DISTRIBUTION AND ABUNDANCE OF *BRACHYRAMPHUS* MURRELETS AND OTHER MARINE SPECIES FROM ICY BAY TO LECONTE BAY, SOUTHEAST ALASKA, 2002-2004

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ABSTRACT

The Kittlitz's murrelet (*Brachyramphus brevirostris*) is one of the rarest and least understood seabirds in the world. Distribution of this species seems to be primarily restricted to tidewater glaciers, glaciated fjords or outflows of glacial streams. Based on results of at-sea surveys in four core population areas, Kittlitz's murrelets have declined up to 84% over the last few decades. The primary objective of our study was to describe the current distribution and abundance of Kittlitz's murrelets in southeast Alaska from Icy Bay to LeConte Bay, including many previously unsurveyed areas. Additionally, we resurveyed an area along the Malaspina Forelands that was previously surveyed in 1992 to estimate trend of Kittlitz's murrelets in this area. We delineated three study areas – Icy Bay and adjacent waters, Outer Coast and adjacent waters, and Mainland Fjords – based on previous survey data and observations of Kittlitz's murrelets, and suitability of habitat. We further divided each study area into 12 geographic-based strata and categorized each as protected or exposed. We conducted at-sea surveys from 7-14 July 2002, 3-11 July 2003, and 6-16 July 2004 using a variety of survey methods and platforms. Over the three year period, we surveyed 327 km of pelagic transects (n=76) and 791 km of shoreline in protected strata, and 864 km of pelagic transects (n=97) in exposed strata. In total, we observed 1,039 Kittlitz's murrelets, 10,407 marbled murrelets (*B. marmoratus*), and 615 *Brachyramphus* murrelets on transect. Kittlitz's murrelets were distributed from Icy Bay to Endicott Arm, with the highest density and population of Kittlitz's murrelets in Icy Bay. Marbled murrelets were well-distributed throughout all study areas with the highest density recorded at the mouth of Lituya Bay, although the largest population estimate was calculated for the Wilderness Bays stratum (Holkham Bay, and Tracy and Endicott Arms). Our results confirm that Kittlitz's murrelets occur in some of the glaciated fjords on the mainland of southeast Alaska

and demonstrate that not only are they present in very exposed areas (e.g., along the outer coast), but also densities in these areas may even exceed those found in more protected, inner fjords. We conclude that Kittlitz's murrelets use a greater variety of habitats than previously acknowledged. We provide recommendations for conducting surveys in protected and exposed strata, and offer guidelines for long-term monitoring of Kittlitz's murrelets in southeast Alaska.

INTRODUCTION

The Kittlitz's murrelet (*Brachyramphus brevirostris*) is one of the rarest and least understood seabirds in the world. Few systematic surveys have focused on documenting distribution and abundance of Kittlitz's murrelets. The majority of the breeding population occurs in Alaska, with small populations in the Russian Far East. Summer records of birds at sea, presumed to be breeding nearby, indicate the species range extends from the Okhotsk Sea, throughout the Bering Sea, and highest densities are reached in the northern Gulf of Alaska (GOA; Day et al. 1999); however, few nest records exist to confirm breeding areas. Nonbreeding distribution is largely unknown except for occasional observations in the GOA.

For most populations, distribution of Kittlitz's murrelets seems to be restricted to tidewater glaciers, glaciated fjords or outflows of glacial streams (Day et al. 1999, 2003, Kuletz et al. 2003b). They tend to forage near tidewater glaciers or glacially-influenced coastal waters, and nest in recently deglaciated areas with few predators (Isleib and Kessel 1973, Day et al. 1999). Freshwater discharge from tidewater glaciers may play an important role in circulation and current strength, local upwelling, gyres, water column stratification, and sediment deposition (Kissling et al. 2007). These oceanographic processes likely influence the availability of preferred forage fish and other important prey (e.g., *Euphausiid* spp.) of the Kittlitz's murrelet.

Limited data exist to assess the conservation status of Kittlitz's murrelets. The world population was recently estimated to be 15,913 birds (range = 7,769 – 26,962; U.S. Fish and Wildlife Service 2007). Research on this rare seabird has been concentrated in Prince William Sound and Glacier Bay where the highest densities of this species were thought to exist (Kendall and Agler 1998). Repeated surveys conducted in these areas have suggested extreme declines of Kittlitz's murrelets. Data collected in Glacier Bay between 1991 and 2000 suggest that the

population has declined by more than 80% (Robards et al. 2003). Trend data from Prince William Sound describe even greater declines (Stephensen et al. 2001, U.S. Fish and Wildlife Service 2007). In response to documented declines, the U.S. Fish and Wildlife Service listed the Kittlitz's murrelet as a candidate species under the Endangered Species Act in May 2004 (69 FR 24875 24904).

Potential reasons for decline are speculative. Several authors have associated declines with glacial retreat (van Vliet 1993, Day et al. 1999, Day et al. 2003, Kuletz et al. 2003b), possibly due to changes in climate. Kuletz et al. (2003b) present clear evidence that Kittlitz's murrelet population changes are correlated with status of nearby glaciers; however, the cause of population declines remains unknown. Other possible reasons for decline include oil pollution, gillnet mortality, and availability of preferred forage fish (van Vliet and McAllister 1994, Piatt and Anderson 1996, U.S. Fish and Wildlife Service 2007). Based on body size and at-sea behavior, the Kittlitz's murrelet was identified as the most vulnerable of all non-endangered birds in the North Pacific to oil spills (King and Sanger 1979), and van Vliet and McAllister (1994) suggested that this species was the most impacted by the *Exxon Valdez* oil spill which occurred in 1989. Kittlitz's murrelets are taken during commercial gillnet fisheries (summarized in Piatt et al. 2007), and this direct morality may be a significant conservation concern for this species. Changes in availability of forage fish due to a marine climate regime shift have been hypothesized as a potential cause of population declines of Kittlitz's murrelets and other piscivorous birds. In the GOA, high-energy, pelagically-schooling forage fish, such as Pacific herring and capelin, are now numerically dominated by fish much lower in energy density, such as cod and walleye pollock (Mueter and Norcross 2000). Consequently, important prey species may have shifted their distribution or are now significantly reduced in numbers, which may lead

to nutritional stress and lower reproductive success or elevated mortality rates for Kittlitz's murrelets.

The primary objective of this study was to describe the current distribution and abundance of Kittlitz's murrelets from Icy Bay to LeConte Bay, including many previously unsurveyed areas in southeast Alaska. Additionally, we resurveyed an area along the Malaspina Forelands that was previously surveyed in 1992 (Kozie 1993) to estimate trend of Kittlitz's murrelets in this area. In this report, we summarize the results of our work conducted from 2002-2004.

STUDY AREA

Southeast Alaska is defined as the region east of the 144th meridian, consisting of the large group of islands called the Alexander Archipelago, and a strip of mainland that stretches from Cape Suckling south to Dixon Entrance. This area is roughly 900 km in length and averages 230 km in width, and is characterized by steep, rugged topography, coastal fjords, and over 2,000 islands. For this study, we delineated three study areas – Icy Bay and adjacent waters (hereafter Icy Bay), Outer Coast and adjacent waters (hereafter Outer Coast), and Mainland Fjords (Fig. 1). We selected these areas because of logistical constraints, previous survey data and observations of Kittlitz's, and suitability of habitat.

The Icy Bay study area extends from Icy Cape to Pt. Manby, and includes Icy Bay itself (Fig. 2). Icy Bay is a coastal fjord that has only existed since 1904, and today is approximately 240 km^2 in area, comprising a shallow outer bay and a deep inner bay. Four fjords radiate from inner Icy Bay and each has an active tidewater glacier at its head (Guyot, Yahtse, Tsaa, and Tyndall; Fig. 2). Although the Tyndall Glacier appears to have stabilized recently, it has

retreated nearly 18 km since 1961 (roughly 0.45 km/year), forming Taan Fjord (Table 1; Koppes and Hallet 2006). The other three tidewater glaciers are considered to be in a stable retracted position (poised to advance), but haven't been revisited since 1988 (Table 1; Porter 1989, Powell 1991). The bordering Malaspina Glacier, a piedmont glacier that empties into Icy Bay via the Caetani River, is thinning (Table 1; Arendt et al. 2002). In 1992, this stretch of coastline was surveyed for seabirds and marine mammals (Kozie 1993), and in 1995, Riou Spit, Gull Island, and the shoreline extending from Kageet Point to the mouth of the Caetani River were surveyed for seabirds (Kozie 1996). The remainder of Icy Bay was not surveyed systematically until this study. Wrangell-St. Elias National Park and Chugach Native Corporation are the primary land managers of this study area, and the State of Alaska regulates the waters within 5.6 km (3 nautical miles) from shore.

The Outer Coast study area extends from Ocean Cape to Cape Spencer (including Lituya Bay), and includes Cross Sound and adjacent bays (Fig. 3). The long stretch of coastline from Ocean Cape to Cape Spencer is approximately 243 km in length, and is relative exposed with few sheltered bays. Several large glacially-fed rivers (e.g., Dangerous and Alsek Rivers) empty into the Pacific Ocean along this coast, resulting in large glacial water plumes. Although there are several recently deglaciated areas along the coast, only three glaciers are considered tidewater. The Lituya, Cascade, and North Crillon Glaciers in Lituya Bay are advancing and thickening (Table 1; Larsen et al. 2007). Once considered tidewater glaciers, LaPerouse and Fairweather are both in retreat and are thinning (Table 1; Larsen et al. 2007). Cross Sound and adjacent bays surveyed in this study are approximately 604 km^2, and include several small islets scattered throughout the sound. Taylor and Dundas Bays on the north side of the sound contain tidewater glaciers (both extensions of the Brady Glacier) that are stable extended (poised for

retreat) and thinning (Table 1; Larsen et al. 2007). A large proportion of the waters in these bays are glacially-affected. The primary land managers of this study area include the U.S. Forest Service (Ocean Cape to Dry Bay) and Glacier Bay National Park (Dry Bay to Pt. Carolus). Except for those waters within national park boundaries, the State of Alaska regulates the waters within 5.6 km (3 nautical miles) from shore.

The Mainland Fjord study area is not continuous, but instead comprises four fjords/bays with tidewater (or recently tidewater) glaciers (Fig. 4). Endicott (48 km in length) and Tracy (42 km in length) Arms located 96 km from Juneau are deep (110-185 fathoms), coastal fjords with actively calving glaciers, making for a popular day-trip for cruise ship passengers and tourists. Holkham Bay located at the entrance to both Tracy and Endicott Arms is much shallower (<100 m) and contains two marine sills at the entrance to both arms. The Sawyer and South Sawyer Glaciers at the head of Tracy Arm are retreating rapidly (roughly 2 km over the past few years) while Dawes and North Dawes Glaciers at the head of Endicott Arm are stable but thinning (Table 1; Larsen et al. 2007). At the head of Thomas Bay lies the Baird Glacier (retreating), which is no longer a tidewater glacier, but the adjacent uplands are recently deglaciated with little vegetation (Table 1; Larsen et al. 2007). LeConte Bay, previously known to be the southernmost population of Kittlitz's murrelets (van Vliet 1993, Agler et al. 1998), contains the very active LeConte Glacier, which is stable retracted (poised to advance) and thinning rapidly (Table 1; Motyka et al. 2003, Larsen et al. 2007).

METHODS

Without prior knowledge of Kittlitz's murrelets in our study areas, we conducted broad-scale surveys to describe distribution and abundance of this species. Consequently, the sampling

design varied among survey years based on logistical constraints and information accumulated during the course of the study. The Icy Bay and Mainland Fjords study areas were surveyed in 2002, and the Outer Coast study area was surveyed in 2003 and 2004.

Sampling design

We defined 12 strata within three study areas based on geographic location, management boundaries, and bathymetry (Fig. 1). To determine sampling design, each stratum was categorized as protected (n=7) or exposed (n=5). Survey boundaries were easily delineated for protected strata, but exposed strata proved difficult to sample efficiently. For both types of strata, we used a systematic sampling design, but in exposed strata we also included adaptive cluster sampling in areas of high murrelet densities. By using both sampling approaches, we were able to maximize spatial coverage with systematic sampling and to obtain more accurate measures of abundance with adaptive cluster sampling by taking advantage of the patchy spatial pattern in which this species occurs.

In protected strata, shoreline and pelagic transects were established (Table 2). Shoreline transects ran parallel to shore and covered waters less than 200 m offshore. Pelagic transects were perpendicular to shore and were at least 1.6 km apart and of unequal length. In Icy Bay and Mainland Fjords, the first transect was established at a random location and subsequent transects were spaced at 2 km intervals. In all other protected strata, transects followed north-south or east-west lines from a USGS topographical map (1:63,360 series), spacing transects 1.6 km apart.

In exposed strata, only pelagic transects were established (Table 3). We delineated boundaries for exposed strata using water depth (except along the Malaspina Forelands): less

than 10 fathoms, 10 fathoms, and greater than 10 fathoms. We chose 10 fathoms as a boundary because this depth is often included on marine charts and is an acceptable depth for the larger vessel (see below) to navigate safely. Transects less than 10 fathoms in depth extended to within 200 m from shore and 150 m from the 10-fathom line. At the 10-fathom line, transects followed this depth continuously and transect width was 300 m. Transects surveyed that were greater than 10 fathoms in depth extended from 150 m from the 10-fathom line to 5.5 km (3 nautical miles) offshore, and were arranged in a sawtooth (i.e., zigzag) pattern. This distance from shore denotes the jurisdictional boundary (sometimes referred to as 'coastal waters') and is also often noted on marine charts. Along the Malaspina Forelands, the boat maintained a distance of approximately 1 km from shore, regardless of water depth but roughly following 10 fathoms, in order to allow for comparison with data collected in 1992 (Kozie 1993).

Cluster sampling occurred at three locations, which formed three distinct strata (i.e., Manby Point, Icy Point, and Mouth of Lituya Bay; see Fig. 2 and 3). Sampling design at these locations differed due to time and logistical constraints. Within the Icy Point stratum, pelagic transects were oriented north-south starting at the 10-fathom line and extending offshore approximately 2 km in length. Spacing between transects was 1.6 km. At the mouth of Lituya Bay, we sampled waters less than 10 fathoms in depth. Transects were spaced 1.6 km apart oriented north to south and extended from 200 m from shore to 150 m from the 10-fathom line. The Manby Point stratum was sampled using a series of perpendicular (5 km in length) and diagonal (8 km in length) transects to facilitate movement between transects (Fig. 2). These transects were arranged directly adjacent to the Malaspina Foreland pelagic transect (approximately 1 km from shore).

Survey protocol

We conducted at-sea surveys from 7-14 July 2002, 3-11 July 2003, and 6-16 July 2004. In 2002, we used strip transect survey methods with strip width dependent on the survey platform (see below), and in 2003 and 2004, we used line transect survey methods assigning each observation to a 25-m distance bin out to 100 m or 150 m on either side of the boat depending on the survey platform (Buckland et al. 2001). We opportunistically recorded observations beyond the maximum distance (100 m or 150 m), but simply considered these birds to be off transect. For all transects in protected strata and under calm sea conditions in exposed strata, we used 5.5-m hard-hulled skiffs with two observers and a boat operator, and transect width was 100 m either side of and ahead of the skiff. Otherwise we used a 20-m vessel, and two observers at the bow recorded all birds 150 m either side of and ahead of the vessel. However, in the Malaspina Forelands stratum, we recorded birds 100 m either side of and ahead of the larger 20 m vessel in order to compare results with the 1992 survey conducted in the same area. We recorded all observations using a GPS-integrated voice recording system (Program SURVEY, J. Hodges, USFWS, Juneau). Although the primary focus of our surveys was to assess the distribution and abundance of Kittlitz's murrelets in our study areas, we were also interested in the closely related congeneric, marbled murrelet. Therefore, for all *Brachyramphus* murrelet observations, we recorded number in group, behavior (e.g., on water, flying, foraging), and the distance (binned in 25-m segments; distance not recorded in 2002). Every 30 minutes we also recorded weather, sea and ice conditions, swell height, wind speed and direction, and water temperature and clarity. All observers were trained in bird identification and distance estimation (2003 and 2004 only) prior to the surveys and observers rotated every 2-3 hours to

stay alert and focused. Most observers were experienced in conducting surveys for *Brachyramphus* murrelets elsewhere in Alaska.

To better understand the complex marine ecosystem and potential threats, we recorded all marine birds and mammals, and human activity (e.g., boats, kayakers, floatplanes) in addition to *Brachyramphus* murrelets during our surveys. We indicated whether or not the object was on or off transect, but did not estimate distance to the object during any of the survey years. We present distribution and abundance maps of these species in Appendix 10. Data were submitted to the North Pacific Pelagic Seabird Database (USFWS & USGS Anchorage, AK) and are available from M. Kissling by request (also summarized in Appendices 7-9).

Data analysis

Species distributions were mapped using ArcView (ESRI, v. 3.3) and transects were buffered by the width of the surveyed strip (200 or 300 m depending on the survey platform; Appendices 1-3). Total stratum area and total surveyed area by stratum were calculated (Tables 2 and 3). We delineated total area in ArcView using available shoreline shapefiles. In areas of heavy ice cover (i.e., Icy Bay and LeConte Bay). we used the continuous trackline recorded during the survey to guide stratum boundaries.

We used program DISTANCE (Thomas et al. 2004) to estimate density, abundance, and associated variances for each stratum. Our sampling unit was individual transects, assumed to be independent of one another, within each stratum. Three key assumptions to successful application of distance sampling theory include (1) birds on the line are detected with certainty, (2) birds are detected at their initial location, and (3) distances are measured without error. These assumptions apply to data collected during all three survey years. Since we did not collect

distance data during the 2002 surveys, we also assumed that all birds within the strip transect were detected (i.e., probability of detection was perfect). We used Akaike's Information Criterion (AIC) to help select the most parsimonious model from a set of potential models to estimate abundance of Kittlitz's and marbled murrelets (Burnham and Anderson 2002). Grouping all Brachyramphus murrelets, we considered survey platform, cluster size, and weather and sea conditions as additional covariates when modeling the detection probability. Based on the minimum AIC value, we selected the uniform detection function with a simple polynomial expansion term to model the probability of detection by survey platform, the only covariate that helped to explain the variability in detection probabilities. Density, population size, and associated variance were estimated for each transect type (i.e., shoreline or pelagic, and less than 10 fathoms, 10 fathoms, or greater than 10 fathoms) for each stratum. These estimates were calculated using DISTANCE (v. 4.1; Thomas et al. 2004). For transects that were repeated within the survey year or across survey years, we averaged estimates within each year and then averaged across years. Estimates were then pooled across all transects in a stratum and weighted by area to estimate density and population size within the stratum (Cochran 1977). We weighted the sum of the variances to estimate the pooled variance (Cochran 1977).

For trend estimation along the Malaspina Forelands, we used summarized data from Kozie (1993). We used least-squares linear regression to estimate population trend over the 10-year period. The number of individuals observed on transect was regressed on year of survey. Due to extremely low sample size, we did not perform statistical tests to determine whether the trend was significant; instead, we concentrated on the magnitude of change over time by fitting a line to the data. These data were not adjusted for differences in detection probabilities. (Note:

On July 10, 2002 one computer stationed on the port side of the boat failed to record data along the Malaspina Forelands. We did not consider data collected on this day during analysis.)

RESULTS

Over the three year period, we surveyed 327 km (82 km^2) of pelagic transects (*n*=76) and 791 km (157 km^2) of shoreline in protected strata (Table 2), and 864 km (242 km^2) of pelagic transects (*n*=97) in exposed strata (Table 3). In total, we observed 1,039 Kittlitz's murrelets, 10,407 marbled murrelets, and 615 *Brachyramphus* murrelets not identified to species on transect (Table 4). Kittlitz's murrelets were distributed from Icy Bay to Endicott Arm (Fig. 5), with the highest density and population of Kittlitz's murrelets recorded in Icy Bay (Table 5). Marbled murrelets were well-distributed throughout all study areas (Fig. 6) with the highest density recorded at the mouth of Lituya Bay, although the largest population estimate was calculated for the Wilderness Bays stratum (Holkham Bay, and Tracy and Endicott Arms; Table 6). Nine Kittlitz's, 32 marbled, and one unidentified *Brachyramphus* murrelet were observed holding fish (Fig. 7), and one mixed pair (i.e., one marbled murrelet and one Kittlitz's murrelet) was observed flying together in Holkham Bay.

Icy Bay Study Area

Icy Bay — We counted 322 Kittlitz's and 42 marbled murrelets on transect in the Icy Bay stratum (Table 4). Density of Kittlitz's in Icy Bay was estimated to be 18.73 birds/km^2 (*N*=2,098; Table 5) with a higher density in pelagic waters (21.21 birds/km^2) compared to the shoreline (4.68 birds/km^2; Table 7). Most birds were located in the northwestern part of the bay, and few birds were observed along the shallow southeastern shoreline or in ice-packed Taan

Fjord (Fig. 8). Marbled murrelets were less abundant within the bay with an overall density of 1.79 birds/km^2 (*N*=199; Table 6) and similar densities along the shoreline (2.04 birds/km^2) and pelagic waters (1.74 birds/km^2; Table 8). Only seven marbled murrelet groups were observed in the bay, and most were located near the mouth (Fig. 9). Icy Bay was the only stratum in which Kittlitz's murrelets outnumbered marbled murrelets (Fig. 10).

Malaspina Forelands — In the Malaspina Forelands stratum, we recorded 95 Kittlitz's and 807 marbled murrelets (Table 4). Overall density of Kittlitz's in this exposed stratum was 4.67 birds/km^2 (*N*=906; Table 5) with a higher density in waters greater than 10 fathoms in depth (5.00 birds/km^2) compared to 10 fathoms (2.47 birds/km^2; Table 9). Kittlitz's murrelets concentrated near Manby Point with few birds observed outside of this area, particularly toward Icy Bay (Fig. 8). In contrast to Icy Bay, marbled murrelets were more abundant in the Malaspina Forelands with an overall density of 27.66 birds/km^2 (*N*=5,367; Table 6). Densities of marbled murrelets were similar in waters 10 fathoms (28.93 birds/km^2) and greater than 10 fathoms in depth (27.47 birds/km^2; Table 10). Generally, this species was well-distributed along the Malaspina Forelands, but was observed infrequently away from shore (Fig. 9).

On 13 July 2002, we observed 43 Kittlitz's, 556 marbled, and 32 unidentified *Brachyramphus* murrelets along the 1992 transect that paralleled the Malaspina Forelands. Interpretation of population trends of Kittlitz's and marbled murrelets along the Malaspina Forelands (1992-2002) is questionable given the extremely small sample sizes and temporal and spatial variability in the distribution of these species. Unequivocally, far fewer Kittlitz's murrelets were observed in this area in 2002 compared to 1992, suggesting a dramatic decline of approximately 90% (Fig. 11a). We found a negative relationship between year and number of Kittlitz's murrelets observed along the Malaspina Forelands ($y = -39.85x + 79823$; $R^2=0.94$).

Conversely, marbled murrelets appear to have increased by 37% during the 10-year period (y = 25.35x + (-50195); R^2=0.87; Fig. 11b). All *Brachyramphus* murrelets, including those not identified to species, declined by approximately 40% (Fig. 11c).

Outer Coast Study Area

Exposed North — In 2003 and 2004, we counted 21 Kittlitz's, 1,693 marbled, and 57 unidentified *Brachyramphus* murrelets on transect in the Exposed North stratum (Table 4). Density of Kittlitz's was relatively low (0.11 birds/km^2; *N*=42) compared to other strata (Table 5). Density was higher in 10 fathoms of water (0.58 birds / km^2) than in waters greater than 10 fathoms in depth (0.08 birds/km^2; Table 9). Kittlitz's murrelets were located near the mouths of the glacially-affected Situk and Dangerous Rivers in 2003 (Fig. 12), and Alsek River in 2004 (Fig. 13). Marbled murrelets were more abundant in 10 fathoms of water (28.41 birds/km^2) than waters greater than 10 fathoms in depth (6.18 birds/km^2; Table 10), and had an overall density estimate of 7.74 birds/km^2 (*N*=2,720; Table 6). Along the 10-fathom line surveyed in 2003, marbled murrelets were well-distributed, but in 2004 when only waters greater than 10 fathoms in depth were surveyed (Fig. 14), distribution was concentrated in the southern portion of this stratum, between Dry Bay and the mouth of the Dangerous River (Fig. 15).

Mouth of Lituya Bay — This stratum represented the only exposed stratum in waters less than 10 fathoms in depth. We counted 16 Kittlitz's, 149 marbled, and 8 unidentified *Brachyramphus* murrelets on transect during surveys conducted in the Mouth of Lituya Bay stratum (Table 4). Density of Kittlitz's murrelets was estimated to be 4.62 birds/km^2 (*N*=149; Table 5), and marbled murrelet density was comparatively high at 42.97 birds/km^2 (*N*=1,390;

Table 6). Distribution of Kittlitz's was stronger to the north of Lituya Bay and close to shore (Fig. 13), while marbled murrelets were well-distributed throughout the stratum (Fig. 15).

Lituya Bay — Relatively few murrelets were observed in Lituya Bay – 5 Kittlitz's, 32 marbled, and 5 unidentified *Brachyramphus* murrelets (Table 4). Overall, density of Kittlitz's murrelets was 0.75 birds/km^2 (*N*=21; Table 5), with no birds recorded on the shoreline transect and a pelagic density of 1.01 birds/km^2 (Table 7). With few birds detected, estimated variance was high (% CV = 34.65; Table 5). All Kittlitz's were observed west of Cenotaph Island and near the mouth of the bay (Fig. 12). Marbled murrelet density was relatively low overall (5.27 birds/km^2; *N*=145; Table 6). Pelagic waters had higher densities of marbled murrelets (6.04 birds/km^2) compared to the shoreline (3.06 birds/km^2; Table 8), and this species was well-distributed throughout the bay (Fig. 14).

Exposed South — Combining 2003 and 2004 counts, we recorded 437 Kittlitz's, 3,940 marbled, and 289 unidentified *Brachyramphus* murrelets in the Exposed South stratum. Density of Kittlitz's (0.51 birds/km^2; *N*=246; Table 5) was relatively low in this large stratum, but density in 10 fathoms of water (4.09 birds/km^2; Table 9) was roughly 20 times greater than in waters greater than 10 fathoms in depth (0.20 birds/km^2; Table 9). Distribution of Kittlitz's murrelets was centered just north of Lituya Bay and near Cape Fairweather in both 2003 (Fig. 12) and 2004 (Fig. 13), and very few birds were located in deep waters away from shore (Fig. 13). Marbled murrelet density was 11.64 birds/km^2, but the population estimate (*N*=5,902) was relatively large given the size of the stratum (Table 6). Similar to Kittlitz's, marbled murrelets were more abundant in 10 fathoms of water (29.46 birds/km^2) than in waters greater than 10 fathoms in depth (10.09 birds/km^2; Table 10). This species was well-distributed in both survey

years (Fig. 14 and 15), except in 2004, few birds were recorded in waters greater than 10 fathoms deep (Fig. 15).

One portion of the 10-fathom transect in this stratum, extending from Dry Bay to Lituya Bay, was surveyed twice in 2003 and once in 2004. On 7 July 2003, Kittlitz's murrelet and marbled murrelet densities (birds/km^2±SE) were estimated as 3.94±0.57 and 28.69±1.70, respectively. On 9 July 2003, densities were 6.64±0.78 and 43.03±2.18, respectively. On 11 July 2004, we resurveyed this transect, estimating densities to be 2.79±0.40 and 22.12±1.32, respectively. Both within year and among year variability along this exposed transect was relatively high, especially for marbled murrelets, but both species exhibited an identical pattern (Fig. 16).

Icy Point — Within the Icy Point stratum, 105 Kittlitz's, 554 marbled, and 98 unidentified *Brachyramphus* murrelets were recorded on transect (Table 4). Overall Kittlitz's density and population in this stratum were estimated as 3.25 birds/km^2 and 170 birds, respectively (Table 5). Density of Kittlitz's murrelets was greatest along the 10-fathom line (7.38 birds/km^2) than in pelagic waters greater than 10 fathoms in depth (2.46 birds/km^2; Table 9). Likewise, distribution was strongest near Icy Point and not many birds were observed away from shore (Fig. 12). Marbled murrelet density in this stratum was estimated as 18.95 birds/km^2 (N=1,000; Table 6), with 27.31 birds/km^2 and 17.36 birds/km^2 estimated to be along the 10-fathom line and in waters greater than 10 fathoms deep, respectively (Table 10). This species was distributed throughout the stratum, but again few birds were observed in deeper waters (Fig. 14).

Outer Coast Bays — No Kittlitz's murrelets were observed while surveying the Outer Coast Bay stratum, but 57 marbled and 7 unidentified *Brachyramphus* murrelets were recorded

on transect. This stratum marked the southern point in the Outer Coast study area where Kittlitz's murrelets became scarce. Marbled murrelet density was also low (5.58 birds/km^2; *N*=62; Table 6) compared to other strata. As in other protected strata, marbled murrelet density was higher in pelagic waters (8.06 birds/km^2) compared to the shoreline (1.54 birds/km^2; Table 8). This species was recorded at least once in all bays, but was more abundant in the larger and more protected Graves Harbor (Fig. 14).

Cross Sound — Only three Kittlitz's murrelets were observed on transect in the Cross Sound stratum, while 1,424 marbled and 47 unidentified *Brachyramphus* murrelets were recorded (Table 4). Due to low sample of Kittlitz's, overall density (0.04 birds/km^2; *N*=22) lacks precision (Table 5). Two observations were made while surveying the shoreline of islands in Cross Sound (one bird observed near Lemesurier Island, and one bird near the Inian Islands), and one bird was recorded at the western entrance to Cross Sound (Fig. 12). Marbled murrelet density was estimated as 16.60 birds/km^2, which translates to a population estimate of 8,794 birds (Table 6). Density in pelagic waters (17.69 birds/km^2) was three times as large compared to density along the shoreline (5.59 birds/km^2; Table 8). Marbled murrelets were fairly well-distributed, but large clumps occurred near the mouth of Taylor Bay and just to the east of Lemesurier Island (Fig. 14), resulting in high variance estimates particularly along the shoreline (Table 8).

Mainland Fjords Study Area

Wilderness Bays — We recorded 35 Kittlitz's murrelets, 1141 marbled murrelets, and nine unidentified *Brachyramphus* murrelets on transect during surveys conducted in the Wilderness Bays stratum. Kittlitz's murrelet density was estimated to be 2.06 birds/km^2

(*N*=562), but with low precision (%CV=38.05; Table 5). Consistent with all protected strata, density was greater in pelagic waters compared to the shoreline (Table 7). The majority (97%) of Kittlitz's murrelets were observed in Holkham Bay and Endicott Arm with several groups congregating near the mouth of Endicott Arm (Fig. 16). Only one bird was recorded in Tracy Arm (Fig. 17). Density of marbled murrelets in this stratum (33.60 birds/km^2) was high compared to other strata, resulting in the largest population estimate for this species across all strata (*N*=9,456; Table 6). Marbled murrelets were more abundant in pelagic waters compared to shoreline waters (Table 8), but birds were evenly distributed throughout the stratum (Fig. 18).

Thomas Bay — Only 556 marbled murrelets were observed in this stratum – no Kittlitz's or unidentified *Brachyramphus* murrelets. The second highest marbled murrelet density (39.52 birds/km^2; *N*=2,737) estimated during our study (only the Mouth of Lituya Bay stratum had a greater density estimate) was recorded in Thomas Bay. Density in pelagic waters was more than two times that along the shoreline (Table 8). Birds were well-distributed throughout the bay except close to the glacial moraine, which extends to the water at the head of the bay (Fig. 18).

LeConte Bay — The LeConte Bay stratum was the smallest included in our survey, and only 12 marbled murrelets on transect were observed in the bay, resulting in the lowest density as well. No Kittlitz's or unidentified *Brachyramphus* murrelets were observed in LeConte Bay. Overall, marbled murrelet density was 0.83 birds/km^2 (*N*=16), and all birds on transect were counted during shoreline surveys. Several groups of marbled murrelets were documented near the entrance to the bay, but were not included on the systematic survey. Of the birds that were recorded on transect during the survey, all were located on the south shore (Fig. 18).

DISCUSSION AND CONCLUSIONS

Kittlitz's murrelets are generally associated with glacial fjords, tidewater glaciers, and recently deglaciated areas (Isleib and Kessel 1973, Day et al. 1999). In southeast Alaska, this species was thought to be restricted to Glacier Bay and glaciated fjords on the mainland (Day et al. 1999). Day et al. (1999) reported that this species occurred in a clumped, rather than a random or even, distribution, and our data were consistent with this finding. With these surveys, we confirmed this species occurs in some of the glaciated fjords on the mainland and we demonstrated that not only are Kittlitz's murrelets present in very exposed areas, but that densities in these areas may even exceed those found in more protected, inner fjords. In the exposed waters of our study, the Alaska Current, the major coastal circulation feature of the GOA that is largely driven by freshwater input, promotes localized nearshore upwelling that either enhances productivity or aggregates prey for *Brachyramphus* murrelets (Reed and Schumacher 1987). In contrast, in protected waters of our study, tidal processes drive nutrient transport and prey aggregations with submerged marine sills acting as key features responsible for small-scale variation in productivity (Hunt 1995). Although tidal-driven processes are more predictable, we recorded large numbers of *Brachyramphus* murrelets in exposed waters presumably taking advantage of increased productivity at localized sites of upwelling. We conclude that this species uses a greater variety of marine habitats than previously acknowledged.

Kuletz et al. (2003b) correlated Kittlitz's murrelet abundance and the status of tidewater and nearshore glaciers in Prince William Sound. In our study areas, the relationship between abundance of Kittlitz's murrelets and the status of tidewater glaciers also followed a pattern. Generally, Kittlitz's murrelet abundance was positively correlated with stable, but not advancing

or retreating tidewater glaciers (Table 1), and with adjacent uplands dominated by ice (Table 11). The highest density of Kittlitz's murrelets was observed in Icy Bay where three of the tidewater glaciers are in a stable-retracted position (poised for advance) and one recently underwent rapid retreat but is now considered stable. Similarly many Kittlitz's murrelets were recorded near LaPerouse, Malaspina, and Dawes (head of Endicott Arm) Glaciers, and all of these are considered stable or thinning in place. Very few Kittlitz's murrelets were observed in Lituya Bay where all of the tidewater glaciers are advancing, but many were recorded near the marine sill that traverses the mouth of the bay. We recorded relatively few Kittlitz's north of Dry Bay (Exposed North stratum) and in Cross Sound where shrubs and forest not rock and ice dominate the adjacent uplands (Table 11). Although climate is a primary factor influencing the advance-retreat cycle, only stable tidewater glaciers are sensitive to changes in climate; once a tidewater glacier begins to advance or rapidly retreat this sensitivity diminishs (Pelto 1987). Generally, given the size of most tidewater glaciers, the advance-retreat cycle (advancing, stable-extended, rapidly retreating, stable-retracted) lasts several hundred years (Post 1975). Although mechanistic understanding is limited, the continued presence of stable tidewater glaciers may influence the likelihood of persistence of Kittlitz's murrelet populations in southeast Alaska. However, breeding status, age, availability of prey, proximity to nesting habitat, and absence of predators are most likely better explanatory variables of distribution and abundance of Kittlitz's murrelets.

Correct identification of *Brachyramphus* murrelets is critical to reliable long-term population monitoring of these species. Given the morphological similarities of Kittlitz's and marbled murrelets, it's likely that some misidentifications occurred during our study. However, we believe this was minimal and was not biased. Most observers over the three-year period had

experience conducting surveys for Kittlitz's murrelets elsewhere in Alaska and many conducted surveys for multiple years of this study. Additionally, all observers were trained prior to surveys and were either professional or recreational bird watchers of high caliber. We believe the population size and trend estimates presented in this report are accurate and reliable.

Icy Bay Study Area

Icy Bay proved to be an important area for Kittlitz's murrelets with an estimated density rivaling or surpassing those in core areas (i.e. Glacier Bay and Prince William Sound; Fig. 19). The only area with similar densities consistently is Harriman Fjord, Prince William Sound, where this species has declined since 1989 (Kuletz et al. 2003b). Furthermore, Icy Bay was the only surveyed region where Kittlitz's outnumbered marbled murrelets, which historically occurred in many areas of southcoastal Alaska (Isleib and Kessel 1973). Although this area proposes logistical difficulties, the high density and population size of Kittlitz's murrelets in Icy Bay suggests that this area could serve as a long-term monitoring site for this species in addition to other population centers such as Prince William Sound and Glacier Bay.

The dynamic ice floes in Icy Bay presented problems during both surveys and data analysis. Heavy ice cover prevented surveys in the upper part of the bay and Tsaa Fjord, and pelagic surveys in Taan Fjord. Without accurate estimates of ice cover, it was difficult to extrapolate survey data to a population estimate because we lacked an accurate estimate of total area of open water. If ice cover was extensive, we may have incorrectly estimated density of murrelets in the bay because birds may have crowded into the limited areas of open water (overestimating density) or moved outside of the area surveyed (underestimating density). We recommend using population size, as opposed to density, as the metric for long-term monitoring

of Kittlitz's murrelets because ice conditions may lead to misinterpretation of trend estimates. Future work should consider potential effects of ice cover on individual and population movements and develop methods for surveying in areas of moderate to heavy ice.

Relative to other core Kittlitz's population areas, Icy Bay receives little boat and human disturbance. During our surveys in 2002, five kayakers, one sailboat, one fishing vessel, and one floatplane were observed over a two-day period in July. While land in northern Icy Bay is within Wrangell-St. Elias National Park, Chugach Native Corporation and the State of Alaska own most of the southern part of the bay. Logging activities have occurred on these lands and a log rafting site permit in Moraine Bay (within Icy Bay) is still active. There are also eight parcels of privately-owned land in or adjacent to Icy Bay, and two fishing/hunting lodges operate from these parcels during the summer months. Seven of the eight private parcels are native allotments, most located in Moraine Bay. One small parcel (5 acres) of private land is located high in the Chaix Hills at the head of Icy Bay and the Bureau of Land Management also administers several small parcels on or near the glaciers. Although resource extraction activities do not currently occur in Icy Bay, the GOA shelf waters adjacent to Icy Bay have oil and gas resources that may be developed in the future if transportation and infrastructure improves (Minerals Management Service 1990).

Our survey along the Malaspina Forelands suggests that Kittlitz's murrelet populations are severely declining in this area. Trend information from Glacier Bay, Prince William Sound, and the Kenai Peninsula indicates that Kittlitz's populations have declined about 70-80% over the last 10-20 years (Robards et al. 2003, Van Pelt and Piatt 2003, U. S. Fish and Wildlife Service 2007). Over the 10-year period between surveys along the Malaspina Forelands, our data indicate only a slightly higher population decline of 90% for Kittlitz's murrelets, but this

trend does not consider *Brachyramphus* murrelets not identified to the species level. Because only 32 unidentified murrelets were recorded during the 2002 surveys, we do not expect these observations to have a significant effect on the overall trend estimate. Trends estimated from two time periods are precarious at best, especially given the huge temporal and spatial variability in the distribution of this species; however, we believe the steep decline in the Kittlitz's murrelet population that we report here for this area to be legitimate.

Outer Coast Study Area

Densities of Kittlitz's murrelets estimated in the Outer Coast study area are comparable to those estimated in other areas of Alaska (Fig. 19), but population estimates are lower (Kendall and Agler 1998) because extrapolation of the data was difficult. Although we observed many Kittlitz's within 10 fathoms of depth near the mouth of Lituya Bay, we were unable to survey the entire coastline at depths less than 10 fathoms because of logistical constraints (e.g., lack of a safe anchorage, safe navigation of boat). Therefore, we consider our population estimates to be a minimum for the Outer Coast study area. Nonetheless, we successfully identified Kittlitz's "hotspots" near the mouth of Lituya Bay, Cape Fairweather, and Icy Point.

The majority of birds observed in the Outer Coast study area were close to shore in shallower waters, but very few birds were present in protected bays. For example, the mouth of Lituya Bay had a high density of birds, but only five Kittlitz's were observed inside Lituya Bay. This may be because the Lituya Bay basin is quite deep (75 fathoms), whereas a shallow sill at 7 fathoms depth occurs at the mouth of the bay. Low densities and numbers of birds were recorded in waters greater than 10 fathoms in depth, and waters within 200 m of shore (Tables 9 and 10). The distribution of Kittlitz's murrelets decreased dramatically just beyond the 10-

fathom line. Our results illustrate that future surveys along the outer coast should focus survey efforts within waters less than or equal to 10 fathoms in depth (if possible), and waters greater than 200 m from the shore. We recorded high densities of Kittlitz's murrelets near Icy Point, but few birds were observed north of Dry Bay where the glacial ice is further from the shoreline (Icy Point: min. distance to ice=0 km, max. distance=12.3 km; Dry Bay: min. distance=12.4 km, max. distance=33.6 km; Table 11). The combination of shallow, but turbid or exposed, water and glacial-affected water seems to be important for this species (Day et al. 2000, 2003), but again mechanistic understanding of this relationship is unclear. In Prince William Sound, changes in the abundance and distribution of Kittlitz's murrelets indicate that this species prefers waters associated with stable or advancing glaciers, as opposed to receding glaciers (Kuletz et al. 2003b). However, this and other studies of Kittlitz's murrelets were conducted in protected, deepwater fjords, and little is known about the association between glacial runoff and Kittlitz's murrelets along more exposed, but relatively shallow coastlines. Regardless, freshwater input alone does not seem to relate positively to Kittlitz's murrelet abundance (Table 11). To increase our understanding of at-sea habitat requirements for this species, future research should investigate the biological link between Kittlitz's distributions and glacial outflow in the unique habitat of the exposed outer coast.

Mainland Fjords Study Area

LeConte Bay has long been recognized as the southern extent of the distribution of Kittlitz's murrelets (Day et al. 1999). Although Van Vliet (1993) suggested that Kittlitz's murrelets were apparently extinct from LeConte Bay, Agler et al. (1998) recorded one Kittlitz's, 37 marbled, and 95 *Brachyramphus* murrelets in LeConte Bay in summer 1994. In addition to

systematic surveys in LeConte Bay, we also navigated the entire bay inspecting each bird; however, Kittlitz's murrelets were not observed during our study in LeConte or Thomas Bay. Based on our surveys, the southernmost population of Kittlitz's murrelets occurred in Endicott Arm.

Density of Kittlitz's murrelets was higher along pelagic transects compared to shoreline transects in the Wilderness Bays stratum; however, 42% of the birds (including one bird holding a fish) were located near the shallow (<30 m) marine sill at the mouth of Endicott Arm. The Wilderness Bays stratum is characterized by steep, rugged fjords and steeply-sloped shoreline. Because this species prefers to forage in shallow water (Day and Nigro 2000), the marine sill at the mouth of Endicott Arm probably provides the best foraging habitat within the stratum. Similarly, in Prince William Sound, Kuletz et al. (2003a) concluded that marine sills were often used by Kittlitz's murrelets and were an important oceanographic feature. Only one bird was observed in Tracy Arm, perhaps a result of frequent boat traffic in this area, which can negatively impact murrelet behavior by forcing flight, an energetically costly behavior (Agness 2006); however, our study did not evaluate boat disturbance issues and this is only speculation. Agler et al. (1998) recorded 56 marbled murrelets and 24 *Brachyramphus* murrelets in the Wilderness Bays stratum. Of these, only six marbled murrelets and three *Brachyramphus* murrelets were observed in Tracy Arm. Again, whether this is a function of boat disturbance would be pure speculation, but certainly nearby Holkham Bay and Endicott Arm support more *Brachyramphus* murrelets than Tracy Arm.

RECOMMENDATIONS

In protected strata, relatively few Kittlitz's murrelets were observed along the shoreline relative to survey effort. In Prince William Sound, Day and Nigro (2000) concluded that Kittlitz's murrelets preferred nearshore (<200 m) habitat, but the proportion of offshore transects to nearshore transects in their study was low. In surveys where pelagic areas were covered more extensively, Kittlitz's murrelets were more abundant in waters >200 m from shore; this distribution pattern was found in Prince William Sound (Kuletz et al. 2003a), Kenai Fjords (Van Pelt and Piatt 2003), Alaska Peninsula (Van Pelt and Piatt 2005), and Kachemak Bay (Kuletz, unpubl. data). Similarly, in our study areas, only 8% of Kittlitz's observations were made while surveying shoreline transects, yet 71% of survey effort was spent on these transects. Future surveys should concentrate survey efforts in pelagic waters, increasing either spatial or temporal coverage, or both if possible. In addition, distance to shoreline is not biologically meaningful and should not be used for stratification in the future. Instead, we recommend stratifying by bathymetry, water clarity, distance to glacier, shoreline substrate, or other environmental variables of biological significance to Kittlitz's murrelets (see Day et al. 2000 for examples). While we recognize the importance of repeating surveys for trend estimates, spending valuable resources surveying poorly stratified transects will not advance our knowledge about the species biology. Spatial modeling exercises would likely offer insight into important physical and oceanographic characteristics which could improve future survey designs.

In exposed strata, the open coastline presented several challenges when sampling for murrelets. Without prior knowledge of Kittlitz's distribution and abundance outside of glaciated fjords and protected bays, we did not know the best stratification to use for minimizing variance and investigating biological hypotheses. This resulted in an evolution of survey designs in

exposed strata, particularly in the Exposed North and Exposed South strata where a lack of adequate mooring sites (only one) between Icy Point and Yakutat made this stretch of coastline difficult to survey. Sea conditions in exposed areas can limit the ability to approach the shoreline or to survey from a smaller, more maneuverable platform. One of the greatest challenges we faced in exposed areas was extrapolation of the data. Therefore, density and population estimates for exposed strata (i.e., Malaspina Forelands, Exposed North, Mouth of Lituya Bay, Exposed South, and Icy Point) presented in this report were minimum estimates.

For future surveys of *Brachyramphus* murrelets in exposed areas, we recommend using a zigzag design similar to the one used during 2004 surveys along the outer coast. However, we suggest spacing endpoints 10 km from one another along the 10-fathom line and truncating transects to a specified length (e.g., 2 km). This approach will reduce effort in areas where few murrelets were observed and will minimize double-counting murrelets near transect endpoints (i.e., the angle between transects will be greater). Additional sampling within 10 fathoms should be accomplished opportunistically (e.g., working from Lituya Bay). Exposed areas with sound study designs should be included in long-term monitoring plans for *Brachyramphus* murrelets, but should not represent core monitoring sites because more assumptions related to the survey design must be made. It would be helpful to understand the movements of murrelets observed in such exposed areas to determine whether there is a more suitable area or time to monitor these birds. Because spatial variation of *Brachyramphus* murrelets can strongly influence the power to detect population trends, we recommend developing spatial models to identify the density gradient and potential sources of variation (Kissling et al. 2007). This is especially true in exposed areas where extrapolation of data is difficult and therefore accurate estimates of population size are nearly impossible.

Although many questions regarding the natural history of Kittlitz's murrelets remain unanswered, the importance of accurate and precise population estimates and trends should not be underestimated. At-sea surveys are the most cost-efficient and logical method for estimating abundance and trends. We emphasize the importance of these long-term data to evaluating the status of the species. To date, all but one area (i.e., Lost Coast, extending from Icy Cape to Kayak Island) of suitable habitat in southeast Alaska has been systematically surveyed for Kittlitz's murrelets. Undoubtedly, greater understanding of the natural history of this species will allow for stronger inferences to be made from data collected during at-sea surveys. Monitoring population size and trend of a declining species in the absence of research to identify factors influencing the population is limiting. While this report has focused on estimating trend, distribution, and population size of Kittlitz's murrelets, we strongly encourage the study of the natural history of this species and identification of factors that may be contributing to the apparent decline.

In conclusion, we recommend the following guidelines for monitoring Kittlitz's murrelets in southeast Alaska:

- Conduct surveys every 1-2 years in areas with populations greater than 1,000 birds or with peak densities greater than 5 birds/km^2 (i.e., Icy Bay, Glacier Bay)
- Conduct surveys every 5 years in areas with populations less than 1,000 birds or with peak densities less than 5 birds/km^2 (i.e., Malaspina Forelands, Yakutat Bay, Outer Coast and associated bays, Wilderness Bays)
- Revisit areas known to support Kittlitz's murrelets previously (e.g., LeConte Bay) every 5 years

- Survey the Lost Coast extending from Icy Cape to Kayak Island, which has not been surveyed but contains similar habitat to the Icy Bay stratum and likely supports relatively large numbers of Kittlitz's murrelets.

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Table 1. Characteristics of major individual glaciers for each study area surveyed for *Brachyramphus* murrelets in southeast Alaska, 2002-2004. See Post (1975) for complete description and definitions of tidewater glacier cycle.

Study Area	Glacier	Glacier type	Glacier phase	Glacier volume change	Reference
Icy Bay	Tyndall	Tidewater	stable	-	Koppes and Hallet 2006
	Tsaa	Tidewater	stable retracted	-	Powell 1991, Porter 1989
	Guyot	Tidewater	stable retracted	-	Powell 1991, Porter 1989
	Yahtse	Tidewater	stable retracted	-	Powell 1991, Porter 1989
	Malaspina	Piedmont (land-terminating)	-	thinning	Arendt et al. 2000
Outer Coast	Grand Plateau	Lake calving	retreating	thinning	Larsen et al. 2007
	Fairweather	Lake calving	retreating	thinning	Larsen et al. 2007
	Lituya	Tidewater	advancing	thickening	Larsen et al. 2007
	Cascade	Land-terminating	advancing	thickening	Larsen et al. 2007
	North Crillon	Tidewater	advancing	thickening	Larsen et al. 2007
	LaPerouse	Land-terminating	stable	thinning	Larsen et al. 2007
	Brady	Tidewater	stable extended	thinning	Larsen et al. 2007
Mainland Fjords	Sawyer	Tidewater	retreating	thinning	Larsen et al. 2007
	South Sawyer	Tidewater	retreating	thinning	Larsen et al. 2007
	North Dawes	Lake calving	stable	thinning	Larsen et al. 2007
	Dawes	Tidewater	stable retracted	thinning	Larsen et al. 2007
	Baird	Land-terminating	stable extended	thinning	Larsen et al. 2007
	LeConte	Tidewater	stable retracted	thinning	Motyka et al. 2003, Larsen et al. 2007

Table 2. Survey effort in protected strata for estimating *Brachyramphus* murrelet density and population estimates, southeast Alaska, 2002-2004. Strata are organized north to south.

Study area	Stratum	Pelagic					Shoreline[a]	
		# of transects	km surveyed (linear)	km^2 surveyed (area)	km^2 available (area)	prop. sampled (%)	km surveyed (linear)	km^2 surveyed (area)
Icy Bay	Icy Bay[b]	9	53.67	10.88	95.18	11.4	84.95	16.84
Outer Coast	Lituya Bay	7	15.15	3.27	20.42	16.0	35.82	7.12
	Outer Coast Bays	11	15.51	3.8	32.33	11.8	101.56	19.79
	Cross Sound[c]	15	157.49	46.21	522.47	8.8	272.96	54.16
Mainland Fjords	Wilderness Bays[d]	22	57.61	12.12	237.03	5.1	219.50	43.48
	Thomas Bay	8	21.16	4.43	58.71	7.5	54.08	10.76
	LeConte Bay	4	5.99	1.30	14.38	9.0	22.00	4.40

[a]In protected stratum, the shoreline was surveyed completely (i.e., 100% sampled).
[b]Available area for pelagic transects in Icy Bay stratum does not include Taan or Tsaa Fjords because heavy ice cover precluded pelagic surveys in these areas. Surveyed area for shoreline transects includes Taan Fjord, but not Tsaa Fjord.
[c]Cross Sound stratum includes Taylor and Dundas Bays.
[d]Wilderness Bays stratum includes Holkham Bay and Tracy and Endicott Arms.

Table 3. Survey effort in exposed strata for estimating *Brachyramphus* murrelet density and population estimates, southeast Alaska, 2002-2004. Strata are organized north to south.

Study area	Stratum	Less than 10 fathoms				10 fathoms[a]		Greater than 10 fathoms			
		# of transects	km^2 surveyed (area)	km^2 available (area)	prop. sampled (%)	# of transects	km^2 surveyed (area)	# of transects	km^2 surveyed (area)	km^2 available (area)	prop. sampled (%)
Icy Bay	Malaspina Forelands[b]					1	25.21	8	10.10	168.86	6.0
Outer Coast	Exposed North[c]					1	23.62	17	36.56	331.64	11.0
	Mouth of Lituya Bay	10	3.77	32.35	11.7						
	Exposed South[d]					1	36.89	44	91.80	485.79	18.9
	Icy Point					1	8.59	13	5.65	45.03	12.5

[a]The 10-fathom line was surveyed completely (i.e., 100% sampled).
[b]Malaspina Forelands stratum includes Manby Point surveys and, as presented here, is not comparable to 1992 survey data.
[c]The Exposed North stratum extends from Ocean Cape to Dry Bay.
[d]The Exposed South stratum extends from Dry Bay to LaPerouse Glacier.

Table 4. Numbers of Kittlitz's (KIMU), marbled (MAMU), and unidentified *Brachyramphus* (BRMU) murrelets observed on shoreline and pelagic transects by year and stratum, southeast Alaska, 2002-2004. Strata are arranged from north to south.

Stratum	Type	2002			2003			2004		
		KIMU	MAMU	BRMU	KIMU	MAMU	BRMU	KIMU	MAMU	BRMU
Icy Bay	protected	322	42	31						
Malaspina Forelands[a]	exposed	95	807	64						
Exposed North[b]	exposed				19	1474	38	2	219	19
Mouth of Lituya Bay	exposed							16	149	8
Lituya Bay	protected				5	32	5			
Exposed South[b]	exposed				340	2438	196	97	1502	93
Icy Point[b]	exposed				105	554	98			
Outer Coast Bays	protected				0	57	7			
Cross Sound	protected				3	1424	47			
Wilderness Bays	protected	35	1141	9						
Thomas Bay	protected	0	556	0						
LeConte Bay	protected	0	12	0						
TOTAL		452	2558	104	472	5979	391	115	1870	120

[a]Malaspina Forelands stratum includes Manby Point surveys and, as presented here, is not comparable to 1992 survey data.
[b]All or some transects of this stratum were surveyed repeatedly in the same year.

Table 5. Kittlitz's murrelet density and population estimates by stratum, southeast Alaska, 2002-2004. Densities are expressed in birds per square kilometer. Strata are arranged from north to south.

Stratum	Type	Density (D)				Population (N)			
		Estimate	% CV	95% confidence interval		Estimate	% CV	95% confidence interval	
Icy Bay	protected	18.73	8.85	15.48	21.98	2098	17.76	1368	2828
Malaspina Forelands	exposed	4.67	17.05	3.11	6.23	906	34.14	300	1512
Exposed North	exposed	0.11	24.79	0.06	0.17	42	47.60	2.79	80.21
Mouth of Lituya Bay	exposed	4.62	24.24	2.42	6.82	149	24.28	78	220
Lituya Bay	protected	0.75	34.65	0.24	1.26	21	68.95	0	49
Exposed South	exposed	0.51	4.47	0.47	0.56	246	13.99	179	313
Icy Point	exposed	3.25	11.54	2.51	3.98	170	23.56	91	249
Outer Coast Bays	protected	0	0	0	0	0	0	0	0
Cross Sound	protected	0.04	58.29	0	0.08	22	107.06	0	69
Wilderness Bays	protected	2.06	38.05	0.52	3.60	582	76.30	0	1452
Thomas Bay	protected	0	0	0	0	0	0	0	0
LeConte Bay	protected	0	0	0	0	0	0	0	0

Table 6. Marbled murrelet density and population estimates by stratum, southeast Alaska, 2002-2004. Densities are expressed in birds per square kilometer. Strata are arranged from north to south.

Stratum	Type	Density (D)				Population (N)			
		Estimate	% CV	95% confidence interval		Estimate	% CV	95% confidence interval	
Icy Bay	protected	1.79	12.80	1.34	2.23	199	51.39	0	399
Malaspina Forelands	exposed	27.66	9.53	22.50	32.82	5367	38.10	1359	9375
Exposed North	exposed	7.74	5.33	6.93	8.54	2720	21.57	1570	3870
Mouth of Lituya Bay	exposed	42.97	22.48	24.04	61.90	1390	22.48	778	2002
Lituya Bay	protected	5.27	6.80	4.56	5.97	145	27.19	68	222
Exposed South	exposed	11.64	1.73	11.25	12.04	5902	15.95	4057	7747
Icy Point	exposed	18.95	2.24	18.12	19.78	1000	9.09	821	1178
Outer Coast Bays	protected	5.58	7.99	4.71	6.46	62	21.55	36	88
Cross Sound	protected	16.60	6.84	14.38	18.83	8794	27.30	4088	13500
Wilderness Bays	protected	33.60	4.52	30.62	36.58	9456	18.14	6094	12818
Thomas Bay	protected	39.52	10.62	31.30	47.75	2737	42.38	463	5011
LeConte Bay	protected	0.83	10.33	0.67	1.00	16	41.25	3.06	28.94

Table 7. Kittlitz's murrelet densities by transect type in protected strata, southeast Alaska, 2002-2004. Densities are expressed as birds per square kilometer. Strata are organized north to south.

Stratum	Pelagic				Shoreline			
	Density (D)	% CV	95% confidence interval		Density (D)	% CV	95% confidence interval	
Icy Bay	21.21	18.45	14.01	32.11	4.68	15.81	3.44	6.38
Lituya Bay	1.01	68.94	0.23	4.55	0	0	0	0
Outer Coast Bays	0	0	0	0	0	0	0	0
Cross Sound	0.04	125.00	0	0.14	0.03	100	0	0.09
Wilderness Bays	2.41	77.75	0.58	10.06	0.25	70.90	0.02	3.87
Thomas Bay	0	0	0	0	0	0	0	0
LeConte Bay	0	0	0	0	0	0	0	0

Table 8. Marbled murrelet densities by transect type in protected strata, southeast Alaska, 2002-2004. Densities are expressed as birds per square kilometer. Strata are organized north to south.

Stratum	Pelagic				Shoreline			
	Density (D)	% CV	95% confidence interval		Density (D)	% CV	95% confidence interval	
Icy Bay	1.74	61.71	0.47	6.41	2.04	28.32	1.18	3.51
Lituya Bay	6.04	31.62	2.85	12.79	3.06	29.08	1.75	5.37
Outer Coast Bays	8.06	35.61	2.43	13.69	1.54	24.51	0.96	2.48
Cross Sound	17.69	28.10	7.95	27.43	5.59	81.54	1.08	28.98
Wilderness Bays	37.39	19.32	25.21	55.45	13.69	17.31	7.43	25.23
Thomas Bay	43.33	45.59	15.61	120.28	17.95	13.02	13.92	23.15
LeConte Bay	0	0	0	0	3.63	41.22	1.67	7.89

Table 9. Kittlitz's murrelet densities by transect type in exposed strata, southeast Alaska, 2002-2004. Densities are expressed as birds per square kilometer. Strata are organized north to south.

Stratum	Less than 10 fathoms				10 fathoms				Greater than 10 fathoms			
	Density (D)	% CV	95% confidence interval		Density (D)	% CV	95% confidence interval		Density (D)	% CV	95% confidence interval	
Malaspina Forelands					2.47	17.66	1.75	3.49	5.00	36.63	2.17	11.52
Exposed North					0.58	27.01	0.27	0.88	0.08	69.31	0.02	0.31
Mouth of Lituya Bay	4.62	24.28	2.78	7.65								
Exposed South					4.09	7.16	3.52	4.67	0.20	34.41	0.10	0.39
Icy Point					7.38	13.97	5.36	9.39	2.46	35.32	1.19	5.10

Table 10. Marbled murrelet densities by transect type in exposed strata, southeast Alaska, 2002-2004. Densities are expressed as birds per square kilometer. Strata are organized north to south.

Stratum	Less than 10 fathoms				10 fathoms				Greater than 10 fathoms			
	Density (D)	% CV	95% confidence interval		Density (D)	% CV	95% confidence interval		Density (D)	% CV	95% confidence interval	
Malaspina Forelands					28.93	8.29	24.59	34.02	27.47	44.07	10.21	73.89
Exposed North					28.41	4.67	25.81	31.01	6.18	28.59	3.41	11.19
Mouth of Lituya Bay	42.97	22.48	26.35	70.10								
Exposed South					29.46	2.63	27.95	30.98	10.09	19.54	6.83	14.90
Icy Point					27.31	7.55	23.27	31.35	17.36	11.43	13.62	22.15

Table 11. Adjacent upland characteristics of each stratum surveyed for *Brachyramphus* murrelets in southeast Alaska, 2002-2004. Summary statistics were estimated by measuring 25 km inland from shoreline within ArcView (ESRI, v. 3.3). Seventy-five percent of nests described in Day et al. (1999) were located within 25 km from the coastline.

Study Area	Stratum	KIMU:MAMU ratio	% Glaciated land	Total land area (ha)	Non-glaciated land (ha)	Glaciated land (ha)	Total river length (km)
Icy Bay	Icy Bay	10:1	77%	272884	61582	211302	128
	Malaspina	1:6	60%	301528	120630	180898	309
Outer Coast	Exposed North	1:680	9%	210098	191523	18575	408
	Exposed South	1:24	46%	331421	179895	151526	239
	Cross Sound	1:400	10%	344175	309464	34711	200
	Mouth of Lituya Bay	1:9	57%	145224	62981	82242	17
	Lituya Bay	1:7	68%	144066	46819	97247	6
	Outer Coast Bays	na	41%	135930	80829	55100	28
	Icy Point	1:6	51%	146757	71964	74793	6
Mainland Fjords	Wilderness Bays	1:16	36%	473166	304322	168844	240
	Thomas Bay	na	28%	241221	173245	67976	158
	Leconte Bay	na	33%	198889	134111	64779	136

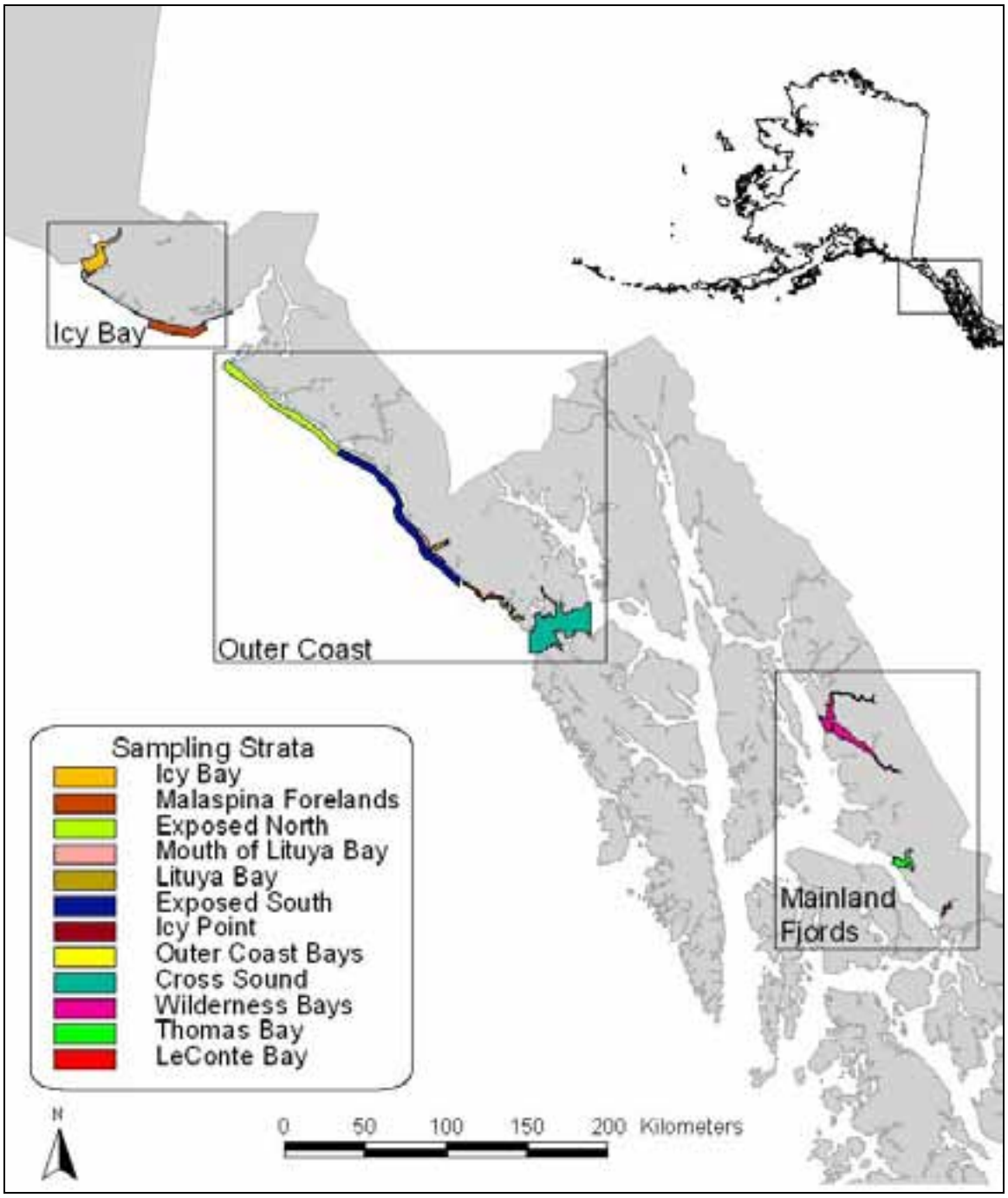

Fig. 1. Three study areas and 12 sampling strata delineated for estimation of *Brachyramphus* murrelet densities and populations in southeast Alaska, 2002-2004. Icy Bay and Mainland Fjords study areas were surveyed in July 2002, and the Outer Coast study area was surveyed in July 2003 and 2004.

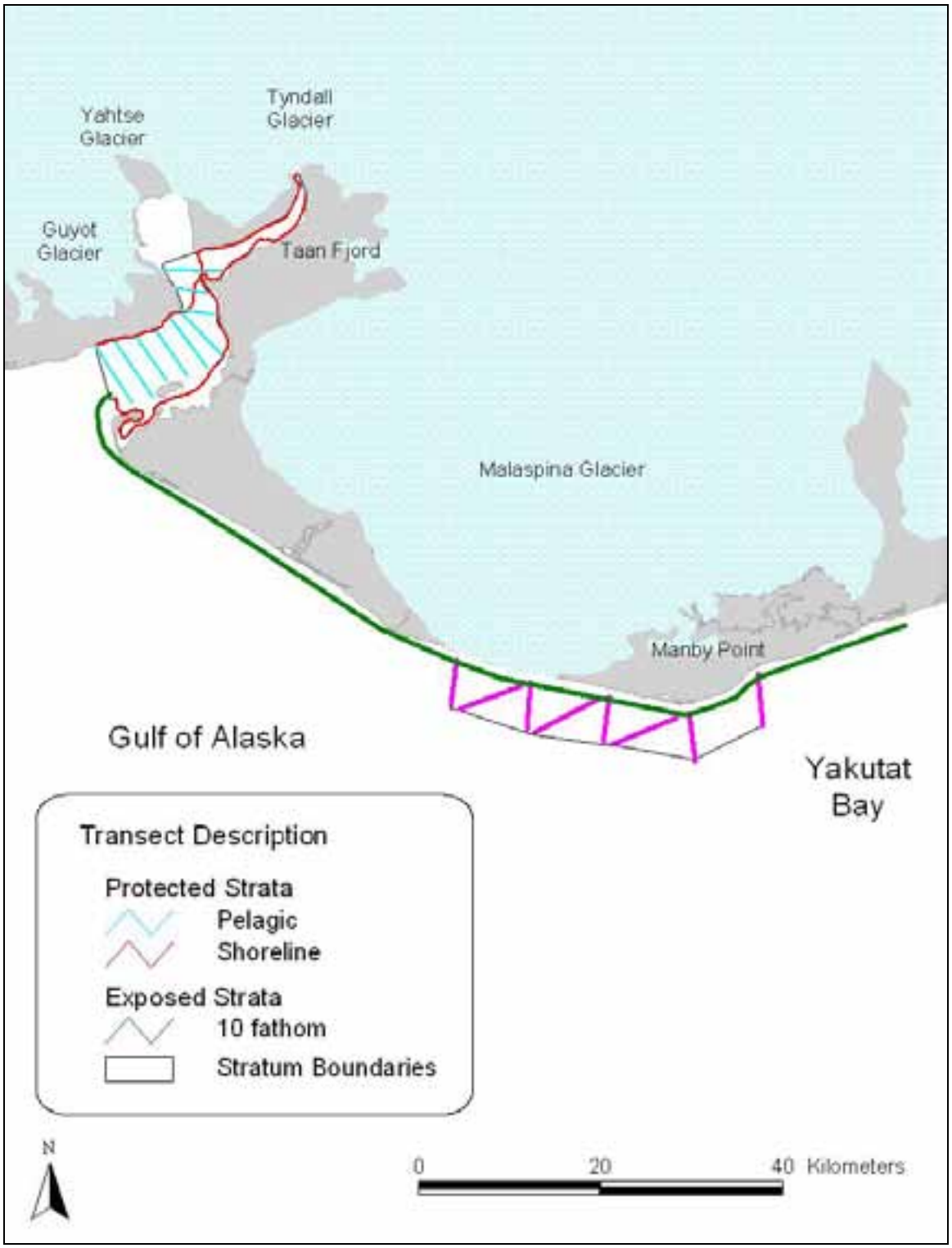

Fig. 2. Transect locations and descriptions, and stratum boundaries in the Icy Bay study area, 2002. The 10-fathom transect that parallels the Malaspina Forelands approximately 1 km offshore was repeated based on 1992 surveys (Kozie 1993).

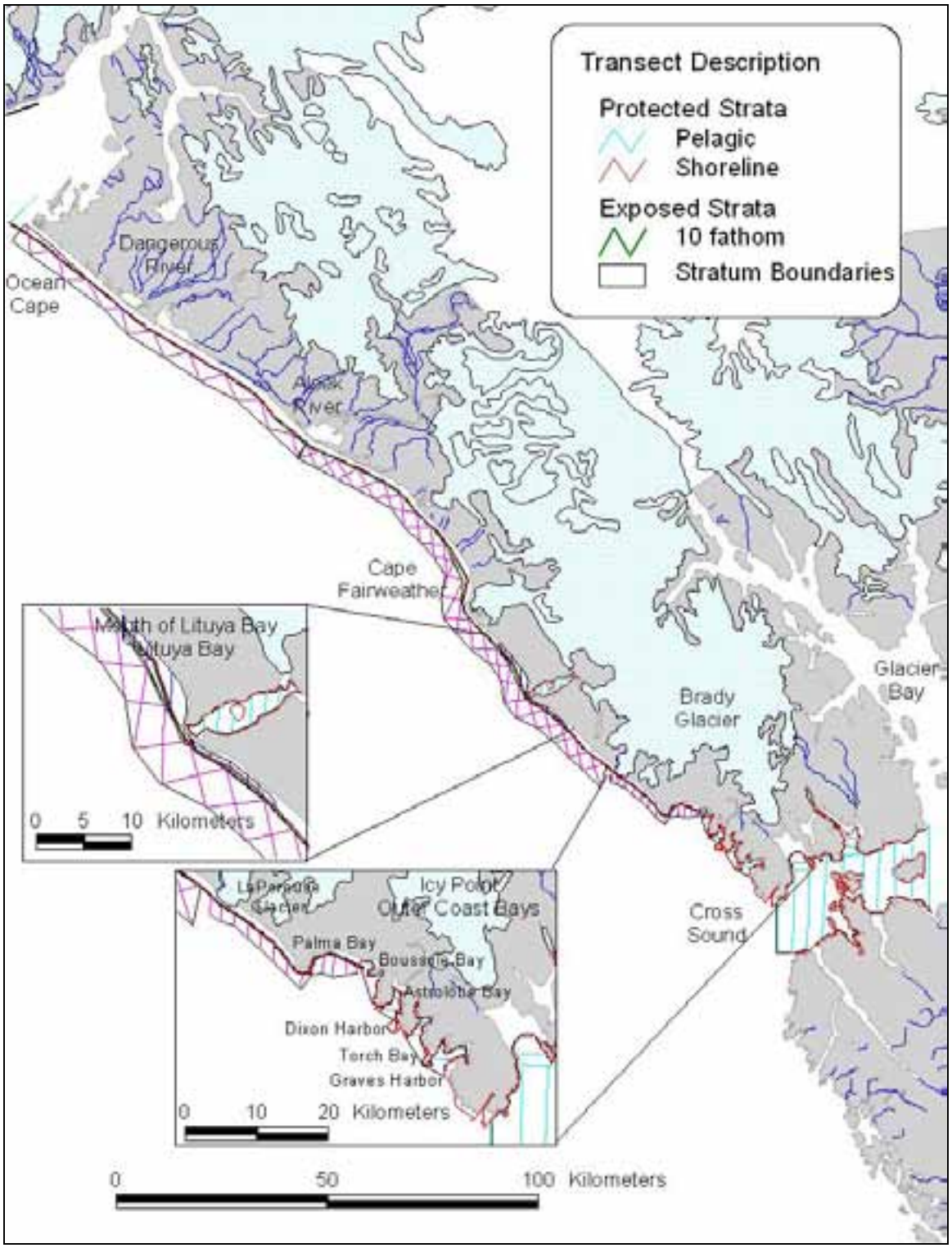

Fig. 3. Transect locations and descriptions, and stratum boundaries in the Outer Coast study area. Different transects were surveyed in 2003 and 2004. See 'Methods' for details.

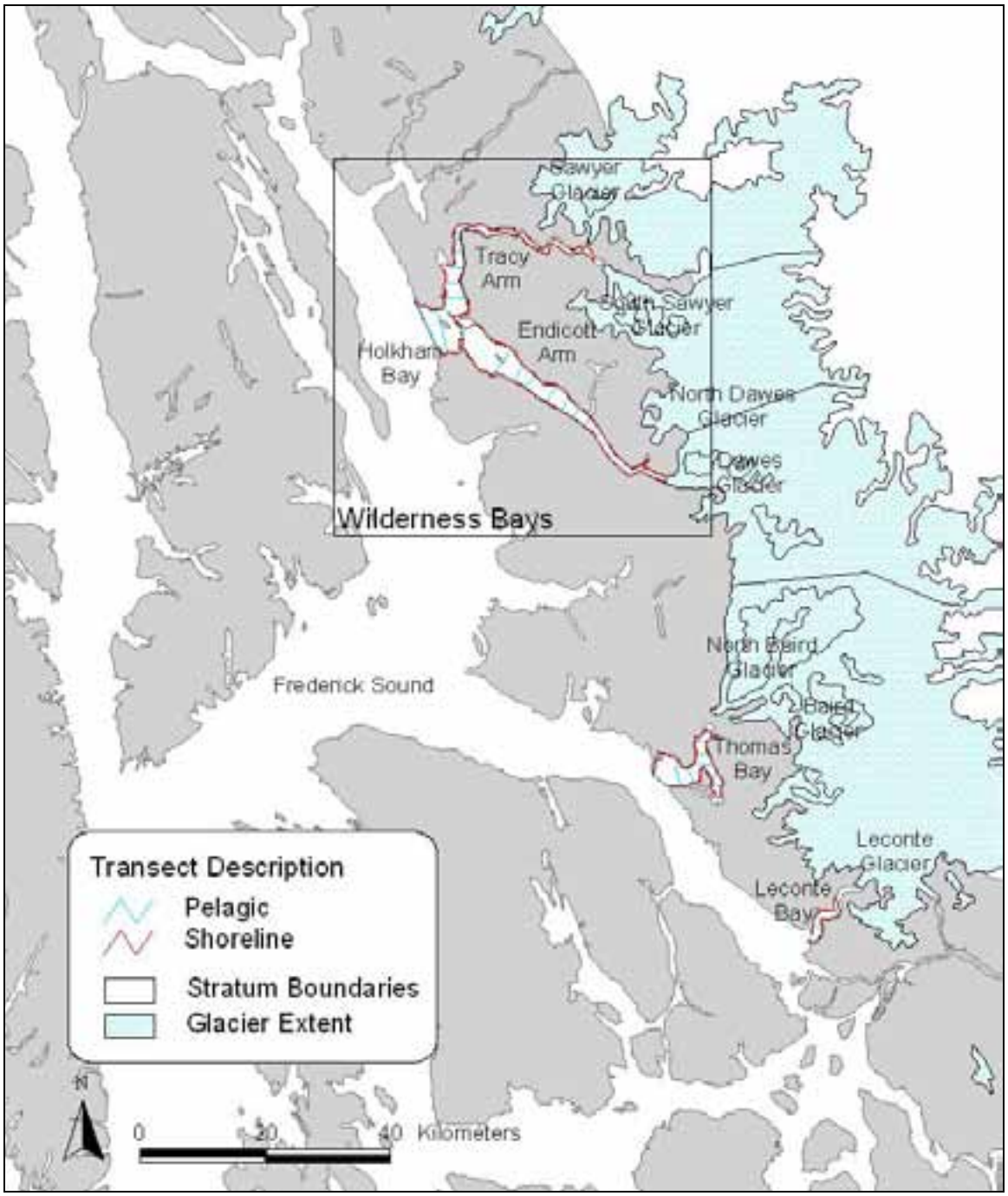

Fig. 4. Transect location and description, and stratum boundaries in Mainland Fjords study area, 2002. Wilderness Bays stratum comprised Tracy Arm, Holkham Bay, and Endicott Arm.

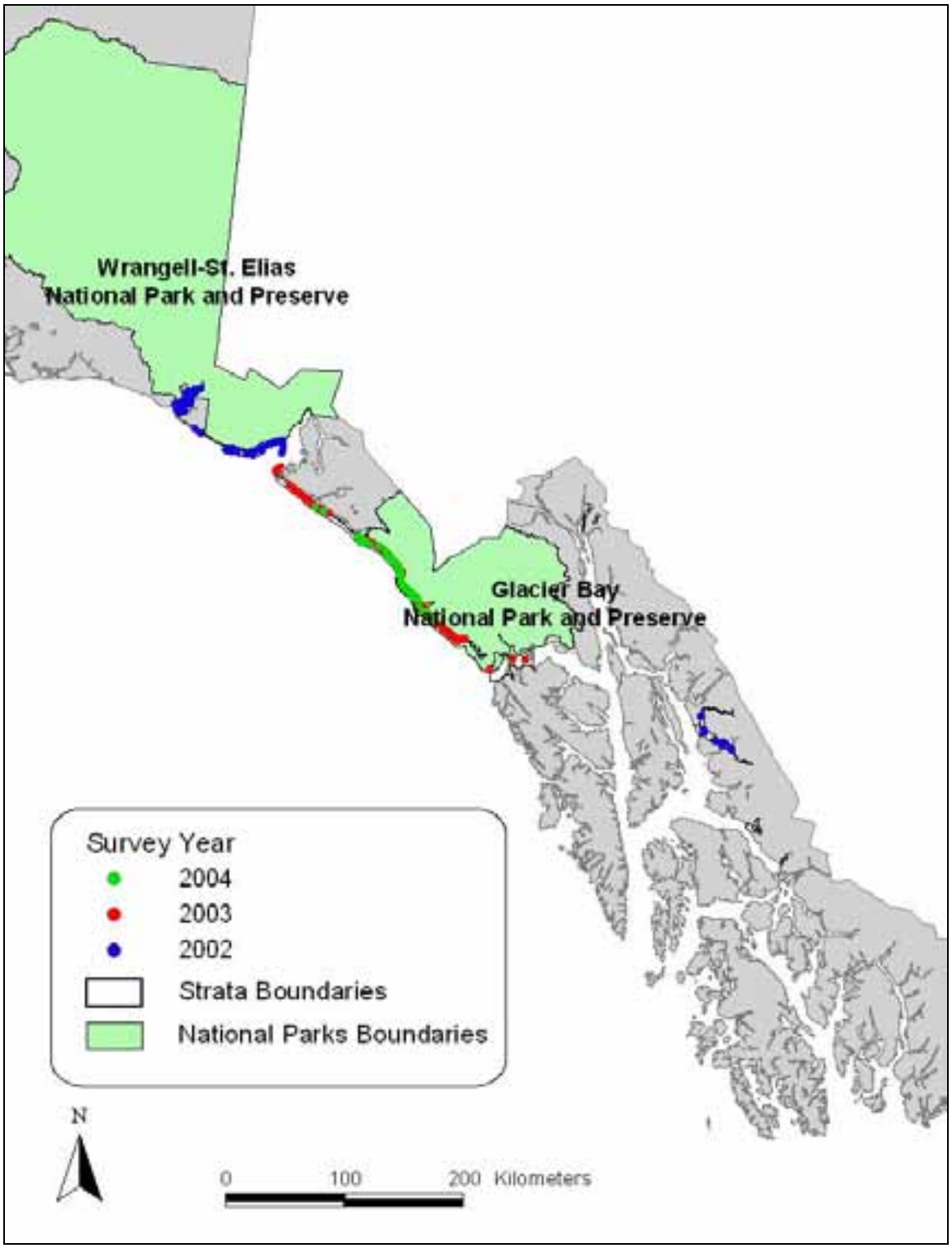

Fig. 5. Kittlitz's murrelet distribution by survey year, southeast Alaska, 2002-2004. On-transect and off-transect observations are included.

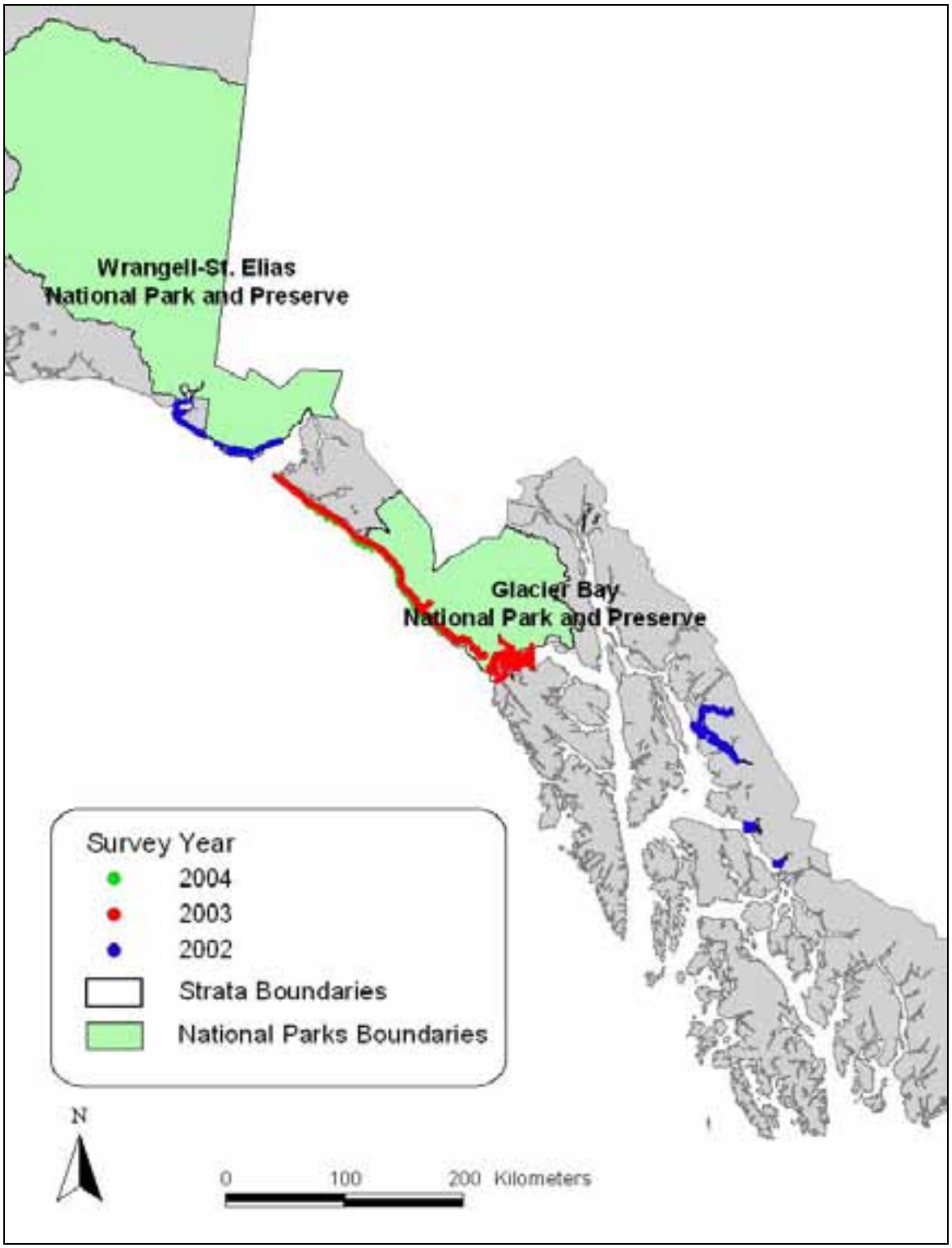

Fig. 6. Marbled murrelet distribution by survey year, southeast Alaska, 2002-2004. On-transect and off-transect observations are included.

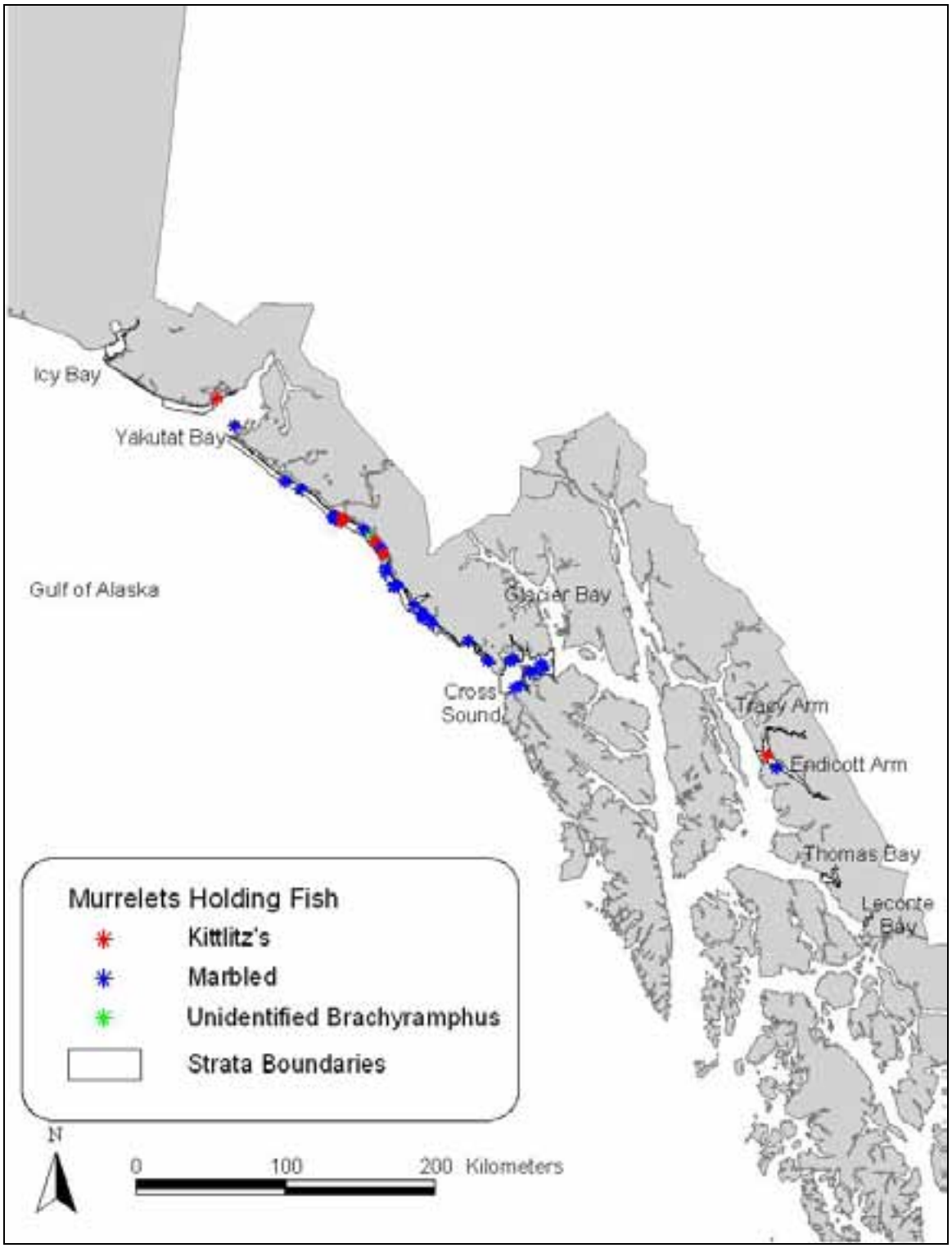

Fig. 7. Distribution of *Brachyramphus* murrelets observed on- and off- transect holding fish, southeast Alaska, 2002-2004.

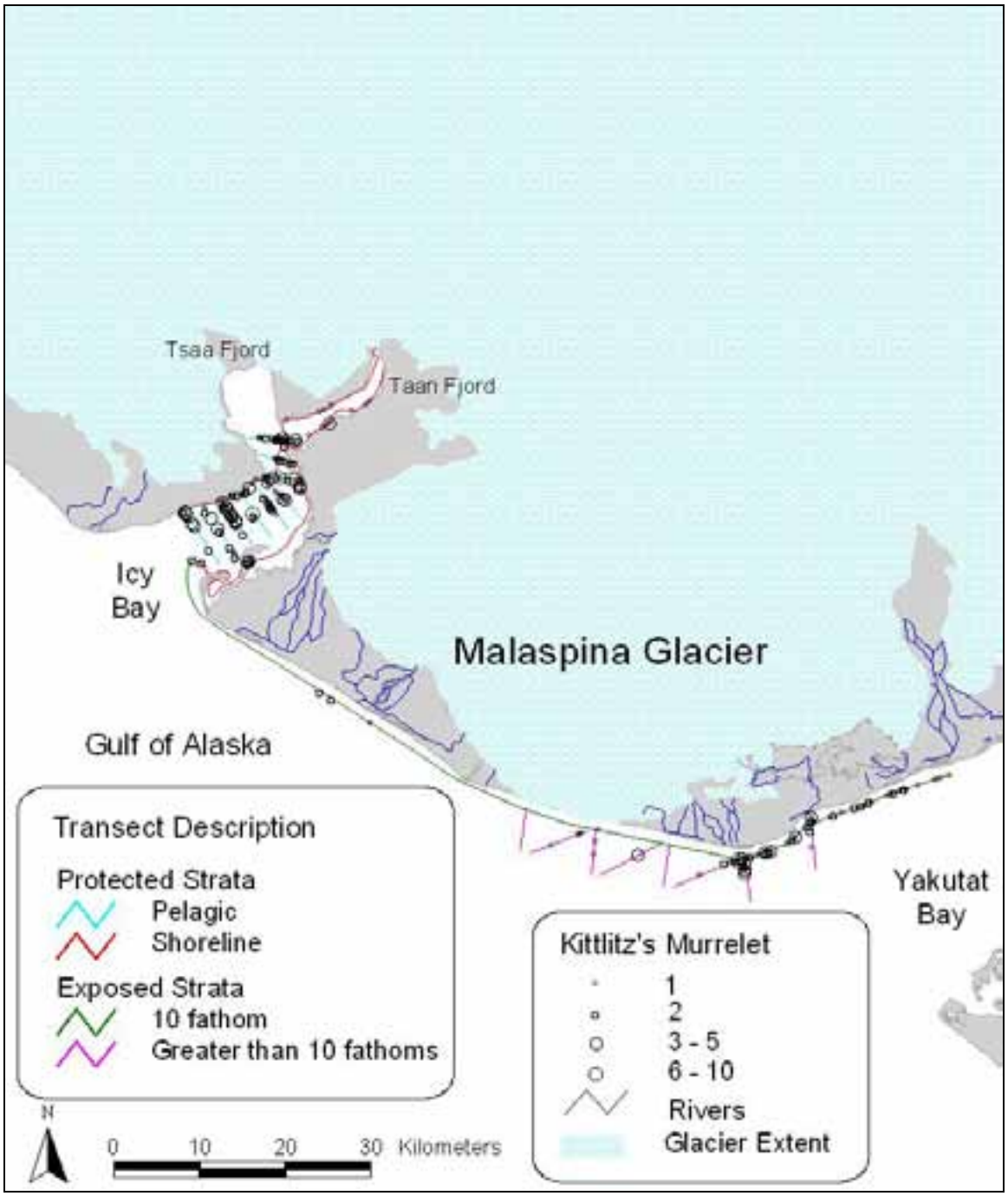

Fig. 8. Kittlitz's murrelet distribution and abundance on-transect in the Icy Bay study area, 7-14 July 2002.

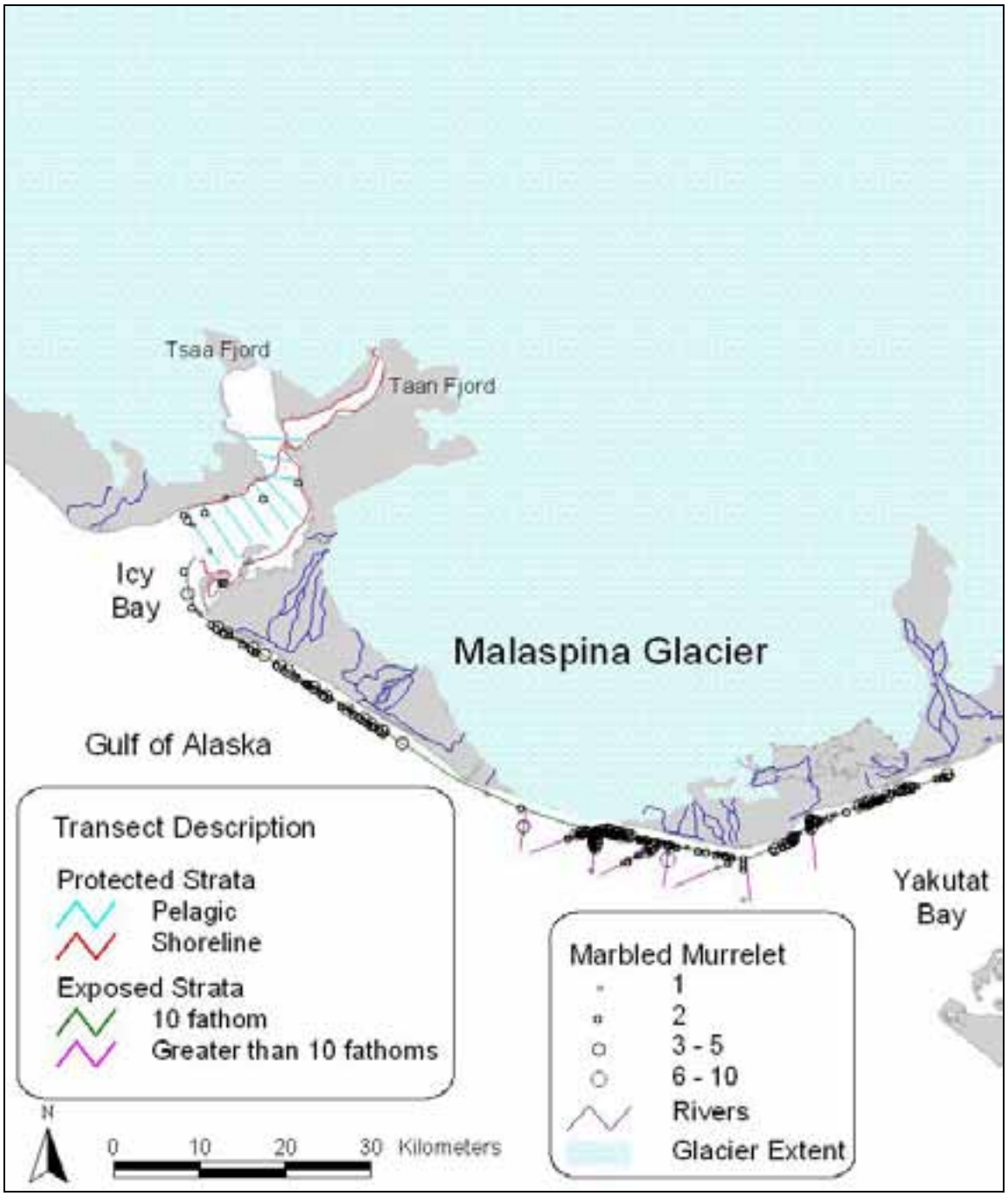

Fig. 9. Marbled murrelet distribution and abundance on-transect in the Icy Bay study area, 7-14 July 2002.

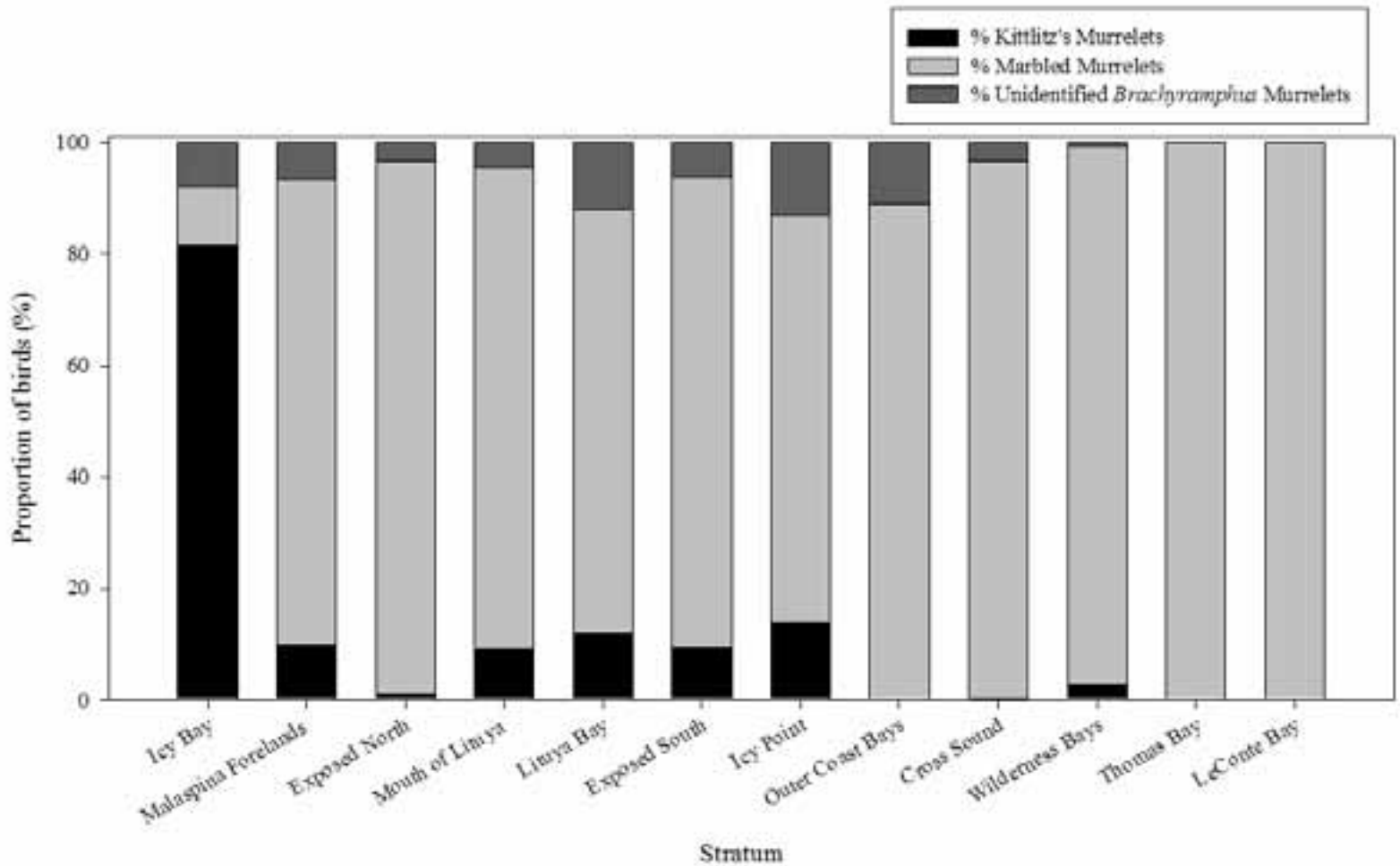

Fig. 10. Proportion of *Brachyramphus* murrelets by species observed on-transect in each stratum, southeast Alaska, 2002-2004. Total raw counts of birds were used to calculate proportions.

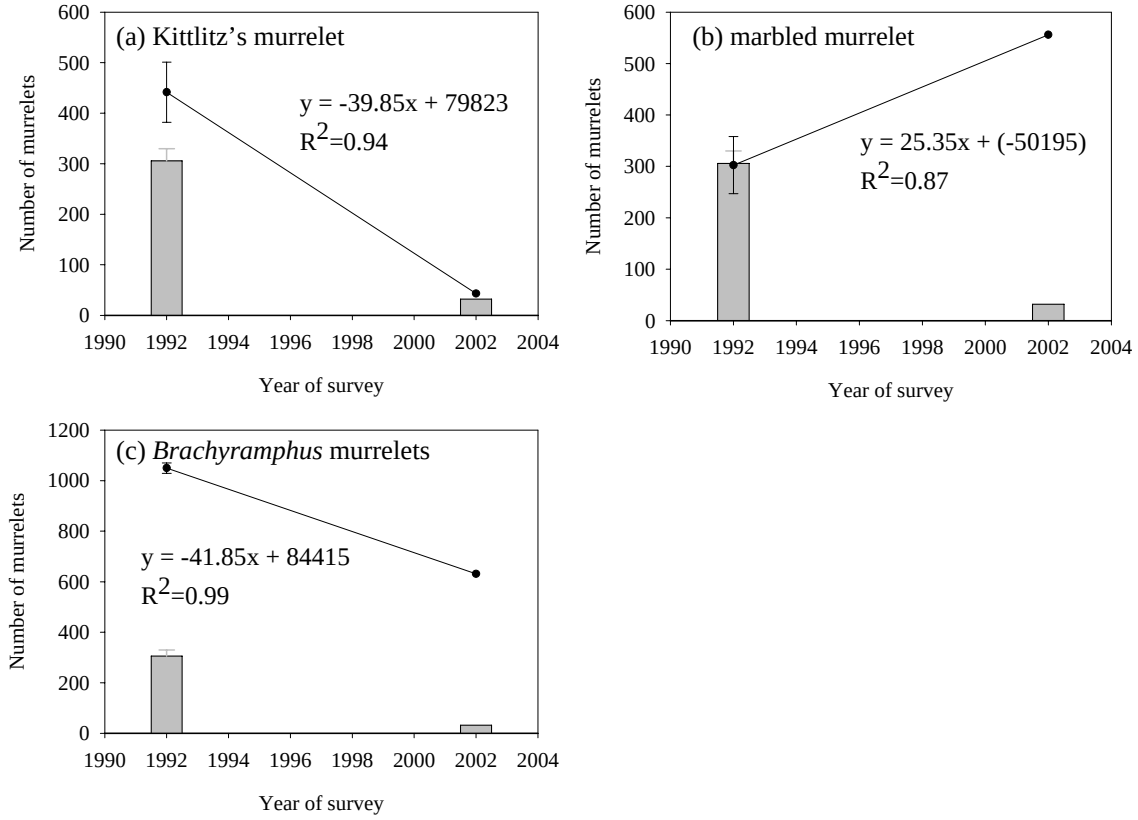

Fig. 11. Population trend of (a) Kittlitz's murrelets, (b) marbled murrelets, and (c) all *Brachyramphus* murrelets (including those not identified to species) along the Malaspina Forelands from 1992 to 2002. Trend estimated using least-squares linear regression. Gray bars described the number of unidentified *Brachyramphus* murrelets recorded on transect. Number of murrelets on the y-axis represents the raw number of birds observed on-transect. Error bars describe one standard error.

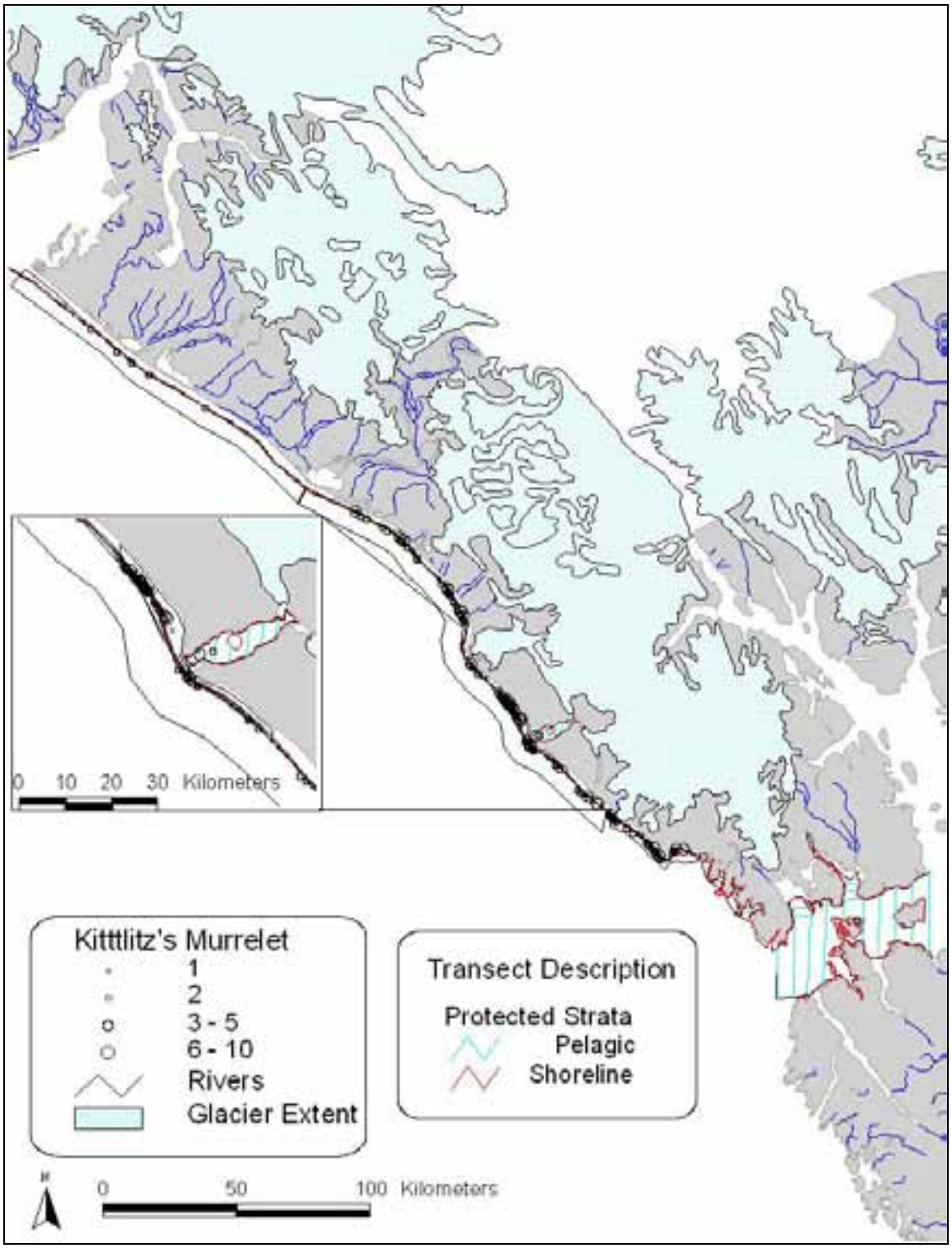

Fig. 12. Kittlitz's murrelet distribution and abundance on-transect in the Outer Coast study area, 3-11 July 2003.

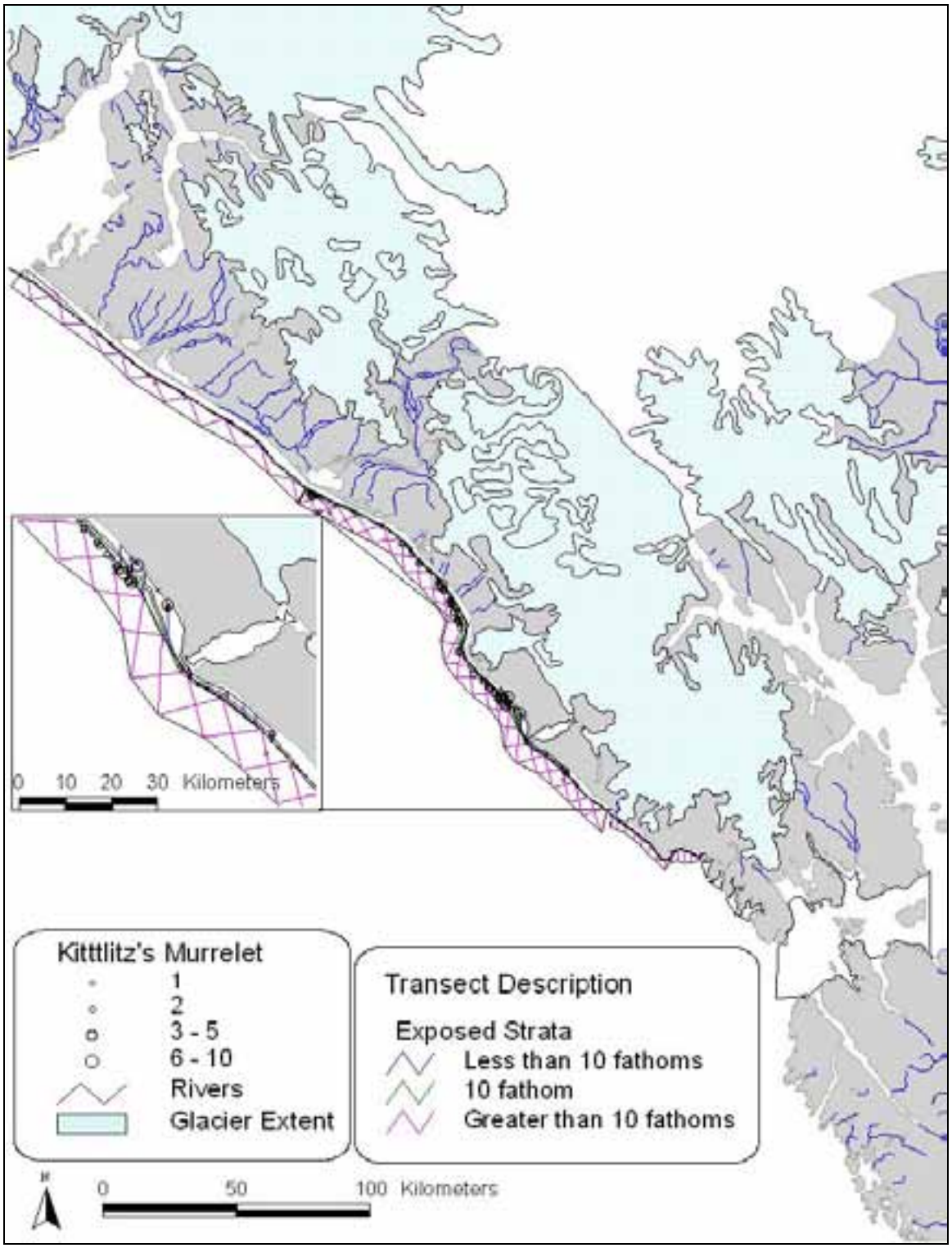

Fig. 13. Kittlitz's murrelet distribution and abundance on-transect in the Outer Coast study area, 6-16 July 2004.

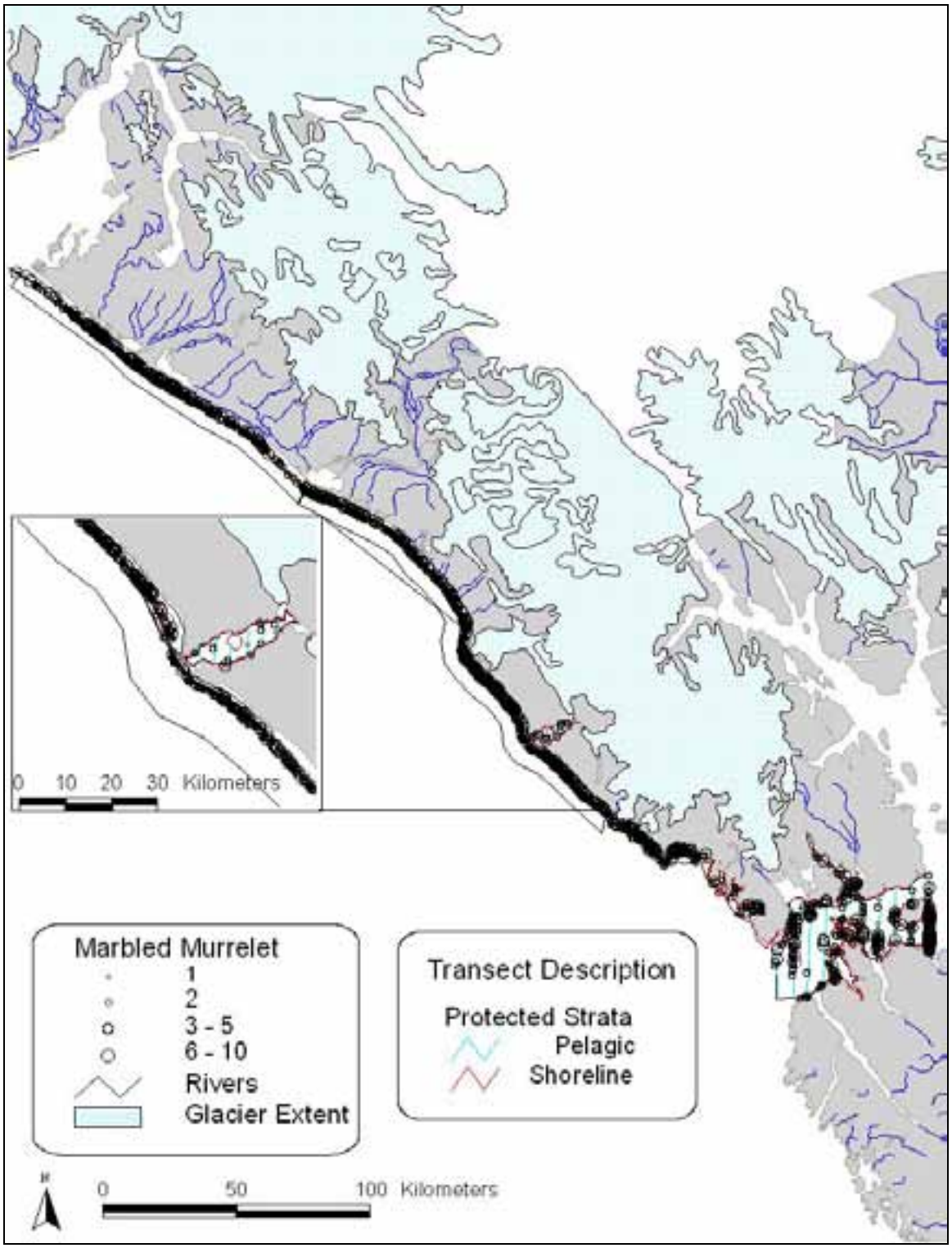

Fig. 14. Marbled murrelet distribution and abundance on-transect in Outer Coast study area, 3-11 July 2003.

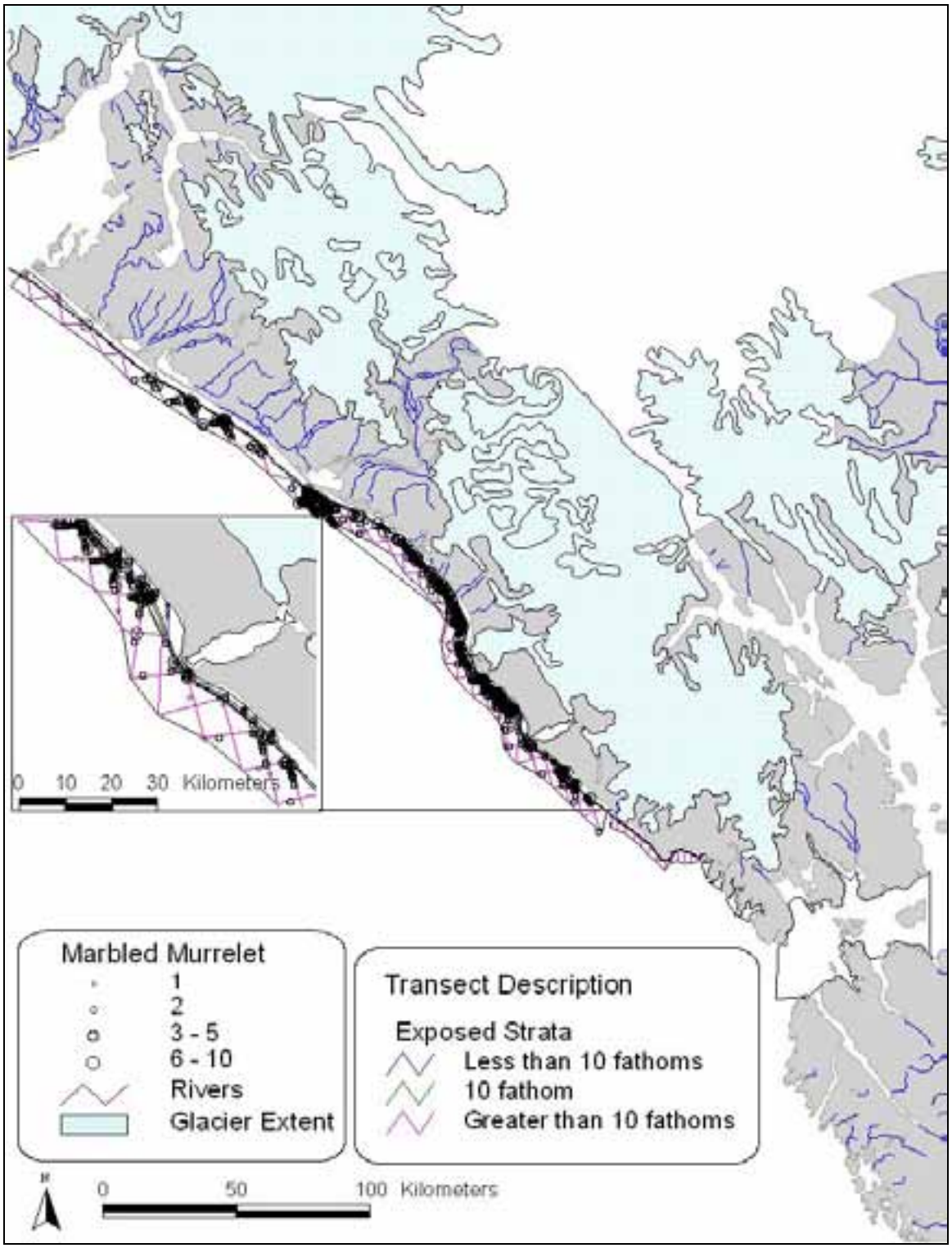

Fig. 15. Marbled murrelet distribution and abundance on-transect in the Outer Coast study area, 6-16 July 2004.

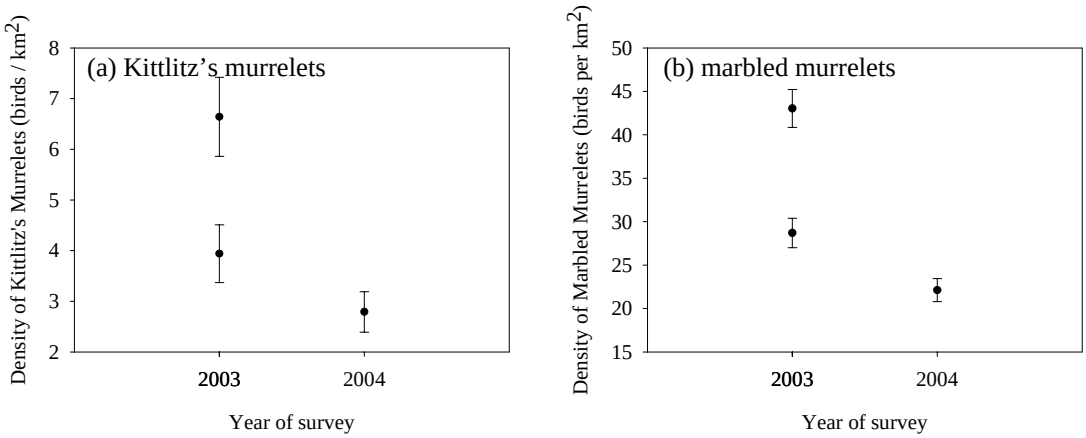

Fig. 16. Interannual and intraannual differences in density estimates of (a) Kittlitz's murrelets, and (b) marbled murrelets along the 10-fathom line from Lituya Bay to Dry Bay (part of Exposed South stratum), southeast Alaska, 2003-2004. Error bars describe one standard error. Two surveys occurred in 2003 on 7 July and 9 July, and one survey occurred in 2004 on 11 July.

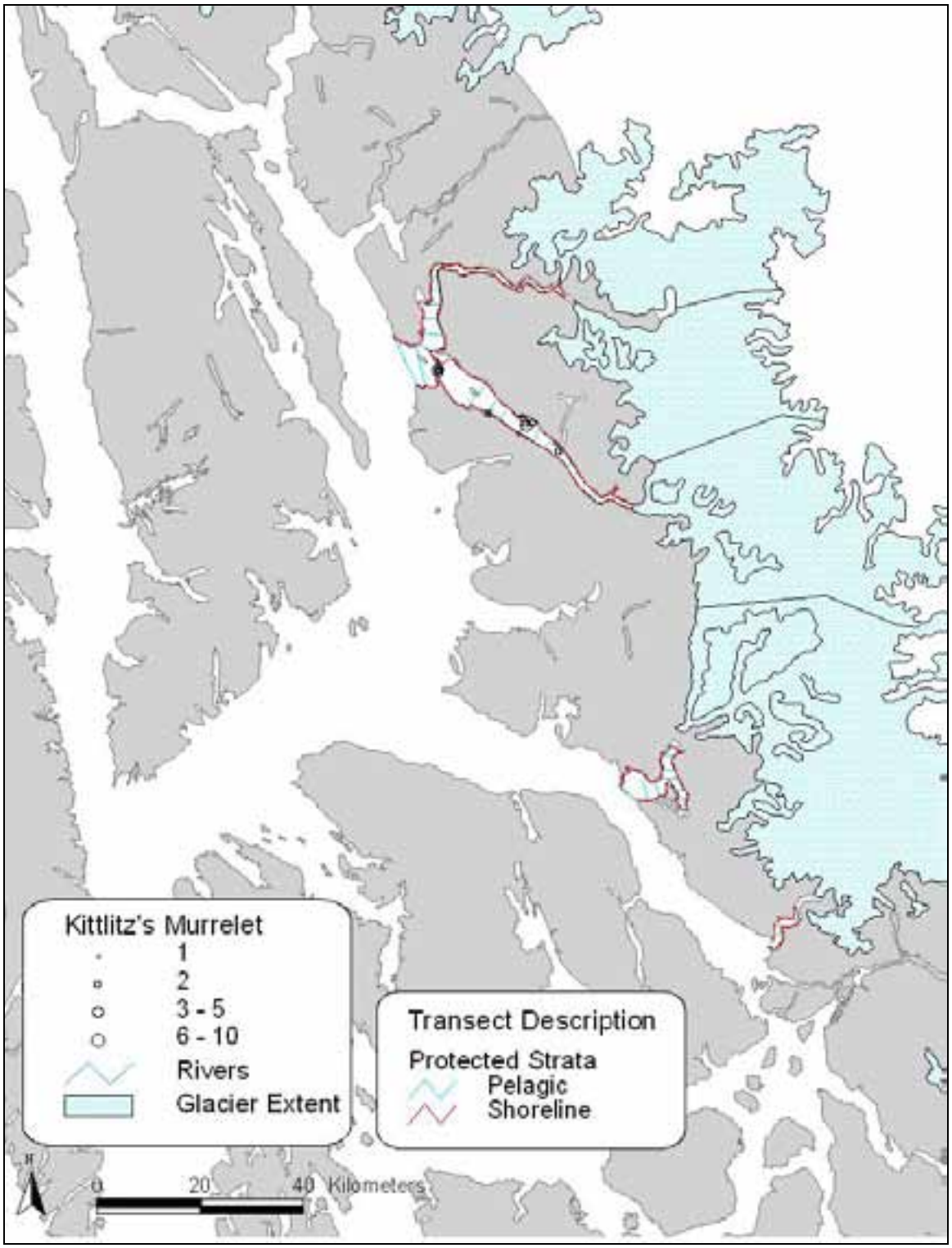

Fig. 17. Kittlitz's murrelet distribution and abundance on-transect in the Mainland Fjord study area, 7-14 July 2002.

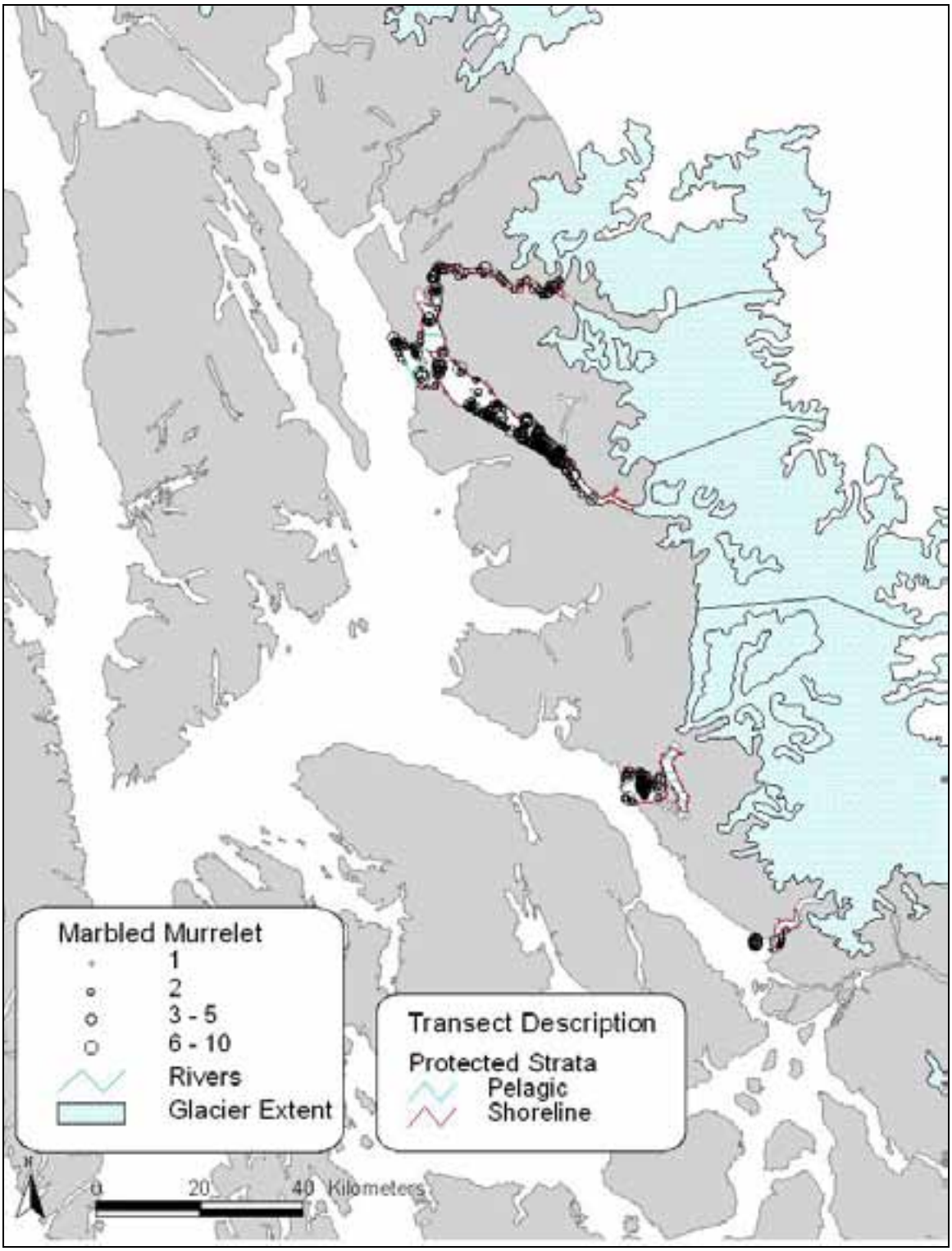

Fig. 18. Marbled murrelet distribution and abundance on-transect in the Mainland Fjord study area, 7-14 July 2002. (Note: GPS failure in Thomas Bay resulted in loss of exact observation locations in the east part of the bay. Observations continued to be recorded, and therefore, density and population estimates for this stratum are correct.)

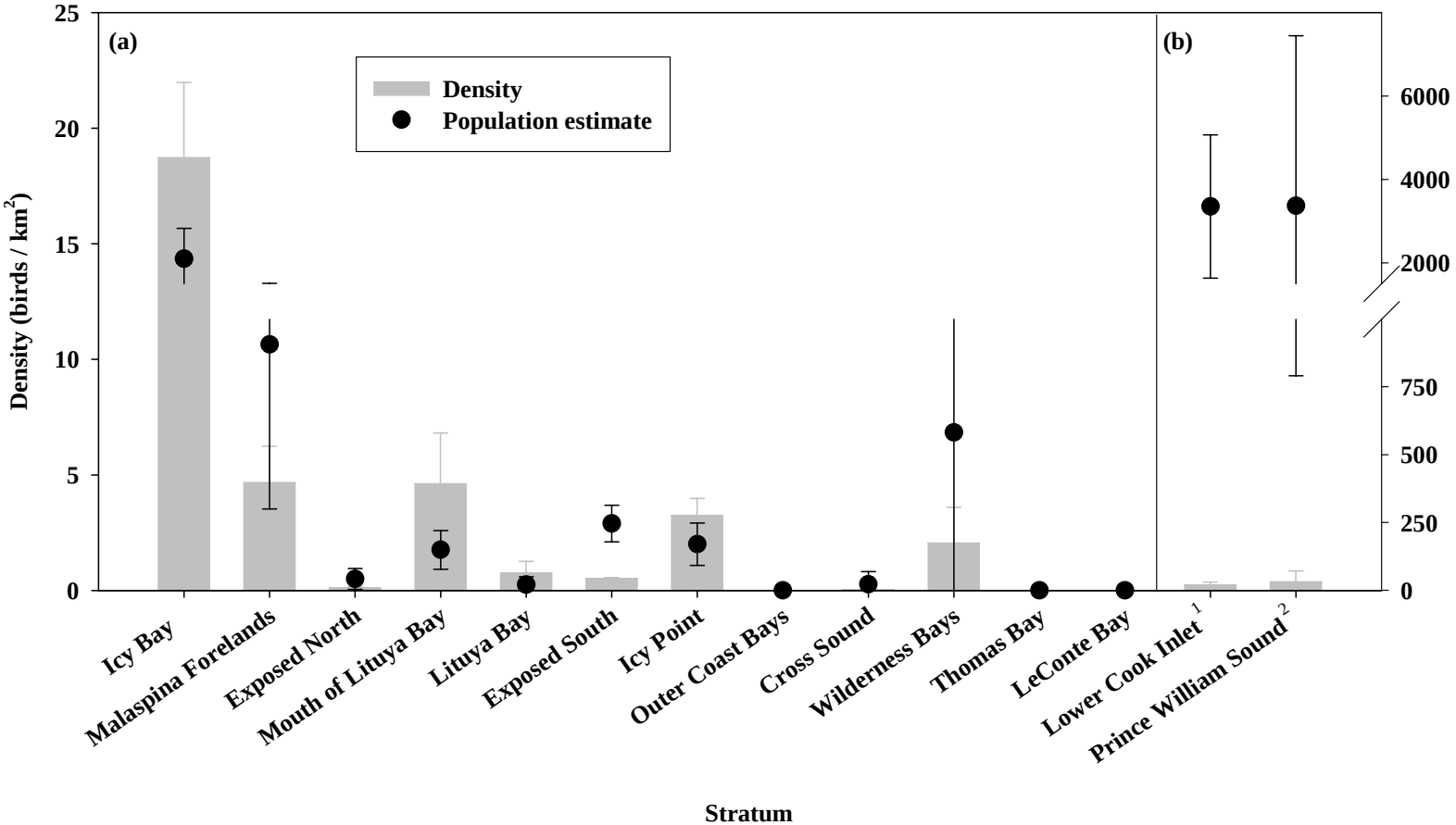

Fig. 19. Density and population estimates of Kittlitz's Murrelets for (a) 12 strata surveyed during this study, southeast Alaska, 2002-2004, and (b) two other regions in Alaska. Error bars represent 95% confidence intervals. ([1]USFWS, unpubl. data; [2]Kendall, and Agler 1998. In 2004, PWS population = 758 birds [USFWS, unpubl. data]).