	Area	% of Total	No. of Transects	Area	% of Total
Shoreline	244.11	1.8	86	68.21	1.9	37	820.74	9.1
Coastal[a]	3,563.00	25.8	112	1,220.89	33.3	61		
Pelagic[a]	9,983.88	72.4	213	2,371.83	64.8	85		
Offshore[a]	13,546.88	98.2	325	3,592.72	98.1	147	8,161.11	90.9
Total[b]	13,790.99	100.0	411	3,660.93	100.0	184	8,981.85	100.0

[a] The coastal and pelagic strata of Lower Cook Inlet and Prince William Sound were defined differently. To prevent confusion in this comparison, we combined the two strata as an offshore stratum. During the winter 1994 survey, Kachemak Bay was used as the coastal stratum.

[b] Total only includes the area for the shoreline and combined offshore strata, so the column labeled "area" will not add vertically.

Table 2. Species groups used to estimate population size of marine birds during summer 1993 and winter 1994 boat surveys of Lower Cook Inlet.

Group / Common Name	Species Name
Loons	
Red-throated loon	*Gavia stellata*
Pacific loon	*G. pacifica*
Common loon	*G. immer*
Yellow-billed loon	*G. adamsii*
Unidentified loon	*G.* sp.
Grebes	
Horned grebe	*Podiceps auritus*
Red-necked grebe	*P. grisegena*
Unidentified grebe	*P.* sp.
Tubenoses	
Northern fulmar	*Fulmarus glacialis*
Sooty shearwater	*Puffinus griseus*
Short-tailed shearwater	*P. tenuirostris*
Unidentified shearwater	*P.* sp.
Unidentified procellariid	*P.* sp. or *F.* sp.
Fork-tailed storm-petrel	*Oceanodroma furcata*
Unidentified storm-petrel	*Oceanodroma* sp.
Shearwaters and fulmars	
Northern fulmar	*Fulmarus glacialis*
Sooty shearwater	*Puffinus griseus*
Short-tailed shearwater	*P. tenuirostris*
Unidentified shearwater	*P.* sp.
Unidentified procellariid	*P.* sp. or *F.* sp.
Shearwaters	
Sooty shearwater	*P. griseus*
Short-tailed shearwater	*P. tenuirostris*
Unidentified shearwater	*P.* sp.
Storm-petrels	
Fork-tailed storm-petrel	*Oceanodroma furcata*
Unidentified storm-petrel	*Oceanodroma* sp.

Table 2 (continued).

Group / Common Name	Species Name
Cormorants	
Double-crested cormorant	*Phalacrocorax auritus*
Pelagic cormorant	*P. pelagicus*
Red-faced cormorant	*P. urile*
Unidentified cormorant	*P.* sp.
Waterfowl	
Brant	*Branta bernicla*
Mallard	*Anas platyrhynchos*
Northern pintail	*A. acuta*
Northern shoveler	*A. clypeata*
Gadwall	*A. strepera*
Unidentified dabbling duck	*A.* sp.
Greater scaup	*Aythya marila*
Unidentified scaup	*A. sp.*
Common eider	*Somateria mollissima*
King eider	*S. spectabilis*
Steller's eider	*Polysticta stelleri*
Harlequin duck	*Histrionicus histrionicus*
Oldsquaw	*Clangula hyemalis*
Black scoter	*Melanitta nigra*
Surf scoter	*M. perspicillata*
White-winged scoter	*M. fusca*
Unidentified scoter	*M.* sp.
Common goldeneye	*Bucephala clangula*
Barrow's goldeneye	*B. islandica*
Unidentified goldeneye	*B. islandica* or *clangula*
Bufflehead	*B. albeola*
Common merganser	*Mergus merganser*
Red-breasted merganser	*M. serrator*
Unidentified merganser	*Mergus* sp.
Unidentified diving/sea duck	
Unidentified duck	
Scaup	
Greater scaup	*Aythya marila*
Unidentified scaup	*A. marila* or *affinis*

Table 2 (continued).

Group / Common Name	Species Name
Eiders	
Common eider	*Somateria mollissima*
King eider	*S. spectabilis*
Steller's eider	*Polysticta stelleri*
Scoters	
Black scoter	*Melanitta nigra*
Surf scoter	*M. perspicillata*
White-winged scoter	*M. fusca*
Unidentified scoter	*M.* sp.
Goldeneyes	
Common goldeneye	*Bucephala clangula*
Barrow's goldeneye	*B. islandica*
Unidentified goldeneye	*B. clangula or islandica*
Mergansers	
Common merganser	*Mergus merganser*
Red-breasted merganser	*M. serrator*
Unidentified merganser	*M.* sp.
Shorebirds	
Black oystercatcher	*Haematopus bachmani*
Unidentified yellowlegs	*Tringa melanoleuca* or *flavipes*
Spotted sandpiper	*Actitis macularia*
Whimbrel	*Numenius phaeopus*
Unidentified shorebird	
Jaegers	
Pomarine jaeger	*Stercorarius pomarinus*
Parasitic jaeger	*S. parasiticus*
Unidentified jaeger	*S.* sp.

Table 2 (continued).

Group / Common Name	Species Name
Gulls	
Bonaparte's gull	*Larus philadelphia*
Mew gull	*L. canus*
Herring gull	*L. argentatus*
Glaucous-winged gull	*L. glaucescens*
Black-legged kittiwake	*Rissa tridactyla*
Unidentified gull	*L.* or *R.* sp.
Terns	
Arctic tern	*Sterna paradisaea*
Aleutian tern	*S. aleutica*
Unidentified tern	*S.* sp.
Alcids	
Common murre	*Uria aalge*
Thick-billed murre	*U. lomvia*
Unidentified murre	*U.* sp.
Pigeon guillemot	*Cepphus columba*
Marbled murrelet	*Brachyramphus marmoratus*
Kittlitz's murrelet	*B. brevirostris*
Brachyramphus murrelet	*B.* sp.
Parakeet auklet	*Cyclorrhynchus psittacula*
Tufted puffin	*Fratercula cirrhata*
Horned puffin	*F. corniculata*
Unidentified puffin	*F.* sp.
Unidentified alcid	Family Alcidae
Murres	
Common murre	*Uria aalge*
Thick-billed murre	*U. lomvia*
Unidentified murre	*U.* sp.
Murrelets	
Marbled murrelet	*Brachyramphus marmoratus*
Kittlitz's murrelet	*B. brevirostris*
Brachyramphus murrelet	*B.* sp.

Table 2 (continued).

Group / Common Name	Species Name
Puffins	
Tufted puffin	*Fratercula cirrhata*
Horned puffin	*F. corniculata*
Unidentified puffin	*F.* sp.

Table 3. List of re-stratifications examined to determine how future surveys be re-stratified to improve precision of estimates in surveys of marine birds and sea otters in Lower Cook Inlet, Alaska.

	Original[a]									
	3 nm coastal				Distance from Colonies (km)[b]				East-West[d]	
Strata	Original	By %	5 nm coastal	No coastal	5	10	15	North-South[c]	No Coastal	Coastal
All Lower Cook Inlet										
Shoreline	≤0.1 nm	≤0.1 nm	≤0.1 nm	≤0.1 nm						
Coastal	>0.1 nm ≤3 nm	>0.1 nm ≤3 nm	>0.1 nm ≤5 nm							
Pelagic	>3 nm	>3 nm	>5 nm	>0.1 nm						
Colonies										
From Colonies					≤5 km	≤10 km	≤15 km			
Pelagic					>5 km	>10 km	>15 km			
North										
Shoreline								≤0.1 nm		
Offshore								>1 nm		
South										
Offshore								>1 nm		
Kamishak Bay										
Shoreline								≤0.1 nm		
Offshore								>1 nm		

Table 3 (continued).

Strata	Original[a]				Distance from Colonies (km)[b]			North-South[c]	East-West[d]	
	3 nm coastal									
	Original	By %	5 nm coastal	No coastal	5	10	15		No Coastal	Coastal
Kachemak Bay										
Shoreline								≤0.1 nm		
Offshore								>1 nm		
East										
Shoreline									≤0.1 nm	≤0.1 nm
Offshore									>1 nm	>1 nm
Coastal										>0.1 nm ≤3 nm
West										
Shoreline									≤0.1 nm	≤0.1 nm
Offshore									>1 nm	>1 nm
Coastal										>0.1 nm ≤3 nm

[a] The original stratification included a shoreline, a coastal, and a pelagic stratum. Transects were re-allocated among these strata by marine bird abundance (by % of birds). We also examined re-stratification with a larger (5 nm) coastal stratum and without the coastal stratum.

[b] We re-stratified by creating a stratum of varying distances around colonies of >500 birds.

[c] North-south denotes re-stratification based on dividing the Inlet into northern and southern strata at Anchor Point and placing Kamishak and Kachemak Bays into separate strata.

[d] We divided the Inlet into east and west strata with a 3 nm coastal stratum and without this stratum.

Table 4. Population estimates ($N \pm$ 95% CI) for species groups of marine birds observed during small boat surveys of Lower Cook Inlet in summer 1993 and a combined small boat and shipboard survey in eastern Lower Cook Inlet in winter 1994.

	Summer 1993		Winter 1994	
Species Group	*N*	CI	*N*	CI
Loons	2,563	1,492	304	193
Grebes	0	0	648	406
Tubenoses	279,375	85,022	1,056	1,005
Shearwaters and fulmars	165,507	57,488	1,056	1,005
Shearwaters	105,805	43,421	0	0
Storm-petrels	113,868	60,099	0	0
Cormorants	6,674	2,497	6,294	1,850
Waterfowl	66,035	71,789	56,607	19,985
Scaup	1,556	1,563	91	149
Eiders	2,844	3,966	5,822	5,435
Harlequin duck	3,774	2,025	1,940	955
Oldsquaw	248	466	11,058	9,556
Scoters	49,077	70,529	29,408	11,281
Goldeneyes	3	7	3,638	2,224
Mergansers	2,103	2,065	1,403	922
Shorebirds	107	87	2	4
Jaegers	511	426	0	0
Gulls	128,946	40,896	16,089	4,752
Terns	6,394	3,885	0	0
Alcids	304,318	139,532	40,271	12,810
Murres	169,192	135,741	25,406	9,603
Guillemots	8,791	3,081	2,914	1,398
Murrelets[a]	58,227	16,058	11,627	7,410
Puffins	66,899	16,409	0	0
Total marine birds	798,042	195,555	122,946	25,804

[a] Marbled and Kittlitz's murrelets only.

Table 5. Population estimates ($N \pm$ 95% CI), by stratum, for species groups of marine birds observed on a small boat survey of Lower Cook Inlet during summer 1993.

Species Group	Shoreline		Coastal		Pelagic		Offshore[a]	
	N	CI	*N*	CI	*N*	CI	*N*	CI
Loons	310	149	857	500	1,396	1,398	2,253	1,485
Grebes	0	0	0	0	0	0	0	0
Tubenoses	0	0	17,465	15,218	261,910	83,649	279,375	85,022
Shearwaters and fulmars	0	0	17,132	15,221	148,375	55,436	165,507	57,488
Shearwaters	0	0	13,848	13,681	91,957	41,209	105,805	43,421
Storm-petrels	0	0	333	482	113,534	60,097	113,868	60,099
Cormorants	2,201	1,297	3,522	1,887	952	997	4,473	2,134
Waterfowl	9,007	3,069	51,062	71,433	5,965	6,455	57,027	71,724
Scaup	747	1,319	619	752	190	373	809	839
Eiders	607	488	2,237	3,936	0	0	2,237	3,936
Harlequin duck	2,965	1,684	809	1,124	0	0	809	1,124
Oldsquaw	10	15	238	466	0	0	238	466
Scoters	2,568	1,314	46,446	70,517	63	124	46,509	70,517
Goldeneyes	3	7	0	0	0	0	0	0
Mergansers	437	398	143	208	1,523	2,015	1,666	2,026
Shorebirds	107	87	0	0	0	0	0	0
Jaegers	3	7	0	0	508	426	508	426
Gulls	21,883	12,390	74,380	38,289	32,683	7,272	107,063	38,974
Terns	17	24	3,141	3,317	3,237	2,023	6,377	3,885
Alcids	3,208	1,281	104,503	135,219	196,607	34,399	301,110	139,526
Murres	540	804	83,421	134,650	85,230	17,158	168,652	135,739
Guillemots	1,477	693	4,521	2,014	2,792	2,226	7,313	3,002
Murrelets[b]	447	345	11,707	7,154	46,074	14,373	57,780	16,055
Puffins	740	665	4,854	2,688	61,305	16,174	66,159	16,396
Total marine birds	37,333	13,586	254,975	168,684	505,733	97,995	760,708	195,083

[a] The coastal and pelagic strata were combined to form the offshore stratum.
[b] Marbled and Kittlitz's murrelets only.

Table 6. Densities (birds/km^2) of species groups of marine birds observed on a small boat survey of Lower Cook Inlet during summer 1993 and listed by stratum.

Species Group	Total	Shoreline	Coastal	Pelagic	Offshore[a]
Loons	0.2	1.3	0.2	0.1	0.2
Grebes	0.0	0.0	0.0	0.0	0.0
Tubenoses	20.3	0.0	4.9	26.2	20.6
Shearwaters and fulmars	12.0	0.0	4.8	14.9	12.2
Shearwaters	7.7	0.0	3.9	9.2	7.8
Storm-petrels	8.3	0.0	0.1	11.4	8.4
Cormorants	0.5	9.0	1.0	0.1	0.3
Waterfowl	4.8	36.9	14.3	0.6	4.2
Scaup	0.1	3.1	0.2	<0.1	0.1
Eiders	0.2	2.5	0.6	0.0	0.2
Harlequin duck	0.3	12.1	0.2	0.0	0.1
Oldsquaw	<0.1	<0.1	0.1	0.0	<0.1
Scoters	3.6	10.5	13.0	<0.1	3.4
Goldeneyes	<0.1	<0.1	0.0	0.0	0.0
Mergansers	0.2	1.8	<0.1	0.2	0.1
Shorebirds	<0.1	0.4	0.0	0.0	0.0
Jaegers	<0.1	<0.1	0.0	0.1	<0.1
Gulls	9.4	89.6	20.9	3.3	7.9
Terns	0.5	0.1	0.9	0.3	0.5
Alcids	22.2	13.1	29.3	19.7	22.2
Murres	12.3	2.2	23.4	8.5	12.5
Guillemots	0.6	6.1	1.3	0.3	0.5
Murrelets[b]	4.2	1.8	3.3	4.6	4.3
Puffins	4.9	3.0	1.4	6.1	4.9
Total marine birds	57.9	152.9	71.6	50.7	56.2

[a] The coastal and pelagic strata were combined to form the offshore stratum.
[b] Marbled and Kittlitz's murrelets only.

Table 7. Relative abundance (%) of marine birds observed on a small boat survey of Lower Cook Inlet during summer 1993, listed by stratum.

Species Group	Total	Shoreline	Coastal	Pelagic	Offshore[a]
Loons	0.3	0.8	0.3	0.3	0.3
Grebes	0.0	0.0	0.0	0.0	0.0
Tubenoses	35.0	0.0	6.9	51.8	36.7
Shearwaters and fulmars	20.7	0.0	6.7	29.3	21.8
Shearwaters	13.3	0.0	5.4	18.2	13.9
Storm-petrels	14.3	0.0	0.1	22.5	15.0
Cormorants	0.8	5.9	1.4	0.2	0.6
Waterfowl	8.3	24.1	20.0	1.2	7.5
Scaup	0.2	2.0	0.2	<0.1	0.1
Eiders	0.4	1.6	0.9	0.0	0.3
Harlequin duck	0.5	7.9	0.3	0.0	0.1
Oldsquaw	<0.1	<0.1	0.1	0.0	<0.1
Scoters	6.2	6.9	18.2	<0.1	6.1
Goldeneyes	<0.1	<0.1	0.0	0.0	0.0
Mergansers	0.3	1.2	0.1	0.3	0.2
Shorebirds	<0.1	0.3	0.0	0.0	0.0
Jaegers	0.1	<0.1	0.0	0.1	0.1
Gulls	16.2	58.6	29.2	6.5	14.1
Terns	0.8	<0.1	1.2	0.6	0.8
Alcids	38.1	8.6	41.0	38.9	39.6
Murres	21.2	1.5	32.7	16.9	22.2
Guillemots	1.1	4.0	1.8	0.6	1.0
Murrelets[b]	7.3	1.2	4.6	9.1	7.6
Puffins	8.4	2.0	1.9	12.1	8.7

[a] The coastal and pelagic strata were combined to form the offshore stratum.
[b] Marbled and Kittlitz's murrelets only.

Table 8. Population estimates ($N \pm$ 95% CI), by stratum, for species groups of marine birds observed on a combined small boat and shipboard survey of eastern Lower Cook Inlet during winter 1994.

Species Group	Shoreline		Bay		Pelagic		Offshore[a]	
	N	CI	*N*	CI	*N*	CI	*N*	CI
Loons	95	39	133	158	75	104	208	189
Grebes	248	111	400	391	0	0	400	391
Tubenoses	0	0	0	0	1,056	1,005	1,056	1,005
Shearwaters & fulmars	0	0	0	0	1,056	1,005	1,056	1,005
Shearwaters	0	0	0	0	0	0	0	0
Storm-petrels	0	0	0	0	0	0	0	0
Cormorants	727	331	3,531	1,398	2,036	1,165	5,566	1,820
Waterfowl	9,038	2,480	30,943	13,560	16,626	14,470	47,569	19,831
Scaup	91	149	0	0	0	0	0	0
Eiders	220	353	3,264	3,016	2,337	4,507	5,602	5,423
Harlequin duck	1,374	563	566	772	0	0	566	772
Oldsquaw	91	48	4,030	2,570	6,937	9,204	10,967	9,556
Scoters	3,332	1,507	21,251	10,033	4,826	4,933	26,076	11,180
Goldeneyes	2,446	1,147	966	1,854	226	443	1,192	1,906
Mergansers	799	542	566	742	38	74	604	746
Shorebirds	2	4	0	0	0	0	0	0
Gulls	2,173	935	8,827	4,422	5,090	1,465	13,916	4,659
Alcids	719	440	31,410	12,581	8,143	2,371	39,553	12,802
Murres	530	413	19,485	9,415	5,391	1,845	24,876	9,595
Guillemots	42	23	1,665	1,034	1,206	940	2,872	1,397
Murrelets[b]	144	65	10,126	7,388	1,357	570	11,483	7,410
Total marine birds	14,611	2,792	75,310	21,069	33,025	14,634	108,335	25,652

[a] The coastal and pelagic strata were combined to form the offshore stratum.
[b] Marbled and Kittlitz's murrelets only.

Table 9. Densities (birds/km^2) of marine birds observed on a combined small boat and shipboard survey of eastern Lower Cook Inlet during winter 1994 and listed by stratum.

Species Group	Total	Shoreline	Bay[a]	Pelagic	Offshore[b]
Loons	0.1	1.4	0.1	<0.1	0.1
Grebes	0.2	3.6	0.3	0.0	0.1
Tubenoses	0.3	0.0	0.0	0.5	0.3
Shearwaters and fulmars	0.3	0.0	0.0	0.5	0.3
Shearwaters	0.0	0.0	0.0	0.0	0.0
Storm-petrels	0.0	0.0	0.0	0.0	0.0
Cormorants	1.7	10.7	2.9	0.9	1.6
Waterfowl	15.5	132.5	25.3	7.0	13.2
Scaup	<0.1	1.3	0.0	0.0	0.0
Eiders	1.6	3.2	2.7	1.0	1.6
Harlequin duck	0.5	20.1	0.5	0.0	0.2
Oldsquaw	3.0	1.3	3.3	2.9	3.1
Scoters	8.0	48.9	17.4	2.0	7.3
Goldeneyes	1.0	35.9	0.8	0.1	0.3
Mergansers	0.4	11.7	0.5	<0.1	0.2
Shorebirds	<0.1	<0.1	0.0	0.0	0.0
Jaegers	0.0	0.0	0.0	0.0	0.0
Gulls	4.4	31.9	7.2	2.2	3.9
Terns	0.0	0.0	0.0	0.0	0.0
Alcids	11.0	10.5	25.7	3.4	11.0
Murres	6.9	7.8	16.0	2.3	6.9
Guillemots	0.8	0.6	1.4	0.5	0.8
Murrelets[c]	3.2	2.1	8.3	0.6	3.2
Puffins	0.0	0.0	0.0	0.0	0.0
Total marine birds	33.6	214.2	61.7	13.9	30.2

[a] During winter 1994, we used Kachemak Bay as our coastal stratum.
[b] The bay and pelagic strata were combined to form the offshore stratum.
[c] Marbled and Kittlitz's murrelets only.

Table 10. Relative abundance (%), listed by stratum, of marine birds observed on a combined small boat and shipboard survey of eastern Lower Cook Inlet during winter 1994.

Species Group	Total	Shoreline	Bay[a]	Pelagic	Offshore[b]
Loons	0.3	0.7	0.2	0.2	0.2
Grebes	0.5	1.7	0.5	0.0	0.4
Tubenoses	0.9	0.0	0.0	3.2	1.0
Shearwaters and fulmars	0.9	0.0	0.0	3.2	1.0
Shearwaters	0.0	0.0	0.0	0.0	0.0
Storm-petrels	0.0	0.0	0.0	0.0	0.0
Cormorants	5.1	5.0	4.7	6.2	5.1
Waterfowl	46.0	61.9	41.1	50.3	43.9
Scaup	0.1	0.6	0.0	0.0	0.0
Eiders	4.7	1.5	4.3	7.1	5.2
Harlequin duck	1.6	9.4	0.8	0.0	0.5
Oldsquaw	9.0	0.6	5.4	21.0	10.1
Scoters	23.9	22.8	28.2	14.6	24.1
Goldeneyes	3.0	16.7	1.3	0.7	1.1
Mergansers	1.1	5.5	0.8	0.1	0.5
Shorebirds	<0.1	<0.1	0.0	0.0	0.0
Jaegers	0.0	0.0	0.0	0.0	0.0
Gulls	13.1	14.9	11.7	15.4	12.9
Terns	0.0	0.0	0.0	0.0	0.0
Alcids	32.8	4.9	41.7	24.7	36.5
Murres	20.7	3.6	25.9	16.3	23.0
Guillemots	2.4	0.3	2.2	3.7	2.7
Murrelets[c]	9.5	1.0	13.5	4.1	10.6
Puffins	0.0	0.0	0.0	0.0	0.0

[a] During winter 1994, we used Kachemak Bay as our coastal stratum.
[b] The bay and pelagic strata were combined to form the offshore stratum.
[c] Marbled and Kittlitz's murrelets only.

Table 11. Comparison of population estimates ($N \pm$ 95% CI) of marine birds observed during shipboard surveys of the pelagic stratum of eastern Lower Cook Inlet during winter 1994. Lines denotes population estimates determined from nine lines of varying lengths surveyed completely by a large vessel, and segments denotes population estimates calculated from a subset consisting of 85 randomly-chosen 2-nm segments similar to the transects used in the summer 1993 survey.

	Lines		Segments	
Species Group	*N*	CI	*N*	CI
Loons	132	123	75	104
Tubenoses	564	1,126	1,056	1,005
Shearwaters and fulmars	564	1,126	1,056	1,005
Cormorants	1,937	1,782	2,036	1,165
Waterfowl	10,739	16,938	16,626	14,470
Eiders	1,354	2,573	2,337	4,507
Oldsquaw	3,329	8,237	6,937	9,204
Scoters	4,363	6,417	4,826	4,933
Goldeneyes	320	798	226	443
Mergansers	38	60	38	74
Gulls	4,119	1,118	5,090	1,465
Alcids	7,993	2,473	8,143	2,371
Murres	5,417	1,988	5,391	1,845
Guillemots	922	787	1,206	940
Murrelets[a]	1,505	541	1,357	570
Total marine birds	25,484	17,727	33,025	14,634

[a] Marbled and Kittlitz's murrelets only.

Table 12. Percentage of times CV's of population estimates from short (2 nm) segments calculated during a Monte Carlo simulation were lower than CV's from data collected along nine lines of varying lengths. We simulated less effort (<Effort) by calculating percentages using 50% of the short segments, then we used 100% of the segments to simulate equal effort and re-calculated the percentages.

Species Group	<Effort	Equal Effort
Loons	0	54
Tubenoses	99	100
Shearwaters and fulmars	99	100
Cormorants	89	100
Waterfowl	98	100
Eiders	0	100
Oldsquaw	100	100
Scoters	92	100
Goldeneyes	100	100
Mergansers	0	36
Gulls	0	59
Alcids	8	100
Murres	33	100
Guillemots	27	96
Murrelets[a]	0	15
Total marine birds	100	100

[a] Marbled and Kittlitz's murrelets only.

Table 13. Number and density of marine birds and mammals counted during an aerial survey of the shoreline of western Lower Cook Inlet during winter 1994. Combined shoreline included the western shoreline and Kachemak Bay. Inside 0.1 nm (200 m) corresponds to the area surveyed by a small boat winter survey, and the 0.2 nm (400 m) zone was similar to the area surveyed previously by air (Erikson 1977, Arneson 1980).

	Western Shoreline				Combined Shoreline			
	Inside 0.1 nm		Total 0.2 nm		Inside 0.1 nm		Total 0.2 nm	
Species	Count	Density	Count	Density	Count	Density	Count	Density
Marine Birds								
Loons	1	<0.1	1	<0.1	11	<0.1	34	<0.1
Grebes	0	0.0	0	0.0	0	0.0	7	<0.1
Cormorants	13	0.1	25	0.1	99	0.5	237	0.7
Waterfowl	1,236	9.8	4,490	18.0	4,888	26.5	11,015	30.8
Green-winged teal	0	0.0	0	0.0	4	<0.1	4	<0.1
Mallard	0	0.0	40	0.2	71	0.4	261	0.7
Scaup	29	0.2	136	0.6	279	1.5	386	1.1
Common eider	4	<0.1	38	0.2	55	0.3	103	0.3
Steller's eider	200	1.6	1,363	5.5	631	3.4	1,805	5.0
Harlequin duck	176	1.4	273	1.1	327	1.8	534	1.5
Oldsquaw	436	3.5	1,155	4.6	511	2.8	1,368	3.8
Black scoter	213	1.7	1,177	4.7	627	3.4	2,054	5.7
Surf scoter	0	0.0	12	0.1	480	2.6	689	1.9
White-winged scoter	2	<0.1	16	0.1	112	0.6	399	1.1
Unidentified scoter	0	0.0	6	<0.1	0	0.0	6	<0.1
Scoters	215	1.7	1,211	4.9	1,219	6.6	3,148	8.8
Goldeneyes	76	0.6	87	0.4	478	2.6	1,215	3.4
Bufflehead	0	0.0	0	0.0	12	<0.1	108	0.3
Mergansers	100	0.8	187	0.8	1,301	7.1	2,083	5.8
Shorebirds	200	1.6	234	0.9	230	1.3	464	1.3
Gulls	31	0.3	49	0.2	848	4.6	1,301	3.6
Herring gull	0	0.0	11	<0.1	1	<0.1	37	0.1

Table 13 (continued).

Species	Western Shoreline				Combined Shoreline			
	Inside 0.1 nm		Total 0.2 nm		Inside 0.1 nm		Total 0.2 nm	
	Count	Density	Count	Density	Count	Density	Count	Density
Glaucous-winged gull	0	0.0	0	0.0	10	<0.1	10	<0.1
Glaucous gull	4	<0.1	4	<0.1	4	<0.1	12	<0.1
Unidentified gull	27	0.2	34	0.1	833	4.5	1,241	3.6
Alcids	0	0.0	2	<0.1	2,421	13.1	7,312	20.4
Murres	0	0.0	2	<0.1	2,421	13.1	7,306	20.4
Murrelets[a]	0	0.0	0	0.0	0	0.0	6	<0.1
Bald eagle	5	<0.1	6	<0.1	81	0.4	102	0.3
Common raven	1	<0.1	1	<0.1	1	<0.1	1	<0.1
Total marine birds[b]	1,486	11.8	4,807	19.3	8,578	46.5	20,852	57.5
Marine Mammals								
Beluga whale	2	<0.1	4	<0.1	2	<0.1	4	<0.1
Sea otter	68	0.5	186	0.8	140	0.8	469	1.3
Steller sea lion	0	0.0	0	0.0	17	<0.1	17	<0.1
Harbor seal	27	0.2	64	0.3	33	0.2	76	0.2

[a] Marbled and Kittlitz's murrelets only.
[b] Bald eagles and common ravens were not included in total marine birds, so this column will not add vertically.

Table 14. Number and density of marine birds and mammals counted during an aerial shoreline survey of Kachemak Bay, Alaska during winter 1994 and population estimates (*N*) from a winter small boat survey in the 0.1 km (200 m) zone. Total 0.2 nm (400 m) includes all area surveyed by air.

Species	Aerial Survey				Boat Survey	
	Inside 0.1 nm		Total 0.2 nm		0.1 nm	
	Count	Density	Count	Density	*N*	Density
Marine Birds						
Loons	10	0.2	33	0.3	81	1.4
Grebes	0	0.0	7	<0.1	218	3.7
Cormorants	86	1.5	212	2.0	377	6.4
Waterfowl	3,652	62.2	6,525	60.0	7,661	130.0
Green-winged teal	4	<0.1	4	<0.1	0	0.0
Mallard	71	1.2	221	2.0	145	2.5
Scaup	250	4.3	250	2.3	85	1.4
Common eider	51	0.9	65	0.6	2	<0.1
Steller's eider	431	7.3	442	4.1	192	3.3
Harlequin duck	151	2.6	261	2.4	1,217	20.6
Oldsquaw	75	1.3	213	2.0	81	1.4
Black scoter	414	7.1	877	8.1	345	5.9
Surf scoter	480	8.2	677	6.2	1,112	18.9
White-winged scoter	110	1.9	383	3.5	781	13.2
Scoters	1,004	17.1	1,937	17.8	2,533	42.9
Goldeneyes	402	6.9	1,128	10.4	2,280	38.6
Bufflehead	12	0.2	108	1.0	256	4.3
Mergansers	1,201	20.5	1,896	17.4	735	12.5
Shorebirds	30	0.5	230	2.1	0	0.0
Gulls	817	13.9	1,252	11.5	930	15.8
Herring gull	1	<0.1	26	0.2	46	0.8
Glaucous-winged gull	10	0.2	10	<0.1	708	12.0
Glaucous gull	0	0.0	8	<0.1	0	0.0
Unidentified gull	806	13.7	1,207	11.1	12	0.2
Alcids	2,421	41.3	7,310	67.2	662	11.2
Murres	2,421	41.3	7,304	67.2	488	8.3
Murrelets[a]	0	0.0	6	<0.1	135	2.3
Bald eagle	76	1.3	96	0.9	180	3.1
Common raven	0	0.0	0	0.0	4	<0.1
Total marine birds[b]	7,092	120.9	15,775	145.1	10,143	171.9

Table 14 (continued).

Species	Aerial Survey				Boat Survey	
	Inside 0.1 nm		Total 0.2 nm		0.1 nm	
	Count	Density	Count	Density	*N*	Density
Marine Mammals						
Sea otter	72	1.2	283	2.6	151	2.6
Steller sea lion	17	0.3	17	0.2	4	<0.1
Harbor seal	6	0.1	12	0.1	26	0.4

[a] Marbled and Kittlitz's murrelets only.

[b] Bald eagle and common raven were not included in total marine birds, so this column will not add vertically.

Table 15. Densities of marine birds from an aerial survey of the Kachemak Bay and western shorelines of Lower Cook Inlet during winter 1994. Shoreline sections follow Arneson (1980): (3) Anchor Point to Homer Spit tip; (4) Homer Spit tip to Peterson Bay; (5) Chinapoot Bay to Point Bede; (8) Tuxedni Bay; (9) Shoreline between Tuxedni Bay and Chinitna Bay; (10) Chinitna Bay; (11) Iniskin Peninsula; (12) Oil Bay, Iniskin Bay and Iliamna Bay; (13) South Head to Chenik Head, includes Ursus Bay and Bruin Bay; (14) Amakadedulia Cove, McNeil Cove, Akumwarvik Bay; and (15) Shoreline between Akumwarvik Bay and Cape Douglas.

	Kachemak Bay Shoreline			Western Shoreline							
Species	3	4	5	8	9	10	11	12	13	14	15
Common loon	0.0	<0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unidentified loon	0.2	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	<0.1
Loons	0.2	0.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	<0.1
Red-necked grebe	0.0	<0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grebes	0.0	<0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cormorants[b]	0.9	2.5	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Waterfowl	28.3	49.5	70.5	6.0	3.2	20.3	47.1	27.5	20.4	4.9	15.0
Green-winged teal	0.0	0.0	<0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mallard	0.0	0.8	3.1	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dabbling ducks	0.0	0.8	3.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scaup[b]	0.0	0.0	4.1	0.0	0.0	<0.1	0.0	2.3	0.0	0.0	0.7
Goldeneyes[b]	0.0	10.6	11.3	2.4	0.0	0.0	0.0	0.0	0.0	0.0	<0.1
Bufflehead	0.0	1.8	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diving ducks	0.0	12.4	16.0	2.4	0.0	<0.1	0.0	2.3	0.0	0.0	0.8
Common eider	3.5	0.0	0.7	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.7
Steller's eider	3.2	0.0	6.9	0.0	0.0	0.0	0.0	9.9	16.4	0.0	0.0
Eiders	6.7	0.0	7.5	0.0	0.0	0.0	0.0	10.0	16.4	0.0	0.7
Harlequin duck	0.0	0.0	4.3	0.0	0.0	0.4	1.2	1.1	0.2	0.0	3.9
Oldsquaw	6.2	1.2	2.0	1.1	0.0	13.6	0.0	9.1	1.4	4.8	5.0
Black scoter	15.4	0.9	12.0	0.0	2.8	2.9	45.9	4.2	1.9	0.0	4.0
Surf scoter	0.0	3.2	9.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
White-winged scoter	0.0	3.9	3.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2

Table 15 (continued).

Species	Kachemak Bay Shoreline			Western Shoreline							
	3	4	5	8	9	10	11	12	13	14	15
Unidentified scoter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Scoters	15.4	7.9	24.6	0.2	2.8	2.9	45.9	4.2	1.9	0.0	4.5
Sea ducks	28.3	9.2	38.4	1.3	2.8	16.9	47.1	24.4	19.9	4.8	14.2
Red-breasted merganser	0.0	27.2	12.9	1.1	0.2	3.4	0.0	0.8	0.5	0.1	<0.1
Mergansers	0.0	27.2	12.9	1.1	0.2	3.4	0.0	0.8	0.5	0.1	<0.1
Bald eagle	7.5	0.3	0.6	<0.1	0.0	0.0	0.2	<0.1	0.0	<0.1	<0.1
Shorebirds[b]	0.0	5.7	0.0	0.0	0.0	8.9	0.0	0.0	0.0	0.0	0.7
Mew gull	0.0	<0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Herring gull	0.0	0.6	0.0	<0.1	0.0	0.3	0.0	<0.1	0.0	0.0	0.0
Glaucous-winged gull	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Glaucous gull	0.2	0.1	<0.1	<0.1	0.0	0.0	0.0	<0.1	<0.1	0.0	<0.1
Unidentified gull	10.0	12.7	10.1	0.0	0.0	<0.1	0.0	0.7	0.0	0.0	<0.1
Gulls	10.1	13.5	10.3	0.1	0.0	0.4	0.0	0.7	<0.1	0.0	<0.1
Alcids	0.0	164.1	10.4	<0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Murres[b]	0.0	164.0	10.3	<0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Murrelets[c]	0.0	<0.1	<0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Northwest crow	0.0	1.2	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Common raven	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	<0.1
Total marine birds[d]	46.9	236.9	95.0	6.2	3.0	29.7	47.3	28.2	20.4	5.0	16.3

[a] Area surveyed was less than Arneson (1980) original sections.
[b] Within these groups, total birds were not identified to species.
[c] Marbled and Kittlitz's murrelets only.
[d] Bald eagles, northwest crows, and common ravens were not included in total marine birds, thus this column will not add vertically.

Table 16. Correction factors (CF) incorporating detection errors in counts of marine birds from aerial surveys in Lower Cook Inlet during winter 1994. Includes corrected counts and densities of species and species groups occurring in both aerial and boat shoreline surveys during winter 1994 calculated for two survey widths: 0.1 nm and 0.2 nm, and in the three survey areas: Kachemak Bay shoreline, western shoreline and combined shoreline (western and Kachemak Bay). The 0.1 nm width for the Kachemak Bay shoreline survey was not modified.

		Kachemak Bay		Western Shoreline				Combined Shoreline			
		Count	Density	Count		Density		Count		Density	
Species Group[a]	CF[b]	0.2 nm	0.2 nm	0.1 nm	0.2 nm	0.1 nm	0.2 nm	0.1 nm	0.2 nm	0.1 nm	0.2 nm
Loons	8.1	268	2.5	8	8	0.1	<0.1	89	276	0.5	0.8
Cormorants	4.4	928	8.5	57	109	0.5	0.4	434	1,038	2.4	2.9
Waterfowl	2.1	13,688	125.9	2,593	9,419	20.6	37.8	10,254	23,107	55.6	64.5
Eiders	0.4	204	1.9	82	565	0.7	2.3	276	769	1.5	2.2
Harlequin duck	8.1	2,104	19.4	1,418	2,200	11.3	8.8	2,636	4,304	14.3	12.0
Oldsquaw	1.1	231	2.1	472	1,252	3.8	5.0	553	1,482	3.0	4.1
Scoters	2.5	4,887	45.0	542	3,056	4.3	12.3	3,076	7,943	16.7	22.2
Goldeneyes	5.7	6,396	58.8	431	493	3.4	2.0	2,710	6,890	14.7	19.2
Bufflehead	21.3	2,301	21.2	0	0	0.0	0.0	256	2,301	1.4	6.4
Mergansers	0.6	1,160	10.7	61	115	0.5	0.5	797	1,275	4.3	3.6
Gulls	1.1	1,425	13.1	35	56	0.3	0.2	965	1,480	5.2	4.1
Alcids	0.3	1,999	18.4	0	0	0.0	0.0	662	2,000	3.6	5.6
Murres	0.2	1,471	13.5	0	0	0.0	0.0	488	1,472	2.6	4.1
Sea otter	2.1	592	5.5	142	389	1.1	1.6	293	981	1.6	2.7

[a] We did not calculate a correction factor for *Brachyramphus* murrelets, because this species group was not sighted within the 0.1 nm aerial survey zone.

[b] Correction factor was calculated for species groups present on the aerial and boat surveys. CF = (boat estimate/aerial count).

Table 17. Densities (birds/km^2) of species groups of marine birds observed on a small boat survey of Prince William Sound during July 1993 (after Agler et al. 1994a) and listed by stratum.

Species Group	Total	Shoreline	Offshore[a]
Loons	<0.1	0.4	<0.1
Grebes	<0.1	<0.1	0.0
Tubenoses	1.6	<0.1	1.7
Shearwaters and fulmars	<0.1	<0.1	<0.1
Shearwaters	<0.1	<0.1	<0.1
Storm-petrels	1.5	0.0	1.7
Cormorants	0.2	1.5	<0.1
Waterfowl	3.1	23.7	1.0
Scaup	<0.1	0.1	0.0
Eiders	0.0	0.0	0.0
Harlequin duck	0.9	10.1	0.0
Oldsquaw	<0.1	<0.1	0.0
Scoters	1.2	3.3	1.0
Goldeneyes	<0.1	0.8	0.0
Mergansers	0.5	4.8	<0.1
Shorebirds	0.6	6.8	0.0
Jaegers	<0.1	<0.1	<0.1
Gulls	13.0	72.3	7.0
Terns	1.0	4.4	0.7
Alcids	21.0	34.4	19.6
Murres	1.8	0.5	2.0
Guillemots	0.4	2.7	0.2
Murrelets[b]	17.8	29.8	16.5
Puffins	0.7	1.1	0.6
Total marine birds	41.3	148.7	30.5

[a] The coastal-pelagic and pelagic strata of Prince William Sound were combined to form an offshore stratum for comparisons with Lower Cook Inlet.

[b] Marbled and Kittlitz's murrelets only.

Table 18. Densities (birds/km^2) of species groups of marine birds observed on a small boat survey of Prince William Sound during March 1994 (Agler et al. 1994d) and listed by stratum.

Species Group	Total	Shoreline	Offshore[a]
Loons	0.2	0.4	0.2
Grebes	0.8	6.7	0.2
Tubenoses	0.0	0.0	0.0
Shearwaters and fulmars	0.0	0.0	0.0
Shearwaters	0.0	0.0	0.0
Storm-petrels	0.0	0.0	0.0
Cormorants	1.3	5.6	0.8
Waterfowl	14.8	119.4	4.2
Scaup	0.2	1.2	<0.1
Eiders	0.0	0.0	0.0
Harlequin duck	2.1	22.1	0.1
Oldsquaw	0.5	1.8	0.3
Scoters	2.3	10.6	1.5
Goldeneyes	5.9	47.2	1.7
Mergansers	2.4	22.2	0.4
Shorebirds	0.3	2.9	0.0
Jaegers	0.0	0.0	0.0
Gulls	7.3	33.9	4.6
Terns	0.0	0.0	0.0
Alcids	10.0	8.1	10.2
Murres	5.8	4.3	5.9
Guillemots	0.1	0.6	<0.1
Murrelets[b]	4.0	3.1	4.1
Puffins	0.0	0.0	0.0
Total marine birds	35.7	190.1	20.2

[a] The coastal-pelagic and pelagic strata of Prince William Sound were combined to form an offshore stratum for comparisons with Lower Cook Inlet.

[b] Marbled and Kittlitz's murrelets only.

Table 19. Relative abundance (%), listed by stratum, of marine birds observed on a small boat survey of Prince William Sound during July 1993 (after Agler et al. 1994a).

Species Group	Total	Shoreline	Offshore[a]
Loons	0.2	0.3	0.1
Grebes	<0.1	<0.1	0.0
Tubenoses	3.8	<0.1	5.6
Shearwaters and fulmars	<0.1	<0.1	<0.1
Shearwaters	<0.1	0.0	<0.1
Storm-petrels	3.7	<0.1	5.6
Cormorants	0.5	1.0	0.3
Waterfowl	7.4	15.9	3.3
Scaup	<0.1	<0.1	0.0
Eiders	0.0	0.0	0.0
Harlequin duck	2.2	6.8	0.0
Oldsquaw	<0.1	<0.1	0.0
Scoters	2.9	2.2	3.2
Goldeneyes	0.2	0.5	0.0
Mergansers	1.1	3.2	<0.1
Shorebirds	1.5	4.6	0.0
Jaegers	0.2	<0.1	0.3
Gulls	31.4	48.6	23.0
Terns	2.5	2.9	2.2
Alcids	50.8	23.1	64.3
Murres	4.4	0.3	6.4
Guillemots	1.1	1.8	0.7
Murrelets[b]	42.9	20.0	54.2
Puffins	1.6	0.7	2.0

[a] The coastal-pelagic and pelagic strata of Prince William Sound were combined to form an offshore stratum for comparisons with Lower Cook Inlet.

[b] Marbled and Kittlitz's murrelets only.

Table 20. Relative abundance (%), listed by stratum, of marine birds observed on a small boat survey of Prince William Sound during March 1994 (Agler et al. 1994d).

Species Group	Total	Shoreline	Offshore[a]
Loons	0.5	0.2	0.7
Grebes	2.1	3.5	0.8
Tubenoses	<0.1	0.0	<0.1
Shearwaters and fulmars	0.0	0.0	0.0
Shearwaters	0.0	0.0	0.0
Storm-petrels	<0.1	0.0	<0.1
Cormorants	3.6	2.9	4.1
Waterfowl	41.3	62.8	20.9
Scaup	0.4	0.6	0.3
Eiders	0.0	0.0	0.0
Harlequin duck	6.0	11.6	0.7
Oldsquaw	1.3	0.9	1.6
Scoters	6.4	5.6	7.2
Goldeneyes	16.5	24.8	8.5
Mergansers	6.8	11.7	2.1
Shorebirds	0.7	1.5	0.0
Jaegers	0.0	0.0	0.0
Gulls	20.4	17.8	22.9
Terns	0.0	0.0	0.0
Alcids	28.0	4.3	50.5
Murres	16.1	2.3	29.3
Guillemots	0.4	0.3	0.5
Murrelets[b]	11.3	1.7	20.5
Puffins	0.0	0.0	0.0

[a] The coastal-pelagic and pelagic strata of Prince William Sound were combined to form an offshore stratum for comparisons with Lower Cook Inlet.

[b] Marbled and Kittlitz's murrelets only.

Table 21. Coefficients of variation (CV) for species and species groups from re-stratification of the study area used for a small boat survey of Lower Cook Inlet during June, 1993. Sample size used to calculate the variance for each stratum was determined on the basis of the population of total marine birds in the stratum.

	Original[a]									
	3 nm coastal				Distance from Colonies (km)[b]				East-West[d]	
Species	Original	By %	5 nm coastal	No coastal	5	10	15	North-South[c]	No coastal	Coastal
Loons	0.30	0.28	0.26	0.26	0.27	0.25	0.25	0.32	0.29	0.34
Northern fulmar	0.36	0.33	0.32	0.33	0.34	0.34	0.35	0.31	0.26	0.25
Shearwaters	0.21	0.19	0.18	0.19	0.20	0.19	0.19	0.19	0.16	0.17
Storm-petrels	0.27	0.24	0.24	0.25	0.26	0.25	0.26	0.24	0.20	0.20
Cormorants	0.19	0.26	0.26	0.25	0.26	0.26	0.29	0.29	0.29	0.29
Scaup	0.51	0.96	0.94	0.90	1.02	1.04	0.86	1.09	0.98	1.02
Eiders	0.71	0.68	0.70	0.69	0.71	0.70	0.73	0.75	0.89	0.79
Harlequin duck	0.27	0.51	0.50	0.49	0.53	0.54	0.49	0.53	0.52	0.52
Oldsquaw	0.96	0.89	0.90	0.88	0.91	0.89	0.92	0.95	0.69	0.69
Scoters	0.73	0.68	0.69	0.67	0.71	0.70	0.62	0.73	0.88	0.80
Goldeneyes	1.00	2.14	2.14	2.14	2.51	2.68	2.01	2.01	2.04	2.04
Mergansers	0.50	0.49	0.48	0.48	0.51	0.50	0.50	0.47	0.60	0.67
Shorebirds	0.42	0.89	0.89	0.89	0.67	0.76	0.83	0.94	0.93	0.91
Jaegers	0.43	0.39	0.38	0.39	0.40	0.39	0.41	0.42	0.48	0.52
Mew gull	0.45	0.83	0.82	0.80	0.90	0.71	0.77	0.71	0.75	0.76
Glaucous-winged gull	0.17	0.17	0.18	0.19	0.16	0.17	0.17	0.19	0.19	0.17
Black-legged kittiwake	0.24	0.25	0.26	0.26	0.24	0.23	0.24	0.21	0.24	0.23
Terns	0.31	0.29	0.30	0.30	0.32	0.31	0.32	0.32	0.27	0.26
Murres	0.41	0.38	0.41	0.42	0.28	0.38	0.38	0.29	0.33	0.31
Pigeon guillemot	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.20	0.19	0.19
Murrelets[e]	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.11	0.11	0.11
Tufted puffin	0.18	0.16	0.16	0.16	0.17	0.16	0.16	0.14	0.12	0.12
Horned puffin	0.19	0.17	0.17	0.17	0.17	0.17	0.18	0.15	0.13	0.13
Total marine birds	0.13	0.12	0.12	0.13	0.10	0.12	0.12	0.10	0.12	0.10
Sea otter	0.27	0.26	0.26	0.25	0.26	0.25	0.25	0.24	0.24	0.27

Table 21 (continued).

	Original[a]									
	3 nm coastal				Distance from Colonies (km)[b]				East-West[d]	
Species	Original	By %	5 nm coastal	No coastal	5	10	15	North-South[c]	No coastal	Coastal
Mean CV	0.38	0.47	0.47	0.47	0.49	0.49	0.46	0.48	0.48	0.47

[a] The original stratification included a shoreline, coastal, and pelagic strata. Transects were re-allocated among these strata by marine bird abundance (by % of birds). We also examined re-stratification with a larger (5 nm) coastal stratum and without the coastal stratum.

[b] We re-stratified by creating a stratum of varying distances around colonies of >500 birds.

[c] North-south denotes re-stratification based on dividing the Inlet into northern and southern strata at Anchor Point and placing Kamishak and Kachemak Bays into separate strata.

[d] We divided the Inlet into east and west strata with a 3 nm coastal stratum and without this stratum.

[e] Marbled and Kittlitz's murrelets only.

Table 22. Rank of coefficients of variation (CV) for species and species groups from re-stratification of the study area used for a small boat survey of Lower Cook Inlet during June, 1993. Sample size used to calculate the variance for each stratum was determined on the basis of the population of total marine birds in the stratum.

	Original[a]									
	3 nm coastal				Distance from Colonies (km)[b]			East-West[d]		
Species	Original	By %	5 nm coastal	No coastal	5	10	15	North-South[c]	No coastal	Coastal
Loons	8	6	3.5	3.5	5	1.5	1.5	9	7	10
Northern fulmar	10	5	4	6	7.5	7.5	9	3	2	1
Shearwaters	10	6	3	6	9	6	6	6	1	2
Storm-petrels	10	4	4	6.5	8.5	6.5	8.5	4	1.5	1.5
Cormorants	1	4.5	4.5	2	4.5	4.5	8.5	8.5	8.5	8.5
Scaup	1	5	4	3	7.5	9	2	10	6	7.5
Eiders	5.5	1	3.5	2	5.5	3.5	7	8	10	9
Harlequin duck	1	5	4	2.5	8.5	10	2.5	8.5	6.5	6.5
Oldsquaw	10	4.5	6	3	7	4.5	8	9	1.5	1.5
Scoters	7.5	3	4	2	6	5	1	7.5	10	9
Goldeneyes	1	7	7	7	9	10	2.5	2.5	4.5	4.5
Mergansers	6	4	2.5	2.5	8	6	6	1	9	10
Shorebirds	1	6	6	6	2	3	4	10	9	8
Jaegers	8	3	1	3	5	3	6	7	9	10
Mew gull	1	9	8	7	10	2.5	6	2.5	4	5
Glaucous-winged gull	4	4	7	9	1	4	4	9	9	4

Table 22 (continued).

Species	Original[a]				Distance from Colonies (km)[b]				East-West[d]	
	3 nm coastal									
	Original	By %	5 nm coastal	No coastal	5	10	15	North-South[c]	No coastal	Coastal
Black-legged kittiwake	5.5	8	9.5	9.5	5.5	2.5	5.5	1	5.5	2.5
Terns	6.5	3	4.5	4.5	9	6.5	9	9	2	1
Murres	8.5	6	8.5	10	1	6	6	2	4	3
Pigeon guillemot	4	4	4	4	4	4	4	10	8.5	8.5
Murrelets[e]	10	6.5	6.5	6.5	6.5	6.5	6.5	2	2	2
Tufted puffin	10	6	6	6	9	6	6	3	1.5	1.5
Horned puffin	10	6	6	6	6	6	9	3	1.5	1.5
Total marine birds	9.5	6	6	9.5	2	6	6	2	6	2
Sea otter	9.5	7	7	4	7	4	4	1.5	1.5	9.5
Total rank	158.8	129.5	130	131	154	134	138.5	139	131	129.5
Mean rank	10	1.5	3	4.5	9	6	7	8	4.5	1.5

[a] The original stratification included a shoreline, coastal, and pelagic strata. Transects were re-allocated among these strata by marine bird abundance (by % of birds). We also examined re-stratification with a larger (5 nm) coastal stratum and without the coastal stratum.

[b] We re-stratified by creating a stratum of varying distances around colonies of >500 birds.

[c] North-south denotes re-stratification based on dividing the Inlet into northern and southern strata at Anchor Point and placing Kamishak and Kachemak Bays into separate strata.

[d] We divided the Inlet into east and west strata with a 3 nm coastal stratum and without this stratum.

[e] Marbled and Kittlitz's murrelets only.

Table 23. Coefficients of variation (CV) for species and species groups from re-stratification of the study area used for a small boat survey of Lower Cook Inlet during June, 1993. Sample size used to calculate the variance for each stratum was determined by the abundance of common murres in each stratum.

	Original[a]									
	3 nm coastal				Distance from Colonies (km)[b]				East-West[d]	
Species	Original	By %	5 nm coastal	No coastal	5	10	15	North-South[c]	No coastal	Coastal
Loons	0.30	0.36	0.39	0.38	0.38	0.46	0.49	1.43	0.47	0.49
Northern fulmar	0.36	0.37	0.41	0.32	0.42	0.41	0.33	0.35	0.24	0.33
Shearwaters	0.21	0.21	0.18	0.19	0.24	0.23	0.19	0.24	0.16	0.19
Storm-petrels	0.27	0.27	0.30	0.24	0.31	0.30	0.25	0.36	0.20	0.25
Cormorants	0.19	0.71	0.96	0.91	0.71	1.16	1.41	1.43	1.26	1.41
Scaup	0.51	3.07	4.23	4.01	2.84	5.92	6.32	20.15	5.78	6.32
Eiders	0.71	0.81	0.97	0.99	1.01	1.11	1.72	1.66	1.41	1.72
Harlequin Duck	0.27	1.61	2.23	2.18	1.71	2.95	3.20	2.16	3.03	3.20
Oldsquaw	0.96	0.74	0.76	0.90	1.14	1.11	0.59	2.25	0.73	0.59
Scoters	0.73	0.55	0.56	0.67	0.86	0.86	1.25	1.41	0.99	1.25
Goldeneyes	1.00	7.09	10.02	10.02	7.09	15.86	5.78	5.79	5.78	5.78
Mergansers	0.50	0.84	1.12	1.09	0.87	1.28	1.43	1.00	1.53	1.43
Shorebirds	0.42	2.94	4.16	4.16	4.48	2.85	5.86	4.52	5.86	5.86
Jaegers	0.43	0.43	0.49	0.39	0.49	0.49	0.49	0.58	0.54	0.49
Mew gull	0.45	2.66	3.71	3.60	2.48	2.42	2.15	2.72	2.10	2.15
Glaucous-winged gull	0.17	0.30	0.39	0.39	0.38	0.38	0.40	0.64	0.38	0.40
Black-legged kittiwake	0.24	0.48	0.62	0.60	0.68	0.43	0.41	0.44	0.38	0.41
Terns	0.31	0.26	0.25	0.30	0.38	0.38	0.25	0.61	0.27	0.25
Murres	0.41	0.31	0.33	0.42	0.16	0.25	0.20	0.20	0.31	0.20
Pigeon guillemot	0.18	0.33	0.42	0.40	0.36	0.48	0.56	0.37	0.51	0.56
Murrelets[e]	0.14	0.14	0.13	0.13	0.16	0.15	0.13	0.13	0.12	0.13
Tufted Puffin	0.18	0.19	0.19	0.18	0.23	0.19	0.19	0.18	0.17	0.19
Horned Puffin	0.19	0.19	0.21	0.17	0.22	0.21	0.18	0.18	0.15	0.18

Table 23 (continued).

	Original[a]									
	3 nm coastal				Distance from Colonies (km)[b]				East-West[d]	
Species	Original	By %	5 nm coastal	No coastal	5	10	15	North-South[c]	No coastal	Coastal
Total marine birds	0.13	0.12	0.14	0.15	0.14	0.13	0.12	0.17	0.13	0.12
Sea otter	0.27	0.40	0.51	0.49	0.59	0.39	0.34	0.30	0.33	0.34
Mean CV	0.38	1.02	1.35	1.33	1.13	1.62	1.26	1.97	1.31	1.37

[a] The original stratification included a shoreline, coastal, and pelagic strata. Transects were re-allocated among these strata by marine bird abundance (by % of birds). We also examined re-stratification with a larger (5 nm) coastal stratum and without the coastal stratum.

[b] We re-stratified by creating a stratum of varying distances around colonies of >500 birds.

[c] North-south denotes re-stratification based on dividing the Inlet into northern and southern strata at Anchor Point and placing Kamishak and Kachemak Bays into separate strata.

[d] We divided the Inlet into east and west strata with a 3 nm coastal stratum and without this stratum.

[e] Marbled and Kittlitz's murrelets only.

Table 24. Possible re-stratifications of the study area used for a small boat survey of Lower Cook Inlet ranked by species and coefficient of variation (CV). Sample size used to calculate the variance for each stratum was determined by abundance of common murres in the stratum.

	Original[a]				Distance from Colonies (km)[b]				East-West[d]	
	3 nm coastal									
Species	Original	By %	5 nm coastal	No coastal	5	10	15	North-South[c]	No coastal	Coastal
Loons	1	2	5	3.5	3.5	6	9	10	7	8
Northern fulmar	5	6	7.5	2	9	7.5	10	4	1	3
Shearwaters	6	6	2	3.5	9.5	8	6	9.5	1	3.5
Storm-petrels	4.5	4.5	6.5	2	8	6.5	9	10	1	3
Cormorants	1	2.5	5	4	2.5	6	10	9	7	8
Scaup	1	4	6	5	2	8	3	10	7	9
Eiders	1	2	3	4	5	7	6	9	8	10
Harlequin duck	1	2	6	5	3	7	8.5	4	8.5	10
Oldsquaw	6	3	4	5	8	7	9	10	2	1
Scoters	5	3	2	4	6.5	6.5	1	10	8	9
Goldeneyes	1	6	8.5	8.5	6	10	6	4	2.5	2.5
Mergansers	1	2	6	5	3	7	8	4	10	9
Shorebirds	1	4	5.5	5.5	7	2	3	8	9.5	9.5
Jaegers	2.5	2.5	5.5	1	5.5	5.5	8	10	9	5.5
Mew gull	1	6	10	9	5	4	8	7	2	3
Glaucous-winged gull	1	2	6.5	6.5	4	4	9	10	4	8
Black-legged kittiwake	1	7	9	8	10	4	6	5	2	3

Table 24 continued.

	Original[a]									
	3 nm coastal				Distance from Colonies (km)[b]				East-West[d]	
Species	Original	By %	5 nm coastal	No coastal	5	10	15	North-South[c]	No coastal	Coastal
Terns	6	3	1.5	5	7.5	7.5	9	10	4	1.5
Murres	9	6.5	8	10	1	4	5	2.5	6.5	2.5
Pigeon guillemot	1	2	6	5	3	7	10	4	8	9
Murrelets[e]	6.5	6.5	3.5	3.5	9	8	10	3.5	1	3.5
Tufted puffin	3.5	7.5	7.5	3.5	10	7.5	3.5	3.5	1	7.5
Horned puffin	5.5	5.5	7.5	2	9.5	7.5	9.5	3.5	1	3.5
Total marine birds	4.5	1.5	7.5	9	7.5	4.5	4.5	10	4.5	1.5
Sea otter	1	6.5	9	8	10	5	6.5	2	3	4
Total rank	77	103.5	148.5	127.4	155	157	177.5	172.5	118.5	138
Mean rank	1	2	6	4	7	8	10	9	3	5

[a] The original stratification included a shoreline, coastal, and pelagic strata. Transects were re-allocated among these strata by marine bird abundance (by % of birds). We also examined re-stratification with a larger (5 nm) coastal stratum and without the coastal stratum.

[b] We re-stratified by creating a stratum of varying distances around colonies of >500 birds.

[c] North-south denotes re-stratification based on dividing the Inlet into northern and southern strata at Anchor Point and placing Kamishak and Kachemak Bays into separate strata.

[d] We divided the Inlet into east and west strata with a 3 nm coastal stratum and without this stratum.

[e] Marbled and Kittlitz's murrelets only.

Table 25. Comparison of power (%) to detect trends in abundance of marine birds for biannual surveys and for surveys occurring every three years. We examined four levels of precision (CV) with an average annual rate of change of 10%.

	CV = 0.2		CV = 0.3		CV = 0.4		CV = 0.5	
Years	Biannual	3 Yrs	Biannual	3 Yrs	Biannual	3 Yrs	Biannual	3 Yrs
10 years	49	32	29	19	20	15	16	12
20 years	>99	74	92	56	74	38	57	29
30 years	>99	>99	>99	92	>99	74	96	57

Table 26. Comparison of power (%) to detect trends in abundance of marine birds for biannual surveys and for surveys occurring every three years. We examined four levels of precision (CV) with an average annual rate of change of 5%.

	CV = 0.2		CV = 0.3		CV = 0.4		CV = 0.5	
Years	Biannual	3 Yrs	Biannual	3 Yrs	Biannual	3 Yrs	Biannual	3 Yrs
10 years	20	15	14	11	11	9	10	8
20 years	85	38	45	23	31	17	24	14
30 years	>99	85	88	45	68	31	52	24

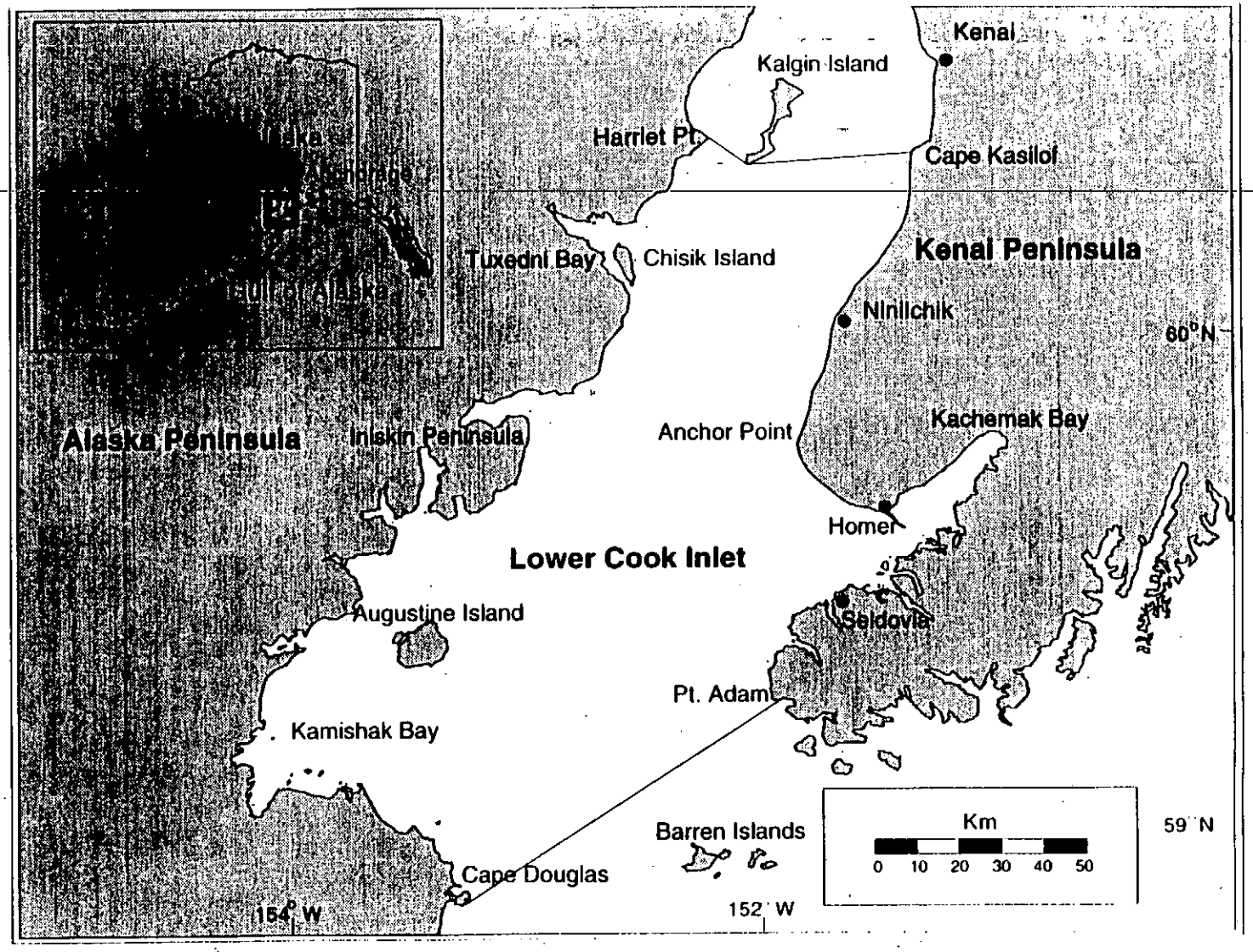

Fig. 1. Study area used for a small boat survey of marine birds and sea otters in Lower Cook Inlet, Alaska, during summer 1993 to estimate population abundance and distribution.

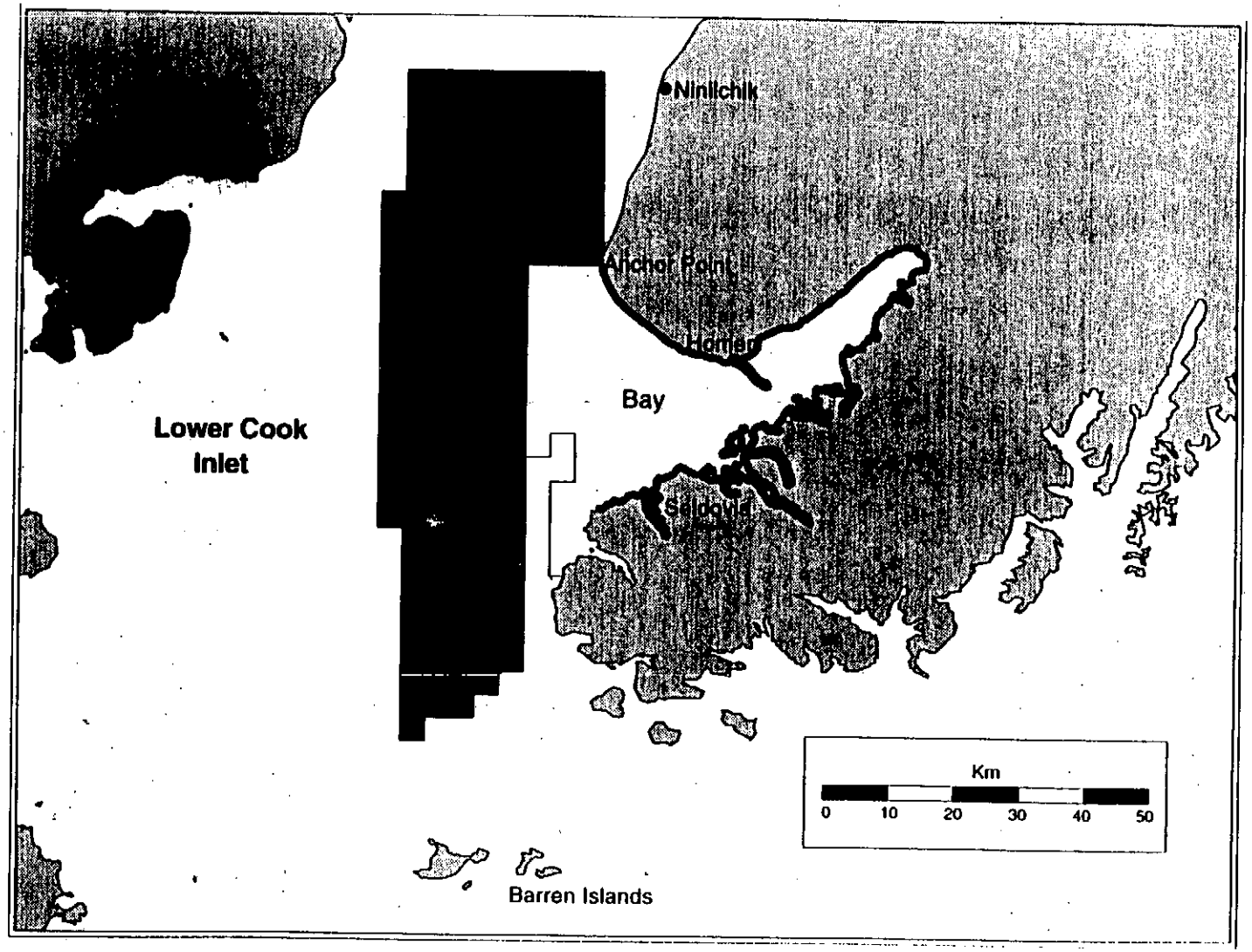

Fig. 2. Study area used for a combined small boat and shipboard survey of marine birds and sea otters in Lower Cook Inlet, Alaska, during winter 1994 to estimate population abundance and distribution. We divided the study area into 3 strata: shoreline, bay, and pelagic. The shoreline stratum is the thick black line, the bay stratum is the light shading, and the pelagic stratum is the dark shading.

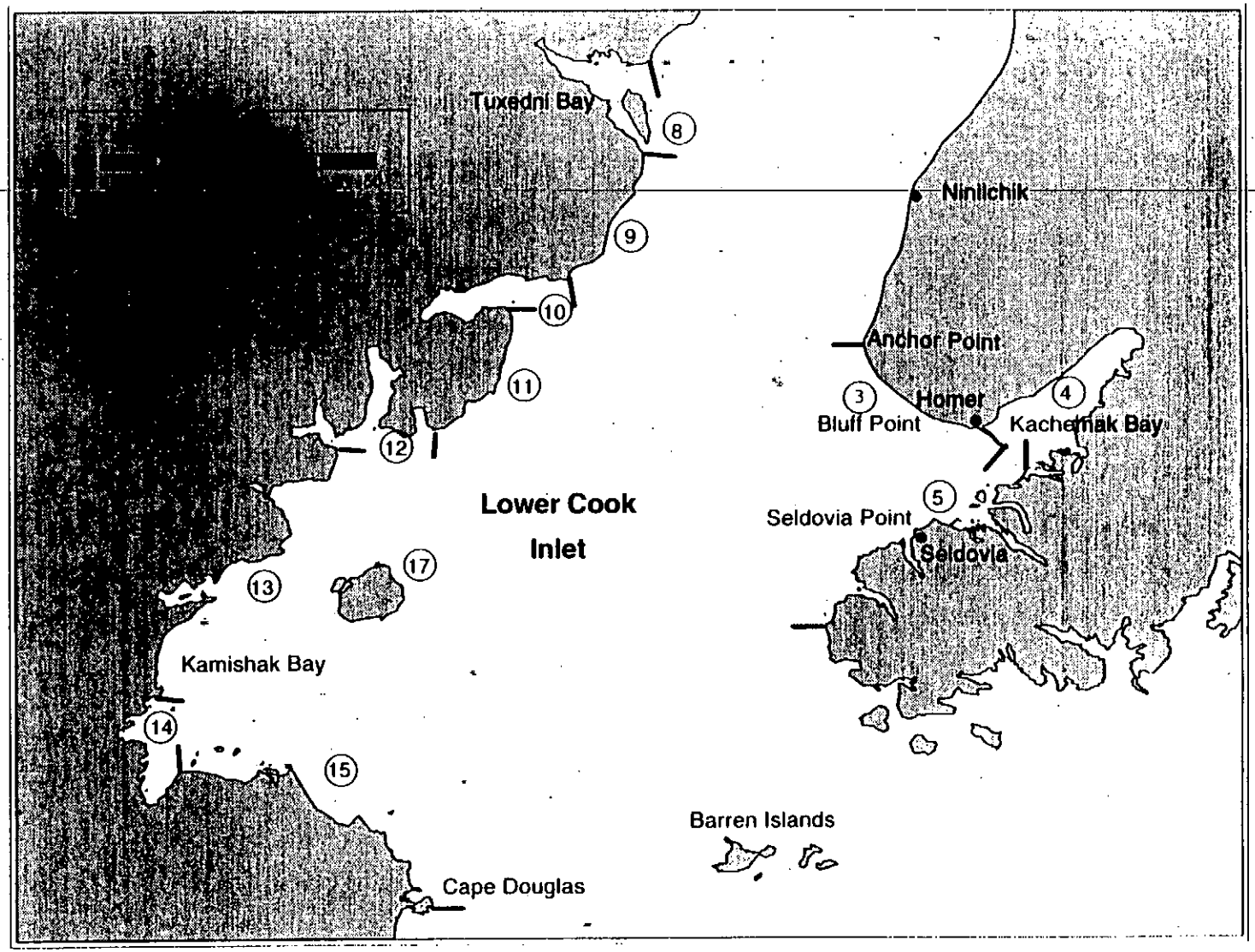

Fig. 3. Study area used for an aerial survey of marine birds and sea otters in Lower Cook Inlet, Alaska, during winter 1994 to estimate population abundance and distribution. Circled numbers indicate segments used by Arneson (1980).

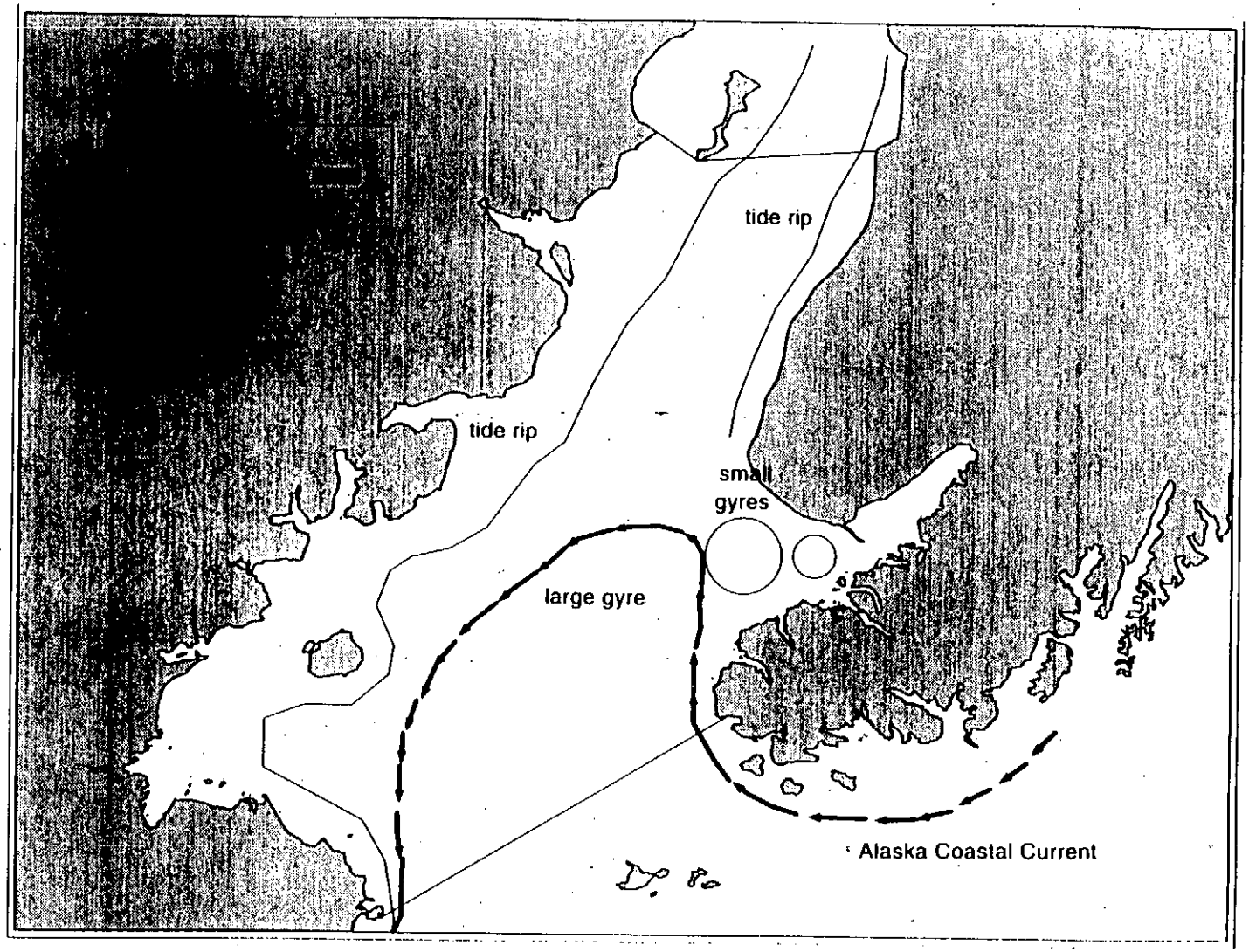

Fig. 4. The major currents and tide rips of Lower Cook Inlet that influence marine bird distribution and abundance (after Burbank 1977). Solid lines running north and south indicate tide rips. Circles represent the position of small gyres in the mouth of Kachemak Bay. The Alaska Coastal Current (dark arrows) enters in the southeastern corner, creating a large gyre in the southern portion of the Inlet.

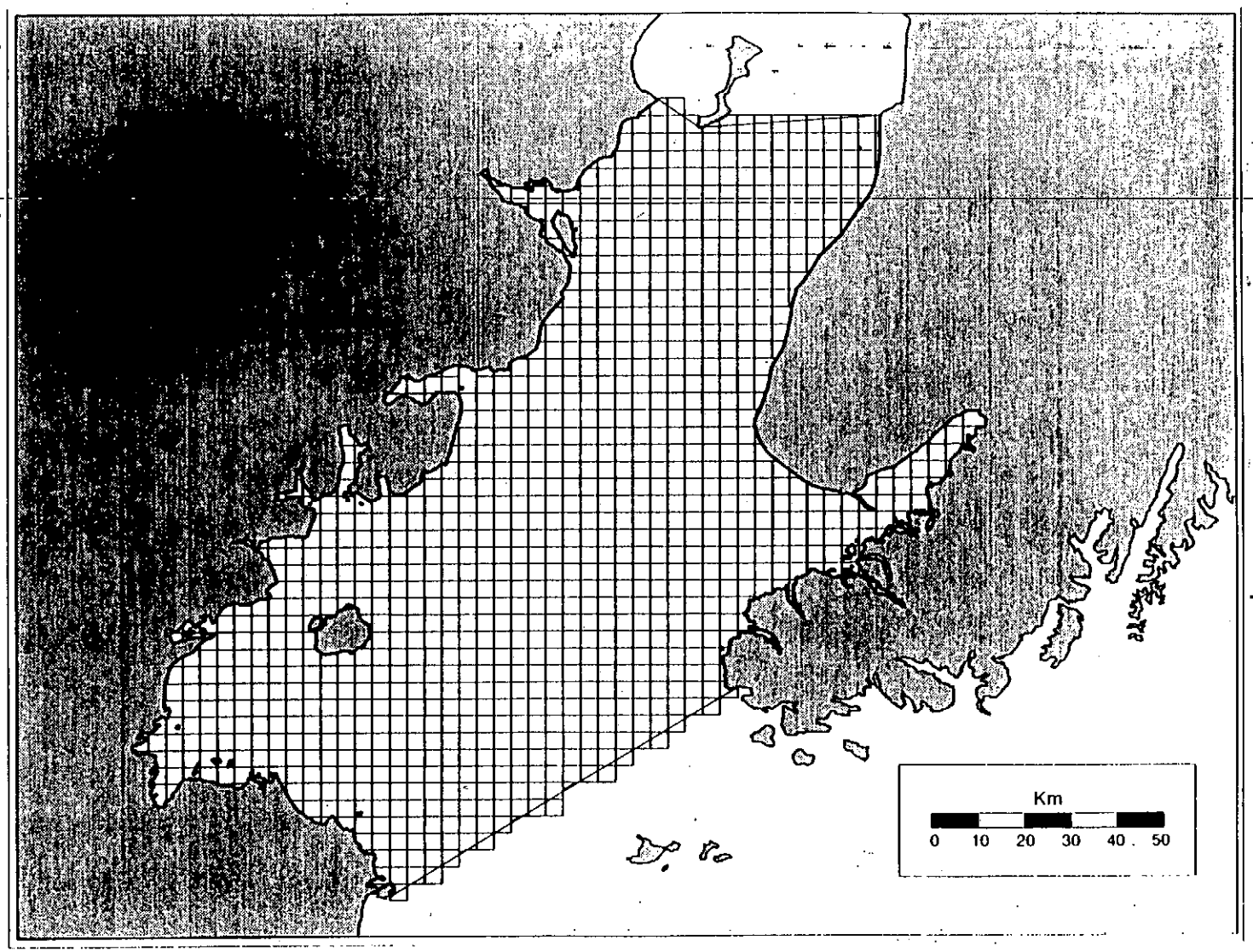

Fig. 5. The 2-minute latitude by 4-minute longitude grid used to separate starting locations of transects for a small boat survey of Lower Cook Inlet, Alaska, during summer 1993. Because of our northern latitude, the 1,096 blocks of the grid were approximately 2 x 2 nm.

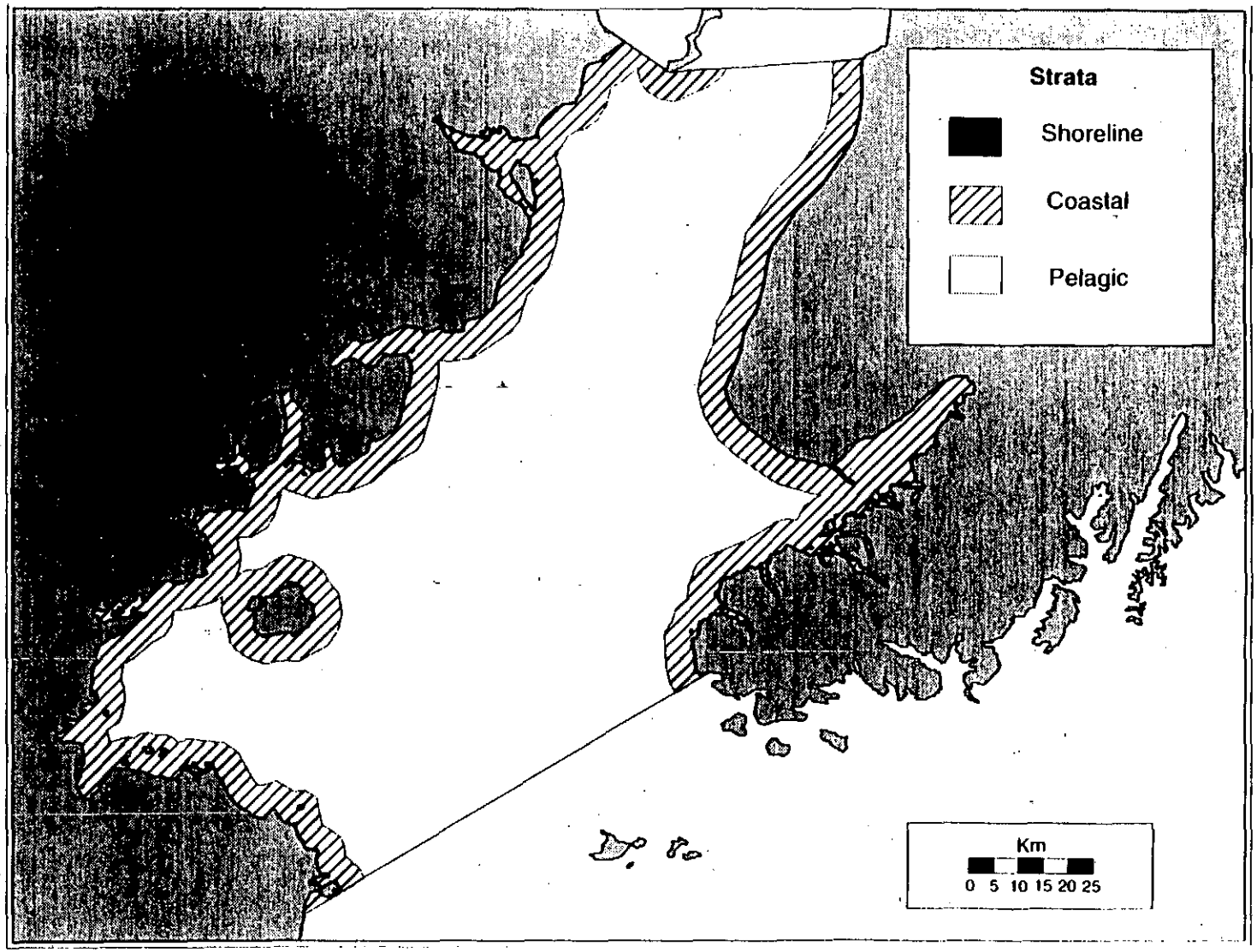

Fig. 6. Location of a 0.1 nm (200 m) shoreline buffer and a 3 nm (5.6 km) coastal buffer used in a survey of Lower Cook Inlet during summer 1993.

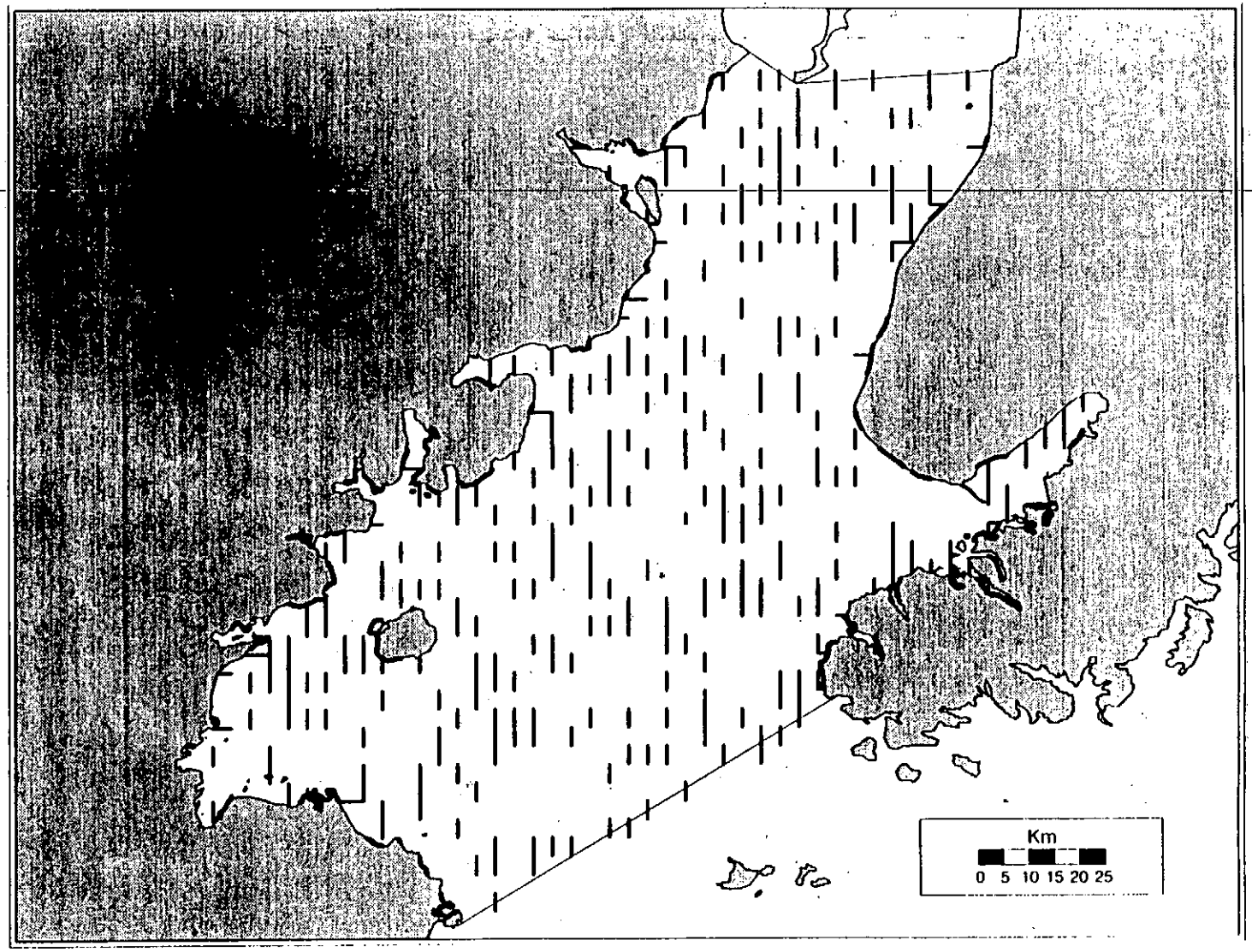

Fig. 7. Randomly-chosen transects (2 nm in length) used in a small boat survey of Lower Cook Inlet, Alaska, during summer 1993 to estimate population abundance and distribution of marine birds and sea otters. Dark lines along the shore indicate shoreline transects.

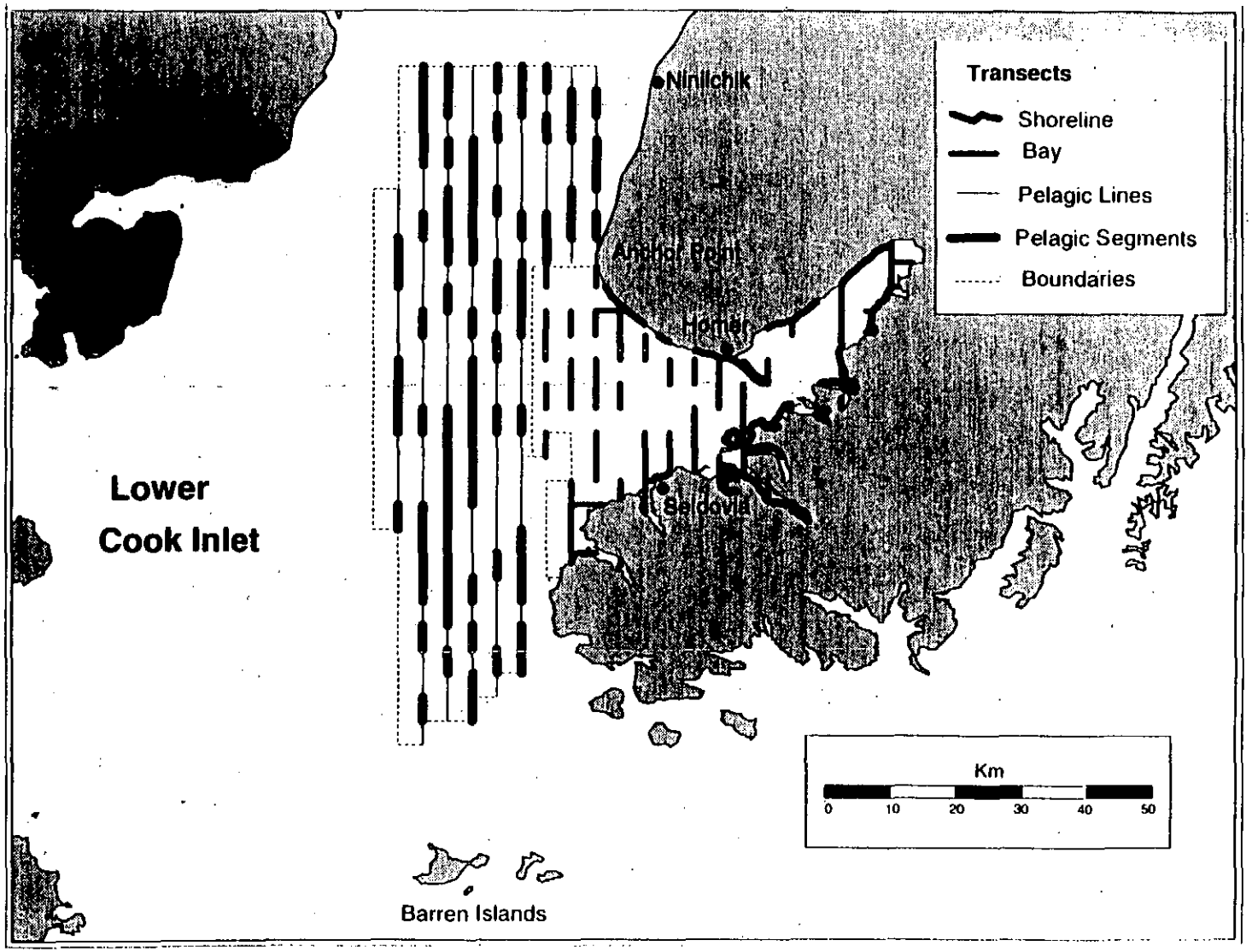

Fig. 8. Transects used in a boat survey of Lower Cook Inlet, Alaska, during winter 1994. The shipboard survey of the pelagic stratum surveyed 9 lines (thin lines), then we selected 85 2-nm segments (thick lines) to calculate our estimates. The bay and shoreline transects were surveyed from small boats.

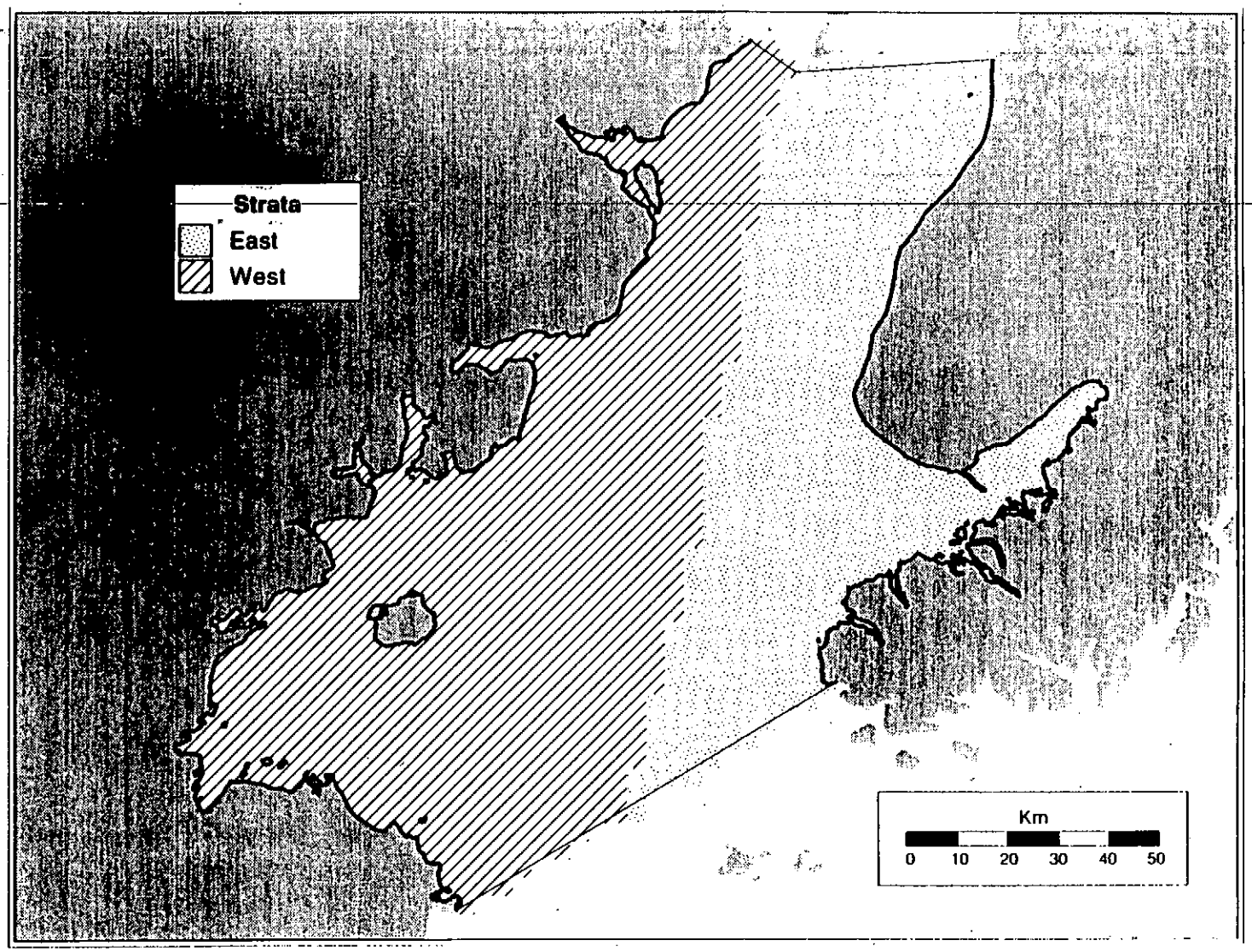

Fig. 9. Location of eastern and western strata used to investigate methods to improve the precision of the population estimate from a survey of Lower Cook Inlet during summer 1993. The 2 strata were further stratified into the pelagic (patterns) and shoreline (dark lines) strata for a total of 4.

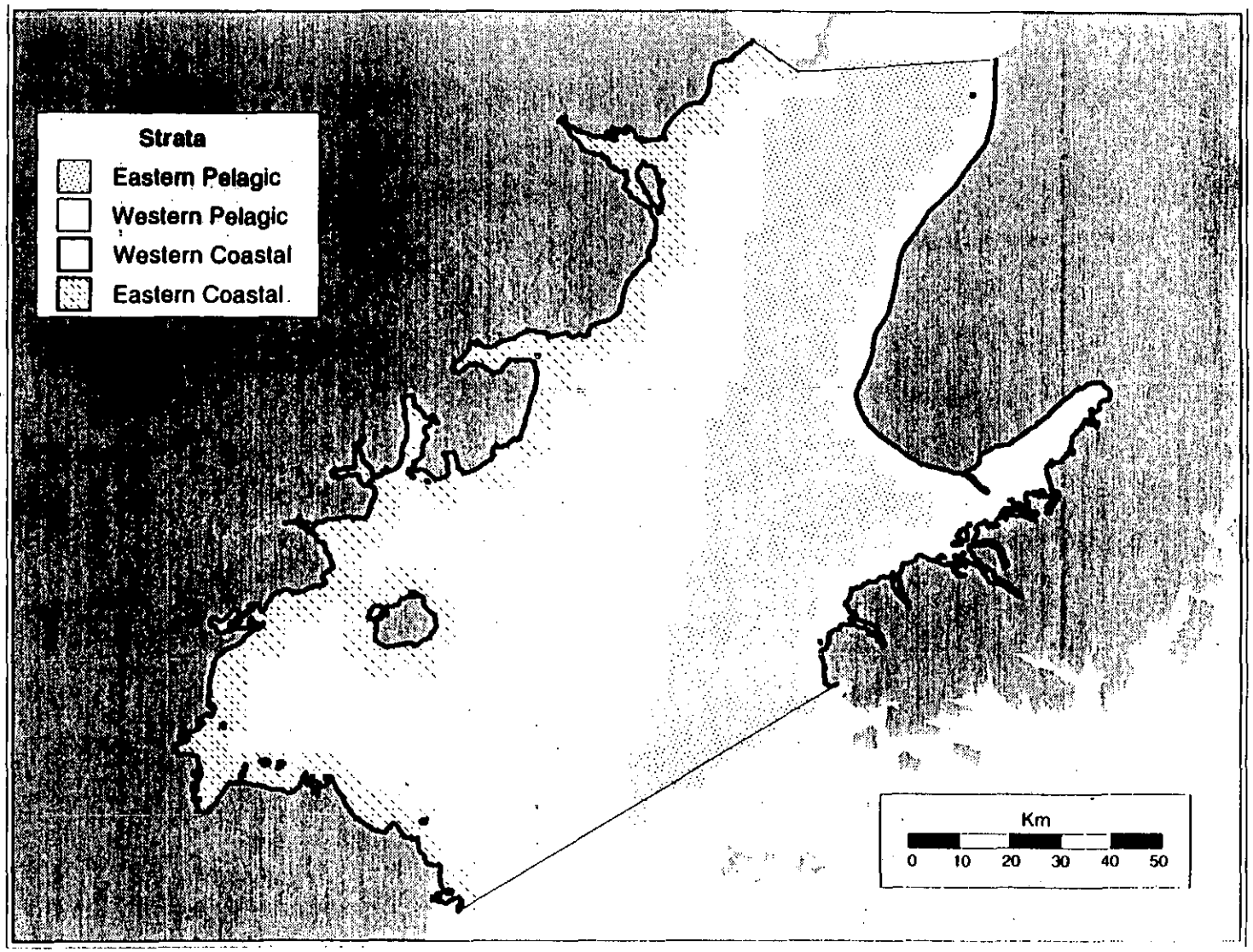

Fig. 10. Location of eastern and western strata used to investigate methods to improve the precision of the population estimate from a survey of Lower Cook Inlet during summer 1993. The 2 strata were further stratified into the pelagic, coastal, and shoreline (dark lines) strata for a total of 6.

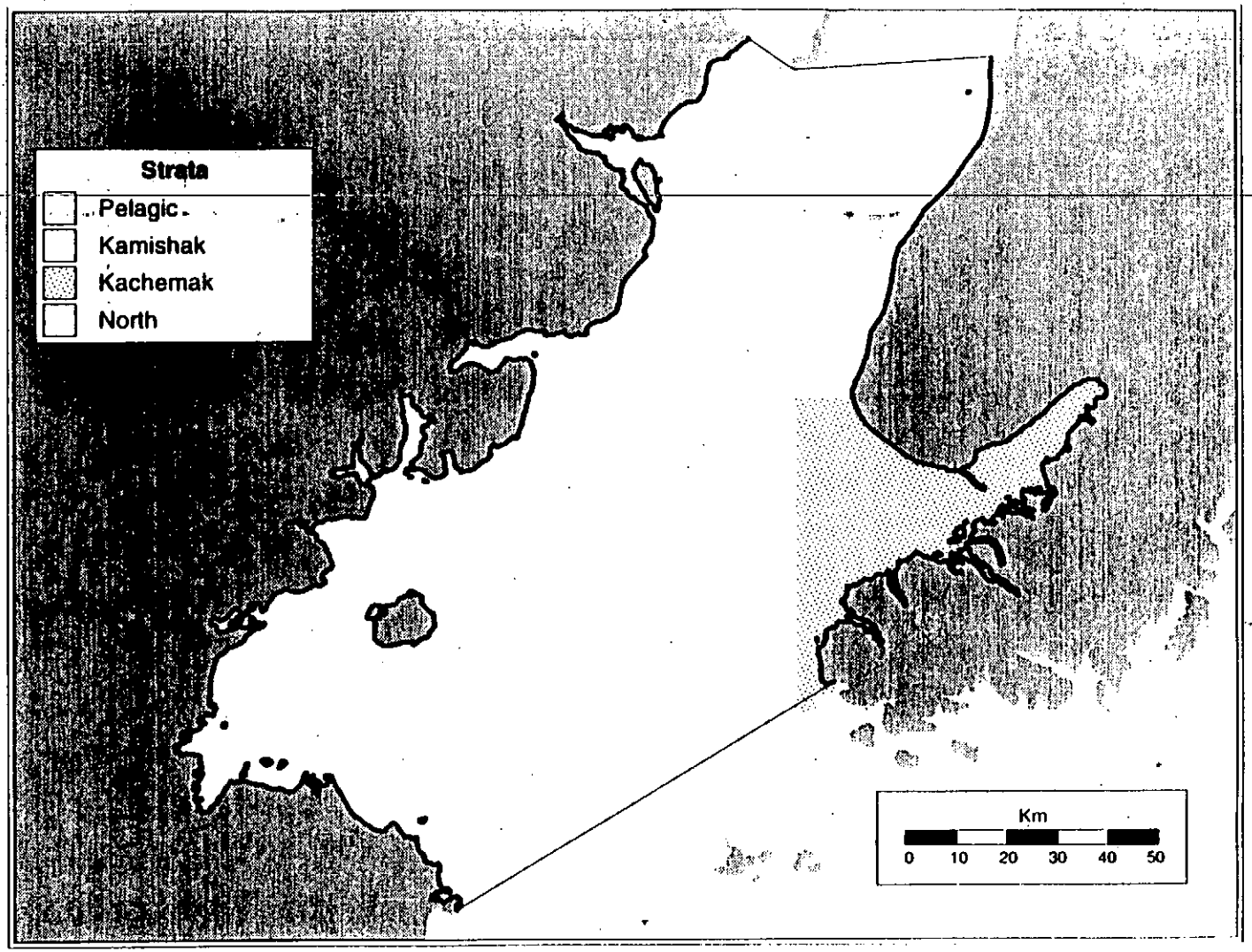

Fig. 11. Location of north, Kamishak Bay, Kachemak Bay, and pelagic strata used to investigate methods to improve the precision of the population estimate from a survey of Lower Cook Inlet during summer 1993. The first 3 strata were further stratified into the pelagic and shoreline (dark lines) strata for a total of 7.

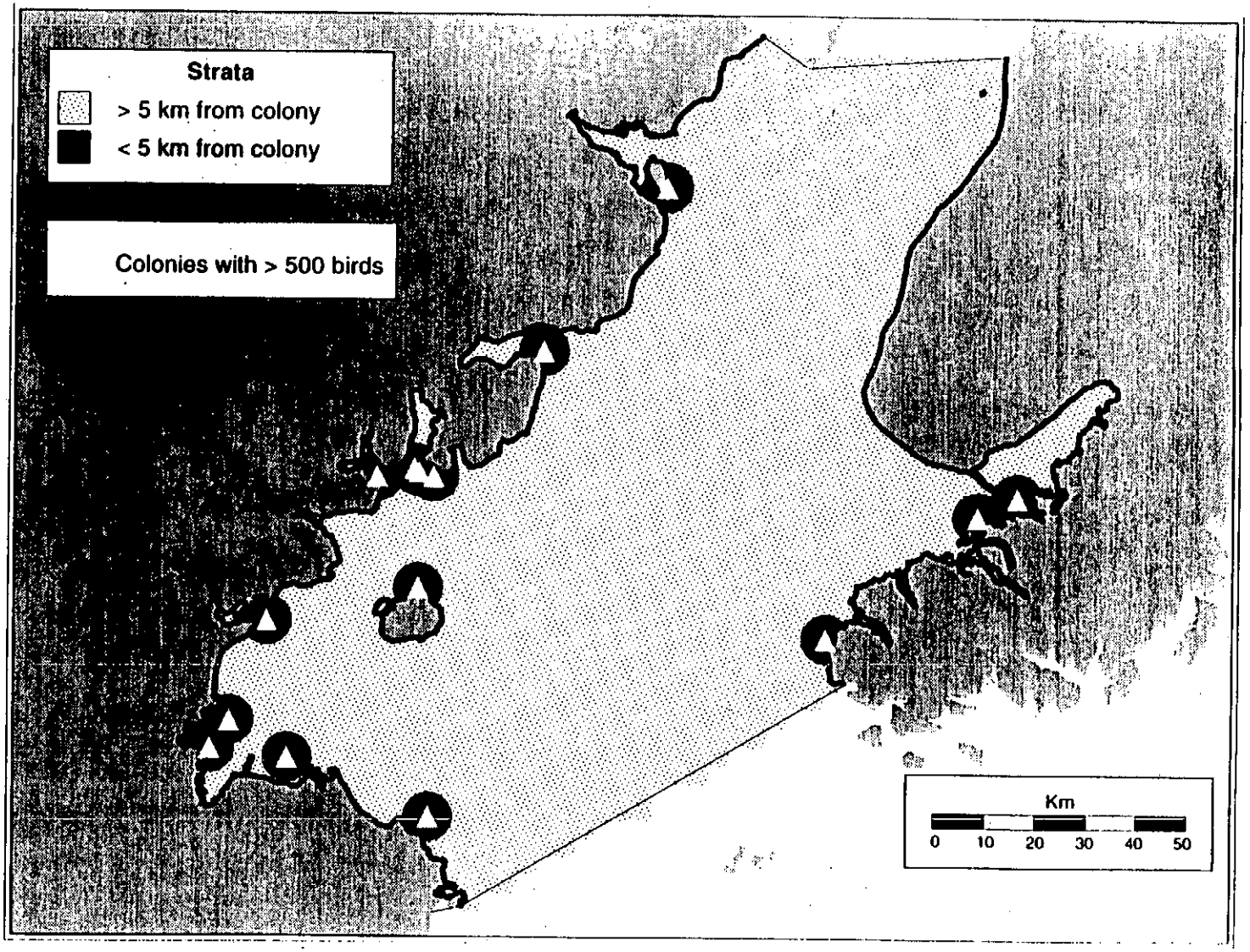

Fig. 12. Location of a 2.7 nm (5 km) buffer around colonies with >500 birds used to examine re-stratification of Lower Cook Inlet to improve precision of estimates of marine bird abundance. These strata were stratified into shoreline and pelagic strata.

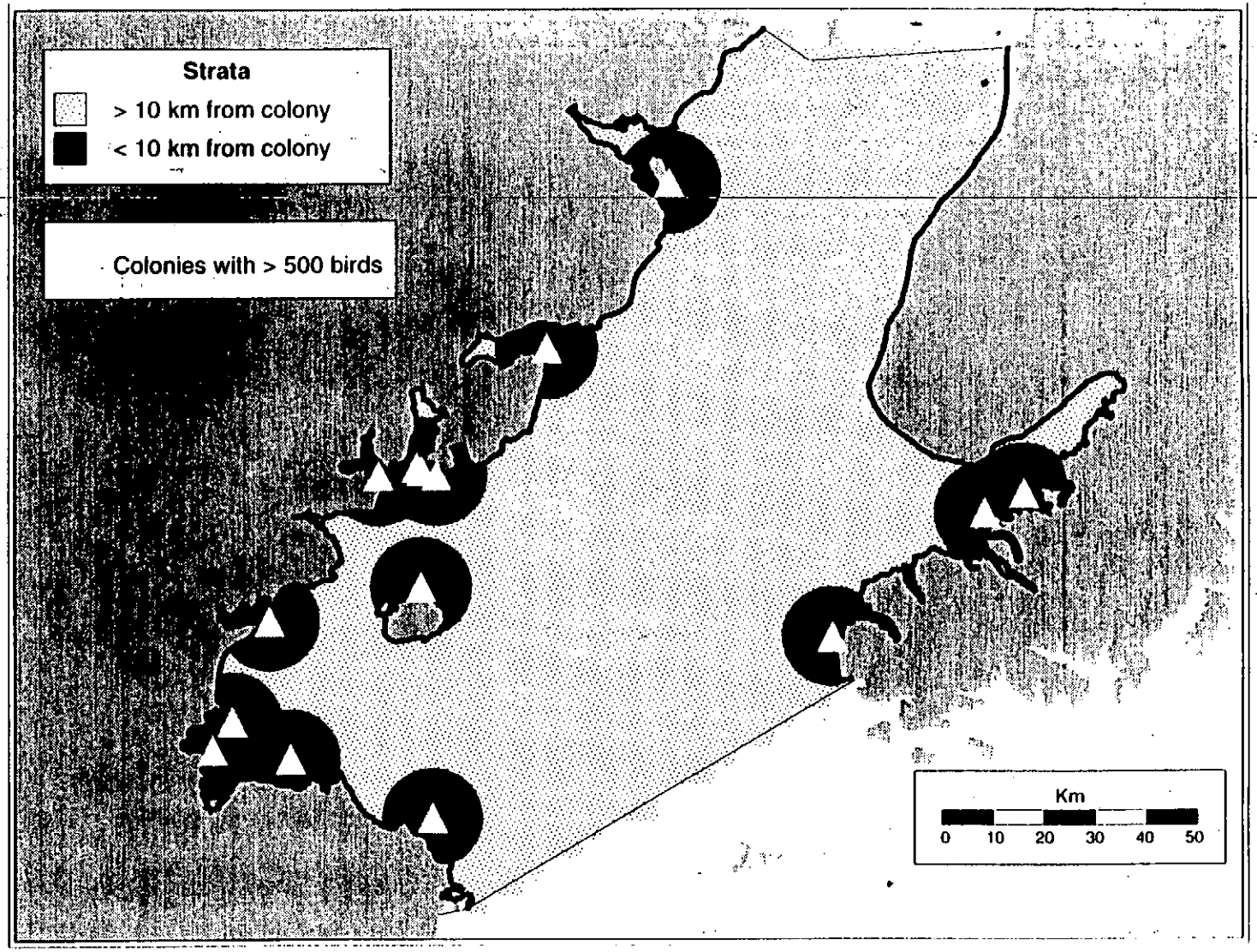

Fig. 13. Location of a 5.4 nm (10 km) buffer around colonies with >500 birds used to examine re-stratification of Lower Cook Inlet to improve precision of estimates of marine bird abundance. These strata were stratified into shoreline and pelagic strata.

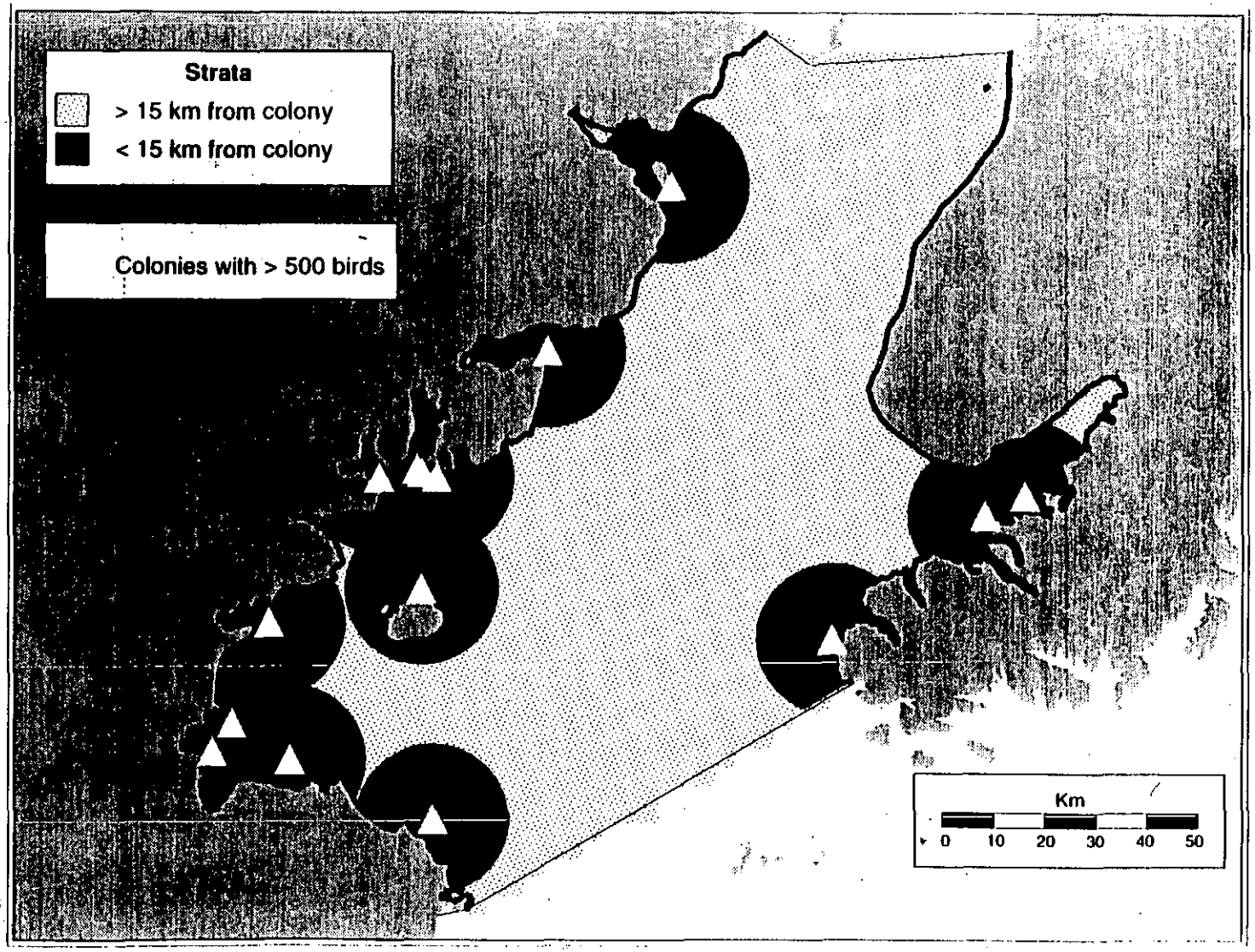

Fig. 14. Location of a 8.1 nm (15 km) buffer around colonies with >500 birds used to examine re-stratification of Lower Cook Inlet to improve the precision of estimates of marine bird abundance. These strata were stratified into shoreline and pelagic strata.

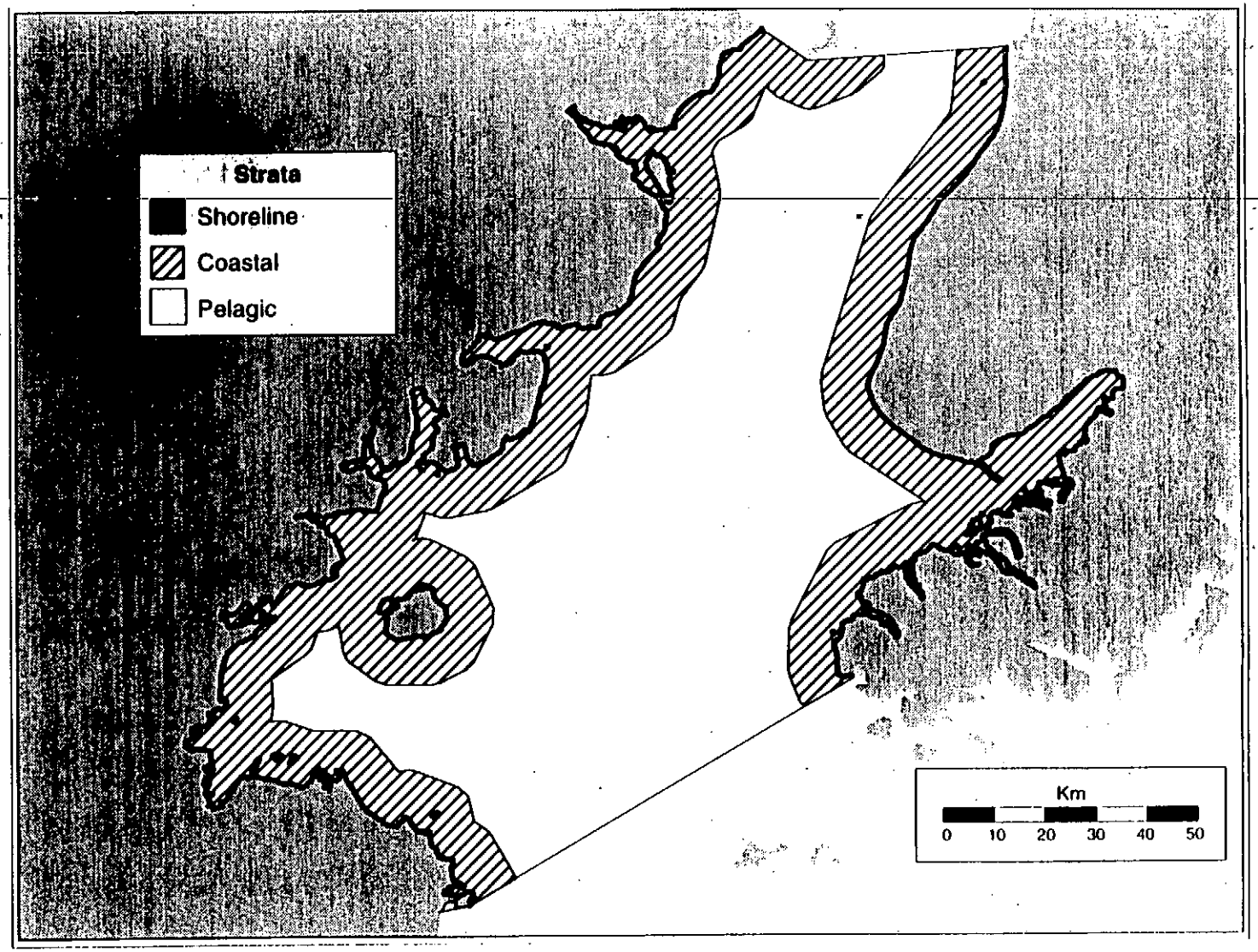

Fig. 15. Location of a 0.1 nm (200 m) shoreline stratum and a 5 nm (9.3 km) coastal stratum used to examine re-stratification of Lower Cook Inlet to improve precision of estimates of marine bird abundance in future surveys.

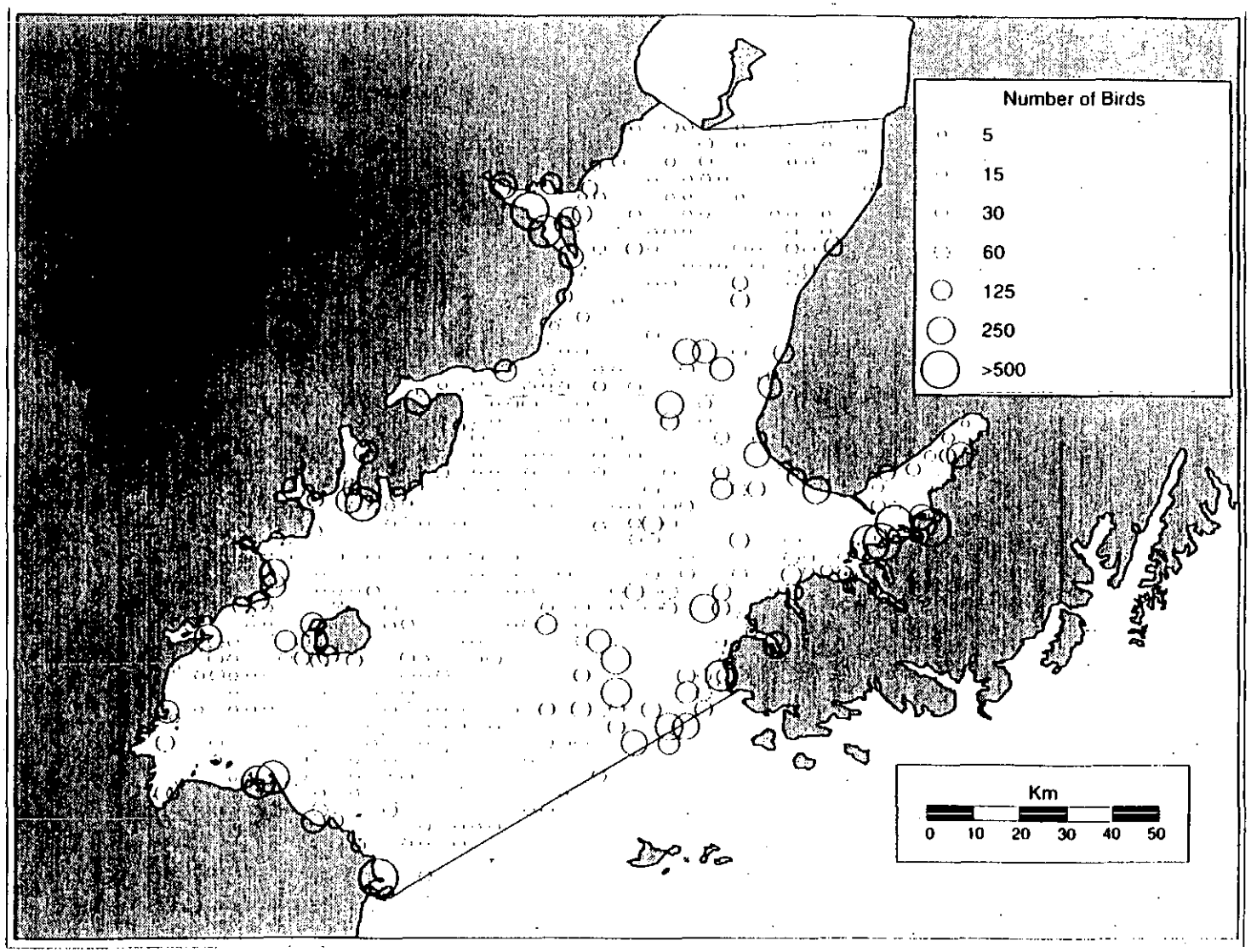

Fig. 16. Summer distribution of marine birds from a small boat survey of Lower Cook Inlet, June 1993. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

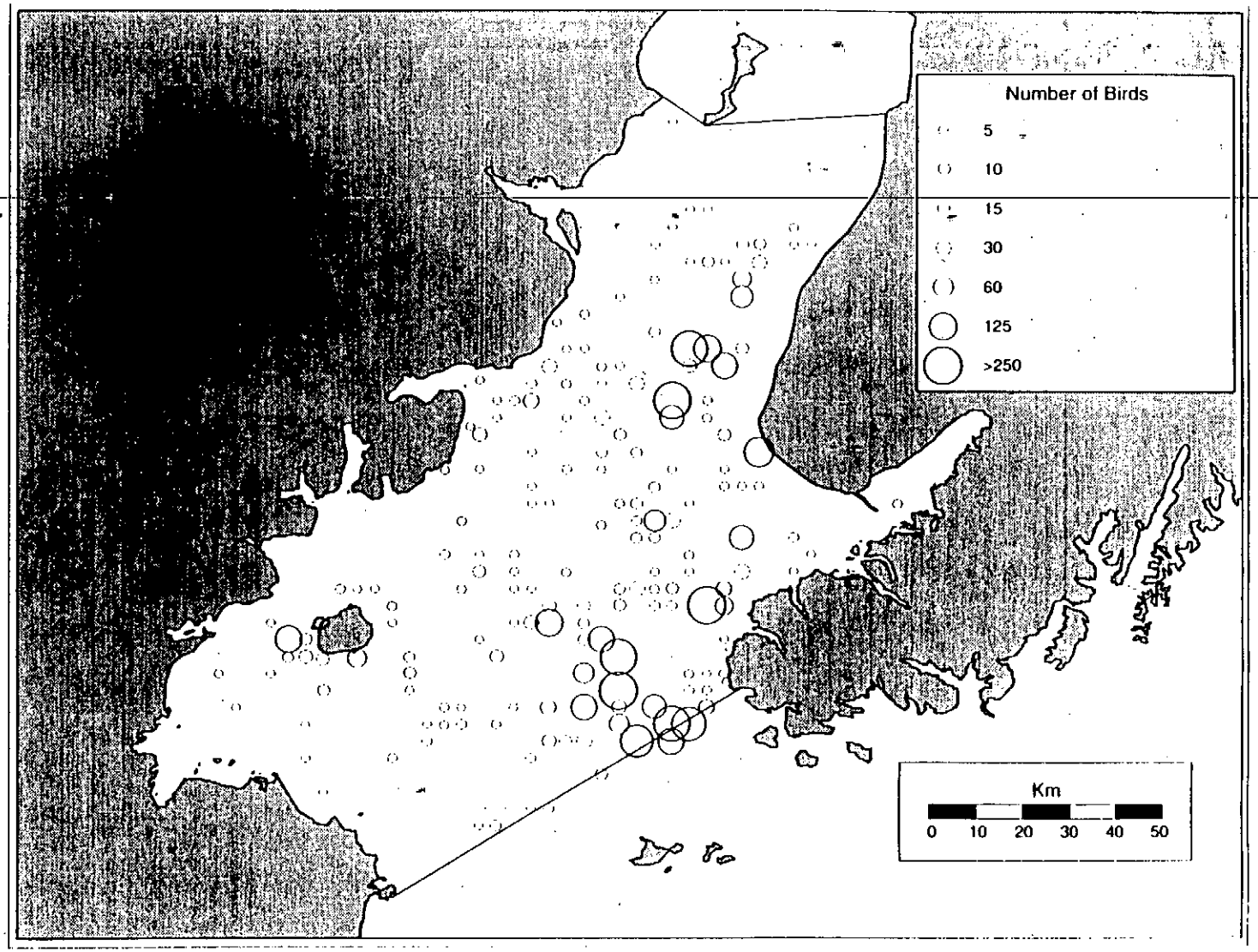

Fig. 17. Summer distribution of tubenoses (shearwaters, fulmars, and storm-petrels) from a small boat survey of Lower Cook Inlet, June 1993. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

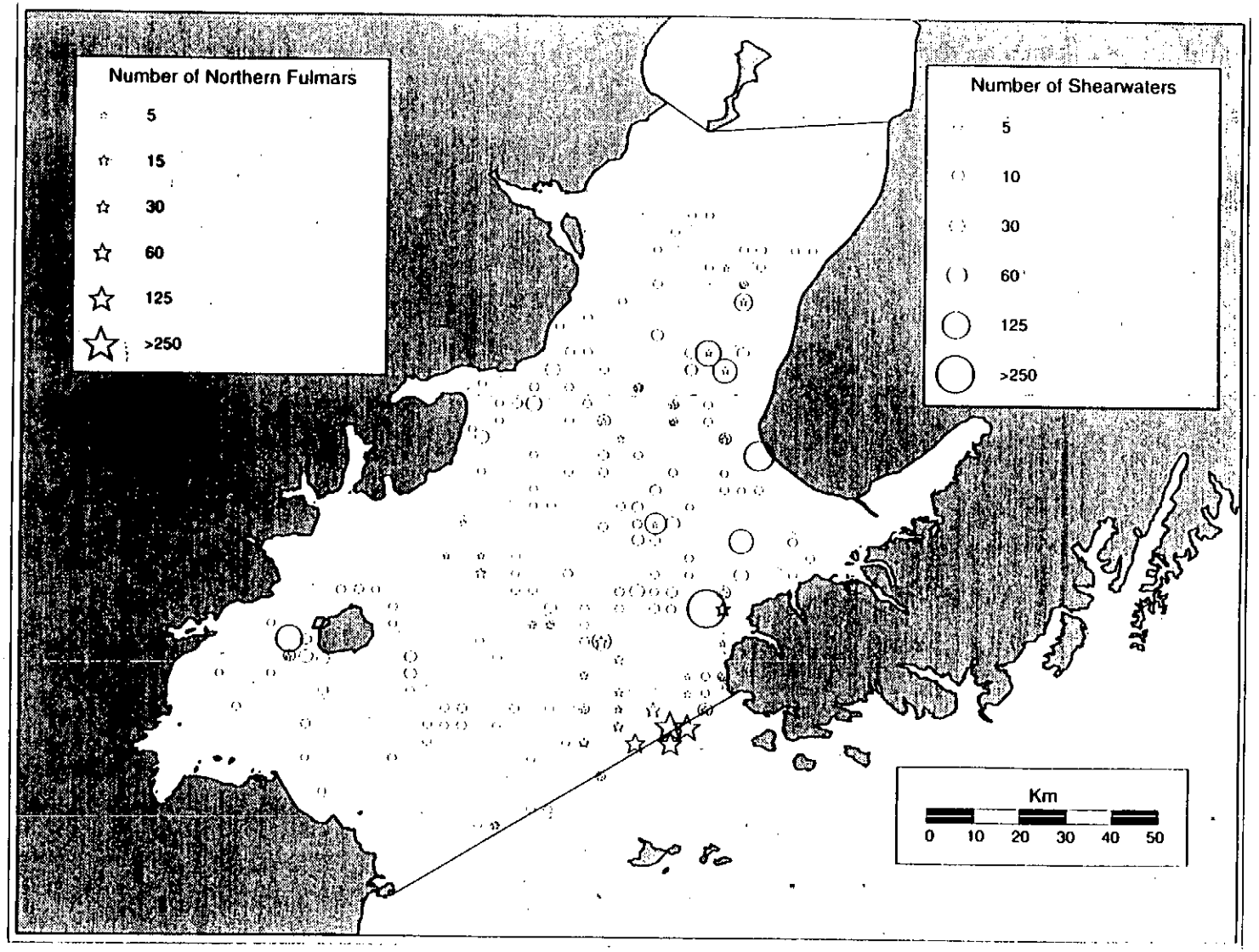

Fig. 18. Summer distribution of northern fulmars and shearwaters from a June 1993 small boat survey of Lower Cook Inlet. Each circle or star represents one transect, and the size of each symbol is dependent upon the number of observations.

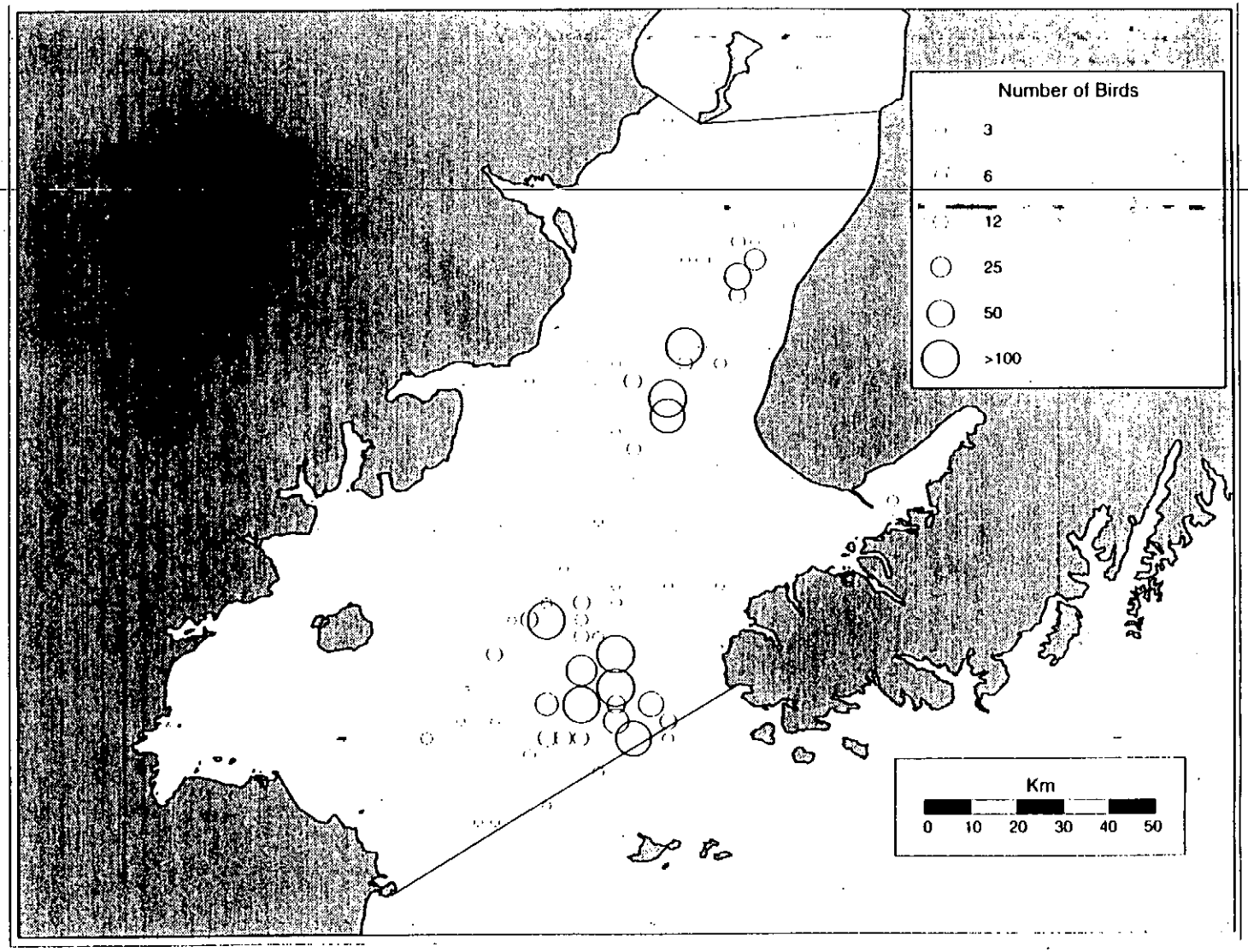

Fig. 19. Summer distribution of fork-tailed storm-petrels from a June 1993 small boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

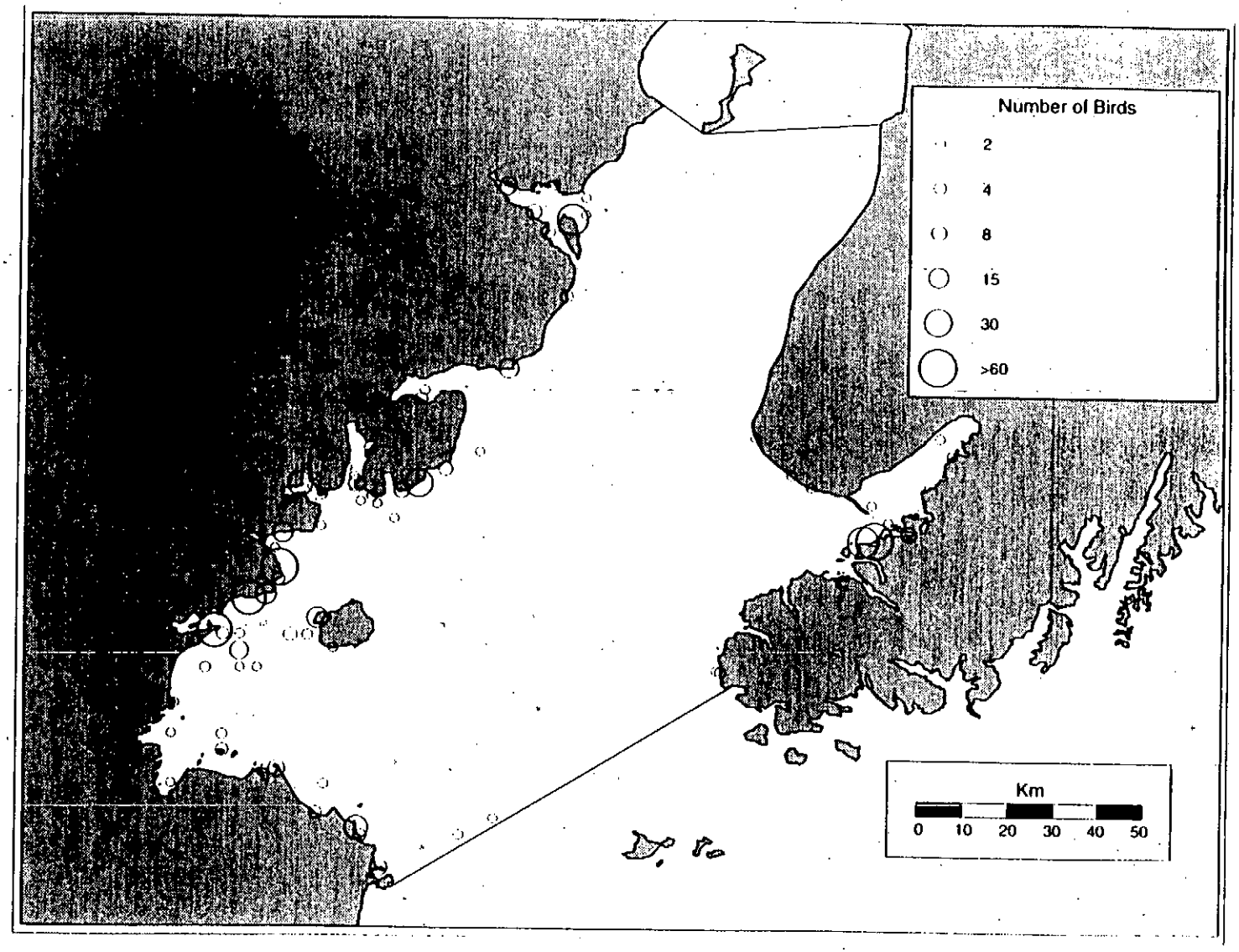

Fig. 20. Summer distribution of cormorants from a June 1993 small boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

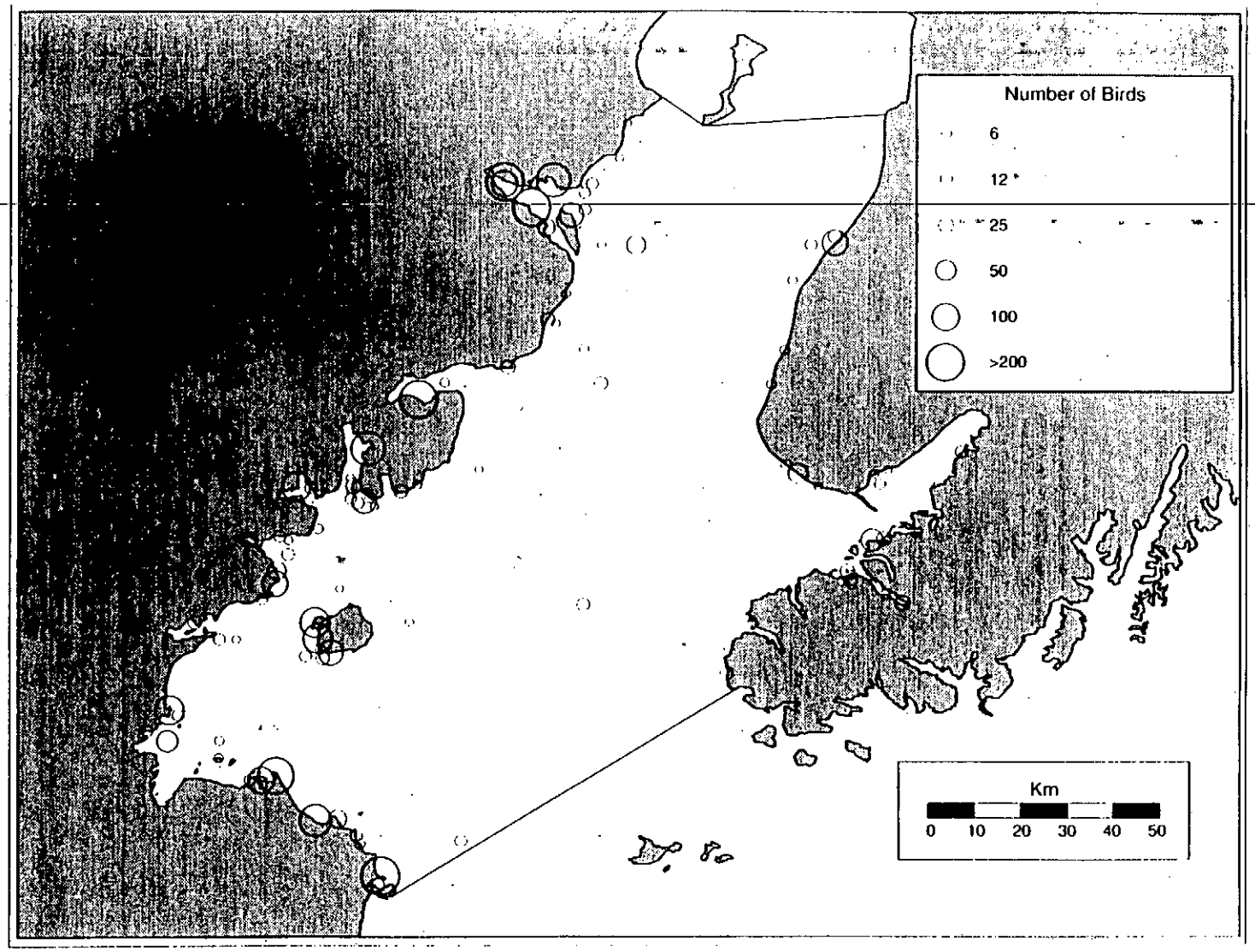

Fig. 21. Summer distribution of waterfowl from a June 1993 small boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

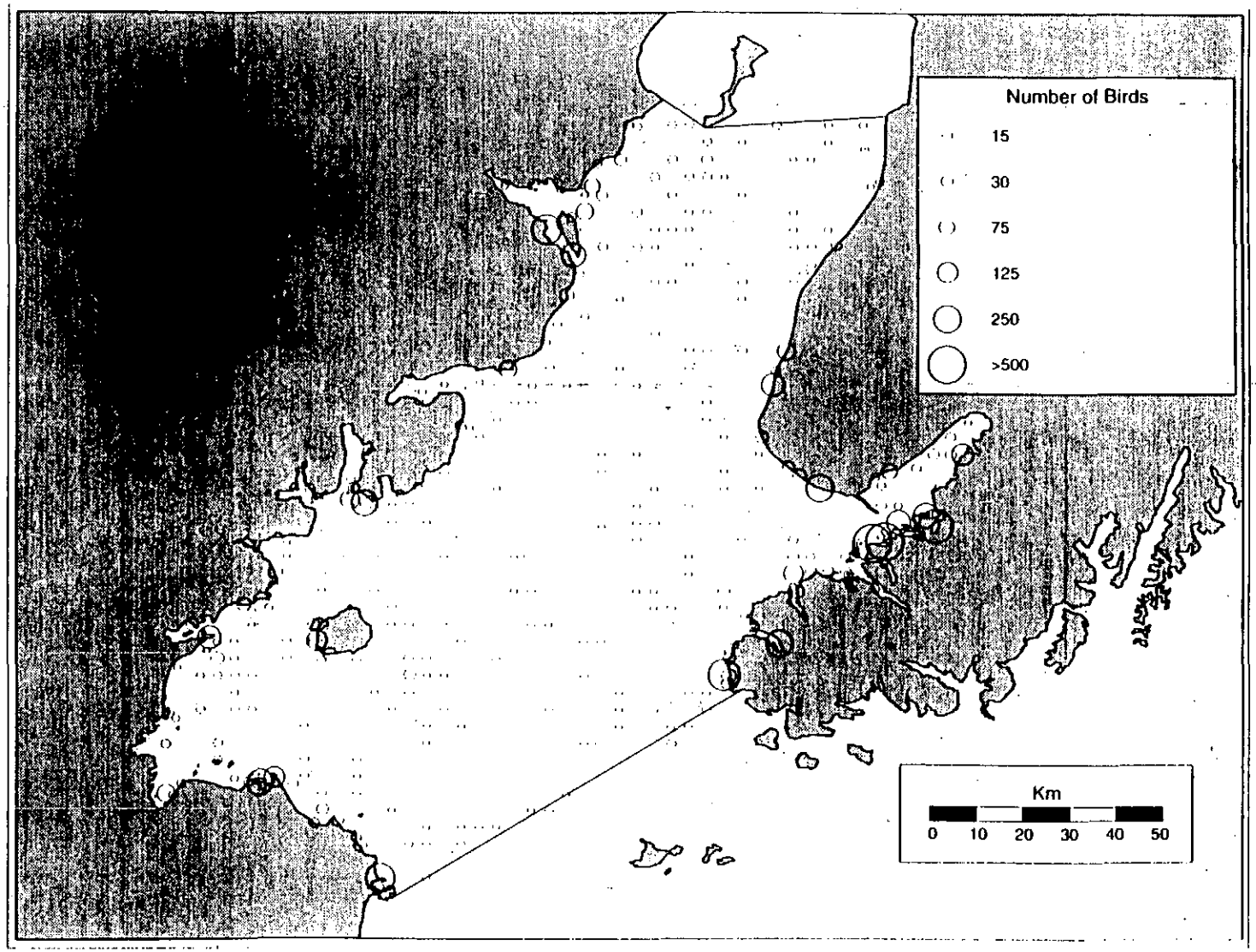

Fig. 22. Summer distribution of gulls from a June 1993 small boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

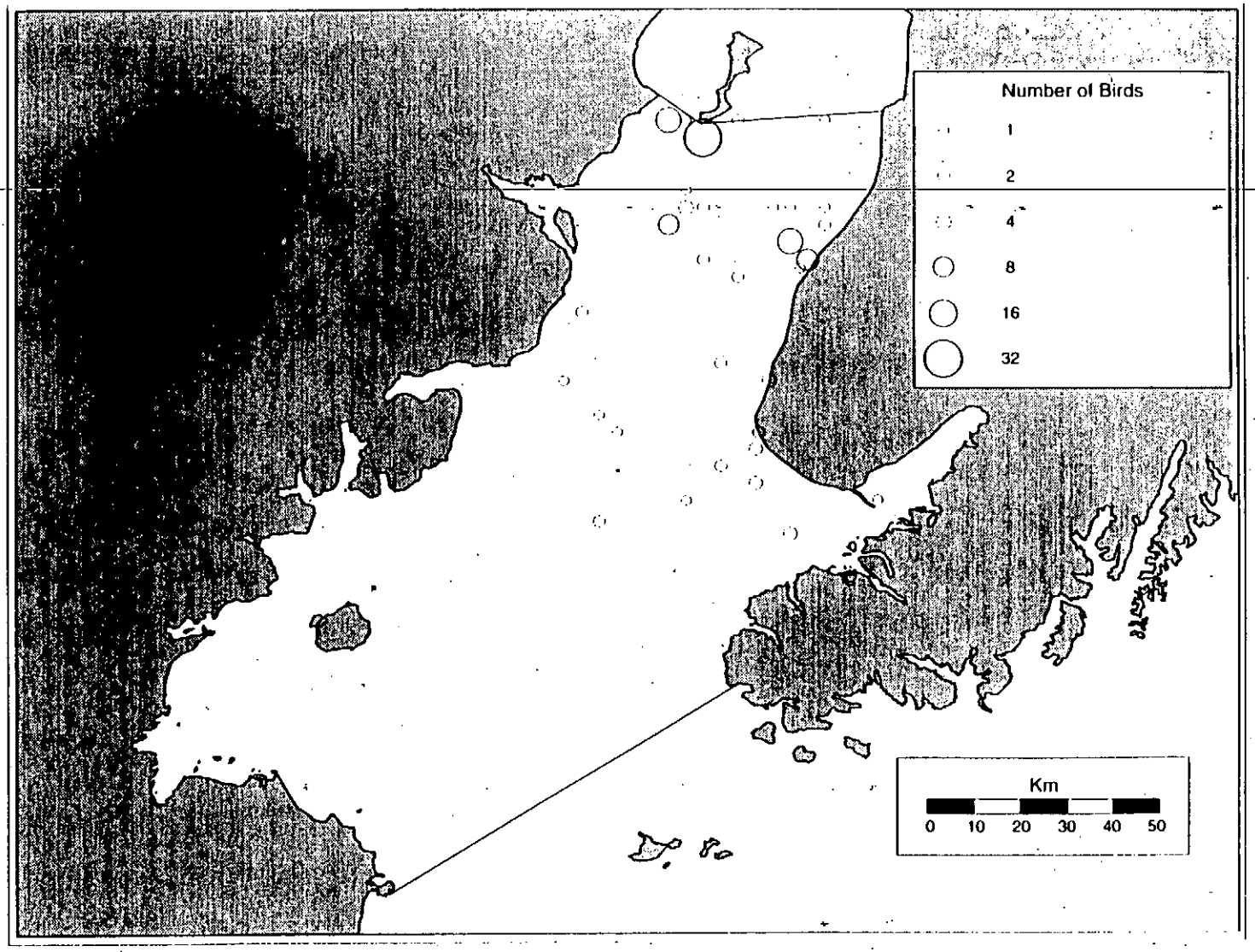

Fig. 23. Summer distribution of terns from a June 1993 small boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

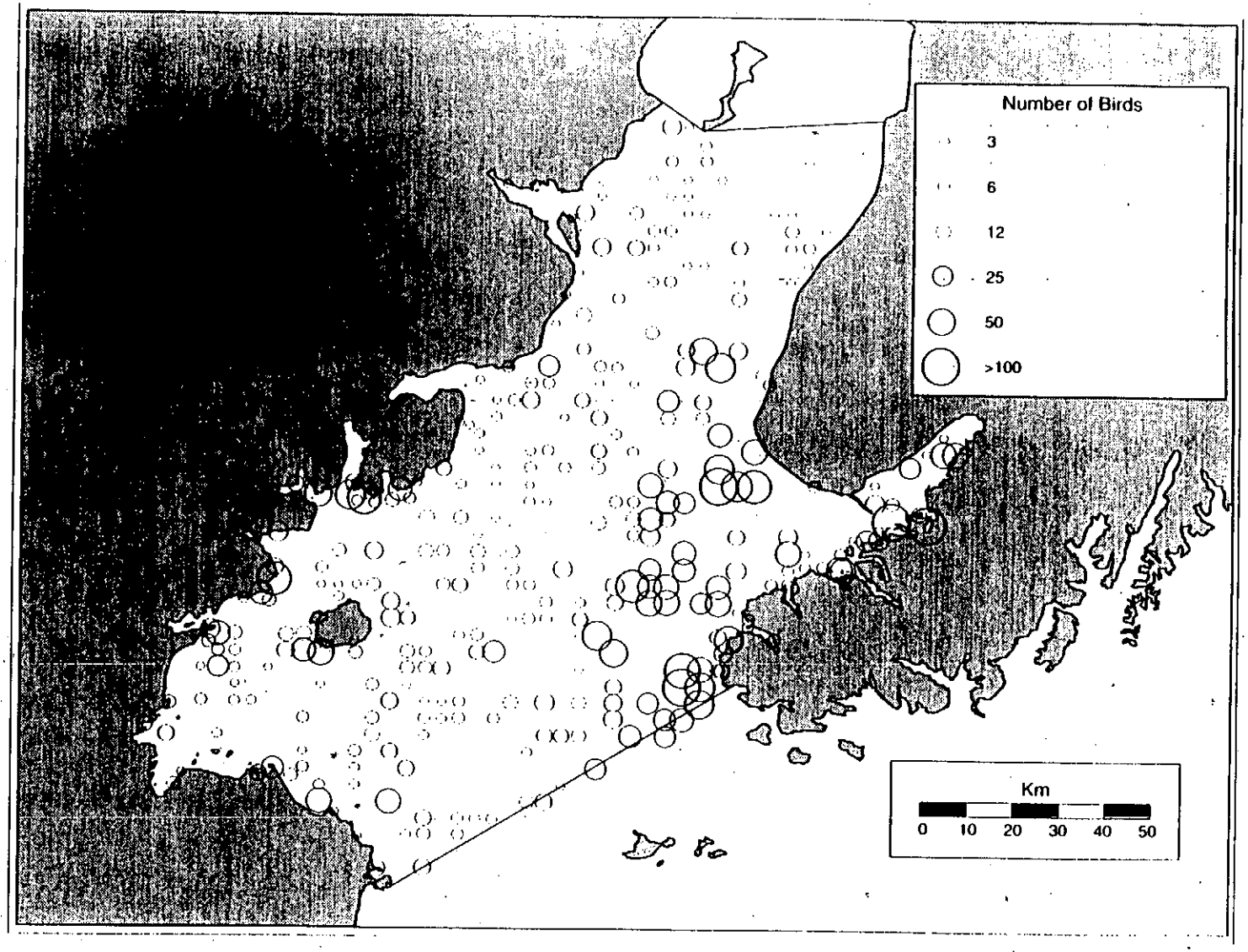

Fig. 24. Summer distribution of alcids from a June 1993 small boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

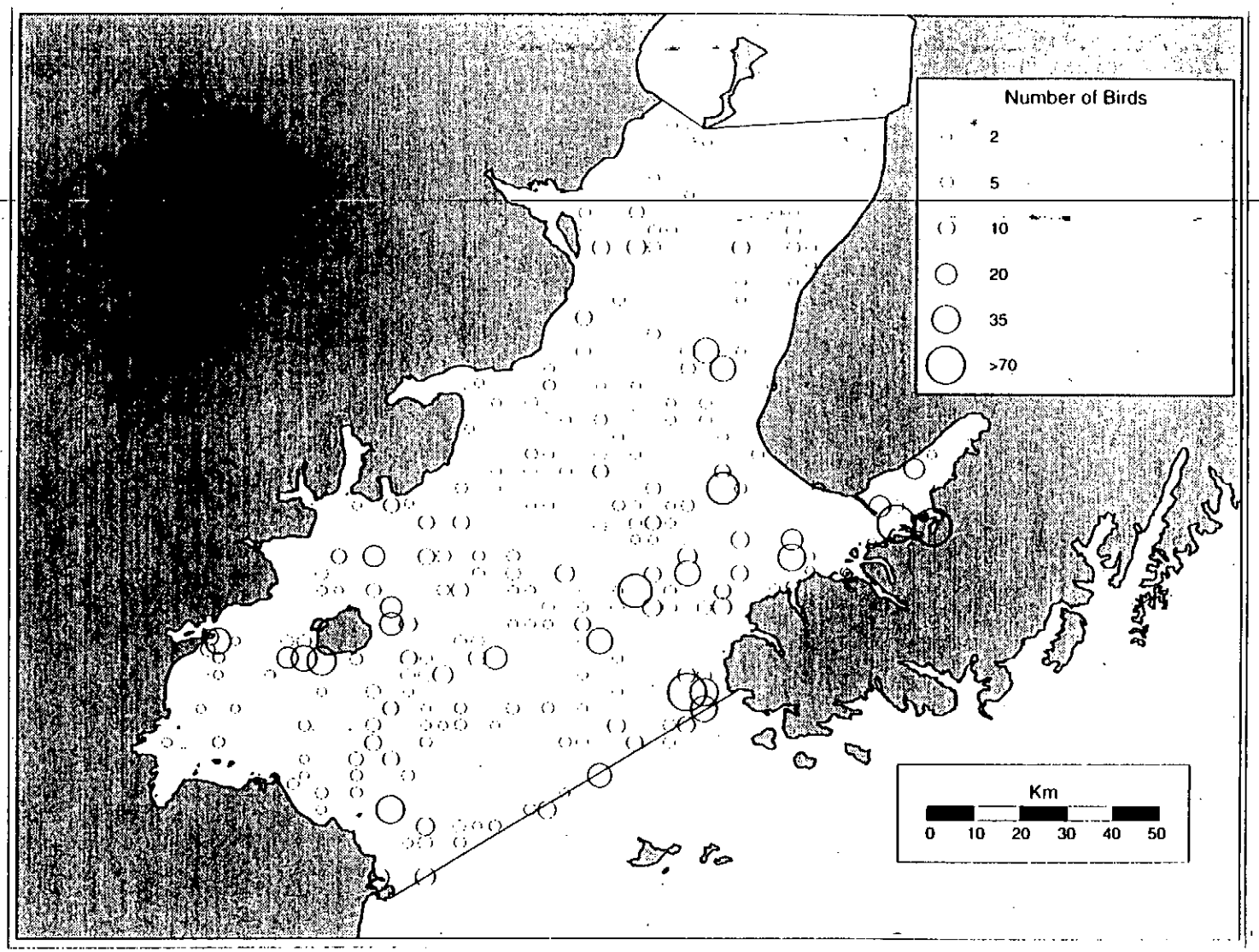

Fig. 25. Summer distribution of murres from a June 1993 small boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

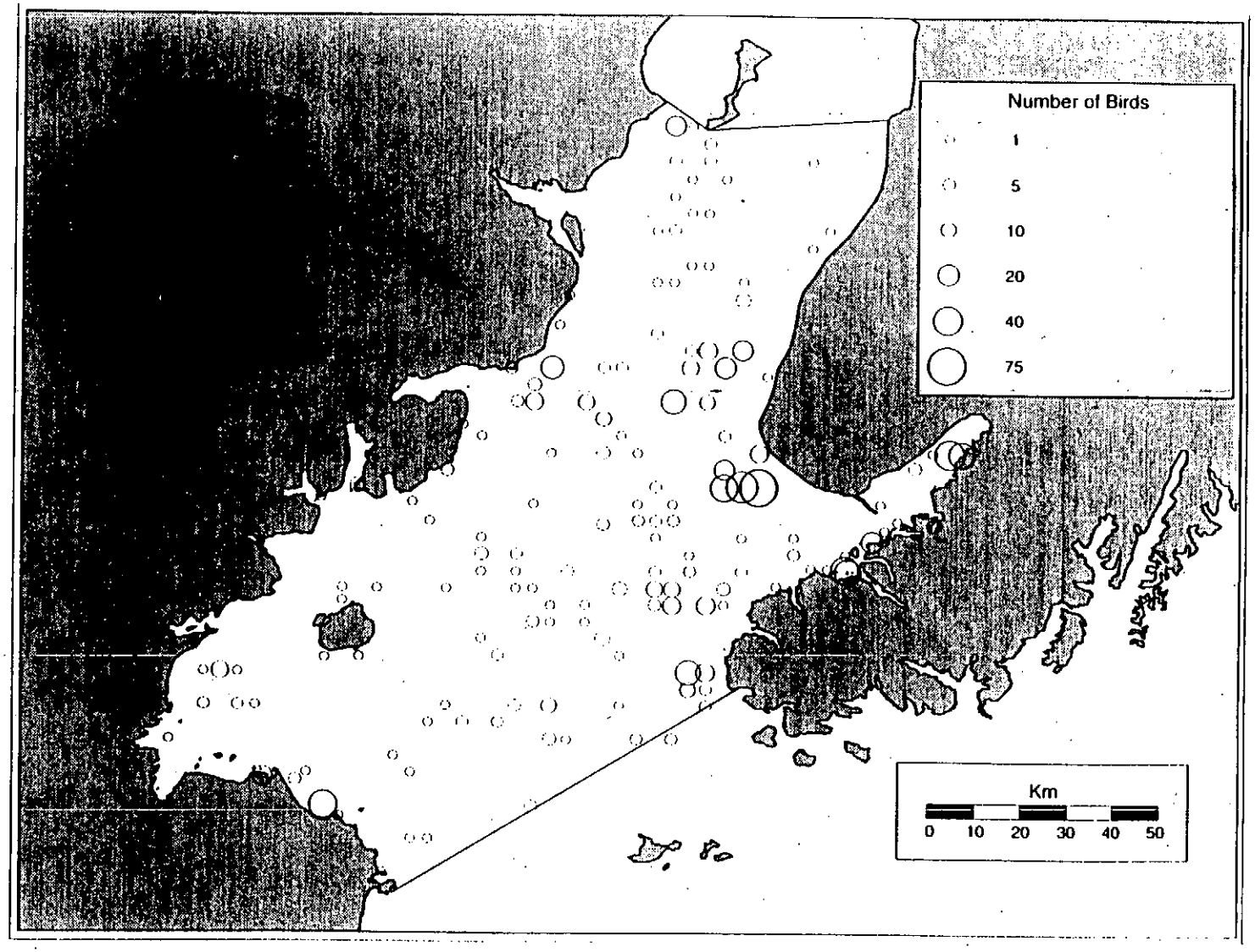

Fig. 26. Summer distribution of *Brachyramphus* murrelets from a June 1993 small boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

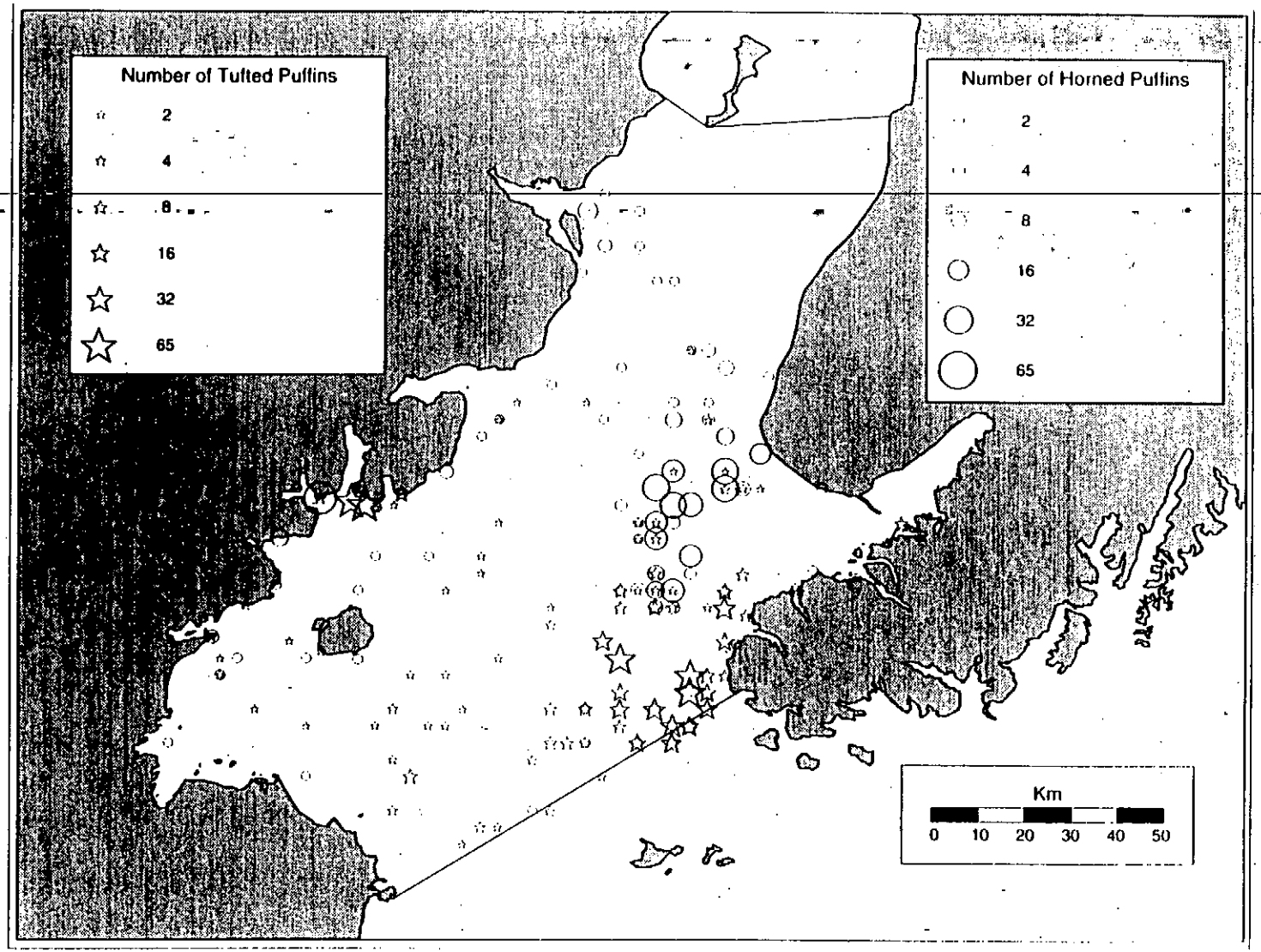

Fig. 27. Summer distribution of tufted and horned puffins from a June 1993 small boat survey of Lower Cook Inlet. Each circle or star represents one transect, and the size of each symbol is dependent upon the number of observations for that transect.

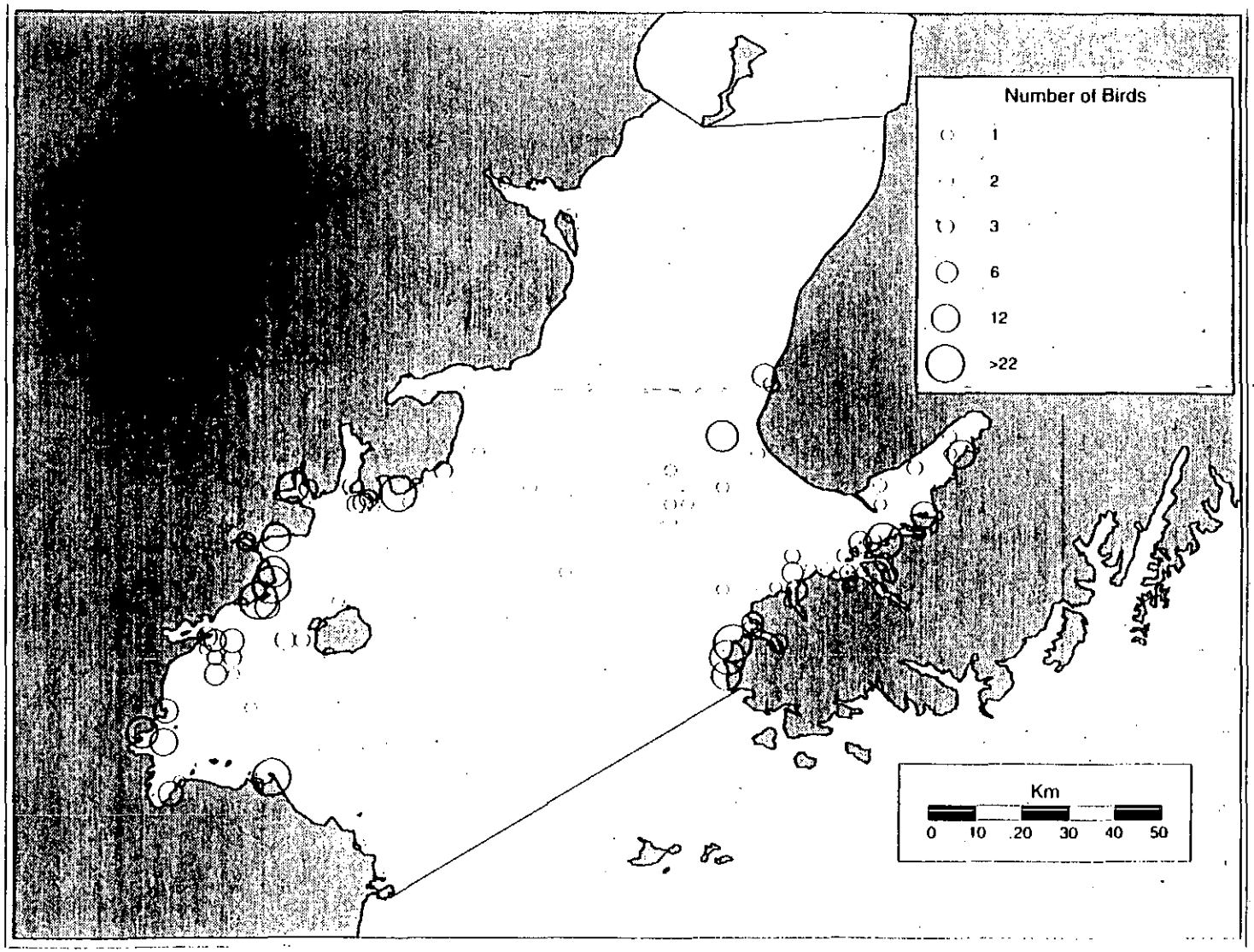

Fig. 28. Summer distribution of pigeon guillemots from a June 1993 small boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

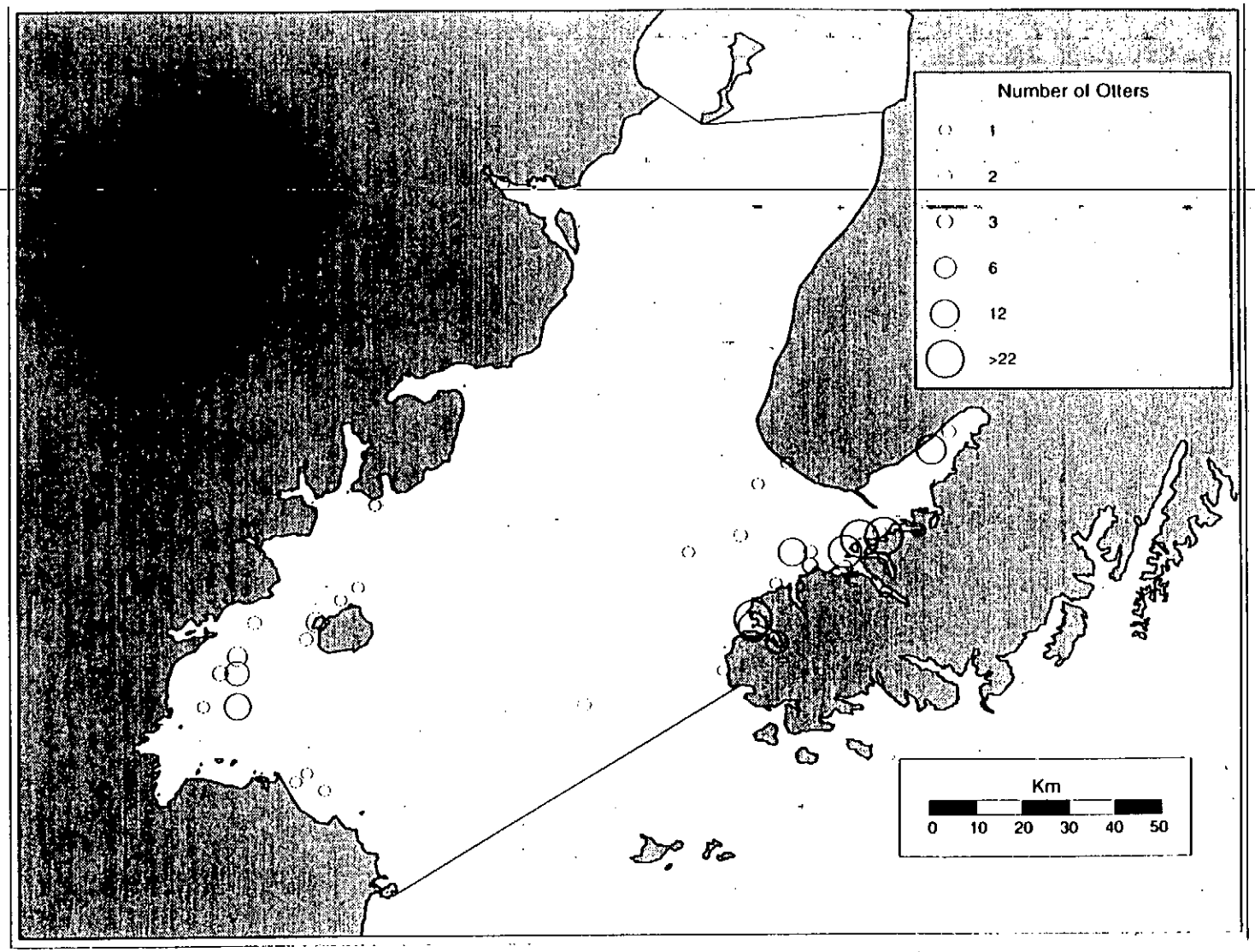

Fig. 29. Summer distribution of sea otters from a June 1993 small boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

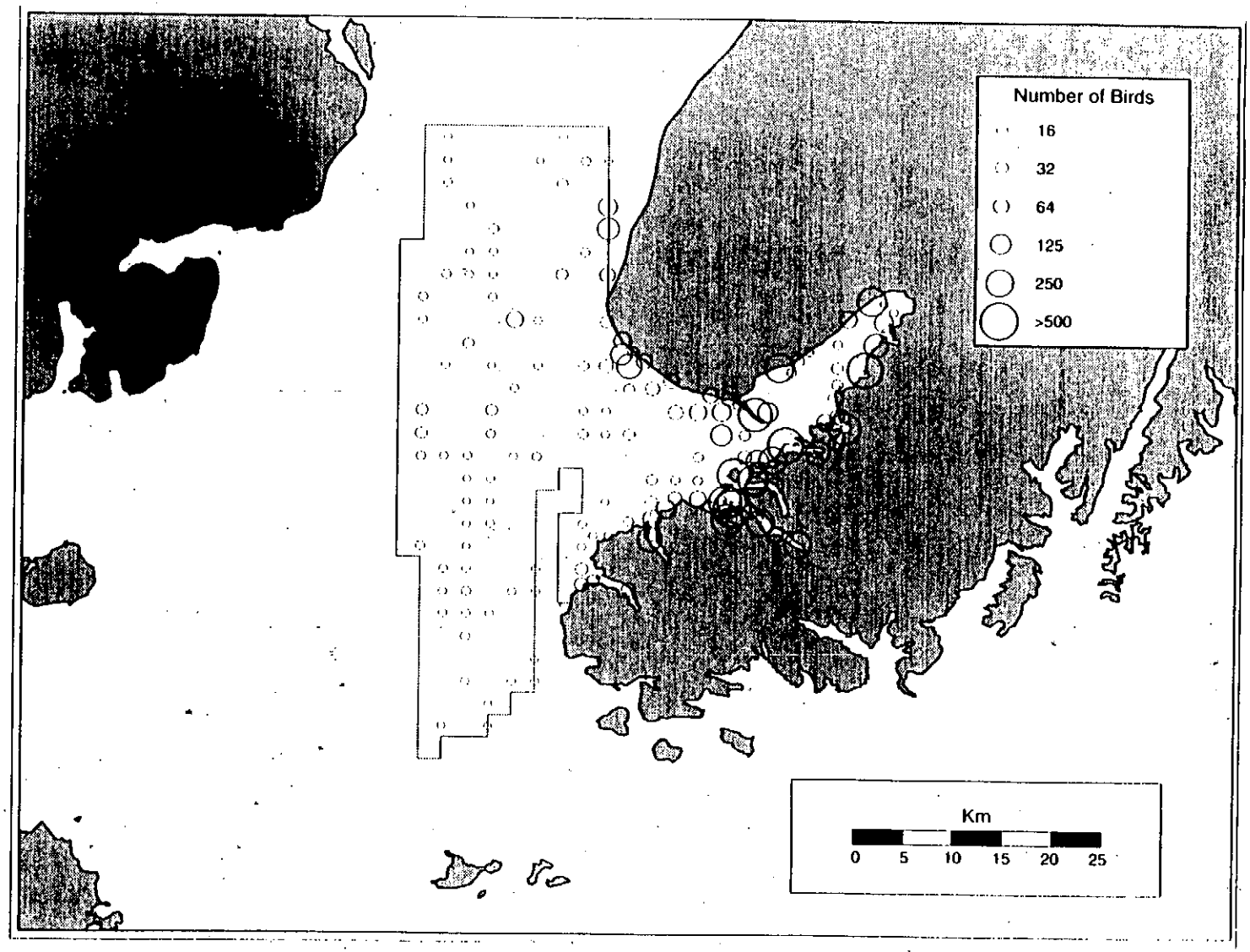

Fig. 30. Winter distribution of marine birds from a February-March 1994 boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

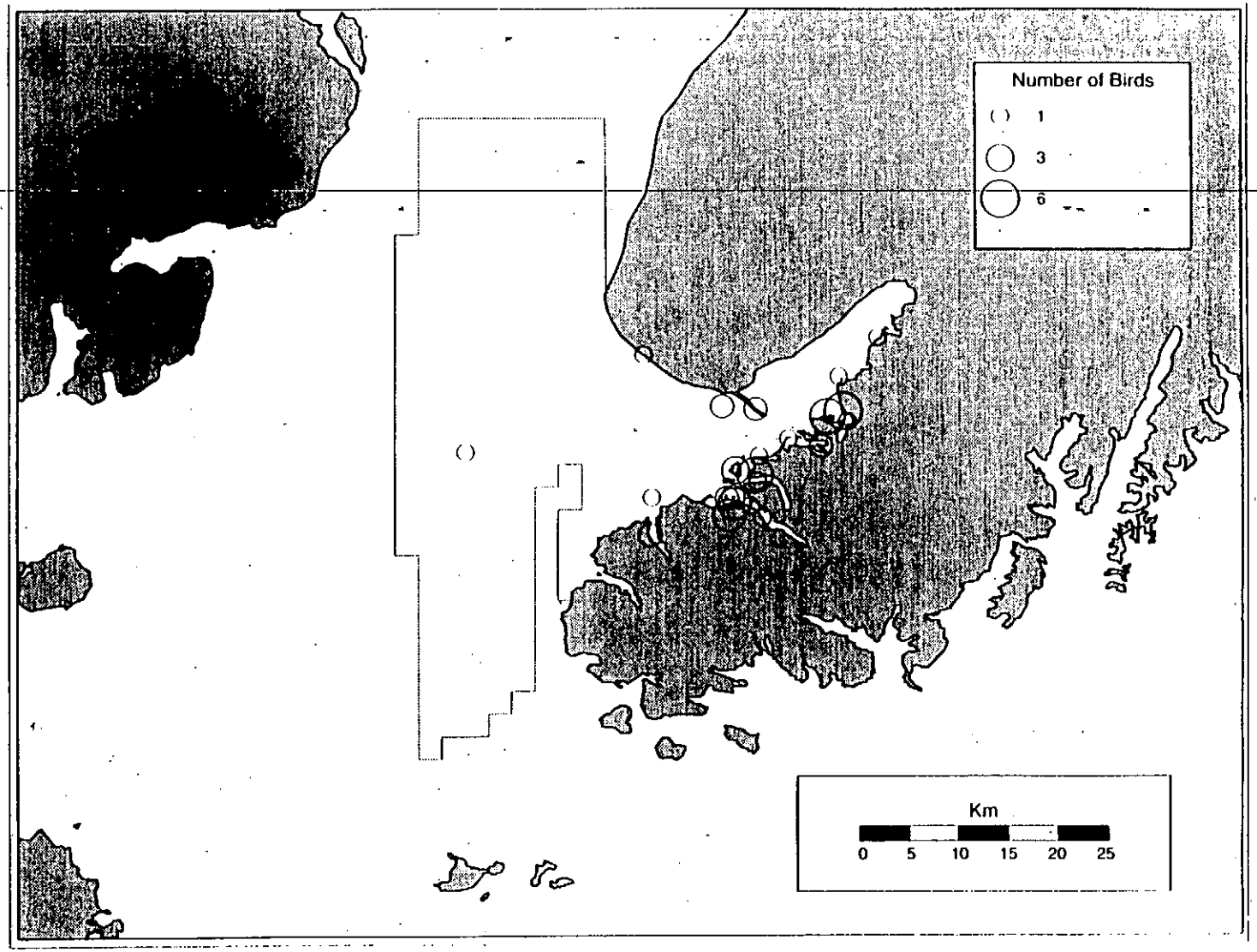

Fig. 31. Winter distribution of loons from a February-March 1994 boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

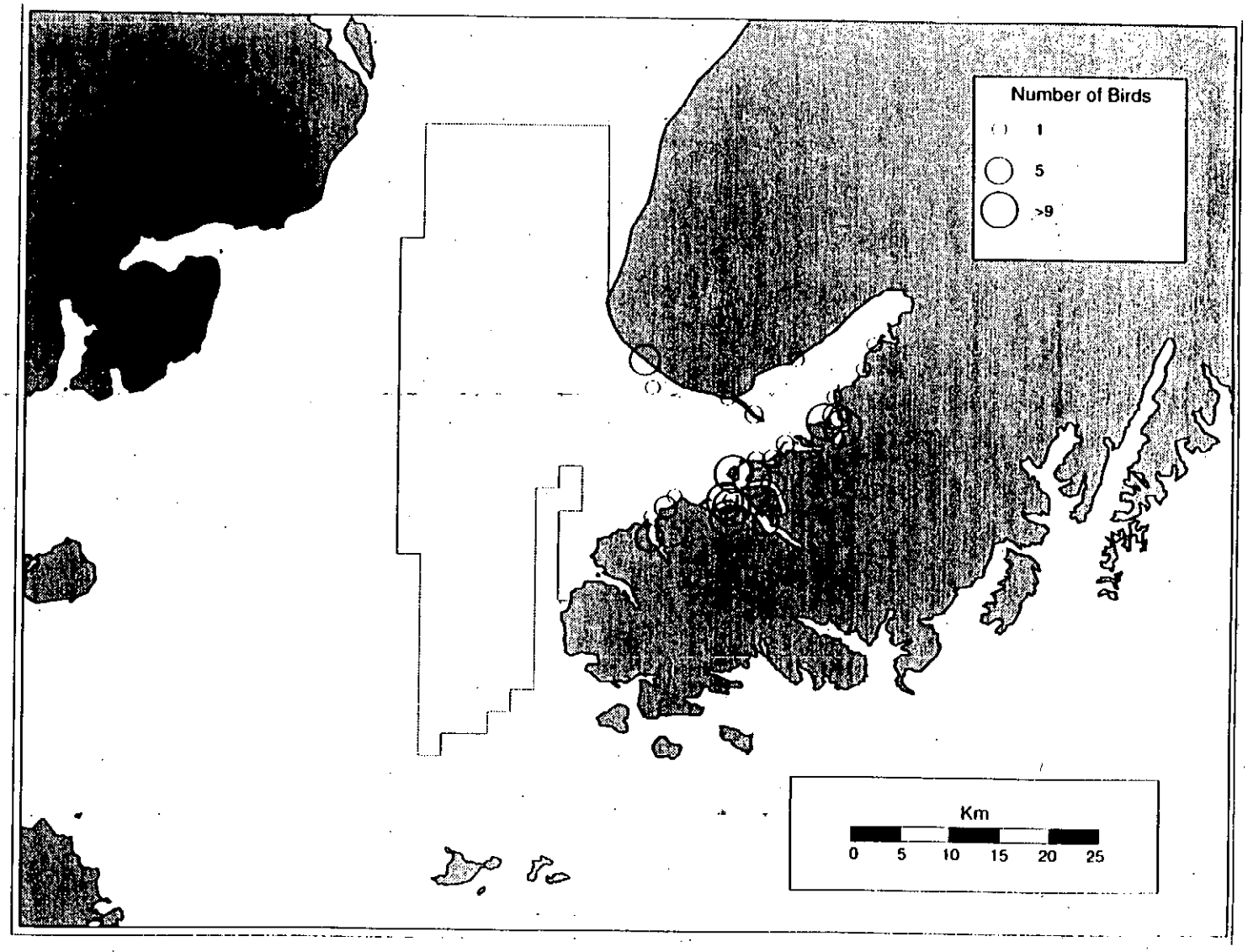

Fig. 32. Winter distribution of grebes from a February-March 1994 boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

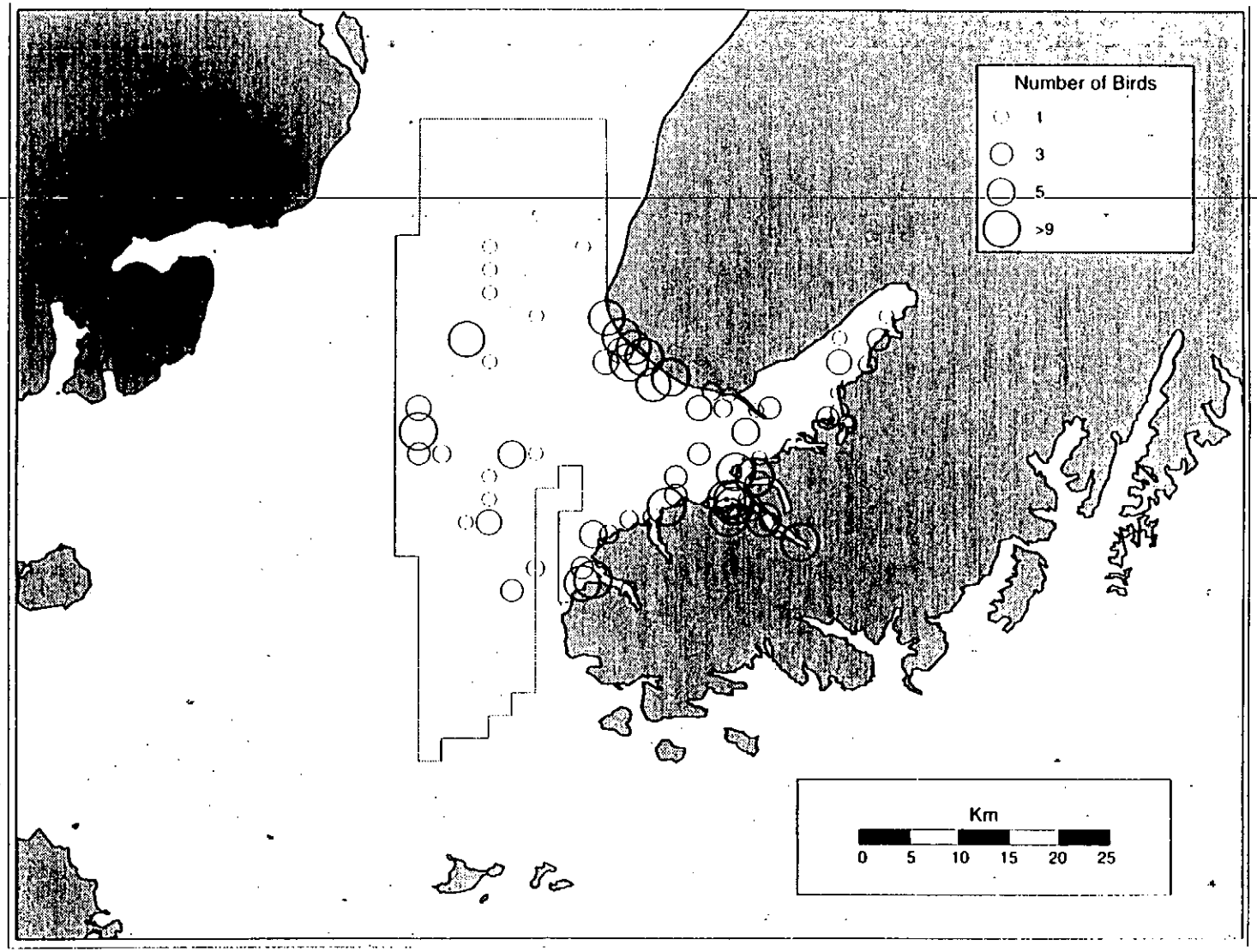

Fig. 33. Winter distribution of cormorants from a February-March 1994 boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

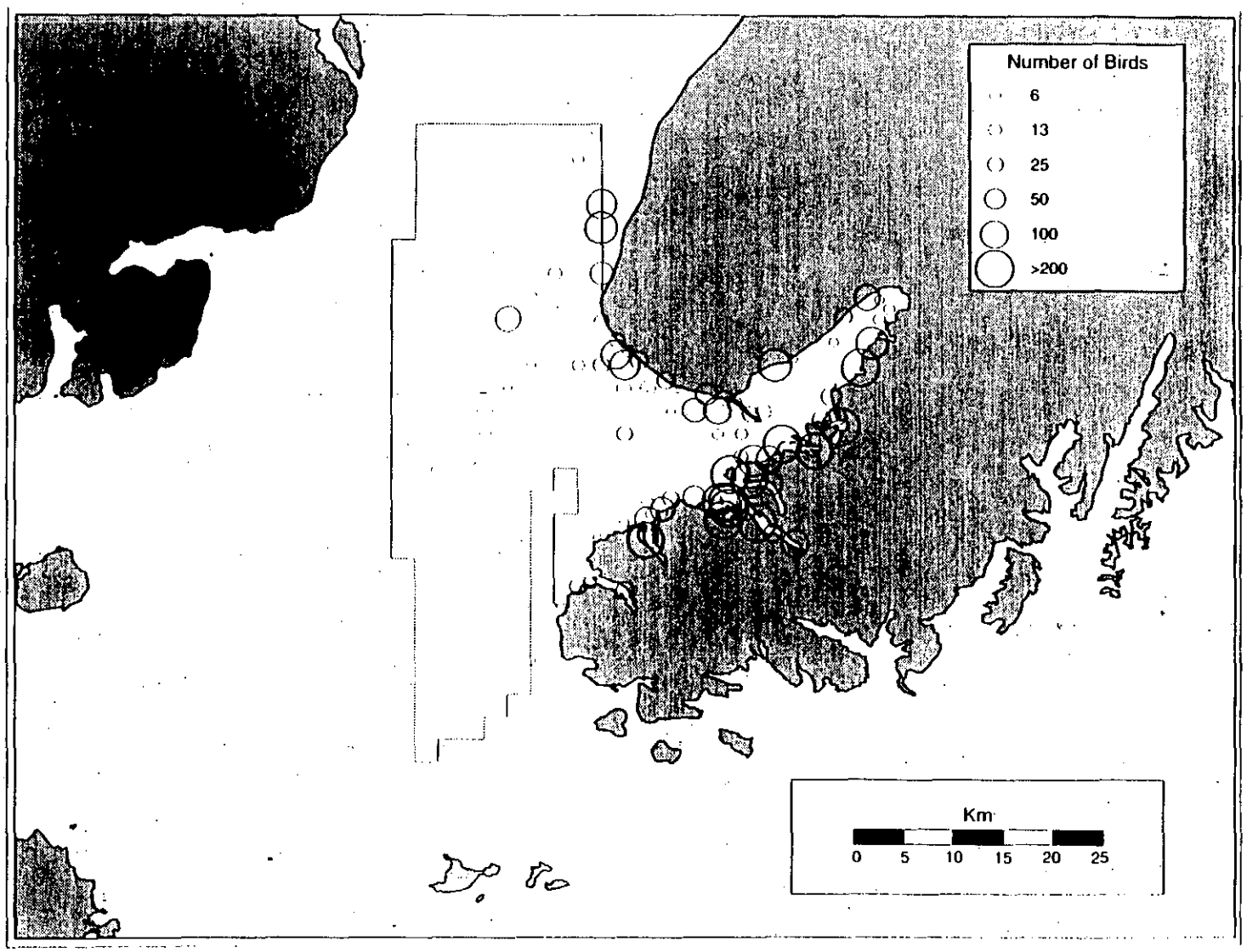

Fig. 34. Winter distribution of waterfowl from a February-March 1994 boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

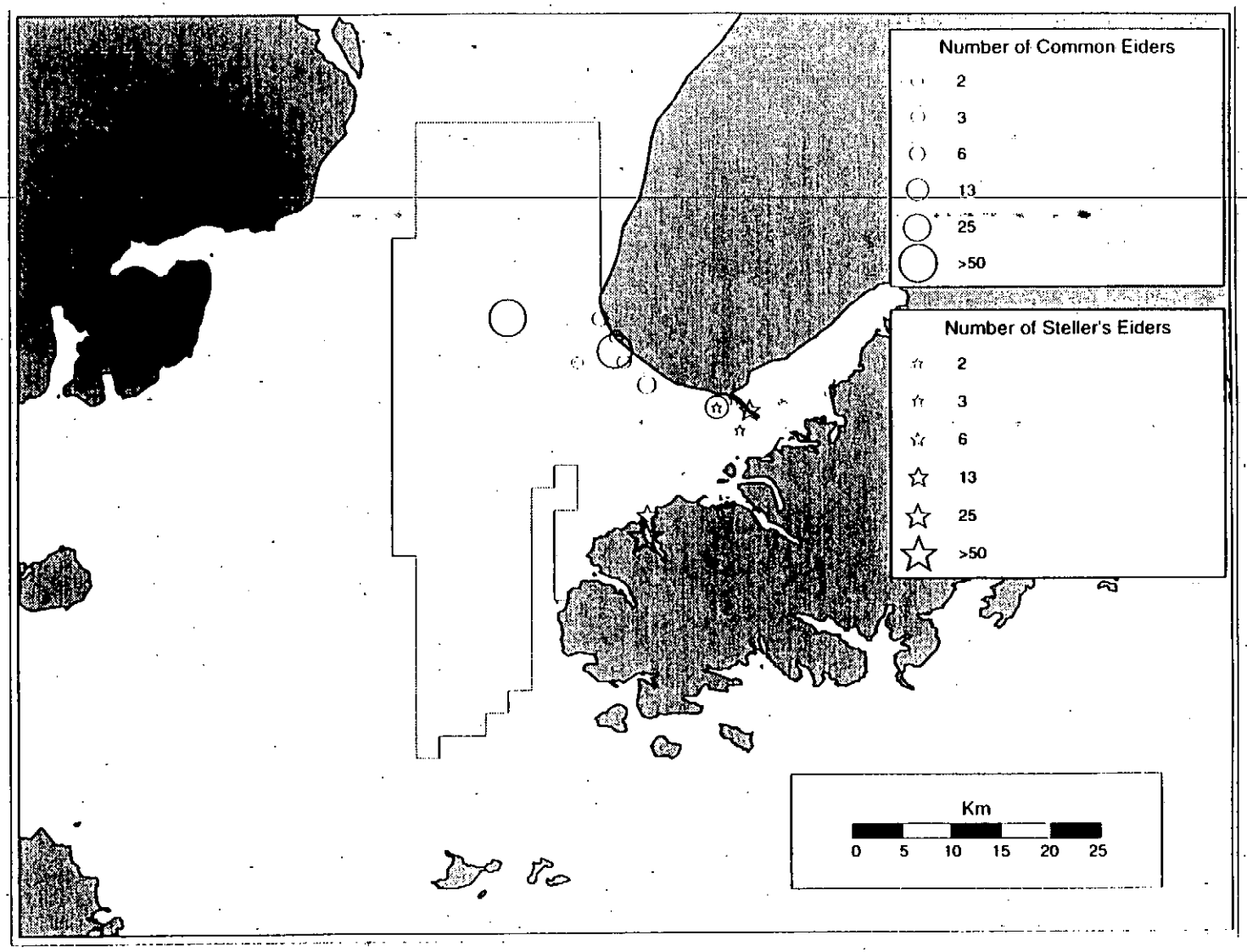

Fig. 35. Winter distribution of eiders from a February-March 1994 boat survey of Lower Cook Inlet. Each circle or star represents one transect, and the size of each symbol is dependent upon the number of observations for that transect.

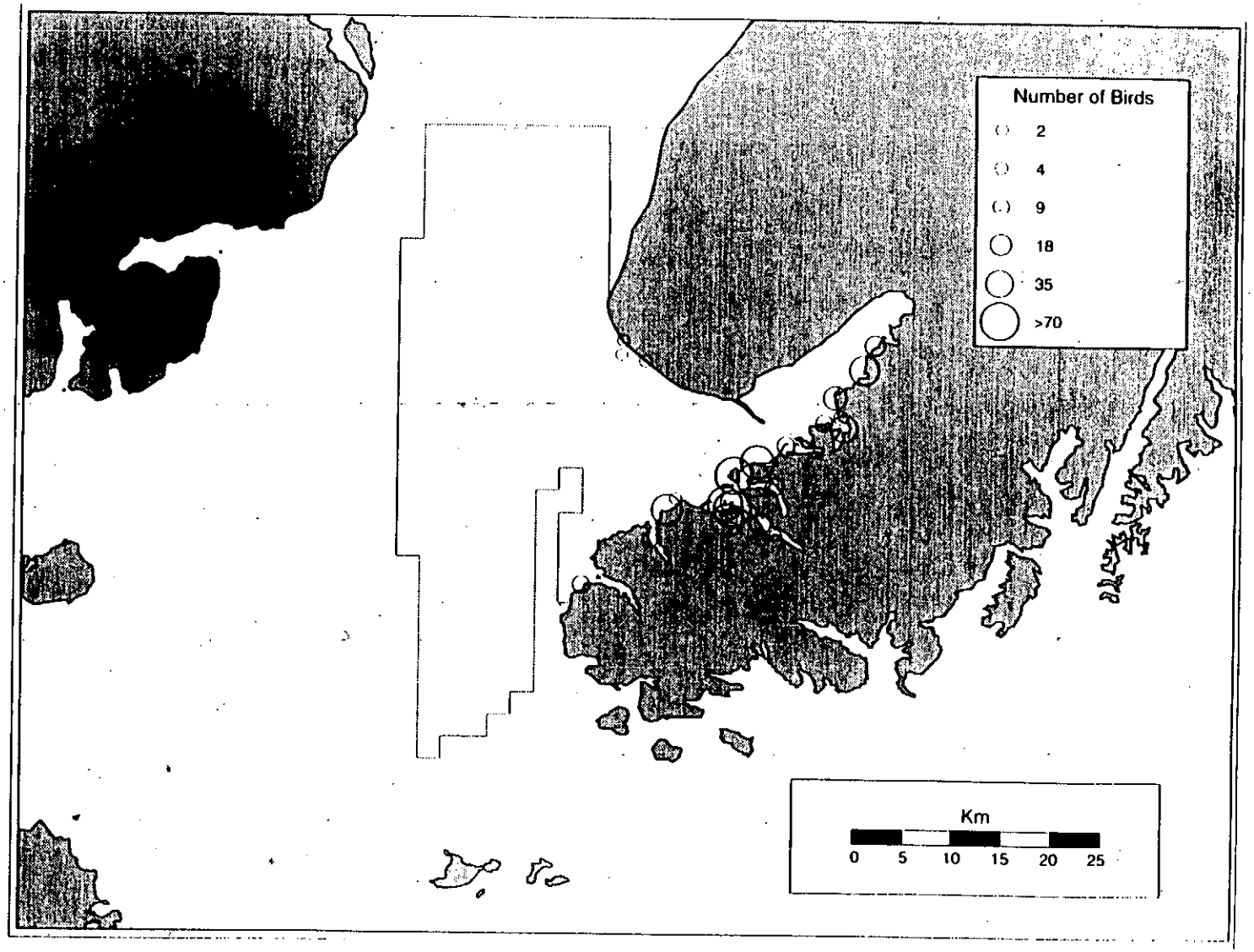

Fig. 36. Winter distribution of harlequin ducks from a February-March 1994 boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

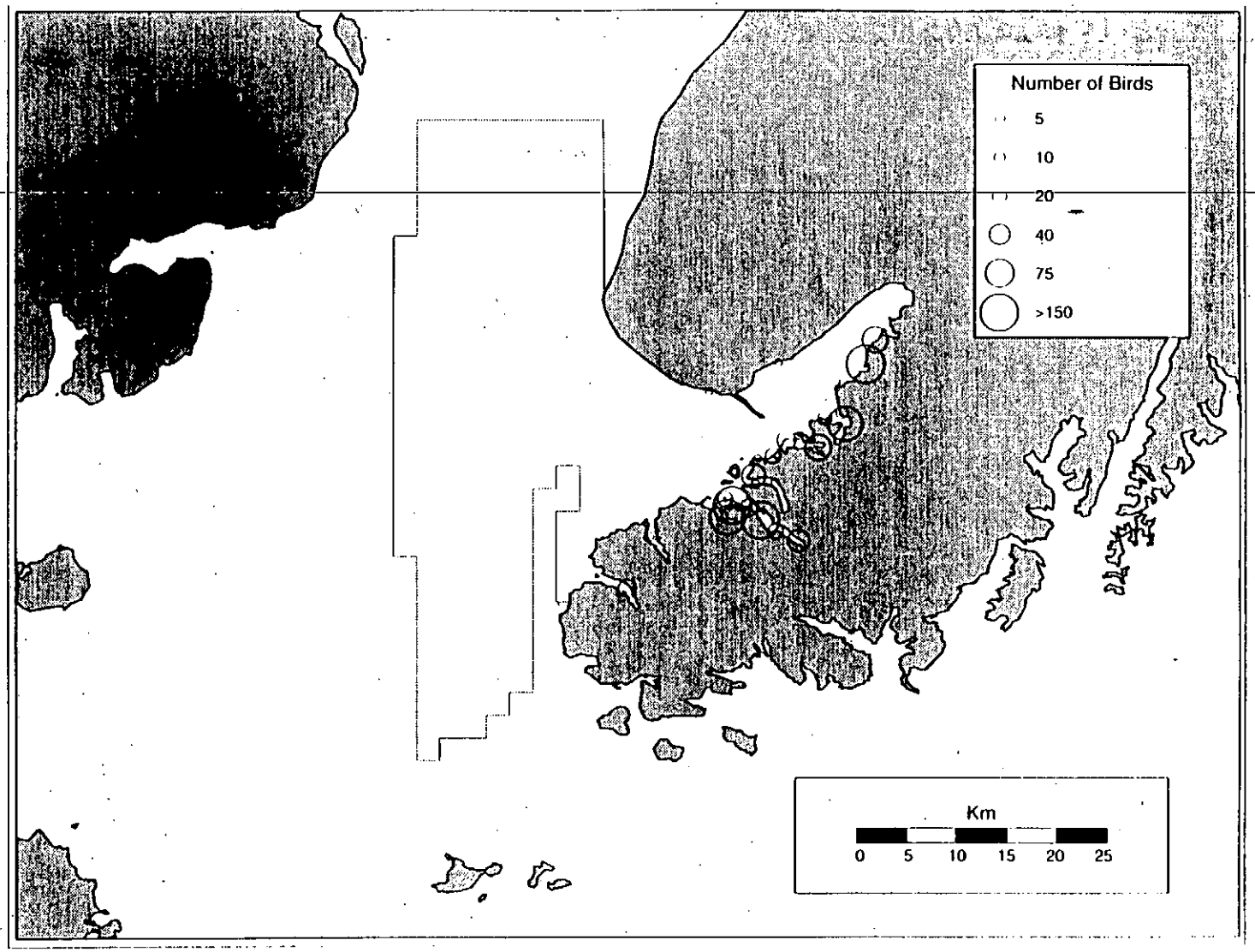

Fig. 37. Winter distribution of goldeneyes from a February-March 1994 boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

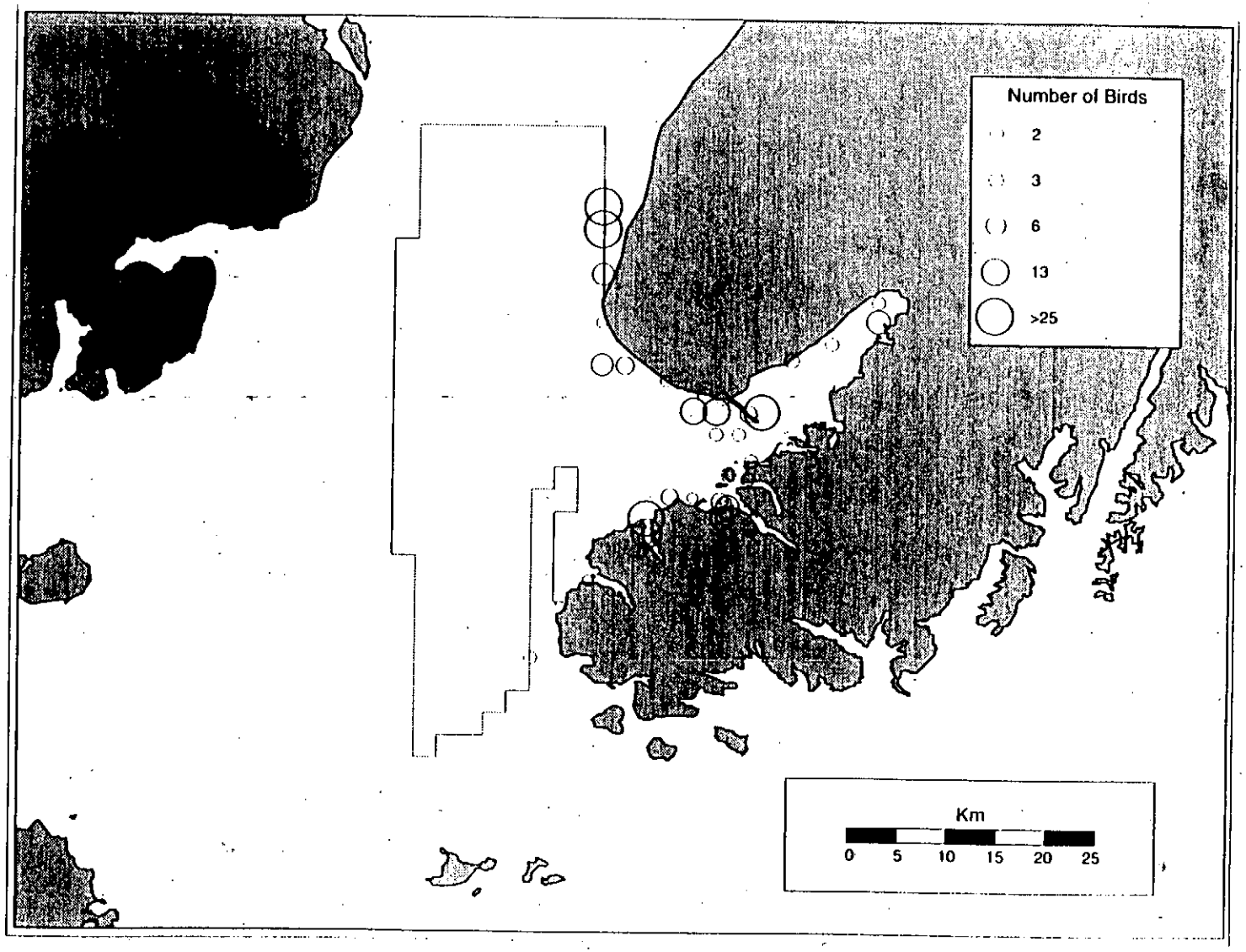

Fig. 38. Winter distribution of oldsquaws from a February-March 1994 boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

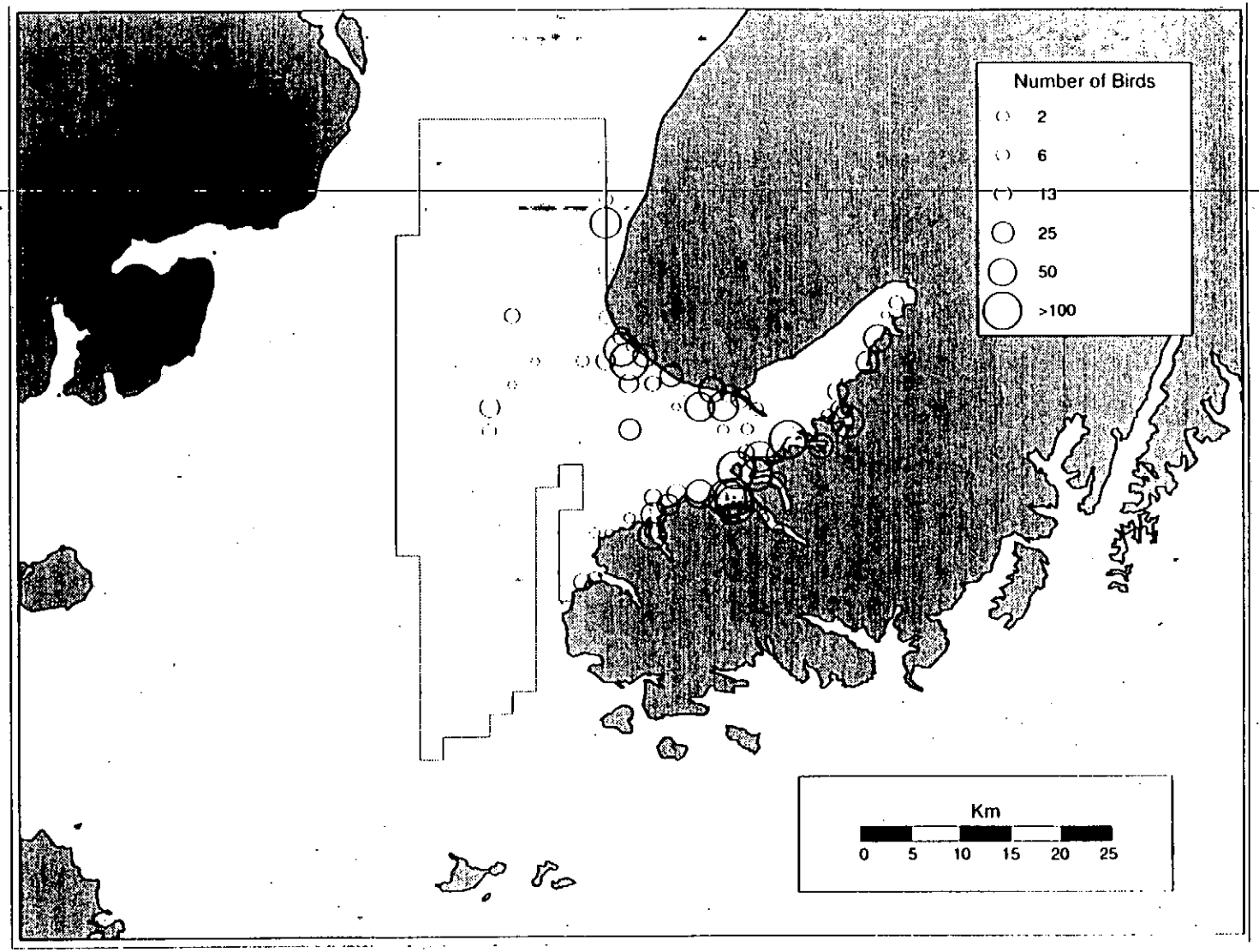

Fig. 39. Winter distribution of scoters from a February-March 1994 boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

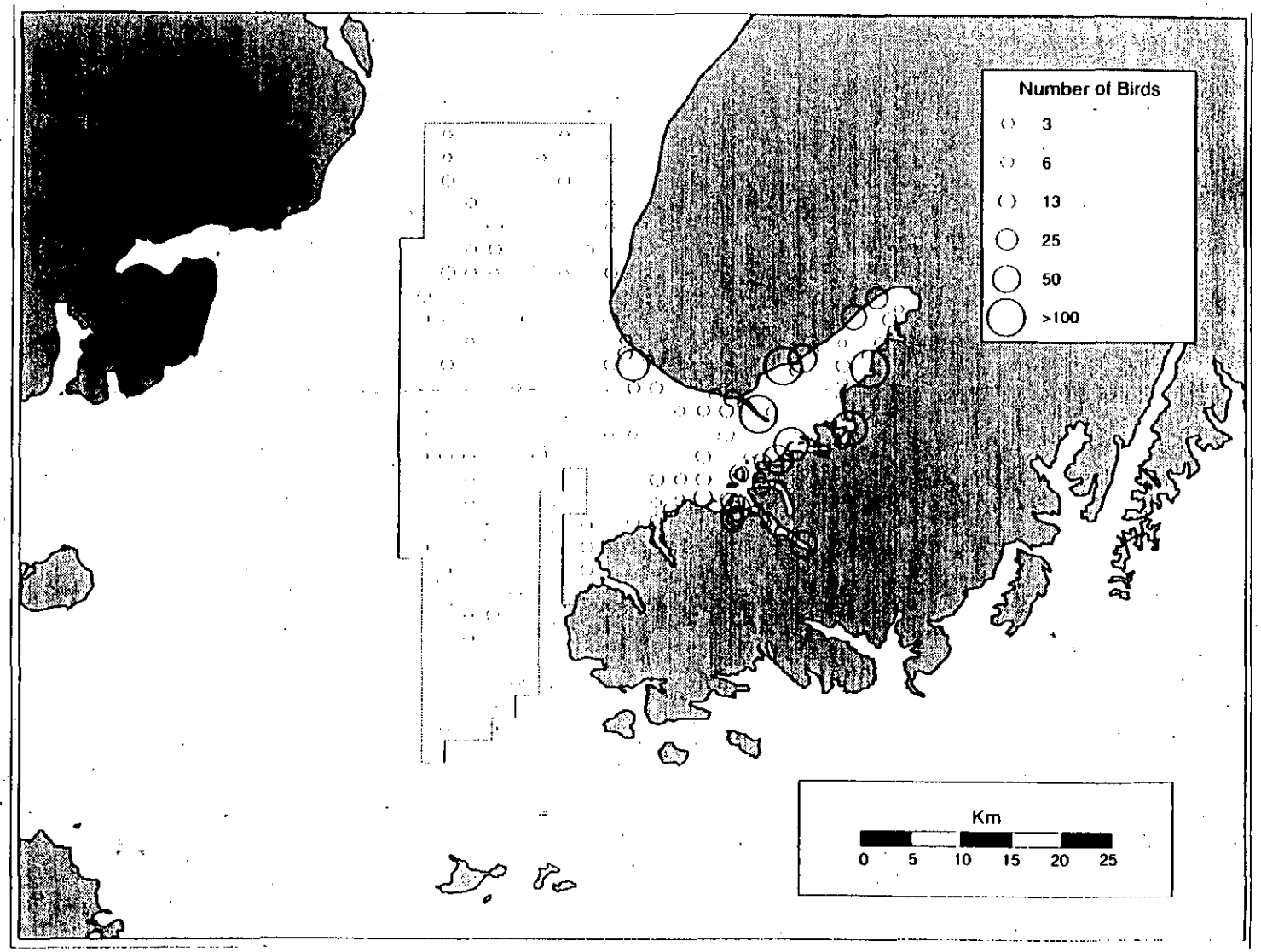

Fig. 40. Winter distribution of gulls from a February-March 1994 boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

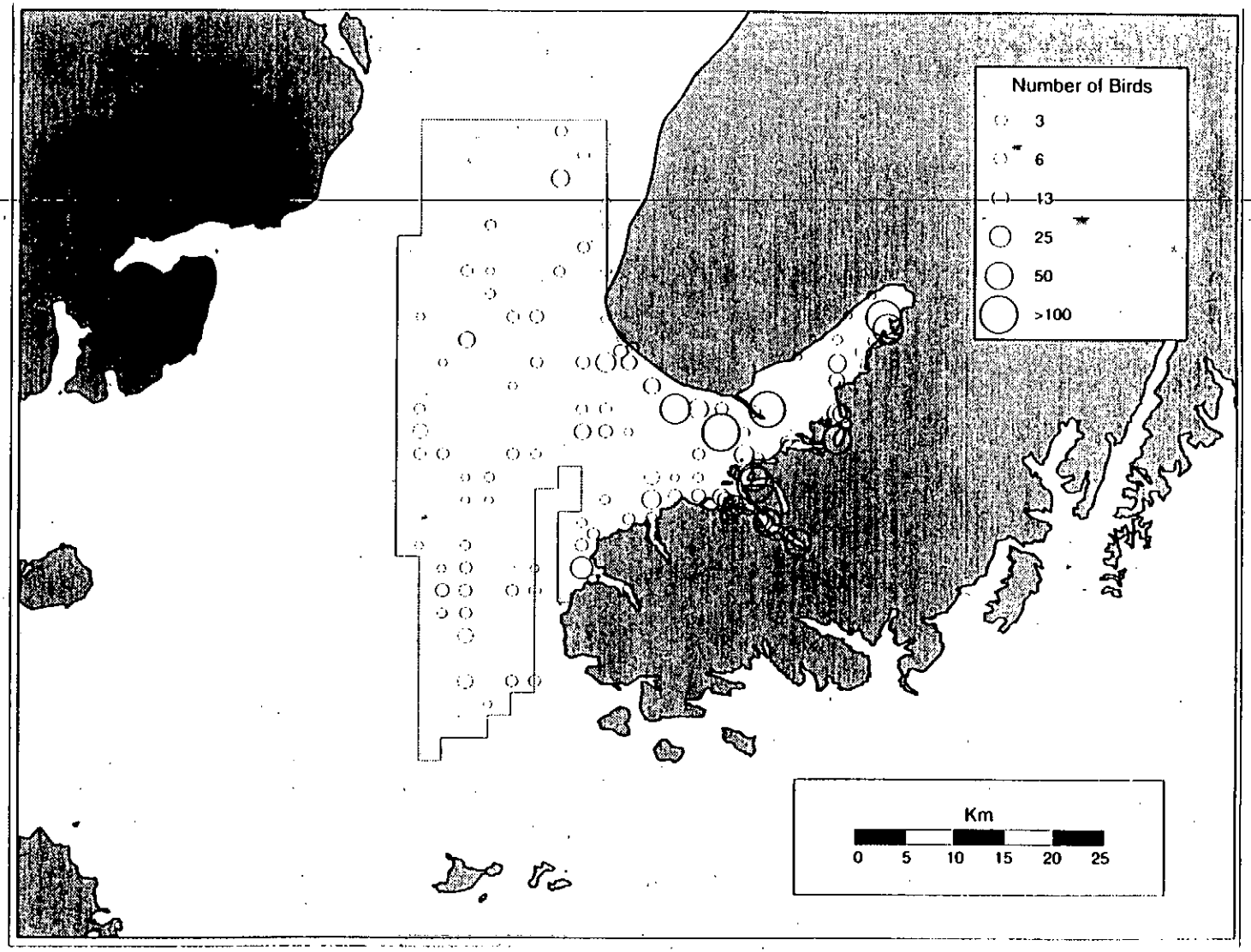

Fig. 41. Winter distribution of alcids from a February-March 1994 boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

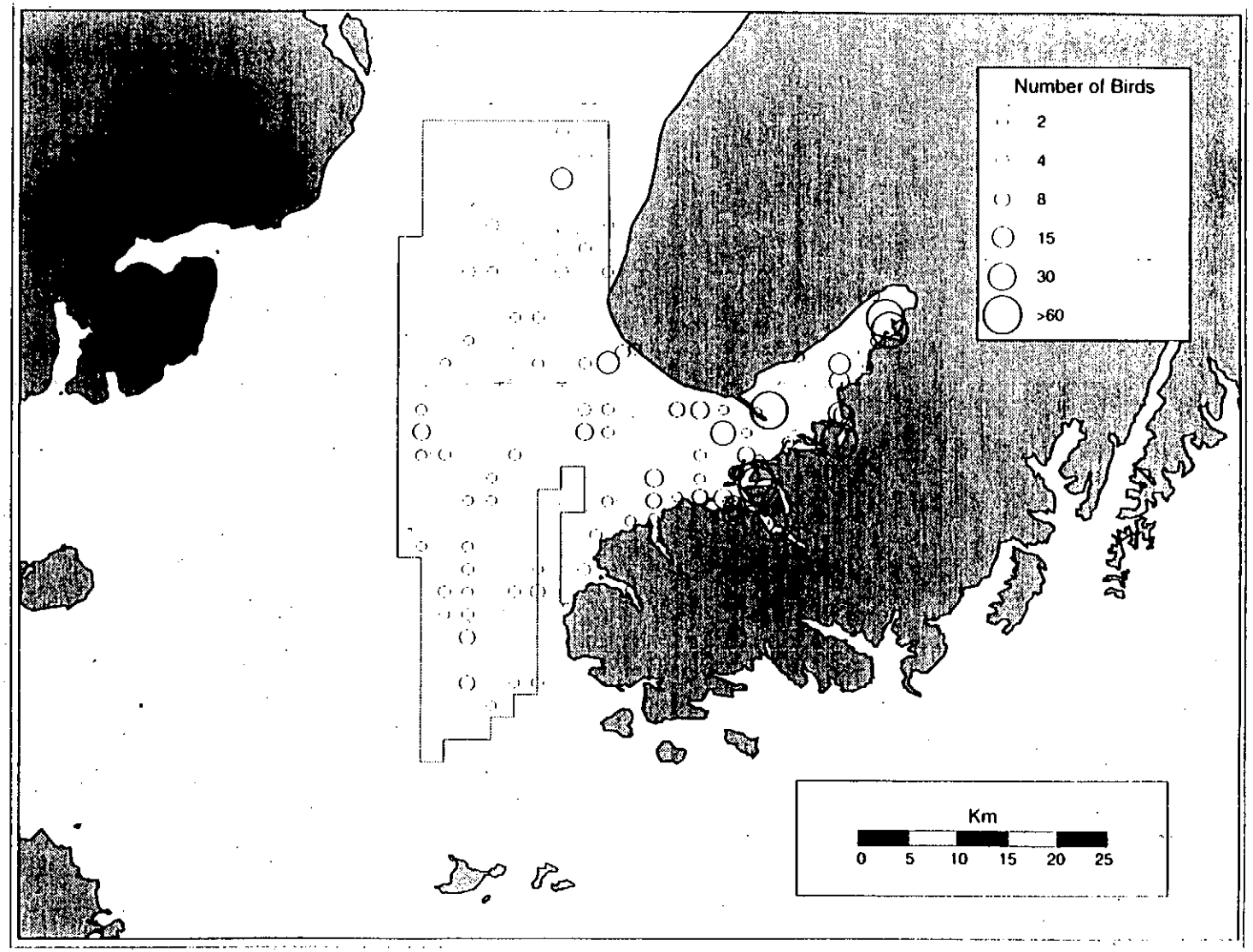

Fig. 42. Winter distribution of murres from a February-March 1994 boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

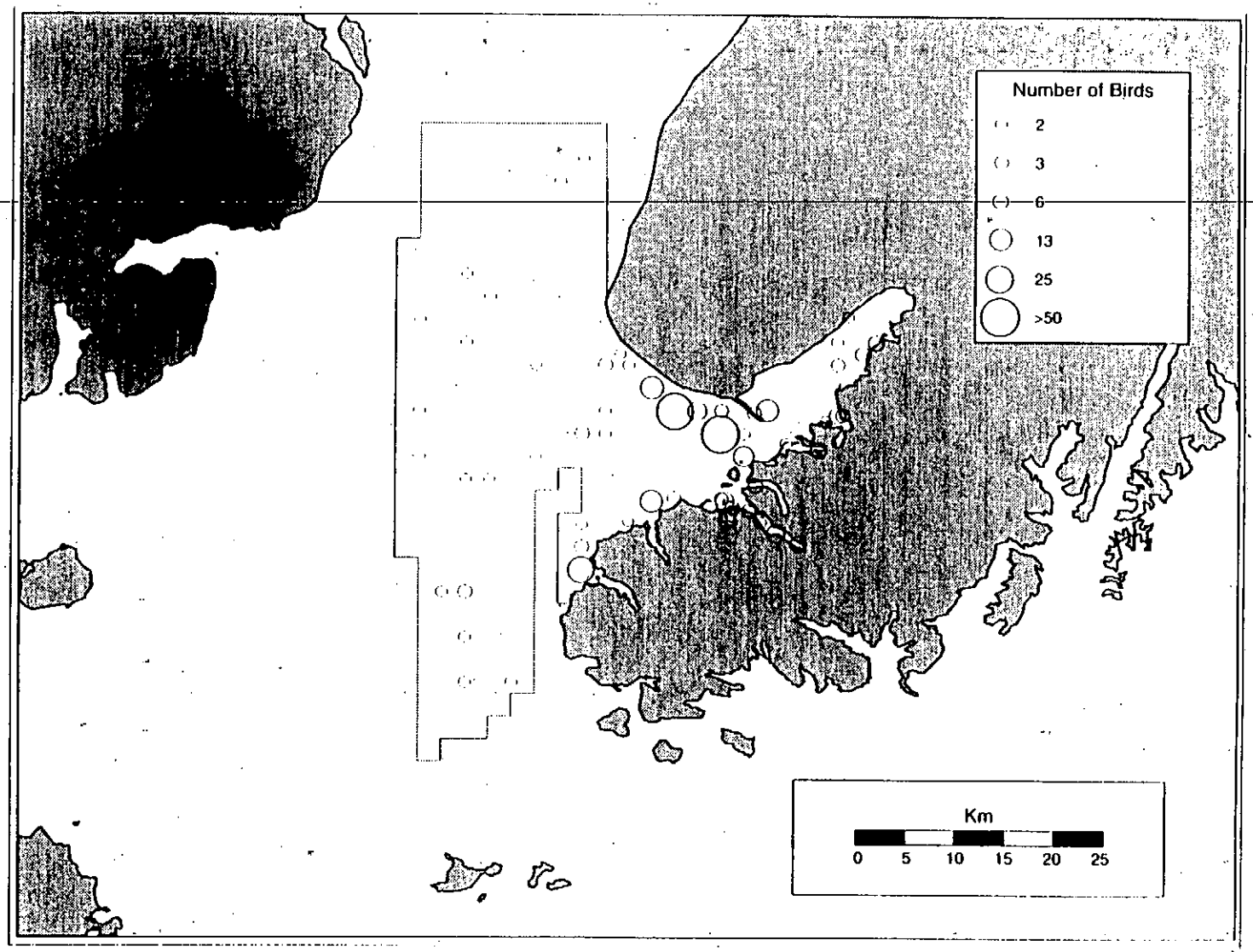

Fig. 43. Winter distribution of *Brachyramphus* murrelets from a February-March 1994 boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

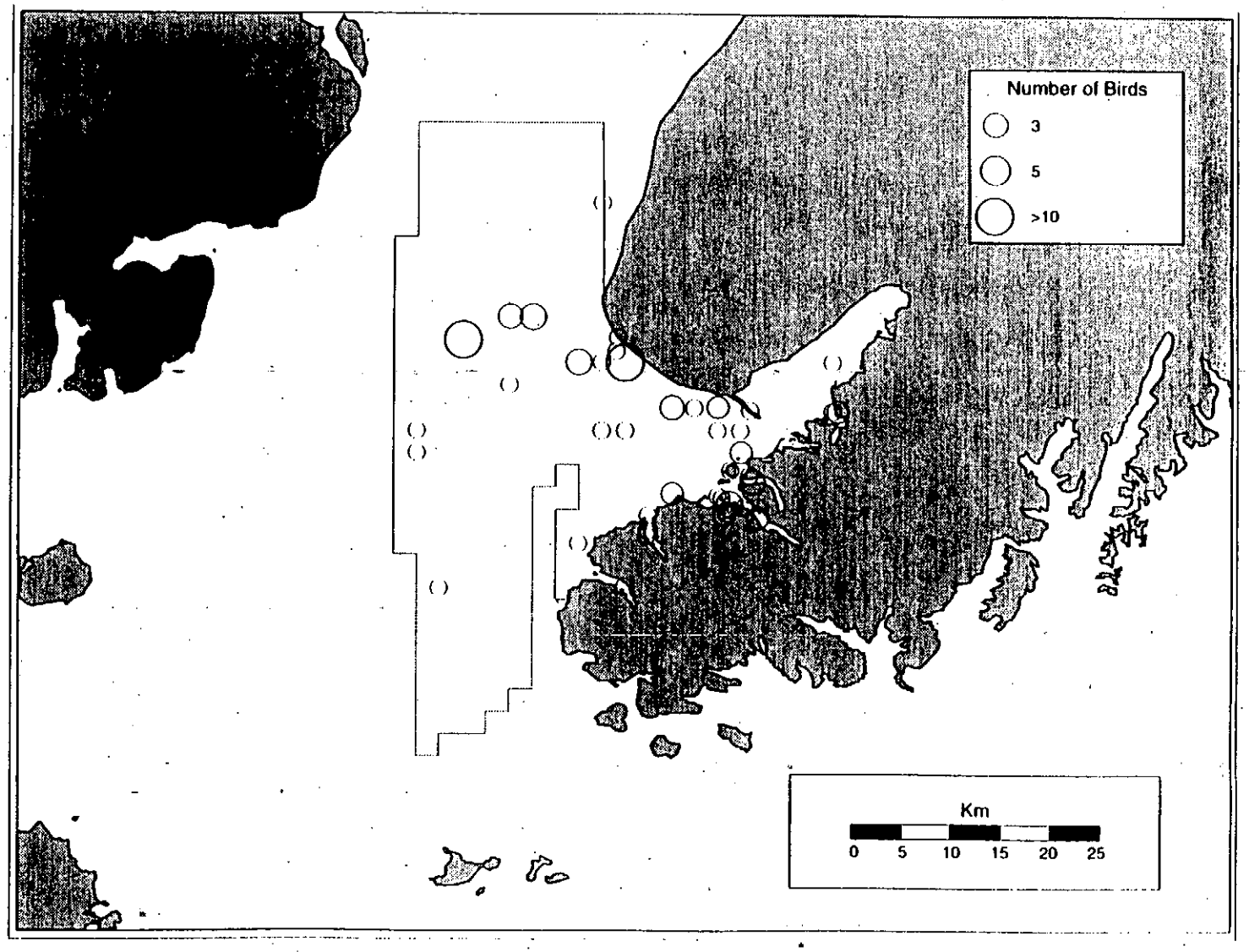

Fig. 44. Winter distribution of pigeon guillemots from a February-March 1994 boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

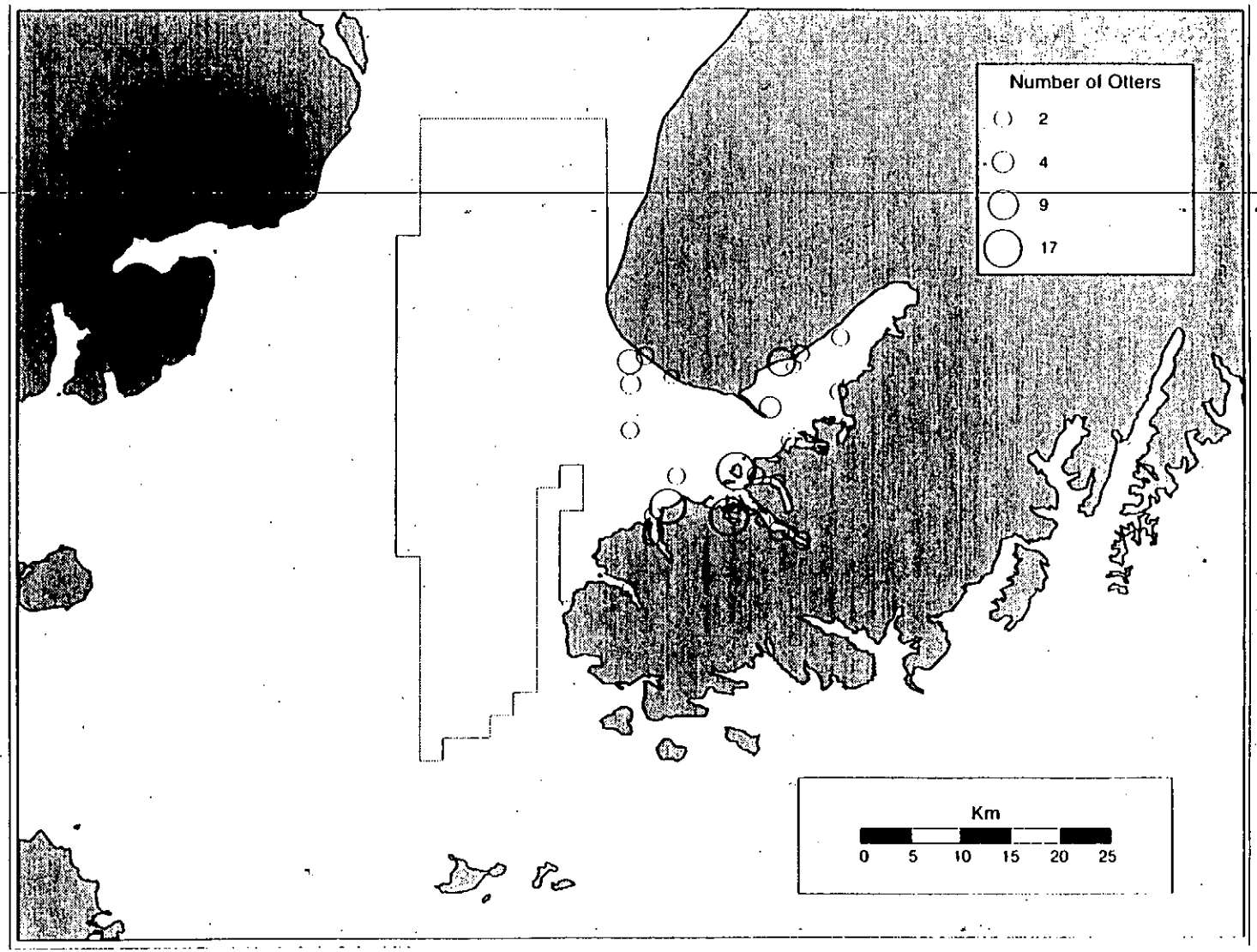

Fig. 45. Winter distribution of sea otters from a February-March 1994 boat survey of Lower Cook Inlet. Each circle represents one transect, and the size of each circle is dependent upon the number of observations for that transect.

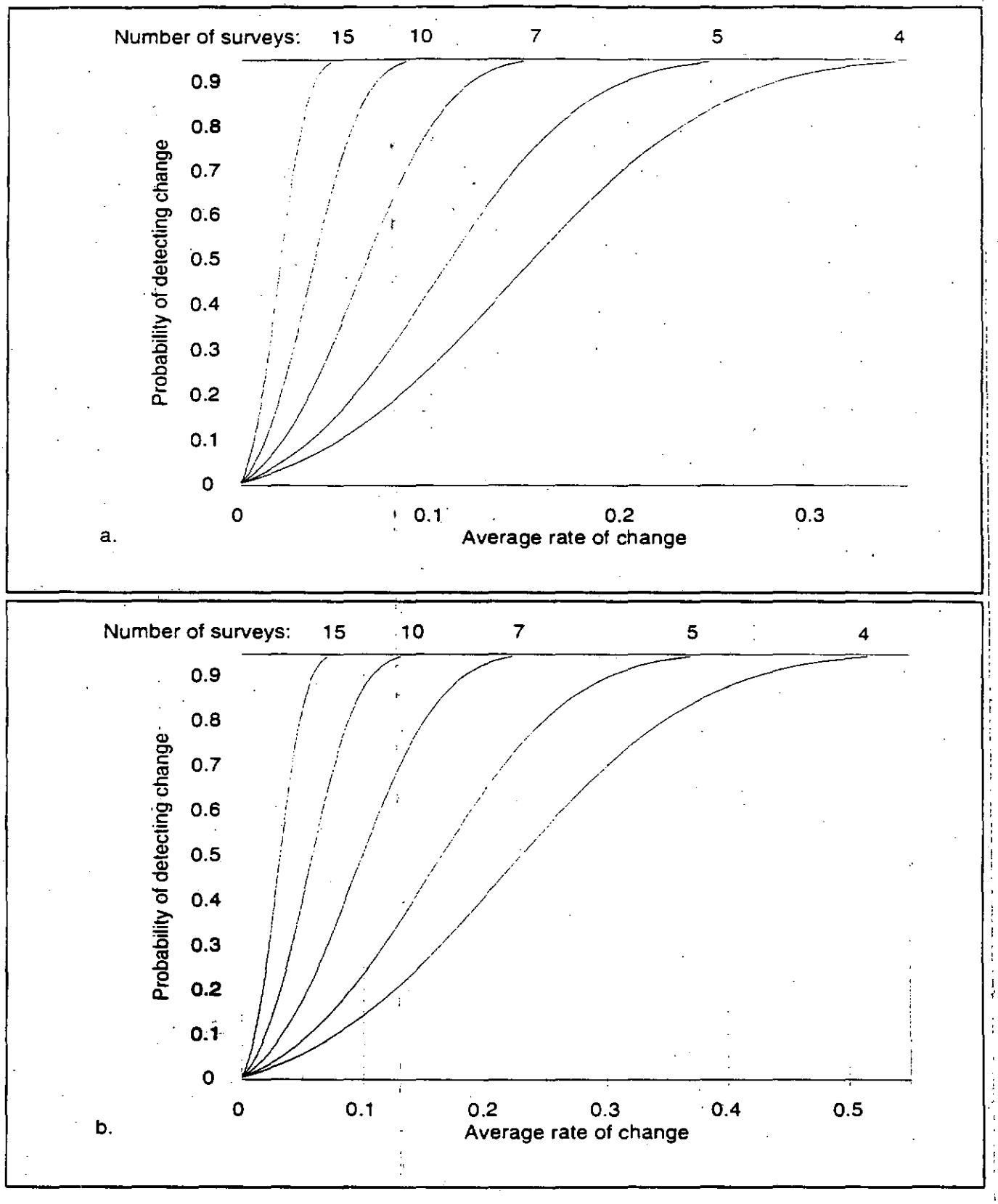

Fig. 46. Power to detect trends in marine bird abundance when confidence level is 0.10 and: (a) mean coefficient of variation is 0.2, or (b) mean coefficient of variation is 0.3.

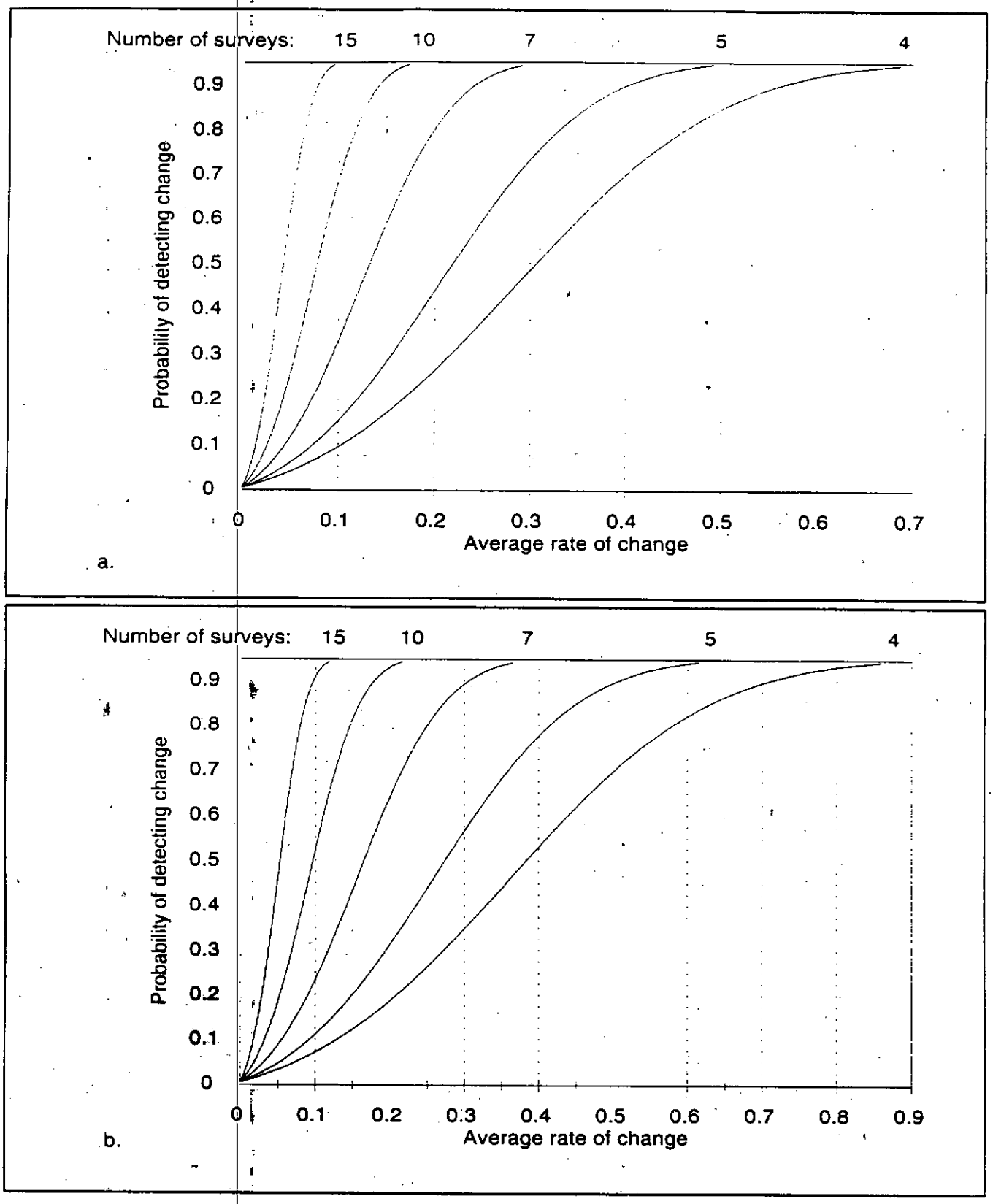

Fig. 47. Power to detect trends in marine bird abundance when confidence level is 0.10 and : (a) mean coefficient of variation is 0.4, or (b) mean coefficient of variation is 0.5.

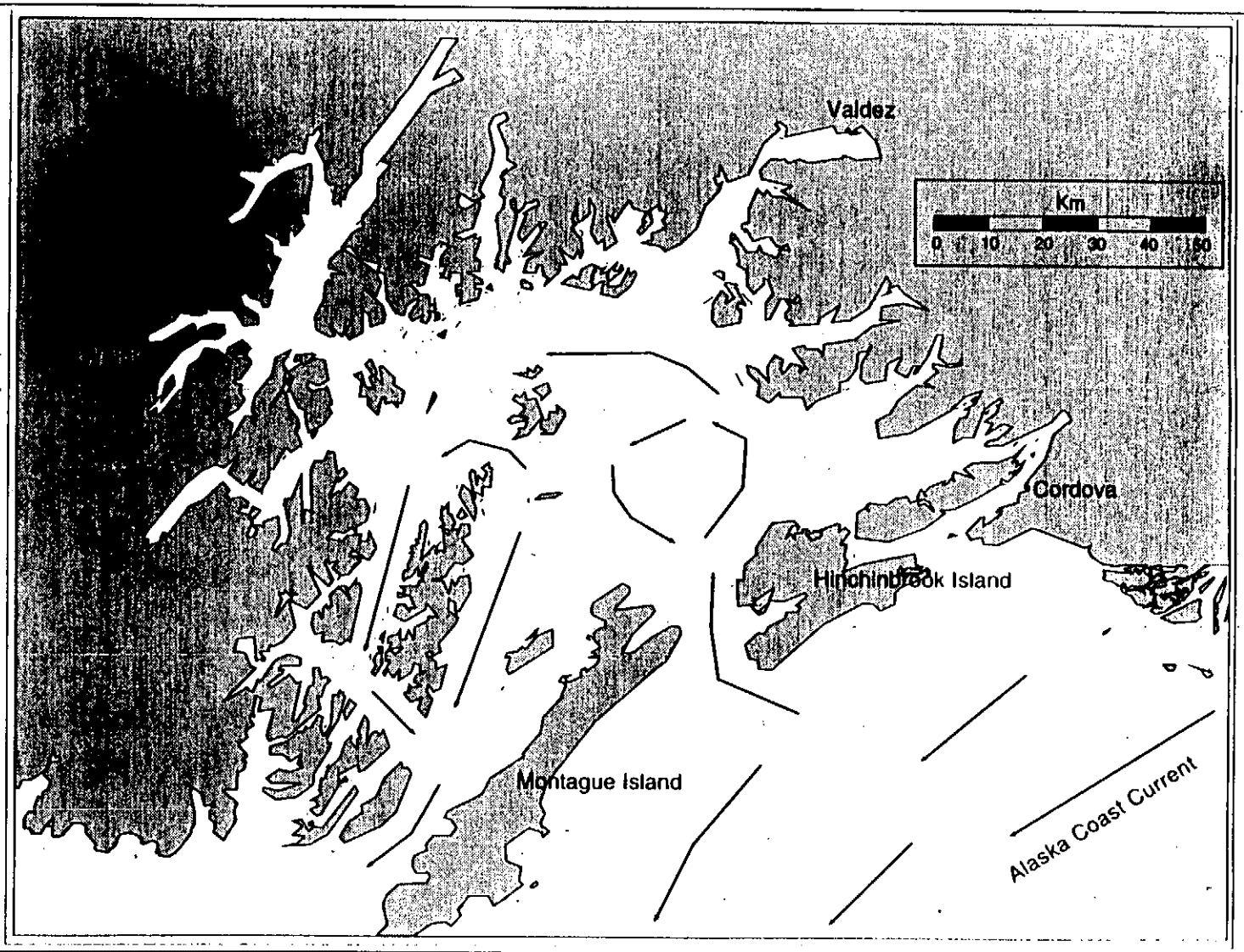

Fig. 48. Prince William Sound study area. Lines delineate major currents.

Appendix A. Estimated population abundance of marine birds ($N \pm$ 95% CI) from small boat surveys of Lower Cook Inlet, Alaska in summer 1993 and a combined small boat and shipboard survey during winter 1994. Species are listed in phylogenetic order (AOU 1983).

Species	Summer		Winter	
	N	CI	*N*	CI
LOONS				
Red-throated loon (*Gavia stellata*)	242	283	0	0
Pacific loon (*Gavia pacifica*)	595	765	44	74
Common loon (*Gavia immer*)	392	266	176	148
Yellow-billed loon (*Gavia adamsii*)	63	124	38	74
Unidentified loon (*Gavia* sp.)	1,270	1,207	46	67
Total loons (*Gavia* spp.)	2,563	1,492	304	193
GREBES				
Horned grebe (*Podiceps auritus*)	0	0	66	43
Red-necked grebe (*Podiceps grisegena*)	0	0	427	379
Unidentified grebe (*Podiceps* sp.)	0	0	155	126
Total grebes (*Podiceps* spp.)	0	0	648	406
TUBENOSES				
Shearwaters and Fulmars (Family Procellariidae)				
Northern fulmar (*Fulmarus glacialis*)	47,168	33,368	1,056	1,005
Sooty shearwater (*Puffinus griseus*)	25,036	15,460	0	0
Short-tailed shearwater (*Puffinus tenuirostris*)	10,550	13,223	0	0
Unidentified shearwater (*Puffinus* sp.)	70,219	37,836	0	0
Total shearwaters (*Puffinus* spp.)	105,805	43,421	0	0
Unidentified fulmar or shearwater (*Fulmarus* or *Puffinus* sp.)	12,533	8,830	0	0
Total fulmars and shearwaters (*Fulmarus* and *Puffinus* spp.)	165,507	57,488	1,056	1,005
Storm-petrels (Family Hydrobatidae)				
Fork-tailed storm-petrel (*Oceanodroma furcata*)	113,804	60,101	0	0
Unidentified storm-petrel (*Oceanodroma* sp.)	63	124	0	0
Total storm-petrels (*Oceanodroma* spp.)	113,868	60,099	0	0
Total tubenoses (Order Procellariiformes)	279,375	85,022	1,056	1,005
CORMORANTS				
Double-crested cormorant (*Phalacrocorax auritus*)	2,179	1,252	2	4
Pelagic cormorant (*Phalacrocorax pelagicus*)	1,828	1,039	5,556	1,777
Red-faced cormorant (*Phalacrocorax urile*)	123	149	40	74
Unidentified cormorant (*Phalacrocorax* sp.)	2,544	1,232	695	480
Total cormorants (*Phalacrocorax* spp.)	6,674	2,497	6,294	1,850

Appendix A (continued).

Species	Summer		Winter	
	N	CI	*N*	CI
WATERFOWL				
Brant (*Branta bernicula*)	343	337	0	0
Dabbling Ducks				
Mallard (*Anas platyrhynchos*)	7	13	263	237
Northern pintail (*Anas acuta*)	43	67	0	0
Northern shoveler (*Anas clypeata*)	7	13	0	0
Gadwall (*Anas strepera*)	7	13	0	0
Unidentified dabbling duck (*Anas* sp.)	1,623	2,424	0	0
Diving Ducks				
Greater scaup (*Aythya marila*)	1,556	1,563	87	149
Unidentified scaup (*Aythya* sp.)	0	0	4	8
Total scaup (*Aythya marila* and *affinis*)	1,556	1,563	91	149
Sea Ducks				
Common eider (*Somateria mollissima*)	2,744	3,959	4,547	4,876
King eider (*Somateria spectabilis*)	0	0	264	517
Steller's eider (*Polysticta stelleri*)	100	193	1,011	1,151
Total eiders (*Polysticta* and *Somateria* spp.)	2,844	3,966	5,822	5,435
Harlequin duck (*Histrionicus histrionicus*)	3,774	2,025	1,940	955
Oldsquaw (*Clangula hyemalis*)	248	466	11,058	9,556
Black scoter (*Melanitta nigra*)	529	937	2,371	1,744
Surf scoter (*Melanitta perspicillata*)	42,776	70,476	1,821	871
White-winged scoter (*Melanitta fusca*)	3,879	2,653	23,424	9,943
Unidentified scoter (*Melanitta* sp.)	1,893	1,838	1,792	1,377
Total scoters (*Melanitta* spp.)	49,077	70,529	29,408	11,281
Common goldeneye (*Bucephala clangula*)	0	0	590	438
Barrow's goldeneye (*Bucephala islandica*)	0	0	1,100	665
Unidentified goldeneye (*Bucephala islandica* or *clangula*)	3	7	1,948	1,921
Total goldeneyes (*Bucephala islandica* and *clangula*)	3	7	3,638	2,224
Bufflehead (*Bucephala albeola*)	0	0	340	288
Common merganser (*Mergus merganser*)	1,496	2,006	994	851
Red-breasted merganser (*Mergus serrator*)	351	321	230	333
Unidentified merganser (*Mergus* sp.)	255	350	179	172
Total mergansers (*Mergus* spp.)	2,103	2,065	1,403	922
Unidentified diving/sea duck	4,371	5,777	2,633	3,418
Unidentified duck	30	44	11	17
Total waterfowl (Family Anatidae)	66,035	71,789	56,607	19,985

Appendix A (continued).

Species	Summer		Winter	
	N	CI	*N*	CI
HAWKS AND EAGLES				
Bald eagle (*Haliaeetus leucocephalus*)	347	89	840	677
SHOREBIRDS				
Black oystercatcher (*Haematopus bachmani*)	40	32	0	0
Unidentified yellowlegs (*Tringa melanoleuca* or *flavipes*)	3	7	0	0
Spotted sandpiper (*Actitis macularia*)	3	6	0	0
Whimbrel (*Numenius phaeopus*)	7	13	0	0
Red-necked phalarope (*Phalaropus lobatus*)	1,704	2,054	0	0
Unidentified phalarope (*Phalaropus* sp.)	825	1,297	0	0
Total phalarope (*Phalaropus* spp.)			0	0
Unidentified shorebird	53	70	2	4
Total shorebirds	107	87	2	4
(Families Haematopodidae and Scolopacidae, except *Phalaropus* sp.)				
JAEGERS				
Pomarine jaeger (*Stercorarius pomarinus*)	511	426	0	0
Total jaegers (*Stercorarius* spp.)	511	426	0	0
GULLS				
Bonaparte's gull (*Larus philadelphia*)	441	538	0	0
Mew gull (*Larus canus*)	721	631	2,648	988
Herring gull (*Larus argentatus*)	190	373	212	178
Glaucous-winged gull (*Larus glaucescens*)	47,841	15,948	10,742	2,594
Black-legged kittiwake (*Rissa tridactyla*)	75,920	35,791	0	0
Unidentified gull (*Larus* or *Rissa* sp.)	3,833	2,465	2,487	2,642
Total gulls (*Larus* and *Rissa* spp.)	128,946	40,896	16,089	4,752
TERNS				
Arctic tern (*Sterna paradisaea*)	5,512	3,686	0	0
Aleutian tern (*Sterna aleutica*)	587	856	0	0
Unidentified tern (*Sterna* sp.)	296	335	0	0
Total terns (*Sterna* spp.)	6,394	3,885	0	0
ALCIDAE				
Murres				
Common murre (*Uria aalge*)	168,446	135,747	23,749	9,587
Thick-billed murre (*Uria Lomvia*)	0	0	38	74
Unidentified murre (*Uria* sp.)	746	597	1,620	625
Total murres (*Uria* spp.)	169,192	135,741	25,406	9,603
Guillemots				
Pigeon guillemot (*Cepphus columba*)	8,791	3,081	2,914	1,398

Appendix A (continued).

Species	Summer		Winter	
	N	CI	*N*	CI
Murrelets				
Marbled murrelet (*Brachyramphus marmoratus*)	7,782	2,726	7,449	6,163
Kittlitz's murrelet (*Brachyramphus brevirostris*)	3,353	1,718	0	0
Unidentified *Brachyramphus* sp.	47,092	14,004	4,178	2,349
Total *Brachyramphus* murrelets (*Brachyramphus* spp.)	58,227	16,058	11,627	7,410
Auklets				
Parakeet auklet (*Cyclorrynchus psittacula*)	63	124	0	0
Puffins				
Tufted puffin (*Fratercula cirrhata*)	37,737	12,946	0	0
Horned puffin (*Fratercula corniculata*)	26,369	9,696	0	0
Unidentified puffin (*Fratercula* sp.)	2,792	1,694	0	0
Total puffins (*Fratercula* spp.)	66,899	16,409	0	0
Unidentified Alcid	1,146	773	324	205
Total Alcids (Family Alcidae)	304,317	139,532	40,271	12,810
KINGFISHERS				
Belted kingfisher (*Ceryle alcyon*)	13	16	15	13
PASSERINES				
Tree swallow (*Tachycineta bicolor*)	3	7	0	0
Violet-green swallow (*Tachycineta thalassina*)	93	164	0	0
Bank swallow (*Riparia riparia*)	310	368	0	0
Unidentified swallow (*Tachycineta* or *Riparia* sp.)	101	104	0	0
Gray jay (*Perisoreus canadensis*)	0	0	2	4
Steller's jay (*Cyanocitta stelleri*)	0	0	2	4
Black-billed magpie (*Pica pica*)	23	28	64	56
Northwestern crow (*Corvus caurinus*)	243	185	835	742
Common raven (*Corvus corax*)	43	26	23	22
Gray-crowned rosy finch (*Leucosticte tephrocotis*)	0	0	212	404
Pine siskin (*Carduelis pinus*)	0	0	85	167
Unidentified passerine	0	0	159	311
Unidentified bird	1,483	867	714	693
MARINE BIRDS				
Total marine birds	798,042	195,555	122,946	25,804

Appendix B. Estimated population abundance of marine mammals ($N \pm$ 95% CI) from boat surveys of Lower Cook Inlet, Alaska in summer 1993 and winter 1994.

Species	Summer		Winter	
	N	CI	*N*	CI
CETACEANS				
Harbor porpoise *(Phocoena phocoena)*	428	402	0	0
Dall's porpoise *(Phocoenoides dalli)*	571	650	302	372
Minke whale *(Balaenoptera acutorostrata)*	48	93	0	0
OTTERS				
Sea otter *(Enhydra lutris)*	5,914	3,094	1,104	592
SEA LIONS				
Steller sea lion *(Eumetopias jubatus)*	286	284	151	221
SEALS				
Harbor seal *(Phoca vitulina)*	2,288	1,698	107	105

Appendix C. Opportunistic sightings of marine mammals observed during boat surveys of Lower Cook Inlet, Alaska in summer 1993 and winter 1994.

Summer 1993

Several whales were sighted while we were moving between transects. We had one sighting of four killer whales (*Orcinus orca*) near Port Graham, and one sighting of three humpback whales (*Megaptera noveangliae*) breaching 20 km north of the Barren Islands. We obtained identification photographs of the killer whales and have forwarded them to the National Marine Mammal Laboratory in Seattle. We had a number of minke whale sightings in Kachemak Bay and along the shoreline north of Anchor Point.

Winter 1994

Killer whales were spotted on two occasions in Kachemak Bay. On 4 February, a group of three or four killer whales was seen near Yukon Island. On 6 February, a group of eight to ten killer whales was spotted between 60-foot Rock and the Homer Spit. One minke whale was observed off Anchor Point.

Appendix D. Counts of marine birds and mammals within the 0.2 nm (400 m) zone during an aerial survey of the Kachemak Bay and western shorelines of Lower Cook Inlet in winter 1994. Shoreline sections follow Arneson (1980): (3) Anchor Point to Homer Spit tip; (4) Homer Spit tip to Peterson Bay; (5) Chinapoot Bay to Point Bede; (8) Tuxedni Bay; (9) Tuxedni Bay to Chinitna Bay; (10) Chinitna Bay; (11) Iniskin Peninsula; (12) Oil Bay, Iniskin Bay, and Iliamna Bay; (13) South Head to Chenik Head, including Ursus Bay and Bruin Bay; (14) Amakadedulia Cove, McNeil Cove, and Akumwarvik Bay; and (15) Akumwarvik Bay to Cape Douglas.

	Kachemak Bay Shoreline			Western Shoreline							
Species	3[a]	4	5[a]	8[a]	9	10	11	12	13	14	15
Marine Birds											
Common loons	0	1	9	0	0	0	0	0	0	0	0
Unidentified loons	1	5	17	0	0	0	0	0	0	0	1
Loons	1	6	26	0	0	0	0	0	0	0	1
Red-necked grebes	0	1	6	0	0	0	0	0	0	0	0
Grebes	0	1	6	0	0	0	0	0	0	0	0
Cormorants[b]	6	102	104	0	0	0	0	0	0	0	25
Waterfowl	193	2,013	4,319	208	33	456	613	1,205	1,153	97	725
Green-winged teal	0	0	4	0	0	0	0	0	0	0	0
Mallards	0	32	189	40	0	0	0	0	0	0	0
Dabbling ducks	0	32	193	40	0	0	0	0	0	0	0
Scaup[b]	0	0	0	0	0	1	0	100	0	0	35
Goldeneyes[b]	0	431	697	84	0	0	0	0	0	0	3
Buffleheads	0	74	34	0	0	0	0	0	0	0	0
Diving ducks	0	505	981	84	0	1	0	100	0	0	38
Common eiders	24	0	41	0	0	0	0	5	0	0	33
Steller's eiders	22	0	420	0	0	0	0	435	928	0	0
Eiders	46	0	461	0	0	0	0	440	928	0	33
Harlequin ducks	0	0	261	0	0	8	16	48	10	0	191
Oldsquaws	42	49	122	38	0	304	0	397	78	95	243
Black scoters	105	35	737	0	31	66	597	183	107	0	193
Surf scoters	0	128	549	0	0	0	0	0	0	0	12
White-winged scoters	0	160	223	8	0	0	0	0	0	0	8
Unidentified scoters	0	0	0	0	0	0	0	0	0	0	6
Scoters	105	323	1,509	8	31	66	597	183	107	0	219
Sea ducks	193	372	2,353	46	31	378	613	1,068	1,23	95	686

Appendix D (continued).

	Kachemak Bay Shoreline			Western Shoreline							
Species	3[a]	4	5[a]	8[a]	9	10	11	12	13	14	15
Red-breasted mergansers	0	1,104	792	38	2	77	0	37	30	2	1
Mergansers	0	1,104	792	38	2	77	0	37	30	2	1
Bald eagles	51	10	35	1	0	0	2	1	0	1	1
Shorebirds[b]	0	230	0	0	0	200	0	0	0	0	34
Mew gulls	0	1	0	0	0	0	0	0	0	0	0
Herring gulls	0	26	0	3	0	7	0	1	0	0	0
Glaucous-winged gulls	0	0	10	0	0	0	0	0	0	0	0
Glaucous gulls	1	5	2	1	0	0	0	1	1	0	1
Unidentified gulls	68	518	621	0	0	2	0	30	2	0	2
Gulls	69	550	633	4	0	9	0	32	1	0	3
Alcids	0	6,673	637	2	0	0	0	0	0	0	0
Murres[b]	0	6,671	633	2	0	0	0	0	0	0	0
Murrelets[c]	0	2	4	0	0	0	0	0	0	0	0
Northwest crows	0	50	60	0	0	0	0	0	0	0	0
Common ravens	0	0	0	0	0	0	0	0	0	0	0
Total marine birds[d]	320	9,635	5,820	215	33	665	615	1,238	1,154	98	789
Marine Mammals											
Beluga whales	0	0	0	0	0	0	0	2	0	2	0
Sea otters	1	152	130	0	0	0	0	18	78	0	90
Steller sea lions	0	16	1	0	0	0	0	0	0	0	0
Harbor seals	0	4	8	0	0	0	0	9	2	0	53

[a] Area surveyed was less than Arneson's (1980) original sections.
[b] Within these groups, total birds were not identified to species.
[c] Marbled and Kittlitz's murrelets only.
[d] Bald eagles and common ravens were not included in total marine birds, thus this column will not add vertically.