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At-sea Density and Distribution of Kittlitz's Murrelets (*Brachyramphus brevirostris*) and Marbled Murrelets (*Brachyramphus marmoratus*) in Glacier Bay, Alaska, Summer 2003

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ABSTRACT

We conducted systematic vessel-based surveys within Glacier Bay, Alaska during the summer of 2003 to determine the density and distribution of Kittlitz's Murrelets *Brachyramphus brevirostris* and Marbled Murrelets *Brachyramphus marmoratus.* Our surveys varied in both temporal scale and spatial extent. Both species of murrelets exhibited clumped distributions in Glacier Bay. The distribution of Kittlitz's Murrelets in June was limited largely to the area north of Willoughby Island and into the lower half of Muir Inlet, and to the upper portion of the West Arm of the bay, particularly around Russell Island. Marbled Murrelets were spread across a much wider area of the bay in June, with higher densities in the Beardslee Islands, West of Point Gustavus, and East of Point Adolphus in Icy Strait. The density of both species in the West Arm was highest in July and lowest in August. The density of Kittlitz's Murrelets in Muir Inlet decreased throughout the season from June to August, whereas Marbled Murrelet density in Muir Inlet was greatest in August. At-sea habitat use by Kittlitz's Murrelets in the West Arm seemed to parallel that of previous studies conducted in Prince William Sound where birds preferred habitats influenced by tide-water glaciers and glacial-river outflows. In Muir Inlet, Kittlitz's Murrelets were found nearing habitats that contained submerged marine sills in addition to habitats with direct glacial input. Kittlitz's Murrelets also used habitats unaffected by glaciers in the lower portions of Glacier Bay.

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INTRODUCTION

The Kittlitz's Murrelet (*Brachyramphus brevirostris*) is one of the rarest seabirds in North America, and most aspects of its biology remain obscure. A summary of limited data as of 1993 suggested a total world population of about 20,000 Kittlitz's Murrelets, of which as many as 50% may occur during the breeding season in areas under the jurisdiction of the National Park Service (van Vliet 1993). Except for small populations in the Russian Far East, most Kittlitz's Murrelets breed in Alaska (Day et al. 1999). Unlike the congeneric Marbled Murrelet (*Brachyramphus marmoratus*), which can be monitored in old-growth nesting areas by counting vocalizations and birds at nest-sites year-round (Naslund 1993), Kittlitz's Murrelets are much less vocal and less likely to be detected in their remote alpine nesting areas (Van Pelt et al. 1998). Distribution and abundance of Kittlitz's Murrelets must therefore be derived from at-sea survey data. However, many areas known to support breeding populations of Kittlitz's Murrelets have been incompletely surveyed. Even in core areas such as Glacier Bay and Cook Inlet where some population estimates are available (Kendall and Kuletz 1999; Piatt et al. unpublished data), more intensive surveys that could provide productivity indices and more precise population estimates (Becker et al. 1997; Kuletz and Kendall 1998) have not been conducted.

Available evidence from Kittlitz's Murrelet surveys that have been replicated in several areas indicates that the species is declining at an alarming rate across their core geographic range. Preliminary analysis of surveys conducted in Glacier Bay in 1991 and 1999/2000 (Drew and Piatt, *in prep*., Robards et al. 2003) suggest that populations declined by more than 80% during that period. Even greater declines in Kittlitz's Murrelet numbers have been observed in Prince William Sound over the past 25 years (Kuletz, *in press*). Citing "significant population declines in its core population centers-Prince William Sound, Malaspina Forelands, and Glacier Bay," on May 4, 2004 the U.S. Fish and Wildlife Service added Kittlitz's Murrelet to the list of species regarded as a candidate for listing as threatened or endangered (69 FR 24875 24904). Because the species is rare and declining, accurate population estimates are urgently needed so that the true status of the species can be determined. These population estimates will require both broad-scale surveys in areas where the species has been known to occur in the past, and higher-replication surveys in core areas to produce more accurate information on population trends and habitat use.

Sources of Kittlitz's Murrelet mortality can be separated into two groups; those that have been reasonably well documented and those about which little or no information is available. Both gillnet entanglement and oil spills have been documented as a source of mortality for the species (Wynne et al. 1991; van Vliet 1993; van Vliet and McAllister 1994; Day et al. 1999). Mortality from gillnet bycatch and oil pollution is of a magnitude large enough to have had overall population effects (van Vliet and McAllister 1994, Day et al. 1999). The number of Kittlitz's Murrelets caught in gillnets is disproportionate to estimates of their population size, suggesting that they are particularly vulnerable to this source of mortality (Day et al. 1999). Significant numbers were also killed by the *Exxon Valdez* oil spill; mortality estimates range between 1% and 10% of the global population (Van Vliet 1993; van Vliet and McAllister 1994; Carter and Kuletz 1995).

The group of undocumented potential causes of mortality includes loss of foraging habitat due to glacial recession, natural and human-caused changes in food abundance, and vessel disturbance in core foraging areas. Because known anthropogenic sources of mortality are either absent from Glacier Bay (e.g., gillnet fishing; Dept. of Interior 1991), or likely not of a scale large enough to account for recent population declines (e.g., oil spills; Eley 2000), there is little reason to believe that these mechanisms have played an important role in the overall population decline in Glacier Bay. However, the paucity of information available on the species makes hypotheses about the undocumented causes of mortality impossible to assess, and there is a critical need for information on foraging ecology and vessel interactions to fill this knowledge gap.

Whereas oil spills and gillnets affect adult survival, widespread breeding failure has also been observed during surveys of Prince William Sound (Day et al. 1999, Day and Nigro

2004), suggesting that other, undocumented factors are impacting productivity. Because the distribution of Kittlitz's Murrelets is closely associated with glaciers throughout its range, and tidewater glaciers in Alaska are in general retreat, the "glacial recession" hypothesis provides an intuitive explanation for population declines (Day et al. 1999; Day and Nigro 2000). In Prince William Sound, population declines have been most severe in fjords where glaciers have exhibited substantial retreats in recent decades , lending further support to the glacial recession hypothesis (Kuletz et al., *in press*). However, no information on foraging behavior and success in glacial and non-glacial waters is currently available, and the factors that make glacial waters attractive to foraging Kittlitz's Murrelets remain unknown. As a result, the glacial recession hypothesis for population decline cannot be critically evaluated. Many piscivorous seabirds in the Gulf of Alaska have suffered population declines over recent decades due to climate-mediated changes in fish community composition (Piatt and Anderson 1996; Agler et al. 1999), and Kittlitz's Murrelets may also have been affected by these broad-scale changes in trophic organization. Marbled murrelets, which have a high degree of dietary overlap with Kittlitz's Murrelets, are also in decline in Glacier Bay (Robards et al. 2003), lending support to the hypothesis that ecological changes beyond those associated exclusively with glacial recession have impacted Kittlitz's Murrelets. Finally, vessel disturbance may also have a negative impact on the species. Cruise ships and tour boats are attracted to the same glacial waters that provide preferred foraging habitat for Kittlitz's Murrelets (Day et al. 1999). Disturbance of foraging behavior caused by vessels could contribute to declines in foraging success, and perhaps ultimately to reduced reproductive output.

This report summarizes the results of systematic, at-sea surveys that were conducted in Glacier Bay, Alaska during the summer of 2003. The goal of this work is to describe the at-sea density and distribution of Kittlitz's and Marbled Murrelets within Glacier Bay at a variety of spatial and temporal scales. The results of this project will be incorporated into the on-going study of Kittlitz's and Marbled Murrelets in Glacier Bay that is being conducted by the Marine Ecology Project of the Alaska Science Center, U. S. Geological

Survey (USGS). The distribution data will also provide valuable information to Glacier Bay National Park personnel to assist in the management of both species.

METHODS

Study Area

This research was conducted in and near Glacier Bay, a Y-shaped fjord in southeast Alaska that ranges about 100 km from its entrance to the head of its arms (Figure 1). Width of Glacier Bay varies from 4 to 8 km in the lower bay; increasing to about 15 km in the middle bay, and then narrowing again in the upper arms. The Fairweather Mountain Range dominates the head of Glacier Bay, with numerous peaks over 3,000 m culminating in Mt. Fairweather at 4600 m. Numerous glaciers (12 tidewater) discharge ice and silt-laden water into the upper arms and inlets. Glacier Bay is connected to the Gulf of Alaska via Icy Strait and Cross Sound (Figure 1).

Glacier Bay became a National Monument on February 25, 1925, and currently lies within the 11,030 km^2 Glacier Bay National Park and Preserve, which was established on December 2, 1980. The area was designated wilderness in December, 1980, designated a Biosphere Reserve in 1986, and a World Heritage Site in 1992.

The complex bathymetry and tidal patterns of Glacier Bay create a high diversity of habitats. Within Glacier Bay, numerous sills (submerged glacial moraines) separate deeper basins (up to 458 m deep), and constrictions along the bay passages have major effects on water movement in the bay. Hooge and Hooge (2002) highlight the role of this bathymetry in influencing oceanography and primary productivity. Glacier Bay also experiences a very large tidal range. The tidal cycle is mixed semi-diurnal (two high and two low tides per day, of unequal heights), with a tidal range (difference between mean high and mean low tides) averaging from 3.7 m at Bartlett Cove to 4.2 m at locations approximately half-way up both the West and East arms. The tidal range further up-bay is even greater. During the largest spring tides, the tidal range can reach 7.3 m at Bartlett Cove, and exceed 7.8 m in the upper arms.

Survey Methods

At-sea surveys of Kittlitz's and Marbled Murrelets were conducted within Glacier Bay from June to August 2003. All surveys were conducted, with some modification, according to strip survey protocols established by the U.S. Fish and Wildlife Service for surveying marine birds (Gould et al. 1982, Gould and Forsell 1989, using modifications in Kendall and Agler 1998, and Agler et al. 1999). Surveys were made from the *MV Predator* and *MV Lutris II* (both 8 m Boston Whalers), and the *RV Alaskan Gyre* (15 m seiner). Observers from the *Predator* and *Lutris II* identified swimming birds and mammals, and flying birds, within 100m of either side or 200 m forward of the vessel (200-m wide strip). The survey area of the *Alaskan Gyre* was increased to 150 m on either side or 300 m forward of the vessel (300-m wide strip) because the vessel's deck-height above the water surface (3.7 m) allowed for a greater viewing distance. For all vessels, only birds and mammals sighted forward of mid-ship were counted. Ground speed of the vessels while conducting surveys was held between 7 – 12 knots.

All birds and mammals that occurred on transect were identified to species or to the lowest taxonomic level possible. Identification of murrelets within the genus *Brachyramphus* can be particularly difficult given the similarity in size, shape and plumage of the Kittlitz's Murrelet and the Marbled Murrelet (see Appendix 1). Both species occur in Glacier Bay, often within the same or similar habitats. Variables such as sea state and ambient light conditions can greatly affect the ability of an observer to positively identify birds of this genus to species. To facilitate greater precision in identifying these two species the survey crew conducted a full week of practice surveys in an area where both species occur, stopping frequently to confirm identification of all murrelets.

Bird and mammal sightings were recorded by entering them directly into a real-time computer data-entry system (DLOG; Glenn Ford, ECI) that logs sightings continuously along with their GPS coordinates. GPS locations were obtained from a Garmin V GPS unit. All flying birds that crossed within a transect were counted, regardless of their elevation. Observers actively scanned ahead of and alongside the survey vessel, and species identifications were confirmed with 7-10 power binoculars. Weather conditions and sea state were constantly monitored. If observation conditions became unsuitable for sighting and identifying birds and mammals at the extreme range of the survey window (300m for the Alaskan Gyre and 200m for the Predator and the Lutris II) then the survey was discontinued until conditions improved. Surveys were not conducted if wave height exceeded 0.3 m in height.

Study Design

The timing and geographic extent of the surveys was chosen to provide data on the annual, monthly, weekly, and daily variations in murrelet density, within key areas of Glacier Bay and Icy Strait. The transect lines used in this study were duplicated from those conducted on the annual, inter-agency (USGS and NPS) Marine Predator Survey (a vessel-based survey which has been conducted in Glacier Bay and Icy Strait during the winter [November – March] and summer [June] since 1999 (Robards et al. 2003).   We chose to replicate the same transects because they provide good coverage of the study area and allow comparison with previous surveys.

Bay-wide Distribution

In an effort to characterize the annual variation of marine birds and mammals within Glacier Bay and Icy Strait, the bi-annual Marine Predator Survey was continued during June 9 to June 14, 2003 (Figure 2). Data on murrelets, collected from the Marine Predator Survey, are included in this report. A more detailed synopsis of all of the species data collected for the Marine Predator Survey, including data from March 2003, can be found in the synopsis report for that project (Piatt et al., *in prep*.).

Monthly Variation

The Marine Predator Survey has provided valuable murrelet distribution information for Glacier Bay and Icy Strait, but it represents only a single time period during the murrelet breeding season. We identified a need to assess variation in murrelet distribution throughout the breeding season, and so we conducted large-scale surveys from July 12 –

19 and August 5 – 11, to compare with data collected during the Marine Predator Survey. Because we did not have the resources to replicate all of the transects of the Marine Predator Survey, we chose to focus on areas in which high numbers of Kittlitz's Murrelets had been previously observed. The areas that we resurveyed in July and August include the West Arm, from Geike Rock north to the head of Tarr Inlet, Muir Inlet from Sebree Island to Muir Glacier, Hugh Miller Inlet, Scidmore Bay and Charpentier Inlet (Figure 3). Some areas were closed to our vessels by ice cover or NPS regulations. While all three vessels were used to survey these areas in June, only the *Predator* was used in July, and both the *Predator* and *Lutris II* were used in August.

Weekly Variation

Weekly surveys on a smaller spatial scale were conducted to characterize meso-scale temporal changes in murrelet distribution. We conducted surveys of two separate areas of Glacier Bay every 5-9 days (mean = 7.4 days, centered on days of near-weekly extreme variation in range of tidal oscillation). Each area was surveyed within one day of the other. We named the survey areas "Upper West Arm" and "Muir Inlet Entrance" based on their relative position within Glacier Bay. The Upper West Arm survey area surrounds Russell Island and included all of Reid Inlet, the Lamplugh Glacier face, and the entrance to Tarr Inlet (Figure 4). The Muir Inlet Entrance survey area covers all of lower Muir Inlet, from Sebree Island, north beyond Muir Point and Point George, to the Southern extent of Hunter Cove (Figure 5). These two sites were chosen for a variety of reasons; 1) each site can be surveyed in a single day, 2) each site has contained a high number of Kittlitz's Murrelets on previous Marine Predator Surveys, 3) the habitat of the two sites is very different (the Upper West Arm contains several tidewater glaciers and numerous glacially-affected streams, whereas the Muir Inlet Entrance contains a large submerged glacial sill and glacial-affected streams but no tidewater glaciers). All three vessels were used to survey these areas in June, but only the *Predator* was used in July, and both the *Predator* and the *Lutris II* were used in August.

Daily Variation

The Upper West Arm area was surveyed daily for five days in order to assess variability at the finest temporal scale of 1-day. The daily surveys were conducted between June 22 and 26 from the *Predator*.

Analysis

For the purposes of analysis, each set of transects that covered a given area of interest is referred to as a survey. Thus, for the analysis of monthly variation in murrelet density, we completed three surveys (n = 41 transects) in the West Arm and three surveys (n = 27 transects) in Muir Inlet. We conducted eight surveys (consisting of a single day of transects each) for weekly variability in both the Upper West Arm area (n = 10 transects) and the Muir Inlet Entrance area (n = 12 transects). For the analysis of daily variation, we conducted five surveys (n = 10 transects) on five consecutive days in the Upper West Arm area.

Kittlitz's Murrelets are typically aggregated at-sea during the breeding season (Day et al. 2000). In Glacier Bay, clumped distribution resulted in highly skewed data and wide variances in density on transects. Transformations did not correct the problems of heteroscedasticity. Non-parametric tests were chosen for analyses because mean transect densities were not normally distributed, some sample sizes between surveys were unbalanced, and because many transect densities (particularly for Kittlitz's Murrelets) were derived from zero counts.

A density estimate (birds/km^2) for each species of murrelet was calculated for each transect. Density estimates included birds observed on the water and flying. Monthly surveys were compared for either the West Arm or Muir Inlet using a Kruskal-Wallis ANOVA, based on ranked data. Multiple comparisons between survey months, and within survey areas, were compared using a Kruskal-Wallis multiple comparison procedure. Weekly surveys were compared for either the Upper West Arm or Muir Inlet Entrance areas using a Kruskal-Wallis ANOVA. The Kruskal-Wallis multiple comparison procedure was used to compare surveys within each area. The daily surveys were compared as a single group with a Kruskal-Wallis ANOVA. Comparison between daily surveys was made with a Kruskal-Wallis multiple comparison procedure. Significance was set at $p = 0.05$ for all Kruskal-Wallis ANOVA and Kruskal-Wallis multiple comparison procedures performed.

RESULTS

Bay-wide Distribution

We sighted 411 Kittlitz's Murrelets during the survey of Glacier Bay and Icy Strait in June. Kittlitz's Murrelets were distributed throughout a wide area, from Icy Strait and the entrance to Glacier Bay, into the Beardslee Islands, throughout the central portion of the bay and into Muir Inlet, and up in West Arm of the bay to the head of Tarr Inlet (Figure 6). The densest concentration of Kittlitz's Murrelets was found from the Marble Islands, North to the mouth of Adams Inlet. Another area of high concentration for the species was in the vicinity of Russell Island, including Reid Inlet and Lamplugh Glacier. Birds were observed over the entire length of Muir Inlet, with the highest densities found at the entrance of the inlet, south of Muir Point. In contrast, Kittlitz's Murrelets were only found in the upper portion of the West Arm, with the exception of a single individual observed in Blue Mouse Cove. Areas where Kittlitz's Murrelets were not observed included Geike Inlet, Wachusett Inlet, Queen Inlet, Rendu Inlet, and all of Icy Strait east of Point Adolphus (Figure 6).

In the West Arm of Glacier Bay the majority of Kittlitz's Murrelets were found in nearshore waters ($\leq$ 200m from shore). In the remainder of the bay, Kittlitz's Murrelets were found in both nearshore and offshore waters ($>$ 200m from shore). When GPS locations of individual birds were overlaid onto a nautical chart of the area (N.O.A.A. chart #17318), birds were estimated to occur in water as shallow as 5 m and deeper than 200 m. While Kittlitz's Murrelets were observed in close proximity to tidewater glaciers and glacier-fed river outflows in the northern areas of Glacier Bay (West Arm and Muir Inlet), birds observed in the southern portions of the bay (Marble Islands, Flapjack Islands, Beardslee Islands) were found in glacially-unaffected waters (see Day et al. 2000 for a thorough description of these habitats). The group size of Kittlitz's murrelets observed on the bay-wide survey ranged between one and 13 individuals, with an average of 1.9 birds/group.

Marbled Murrelets were the fifth most abundant species observed during the bay-wide survey, and second in abundance only to Black-legged Kittiwakes (*Rissa tridactyla*) for non-waterfowl species. We counted 2,843 Marbled Murrelets throughout Glacier Bay and Icy Strait. Marbled Murrelets were well distributed throughout the bay in June, in nearly all of the major bays, coves or inlets (Figure 6). The greatest density of Marbled Murrelets was found south of Willoughby Island and in Icy Strait, west of Point Adolphus. A large group of birds was observed just east of Strawberry Island in the Beardslee Islands. Another large group was observed just to the west of Point Gustavus, in the entrance to Glacier Bay. In Icy Strait, the area between Lemesurier Island and Point Adolphus contained another large group of Marbled Murrelets. While the upper half of Glacier Bay contained fewer Marbled Murrelets than the lower half, there were a few large concentrations of birds in the entrance to Muir Inlet and off Point George near the entrance to Adams Inlet. The lowest concentrations of Marbled Murrelets were found in the West Arm of Glacier Bay and east of Point Adolphus in Icy Strait (Figure 6).

In the West Arm and Geikie Inlet, Marbled Murrelet distribution was similar to that of Kittlitz's Murrelet, with most birds using nearshore waters. In the remainder of the bay Marbled Murrelets were found in both nearshore and offshore waters. While most Marbled Murrelets were found in shallower waters, some birds (particularly those in the entrance to Beartrack Cove and between North Marble and Drake Islands) were found in water > 200 m deep (estimated from N.O.A.A. chart #17318). Group size ranged from 1 – 32 individuals, with an average of 2.5 birds/group.

Monthly Variation

West Arm

There was a significant ($p = 0.004$) change in the density of Kittlitz's Murrelets in the West Arm of Glacier Bay during the summer of 2003 (Figure 7). The density of Kittlitz's

Murrelets in the West Arm during the June survey was 1.0 ± 0.5 birds/km^2. Kittlitz's Murrelet density increased significantly (p = 0.014) in July to 3.5 ± 2.3 birds/km^2, then decreased significantly (p = 0.002) in August to 0.2 ± 0.1 birds/km^2. The majority of the birds observed in June and July were sighted on transects in the upper portion of the West Arm, up-bay from Composite Island (Figure 8a-c). In August, the few birds that were observed in the West Arm, were sighted on transects in both the upper and lower portions of the arm (Figure 8a-c).

Marbled Murrelet density remained fairly constant in the West Arm from June to early August with no significant (p = 0.125) difference in mean monthly density. The mean monthly density ranged from a high of 8.2 ± 1.7 birds/ km^2 in July to a low of 4.7 ± 1.1 birds/ km^2 in August (Figure 7). The distribution of Marbled Murrelets in the West Arm was split between the upper and lower portions of the arm (Figure 8a-c). Marbled Murrelets were observed almost exclusively on nearshore transects in June and July, whereas in August some birds were observed on offshore transects, particularly in the lower portion of the West Arm. Some of the birds observed offshore in August were found in water > 250 m in depth.

Muir Inlet

The mean density of Kittlitz's Murrelets in Muir Inlet was greatest in June (4.3 ± 2.3 birds/km^2) and least in August (0.4 ± 0.3 birds/km^2; Figure 9). There was no significant difference (p = 0.098) in the density of birds in Muir Inlet between June and July or between July and August (p = 0.055), but there was a significant difference between densities in June and August (p = 0.010; Figure 9). In June and August most Kittlitz's Murrelets in Muir Inlet were observed in the lower portion of the inlet, south of Hunter Cove (Figure 8a-c). During July, a large concentration of Kittlitz's Murrelets (n = 41) were observed in the upper portion of the inlet, where the outflow from McBride Glacier enters the main-stem of the inlet (Figure 8b).

Throughout the summer, most of the Kittlitz's Murrelets observed in Muir Inlet were found on offshore transects, particularly in the entrance to the inlet, south of Muir Point

(Figure 8a-c). Some Kittlitz's Murrelets were seen on the nearshore transects which cover the mouth of Adams Inlet, and on the nearshore transects up-bay from McBride Glacier to Muir Glacier. Due to the presence of large amounts of ice, we were not able to survey the inlet that has been formed due to the retreat of McBride Glacier.
There was a significant change ($p = 0.038$) in the density of Marbled Murrelets in Muir Inlet from June to August, 2003. The density of Marbled Murrelets in Muir Inlet ranged from a low of 12.1 ± 4.9 birds/ km^2 in July to a high of 30.9 ± 7.4 birds/ km^2 in August (Figure 9). There was no significant change in Marbled Murrelet density from June to July ($p > 0.250$), however, there was a significant increase in Marbled Murrelet density from July to August ($p = 0.012$). Marbled Murrelets were found in Muir Inlet from the entrance near Sebree Island north to Riggs Glacier, during all three monthly surveys (Figure 8a-c), but the majority of birds were found south of the entrance to Wachusett Inlet. Within Muir Inlet, Marbled Murrelets were observed on both nearshore and offshore transects (Figure 8a-c), and in both shallow and deep water.

Weekly Variation

Upper West Arm

Kittlitz's Murrelets were observed during surveys of the Upper West Arm throughout the summer of 2003. The mean density of Kittlitz's Murrelets on these surveys ranged from a high of 15.8 ± 7.8 birds/km^2 on July 13, to a low of 0.2 ± 0.1 birds/km^2 on August 6 (Figure 10). Due to the high variance within surveys, statistically significant differences were observed only between the August 6 survey and all other survey days. However, the data display a temporal trend, beginning the season with moderate densities, peaking after mid-season (July 13), and steadily declining until the end of the season (Figure 10).

Kittlitz's Murrelets were found consistently in several locations in the Upper West Arm area. Kittlitz's Murrelets were found in Reid Inlet on every weekly survey, with the exception of August 6 (Figure 11a-h). The entrance to Reid Inlet appears attractive throughout the season to Kittlitz's Murrelets and other species, including Marbled Murrelets, Pigeon Guillemots (*Cepphus columba*), Arctic Terns (*Sterna paradisaea*), and Black-legged Kittiwakes. This area yielded the highest densities of Kittlitz's Murrelets recorded on a single transect, on July 1 (47.2 birds/km^2; Figure 11c) and July 13 (75.5 birds/km^2; Figure 11e). The coastline between Reid Inlet and Lamplugh Glacier (including the face of the glacier) was another area in which Kittlitz's Murrelets were sighted consistently (Figure 11a-h).

The mean density of Marbled Murrelets in the Upper West Arm area followed a weekly trend similar to the density of Kittlitz's Murrelets , with moderate density early in the season (June 15 to July 6), a peak in mid-season (July 13), and a decline late in the season (July 28 to August 6; Figure 10, 11a-h). The mean density of Marbled Murrelets in the Upper West Arm area ranged from a high of 18.0 ± 4.5 birds/km^2 on July 13 (Figure 11e), to a low of 5.3 ± 1.3 birds/km^2 on August 6 (Figure 11h). Owing to high variance in Marbled Murrelet densities transects, the only statistically significant differences observed, were between the July 13 survey (peak density) and both the July 28 and August 6 surveys (Figure 10).

Muir Inlet Entrance

There was a significant difference between the densities of Kittlitz's Murrelets observed on June 30 and July 14, July 21, July 29, and August 5, in the Muir Inlet Entrance (Figure 12). The weekly density and distribution of Kittlitz's Murrelets in Muir Inlet Entrance show both similarities and differences in trend compared to those observed in the Upper West Arm area. The mean density of Kittlitz's Murrelets in the Muir Inlet entrance reached a high of 16.7 ± 16.2 birds/km^2 on June 30, and a low of 0.8 ± 0.3 birds/km^2 on July 21. This difference between high and low densities is similar in magnitude to that observed in the Upper West Arm area (Figures 10 and 12). However, the peak in Kittlitz's Murrelet density in the Muir Inlet Entrance area was observed 13 days before the peak in density observed in the Upper West Arm area (July 13; 15.8 ± 7.8 birds/km^2). On July 14, one day after the peak of Kittlitz's Murrelet density in the Upper West Arm area, a density of 2.6 ± 1.3 birds/km^2 was observed in Muir Inlet Entrance area. While Kittlitz's Murrelets were found both nearshore and offshore in the Muir Inlet Entrance area, the overwhelming majority of birds were found on offshore transects (Figure 13a-h).

Mean density of Marbled Murrelets in the Muir Inlet Entrance area ranged significantly, from 13.5 ± 4.0 birds/km^2 on June 21, to 42.7 ± 31.2 birds/km^2 on July 29, and 42.7 ± 11.9 birds/km^2 on August 5 (Figure 12). There was no significant difference ($p = 0.545$) in the density of Marbled Murrelets between the July 29 and August 5 surveys, despite apparent differences in bird distribution between the two surveys (Figure 13g & h). On July 29 we encountered a large number of Marbled Murrelets (219 birds) on one transect in the southern portion of the entrance to Adams Inlet (Figure 13g) whereas on August 5 the birds were more dispersed across the survey area (Figure 13h). Many of the birds observed on July 29 were actively feeding, and we observed several fish-holding individuals. Throughout the summer, Marbled Murrelets were observed on both coastal and offshore transects in this area (Figure 13a-h).

Daily Variation

The mean density of Kittlitz's Murrelets in the Upper West Arm area ranged from a high on June 22 of 5.2 ± 1.5 birds/km^2 to a low of 2.9 ± 0.8 birds/km^2 on June 26 (Figure 14) yet there was no significant difference across the five survey days ($p = 0.474$). The mean density of Marbled Murrelets in the same area over the five-day period varied from a high of 14.1 ± 5.2 birds/km^2 on June 22 to a low on June 24 of 5.4 ± 1.2 birds/km^2 (Figure 14), but the differences were not statistically significant ($p = 0.187$).

While the density of both species of murrelet did not differ significantly over the five day period, the distribution of the birds did vary spatially (Figure 15a-e). The entrance to Reid Inlet for example, contained only four Kittlitz's Murrelets on June 23 (Figure 15b), but on June 24 the same area contained 17 birds (Figure 15c). Likewise, the coastal transect segment to the East of Russell Island (in the Northeast corner of the transect area) contained six Marbled Murrelets on June 24 yet the next day the same transect contained 52 (Figure d). Clumped distribution is common for these species as reported from other areas (Day and Nigro 1999, Day et al. 2000). In general, both species were distributed throughout the survey area over the five days (Figure 15a-e). We recorded at least one murrelet on each transect ($N = 10$) surveyed within the area for each day, and eight of the ten transects contained at least one individual of each species, each day (Figure 15a-e).

DISCUSSION

Pattern of Distribution

In Prince William Sound, Kittlitz's Murrelets occur in a clumped, rather than even or random distribution (Day and Nigro 1999, Day et al. 2000). Both Kittlitz's Murrelets and Marbled Murrelets showed a clumped distribution in Glacier Bay during the summer of 2003. The survey of Glacier Bay and Icy Strait performed in June 2003 (Figure 6) shows a clumped distribution for both species, on a broad scale. Both species showed high densities in certain hotspots (Muir Inlet Entrance and Upper West Arm for Kittlitz's Murrelets), and both species showed holes in their distribution where few, if any birds occurred (Figure 6). The same trend is found on a smaller spatial scale in the Upper West Arm. Surveys from June 22 to June 26 show a clumped distribution for both species on a daily basis and a changing spatial distribution over the five survey days. Despite the differences in spatial distribution there was no significant difference in mean density between surveys for either species over the five day period (Figure 14). This result suggests that murrelet use of micro-habitat (a particular stream outwash or glacier face) varies from day to day, but the overall use of a larger meso-scale habitat (the upper West Arm) may not change much over this time scale.

Distribution and Habitat

Both Kittlitz's and Marbled Murrelets have shown a preference for nearshore and shallow waters. In Prince William Sound, Kittlitz's Murrelets feed primarily in the nearshore zone and also in shallow water (Day and Nigro 2000). Marbled Murrelets off the coast of central California were found overwhelmingly (99%), in water less than 25 m deep (Becker and Bessinger 2003). While not completely limited to nearshore waters in the West Arm of Glacier Bay, Kittlitz's and Marbled Murrelets were most often found in nearshore or shallow water in the West Arm throughout the summer of 2003. Although data on feeding activity was not collected for every murrelet sighting, active feeding by both species was observed in the entrance to Reid Inlet and within Reid Inlet (both shallow, nearshore areas). In contrast, Kittlitz's Murrelets were often recorded on offshore transects in Muir Inlet, and in water that exceeds 25 m depth. Marbled Murrelets were recorded on both nearshore and offshore transects, and in both shallow and deep water.

The distribution of Kittlitz's Murrelet has been linked to glacial fjords in both south-eastern Alaska (Day et al. 1999) and Prince William Sound (Islieb and Kessel 1973, Kendall and Agler 1998, Day and Nigro 1999). Habitats affected by tide-water glaciers or glacier-river outflows are preferred by Kittlitz's Murrelets in Prince William Sound (Day et al. 2000). In contrast, Kittlitz's Murrelets are less often observed in marine-sill-affected and glacial-unaffected habitats, despite the availability of these habitats within Prince William Sound (Day et al. 2000). In the West Arm of Glacier Bay, Kittlitz's Murrelets were often observed in the vicinity of Reid Inlet, Reid Glacier and Lamplugh Glacier (Figure 8a-c, Figure 11a-h, Figure15a-e). This area contains some of the highest concentrations of glacier-affected and glacier-stream-affected habitat in Glacier Bay. The southern portion of the West Arm does not contain glacier-affected habitat and Kittlitz's Murrelets were rarely observed in the area.

The northern portion of Muir Inlet contains tidewater glaciers (Muir, Riggs and McBride Glaciers), and numerous glacier-fed streams while the southern portion of Muir Inlet contains no tidewater glaciers and fewer glacier-fed streams, but the density of Kittlitz's Murrelets in southern portion was greater than in the northern portion in June and August (Figure 8a-c). A large, shallow marine sill is present south of Point George and extends south to Sebree Island. The density of both Kittlitz's and Marbled Murrelets in the southern half of Muir Inlet was greatest in the vicinity of this marinesill. The glacial river outflow from the Casement Glacier also contributes a large amount of silty runoff into the entrance of Adams Inlet. The sediment plume from this outflow can extend well past Muir Point on a falling tide. We often observed both species feeding in this area, including a large group of Marbled Murrelets (> 200) that were part of a mixed species feeding flock, on July 30, 2003. In Prince William Sound, the turbulent flow of water over marine sills is not considered an important micro-habitat feature for Kittlitz's Murrelet feeding (Day and Nigro 2000) but our data suggest that this habitat feature, perhaps combined with the sediment input from the Casement Glacier outflow, could be important to foraging Kittlitz's and Marbled Murrelets in this area of Glacier Bay.

While the distribution of Kittlitz's Murrelet in the northern areas of Glacier Bay appears to be influenced by the presence of tidewater glaciers, glacier-river outflows and possibly submerged marine sills, in the southern portions of Glacier Bay Kittlitz's Murrelets were found in areas > 10 km from a tidewater glacier or glacier-river outflow. On several occasions in July we observed groups of Kittlitz's Murrelets actively feeding in the area between Boulder and Flapjack Islands which receives little direct glacial input. Future management of this species in Glacier Bay National Park will need to consider the potential importance of these glacially-unaffected habitats.

Given their affinity for glacier affected habitats in Prince William Sound, it is not surprising that Kittlitz's Murrelets there exhibit a preference for areas of light ice cover (0.5% - 15%), and use areas of moderate ice cover (20 – 45%) in proportion to the availability of that ice cover type (Day et al. 2000). Kittlitz's Murrelets observed in the West Arm were found in the areas that generally experience light to moderate ice cover. A small amount of ice was typically present on transects covering Reid Inlet and the entrance to Reid Inlet. Moderate ice cover was typical for the area near Lamplugh Glacier. Ice cover in excess of 45% was only observed in Johns Hopkins Inlet and in Tarr Inlet in the vicinity of the Margerie Glacier. The distribution of ice in Muir Inlet seems to be largely confined to the northern half of the Inlet. We did not encounter ice on transect in Muir Inlet south of Point George. While Kittlitz's Murrelets in the West Arm seem to prefer areas of light to moderate ice cover, similar to birds in Prince William Sound, birds in the entrance to Muir Inlet are using ice-free water more often.

Density and Nesting Chronology

The trend in density that we observed in the Upper West Arm fit loosely with Day's (1996) estimates of nesting chronology for the species in Southeast Alaska. Precise estimates of the nesting chronology of Kittlitz's Murrelet in Glacier Bay are difficult to calculate given the lack of information on the species in the area. However, estimates for Southeastern Alaska have been put forth for egg-laying (May 15 – June 14), hatch date (June 14 – July 14) and fledging (July 8 – August 6; Day 1996). The weekly data from the Upper West Arm area display a trend; moderate densities mark the beginning of the season (4 – 11 birds/km^2; June15 – July 6), peak after mid-season (15.8 birds/km^2; July 13), and steadily decline until the end of the season (July 20 – August 6; Figure 10). The moderate density of Kittlitz's Murrelets in the Upper West Arm area in June corresponds with Day's (1996) predictions for incubation and early chick-rearing. During this time, at least one of the members of a breeding pair would be attending the nest. This would serve to reduce the number of birds available to be observed on the water. As the season progresses into late chick rearing, and prior to fledging, both parents would available to forage and the number of birds observed on the water would be expected to increase. Finally, after fledging occurs, adults and fledglings may be leaving the Upper West Arm area to find more productive foraging areas within or outside of the bay, leading to a rapid decline in density for the upper bay

Continuing Research

While the trends in distribution and density that we observed during the summer of 2003 are yielding useful information on seasonal variability, we are still fairly ignorant about factors that may be driving these changes in distribution. Fish distribution or other environmental factors could be having a marked effect on the distribution and density of murrelets. In 2004 we will expand our research in Glacier Bay to directly assess how habitat features influence murrelet distribution. Habitat characteristics and use will be determined through a combination at-sea surveys and radio-telemetry of individuals. Key elements of murrelet habitat including physical, biological, and oceanographic features will be measured and related to murrelet presence to determine what habitat features are preferred by each species.

ACKNOWLEDGEMENTS

We are grateful to the USGS Natural Resources Preservation Program for funding this study of murrelets, and to Glacier Bay National Park for logistic support of field operations. In particular, we appreciate support and assistance received from Mary Kralovec, Rusty Yerxa, Lisa Etherington, Tomie Lee, Jed Davis, and Bruce McDonaugh. Numerous people assisted with data collection, including Brenda Bellachey, Heather Coletti, Jim De la Bruere, Melanie Dohner, George Esslinger, Gavin McMorrow, Aileen Miller, Dan Monson, Justin Smith, and Jennifer Wetzel. We are indebted to Thomas van Pelt for help in developing the Alaska and Glacier Bay study plans for murrelets, some of which was included in this report. We thank David Irons and Shawn Stevenson for logistic support in the use of the U.S. Fish and Wildlife Service vessel, M/V *Predator*.

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Figure 1. Glacier Bay study area in Southeast Alaska.

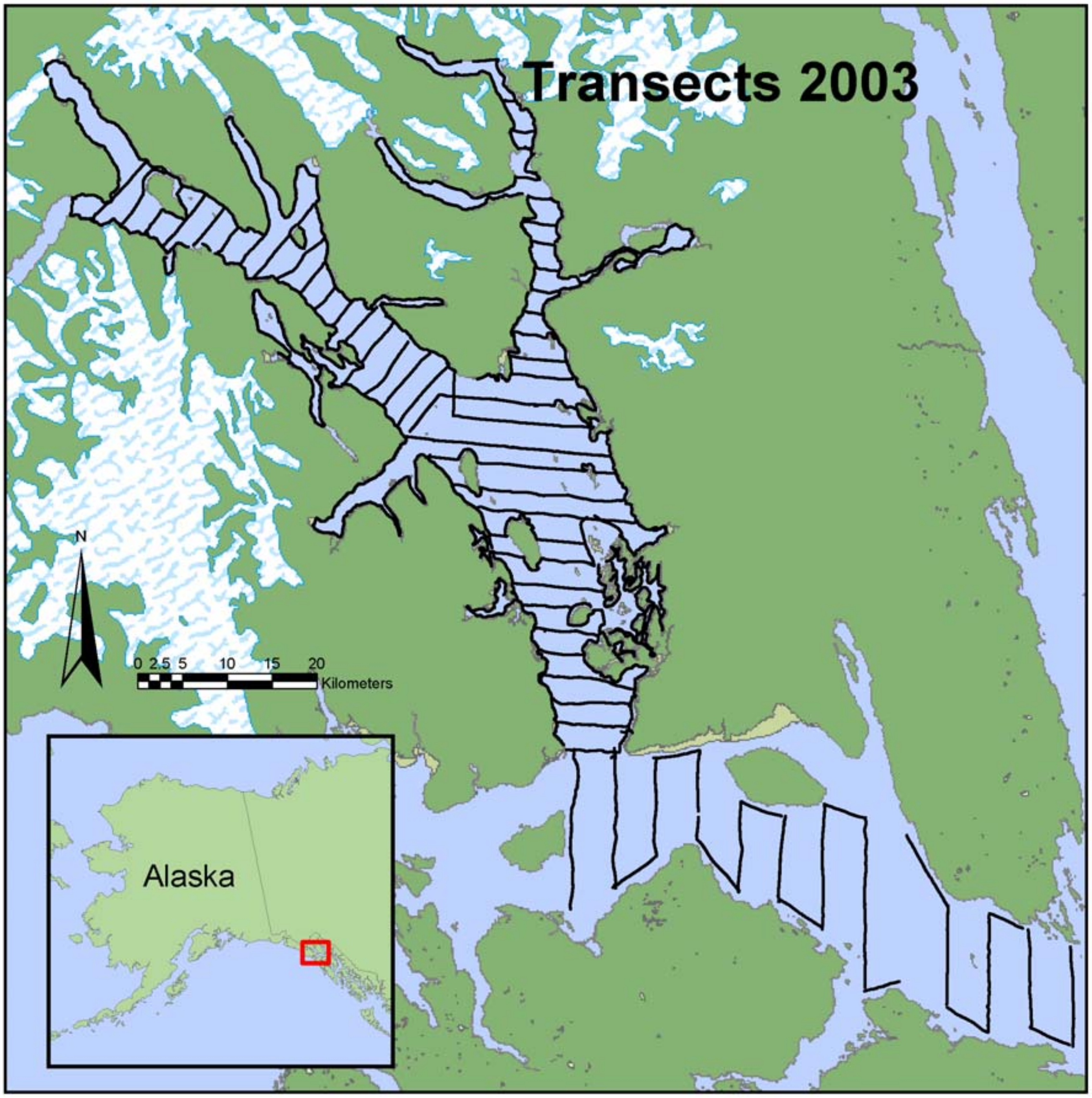

Figure 2. Survey tracks in Glacier Bay National Park and Icy Strait, Alaska from the June 2003 Marine Predator Survey (June 9-14). Surveys were conducted aboard the *RV Alaska Gyre, MV Predator* and *MV Lutris II*.

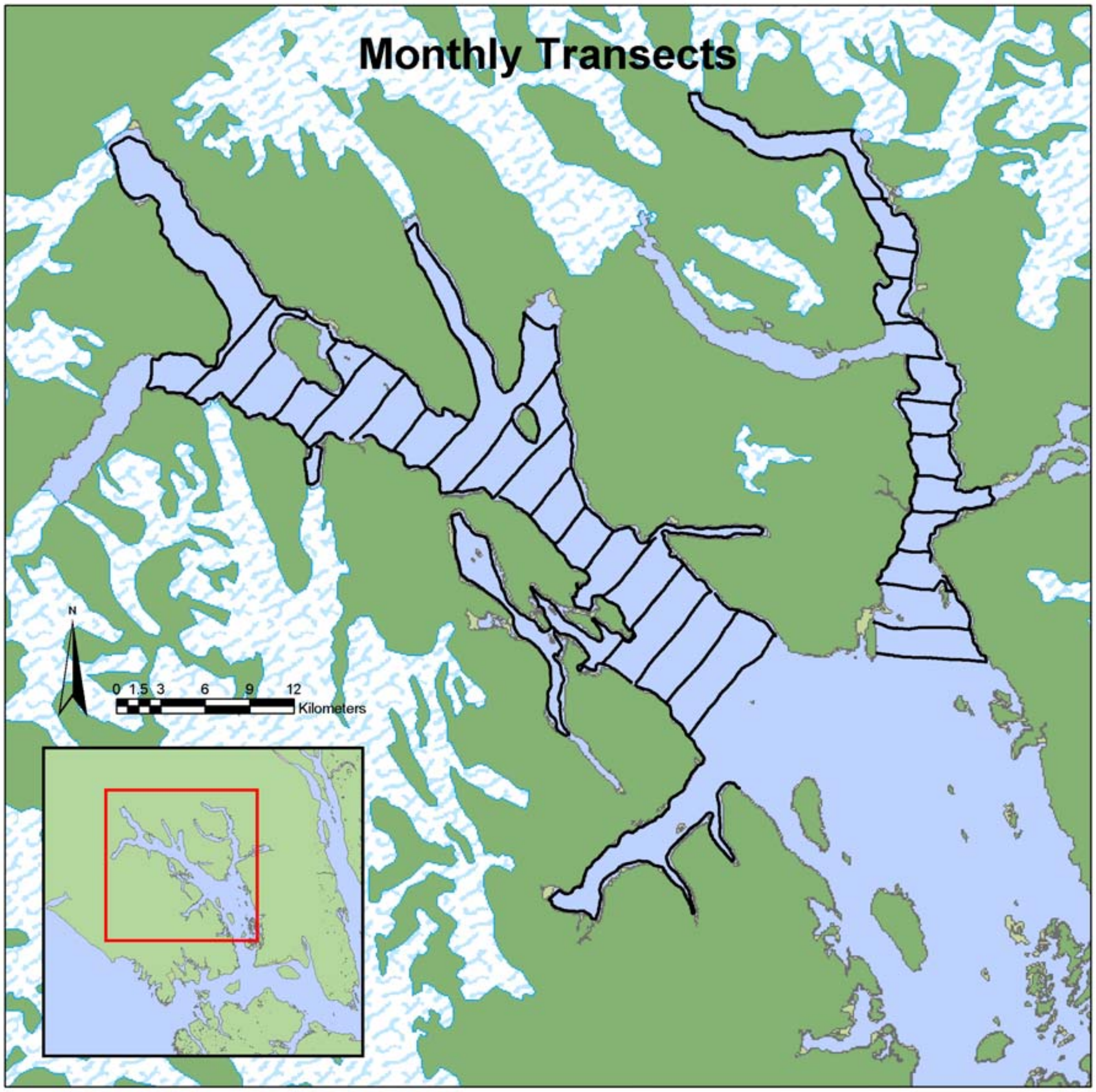

Figure 3. Survey tracks in the West Arm and Muir Inlet, Glacier Bay National Park, Alaska. Surveys were conducted monthly during June – August, 2003, aboard the *RV Alaska Gyre, MV Predator* and *MV Lutris II*.

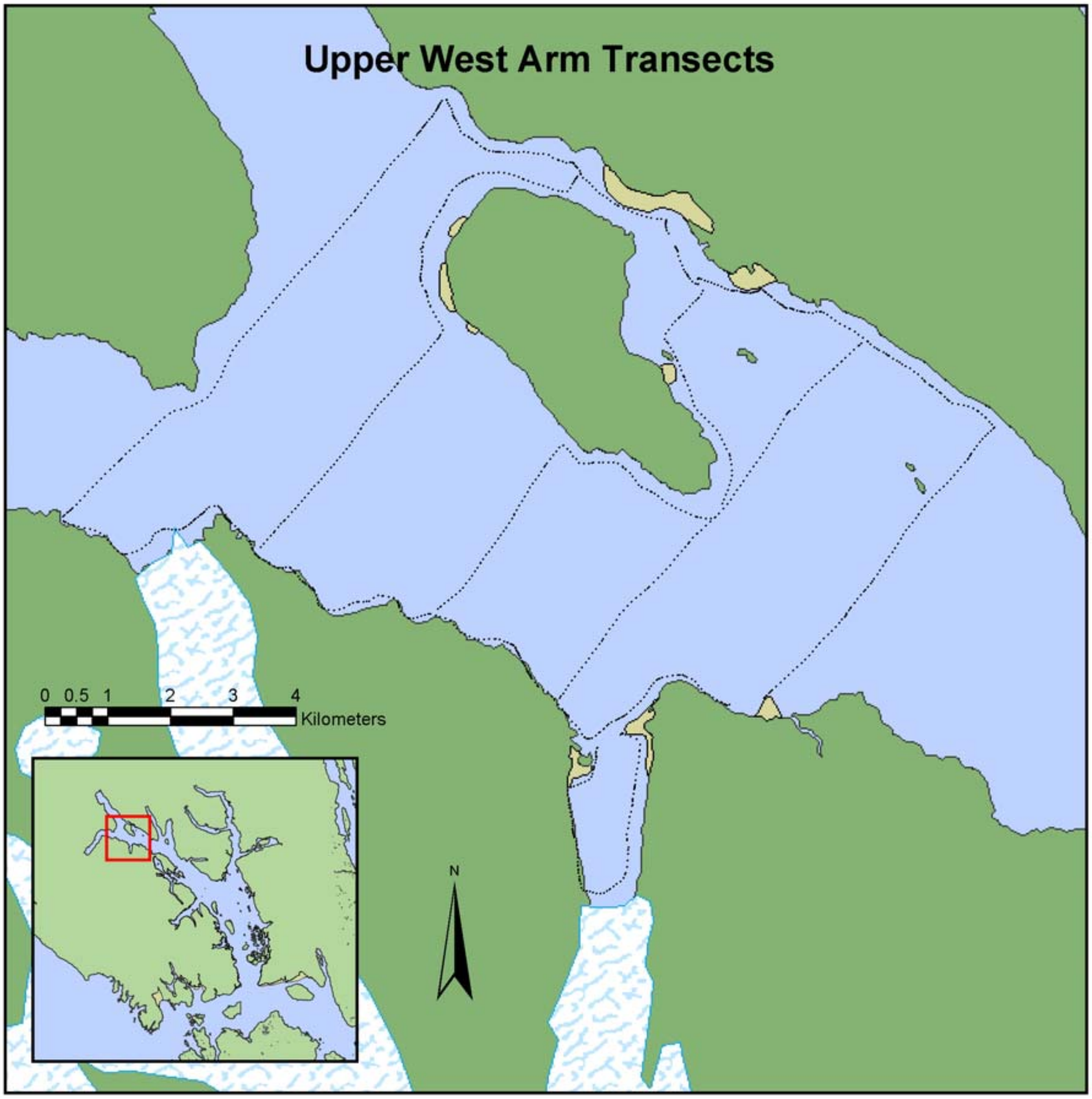

Figure 4. Survey tracks in the Upper West Arm area of Glacier Bay National Park, Alaska. Surveys were conducted weekly from June 15 - August 6, 2003, aboard the *RV Alaska Gyre, MV Predator* and *MV Lutris II*. Surveys were also conducted daily from June 22 - June 26, 2003 aboard the *MV Predator.*

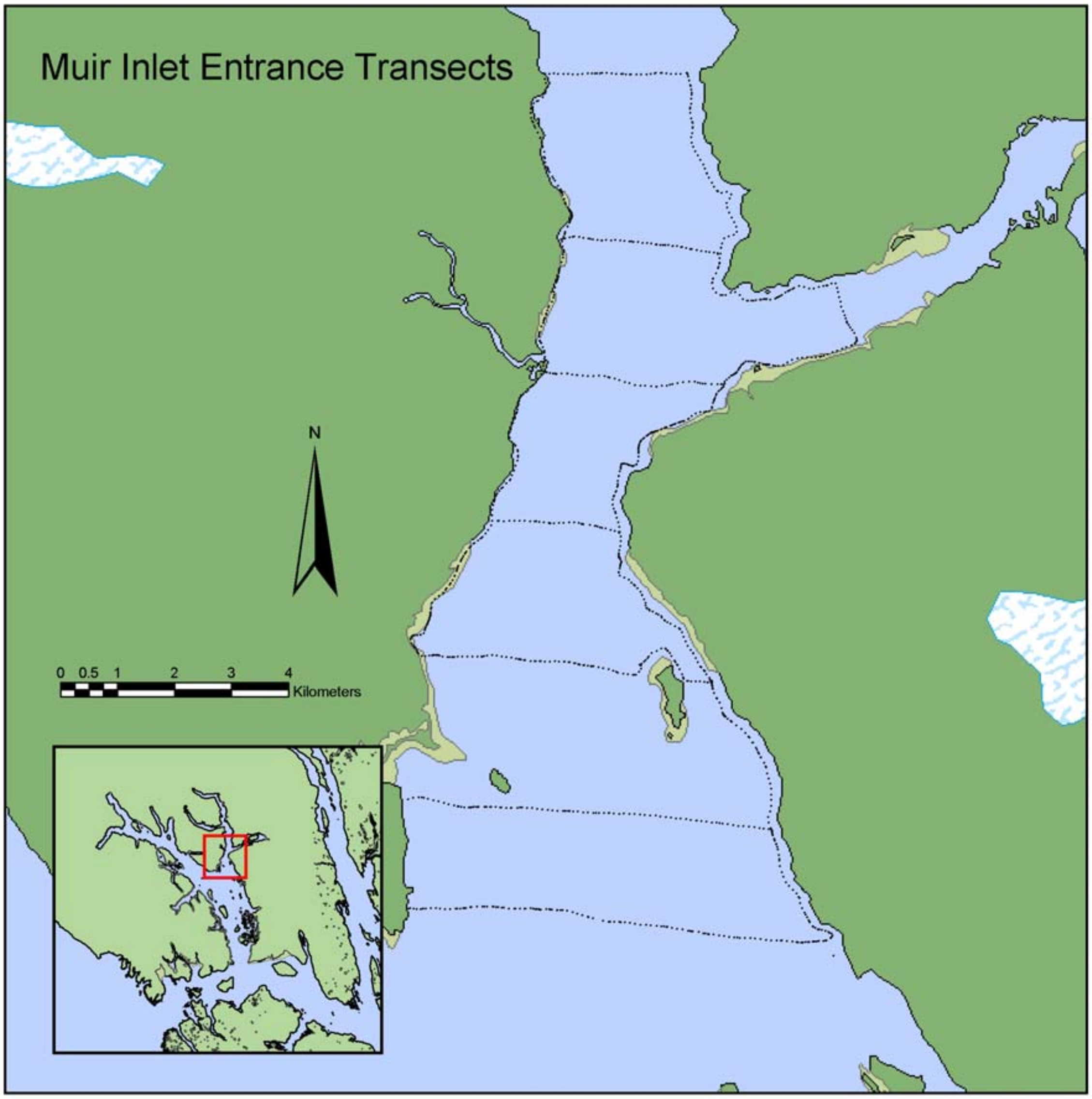

Figure 5. Survey tracks in the Muir Inlet Entrance area of Glacier Bay National Park, Alaska. Surveys were conducted weekly from June 14 - August 5, 2003, aboard the *RV Alaska Gyre, MV Predator* and *MV Lutris II*.

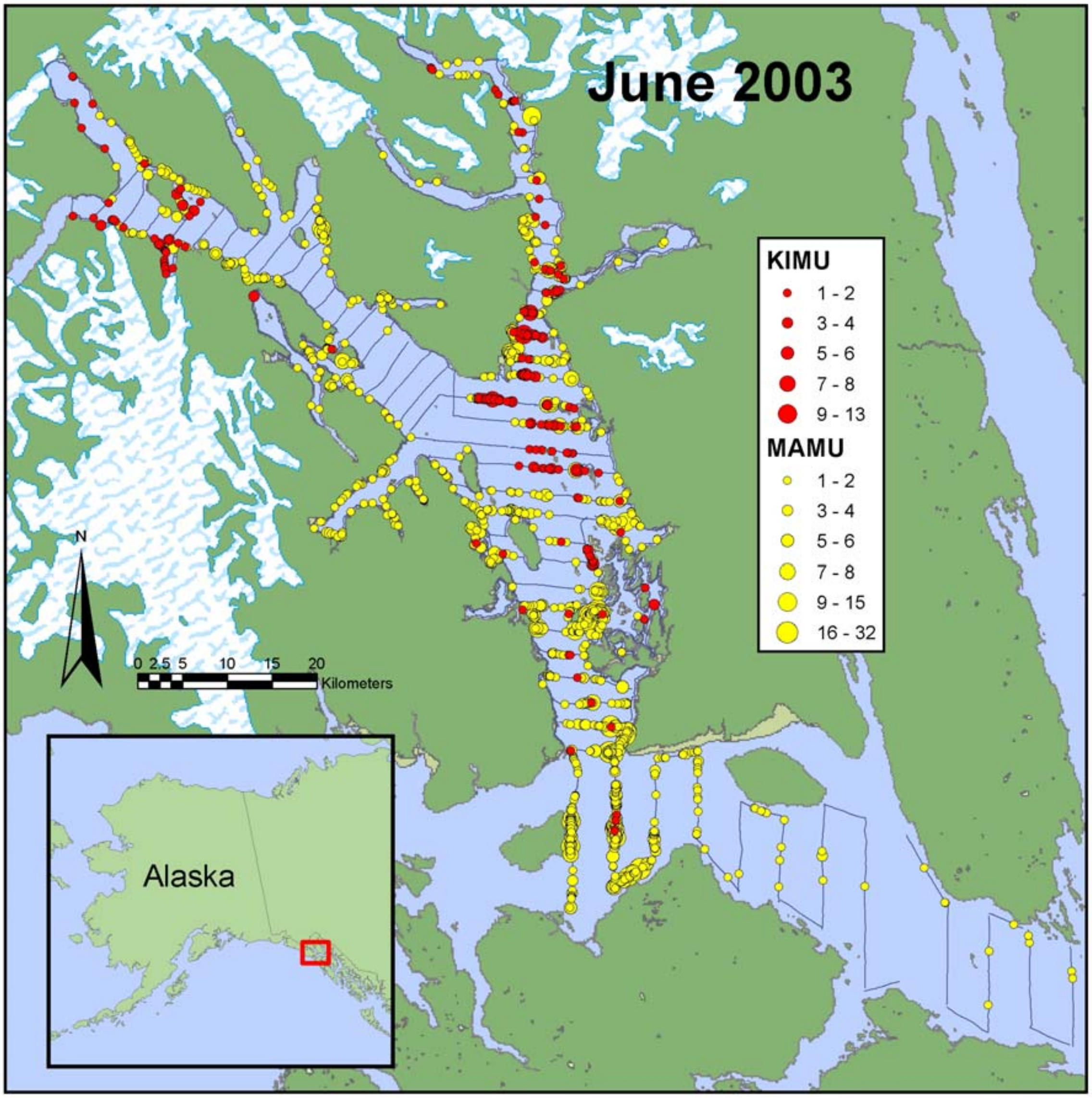

Figure 6. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in Glacier Bay and Icy Strait, Alaska during surveys conducted from June 9 – 14, 2003. Blue lines indicate survey tracks. Surveys were conducted aboard the *RV Alaska Gyre, MV Predator* and *MV Lutris II*.

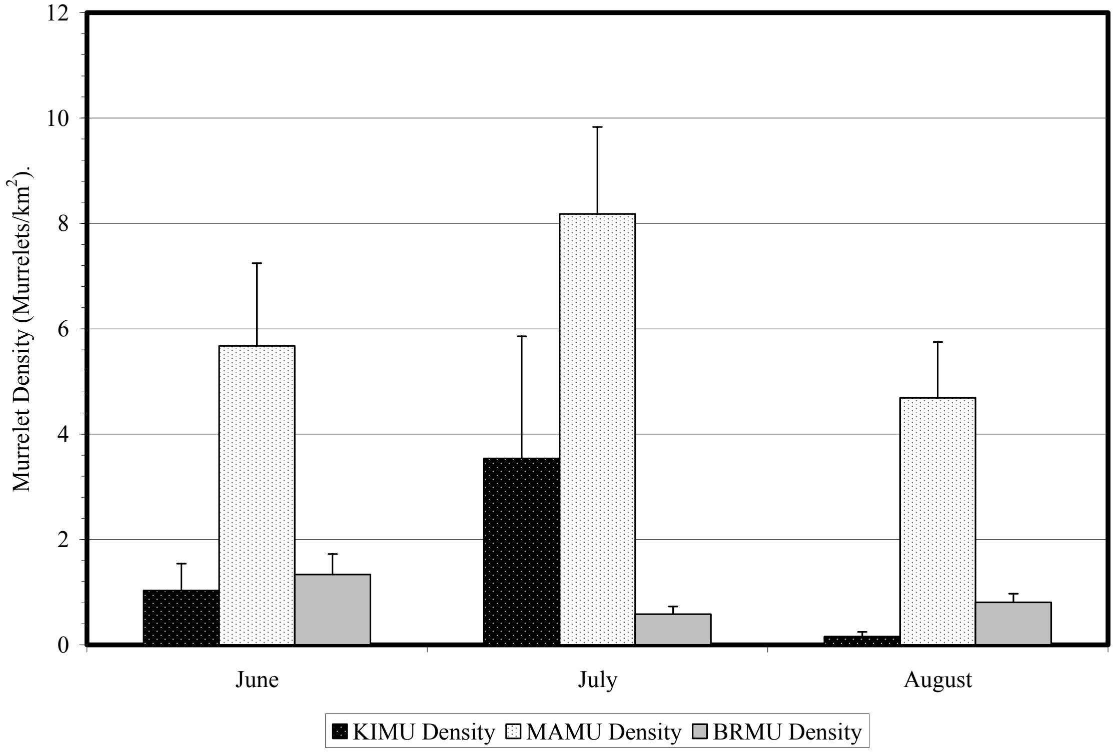

Figure 7. Density (birds/km^2; + 1 SE) of Kittlitz's Murrelets (KIMU), Marbled Murrelets (MAMU), and unidentified murrelets (BRMU), in the West Arm of Glacier Bay National Park, from June to August 2003.

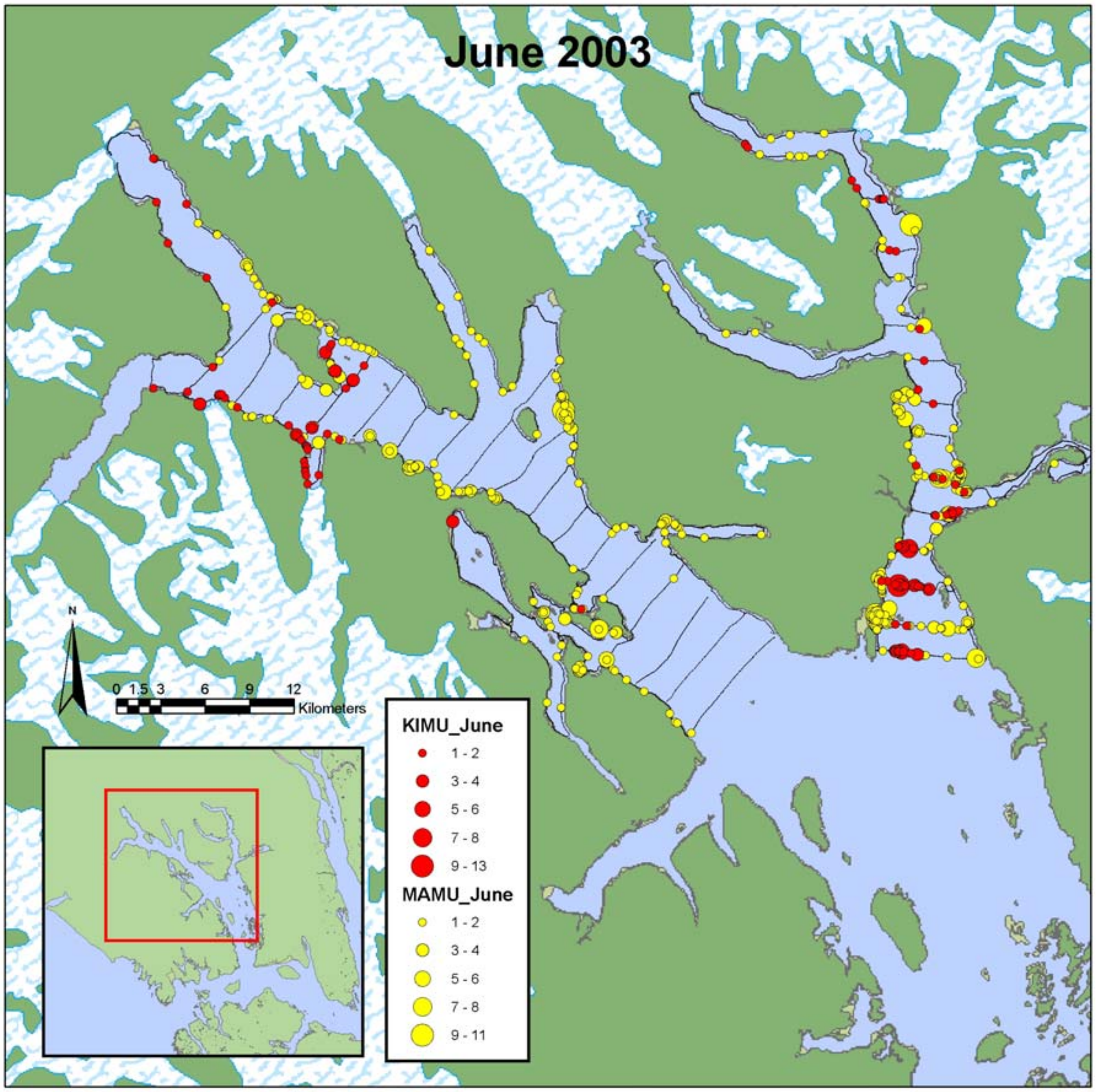

Figure 8a. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the West Arm and Muir Inlet of Glacier Bay National Park during surveys conducted in June 2003. Black lines indicate survey tracks. Surveys were conducted aboard the *RV Alaska Gyre, MV Predator* and *MV Lutris II*.

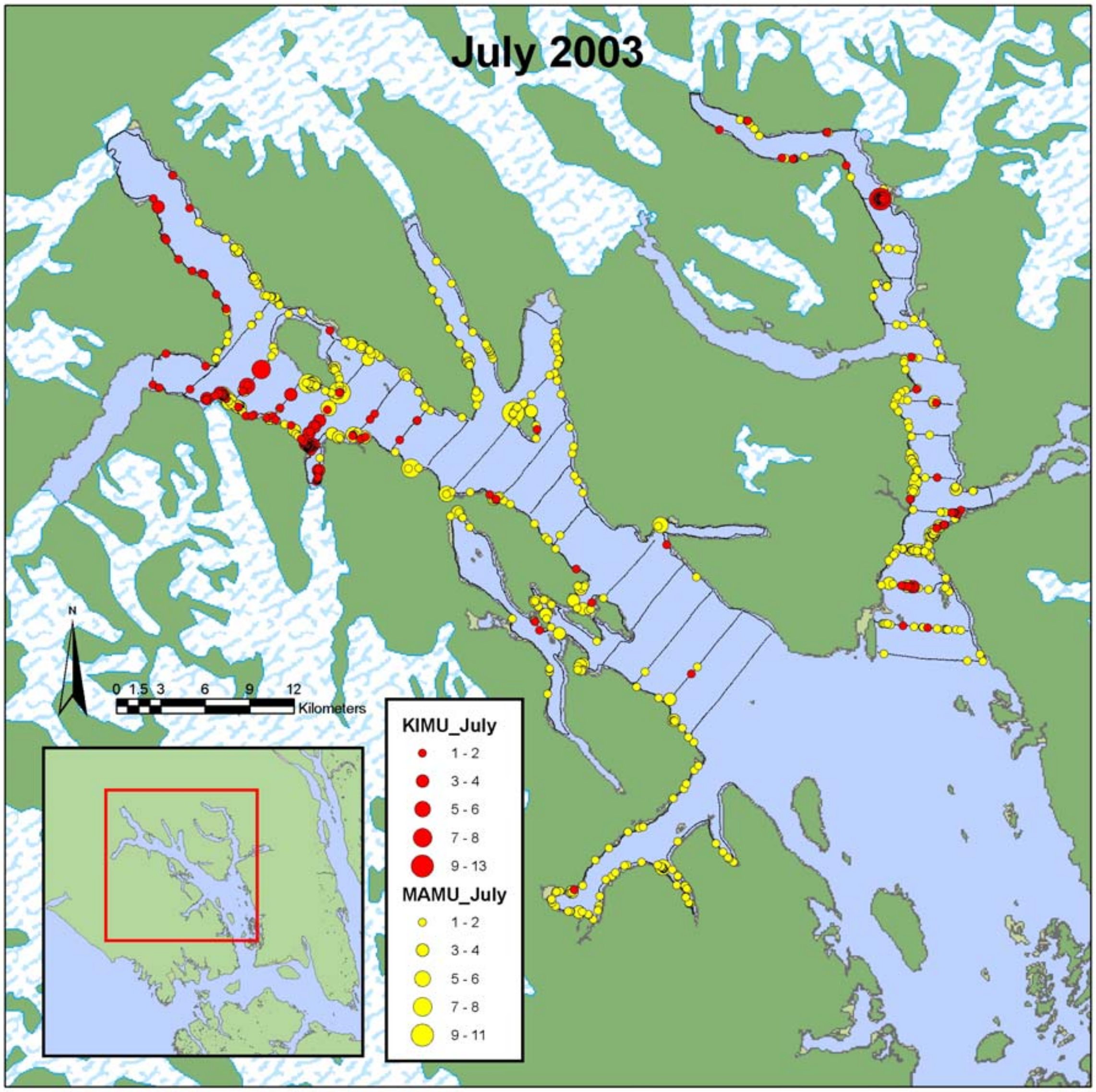

Figure 8b. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the West Arm and Muir Inlet of Glacier Bay National Park during surveys conducted in July 2003. Black lines indicate survey tracks. Surveys were conducted aboard the *MV Predator.*

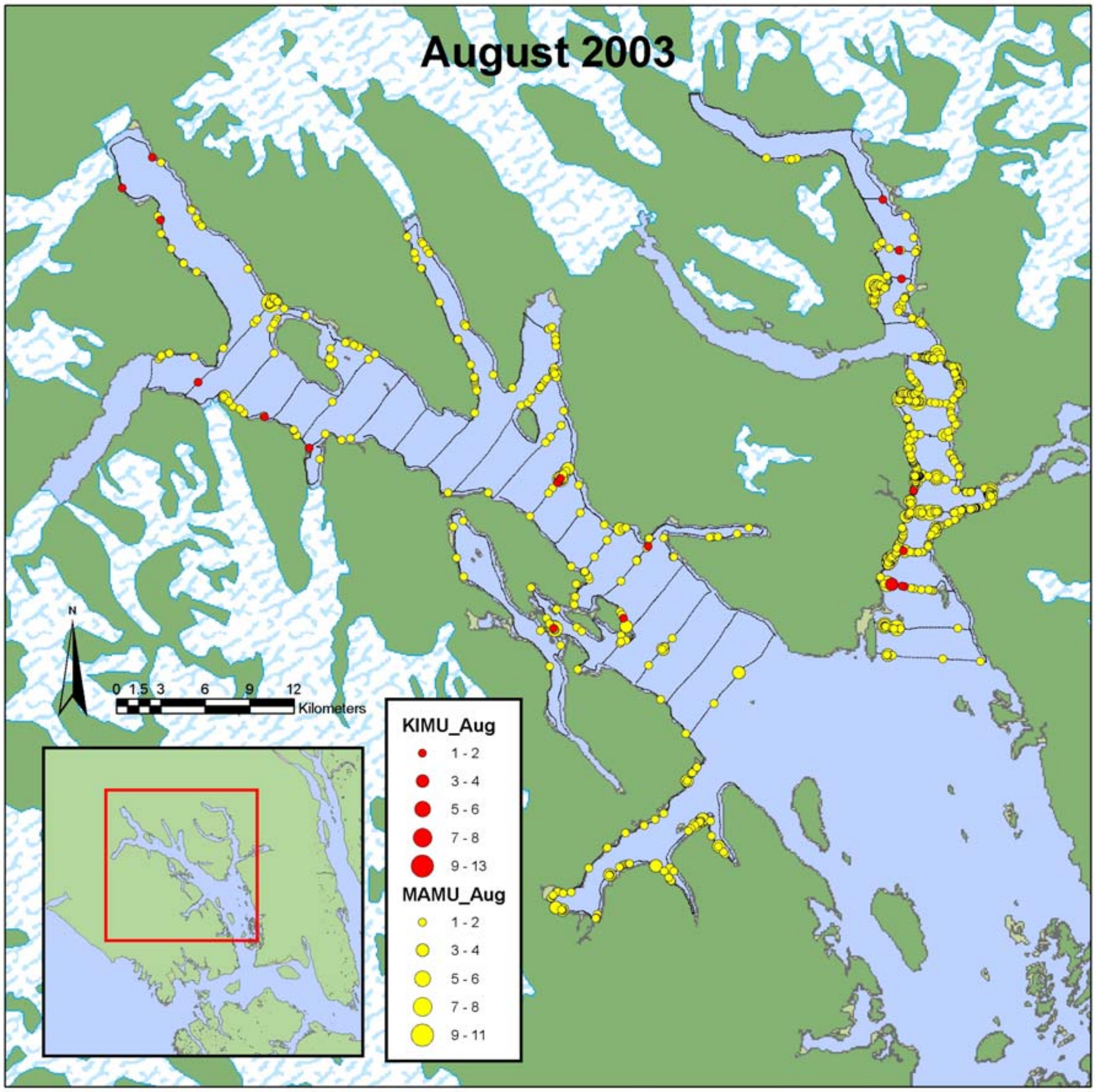

Figure 8c. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the West Arm and Muir Inlet of Glacier Bay National Park during surveys conducted in August 2003. Black lines indicate survey tracks. Surveys were conducted aboard the *MV Predator* and the *MV Lutris II*.

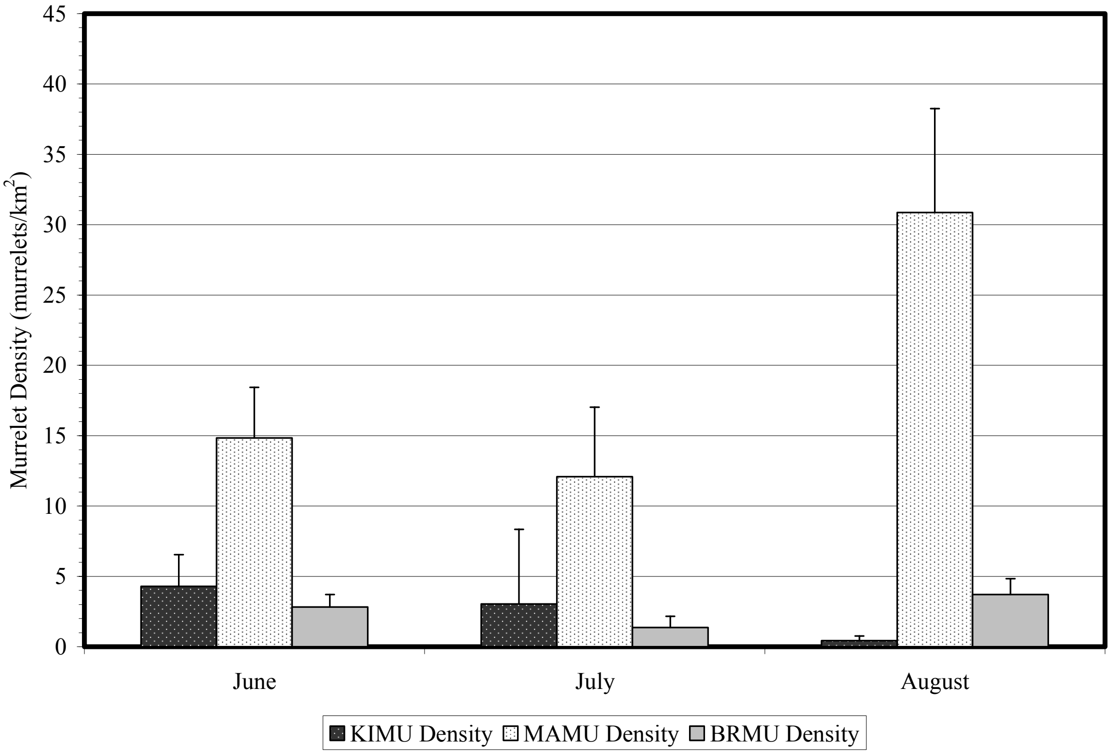

Figure 9. Density (birds/km^2; + 1 SE) of Kittlitz's Murrelets (KIMU), Marbled Murrelets (MAMU), and unidentified murrelets (BRMU), in Muir Inlet, Glacier Bay National Park, from June through August 2003.

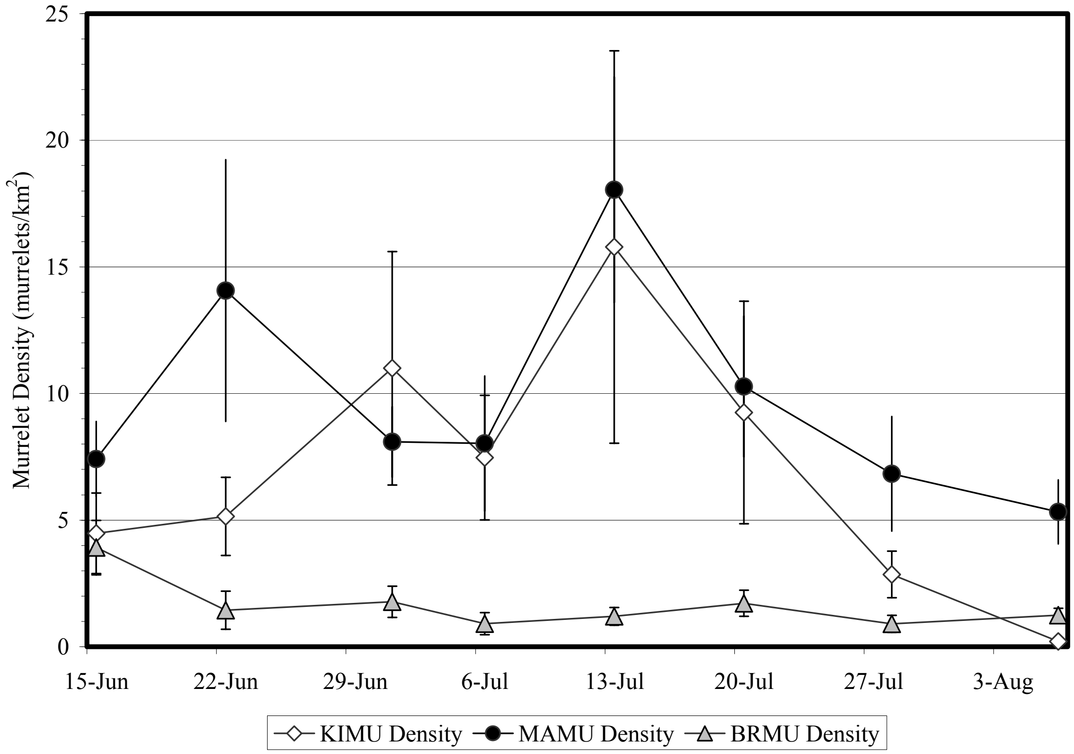

Figure 10. Density (birds/km^2; ± 1 SE) of Kittlitz's Murrelets (KIMU), Marbled Murrelets (MAMU), and unidentified murrelets (BRMU), in the Upper West Arm area of Glacier Bay National Park. Surveys were conducted weekly (mean = 7.4 days) from June 15 through August 6, 2003.

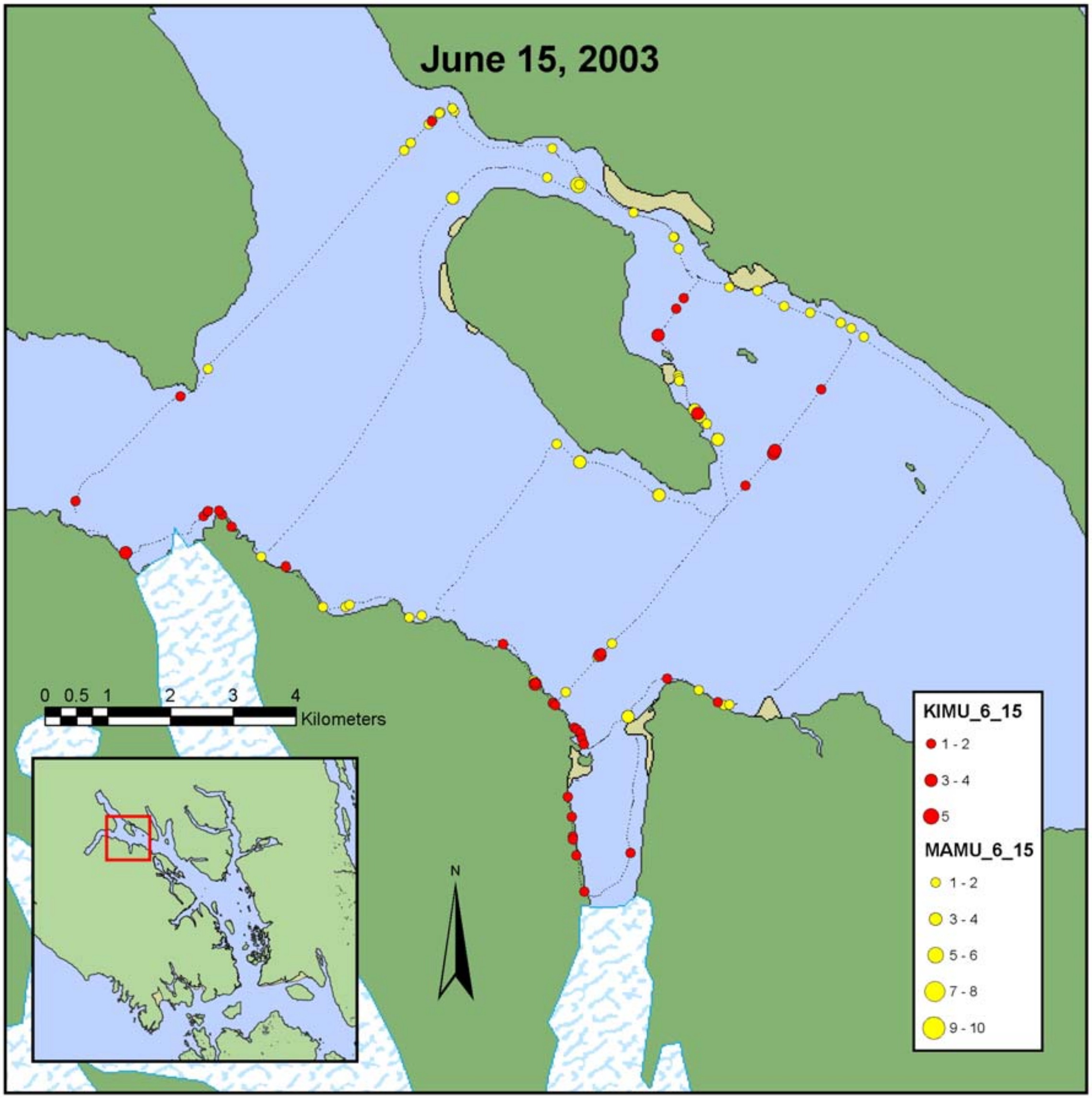

Figure 11a. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the Upper West Arm area of Glacier Bay National Park during a survey conducted on June 15, 2003. Black lines indicate survey track. The survey was conducted aboard the *MV Predator*.

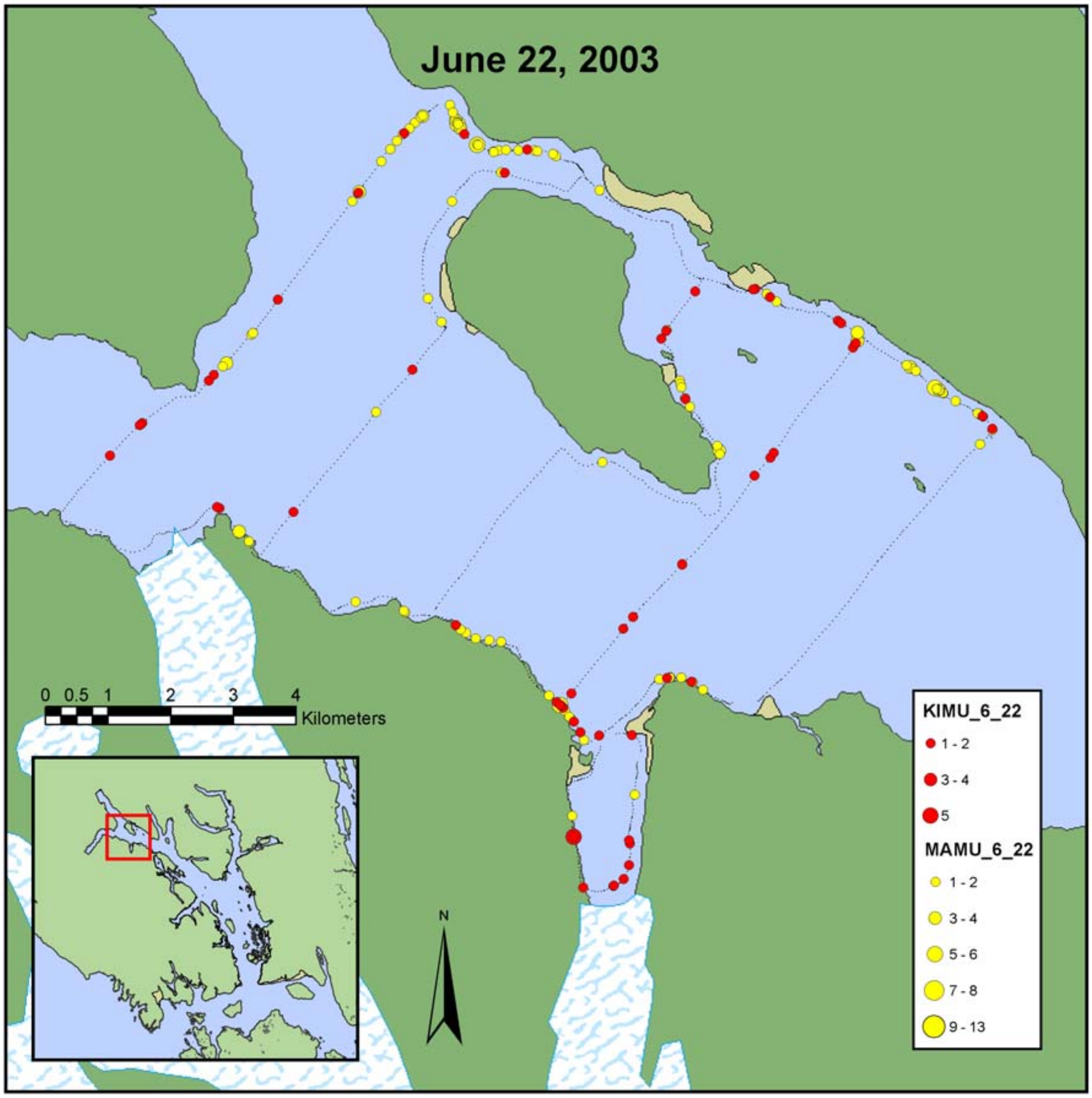

Figure 11b. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the Upper West Arm area of Glacier Bay National Park during a survey conducted on June 22, 2003. Black lines indicate survey track. The survey was conducted aboard the *MV Predator*.

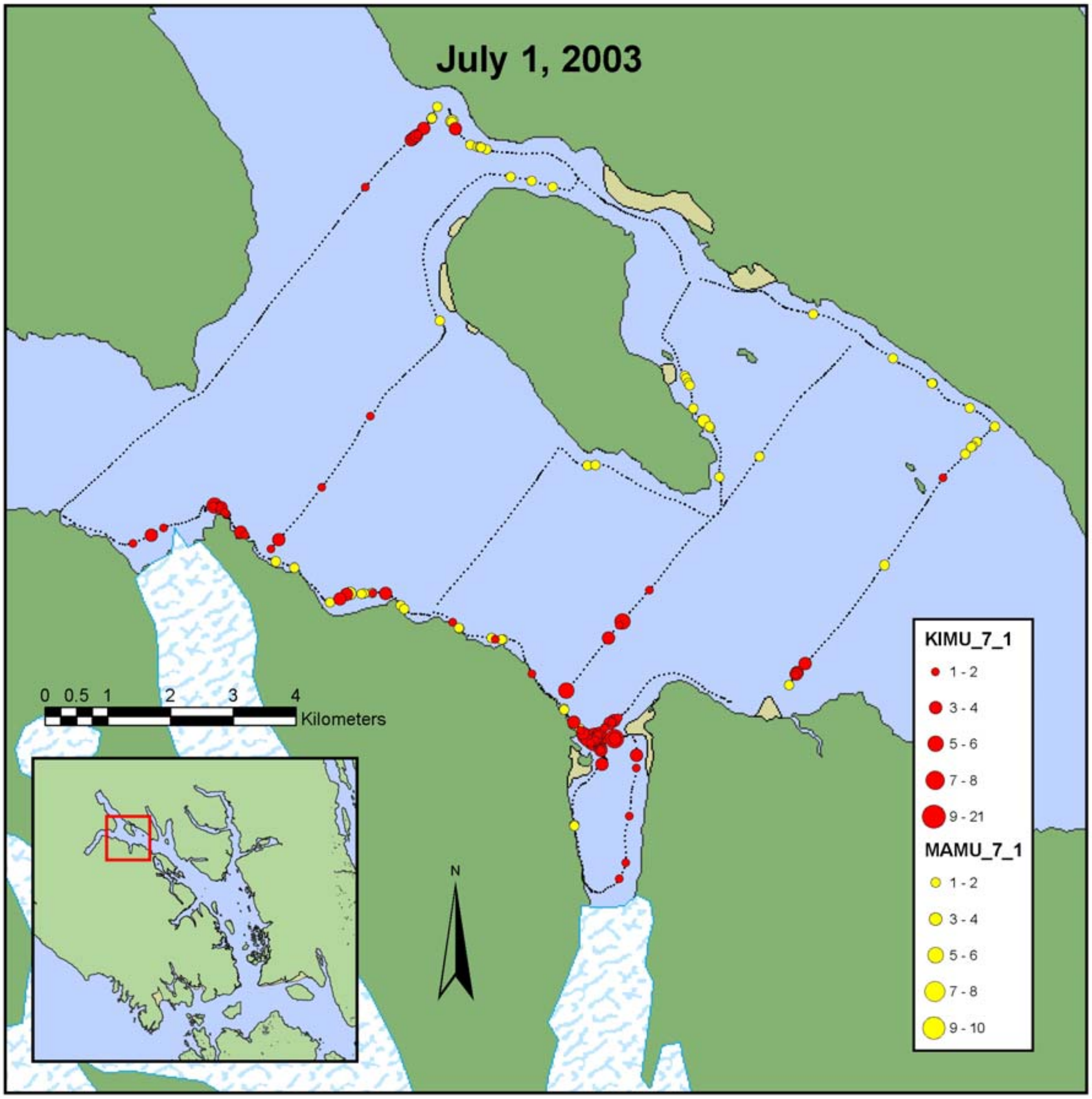

Figure 11c. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the Upper West Arm area of Glacier Bay National Park during a survey conducted on July 1, 2003. Black lines indicate survey track. The survey was conducted aboard the *MV Predator*.

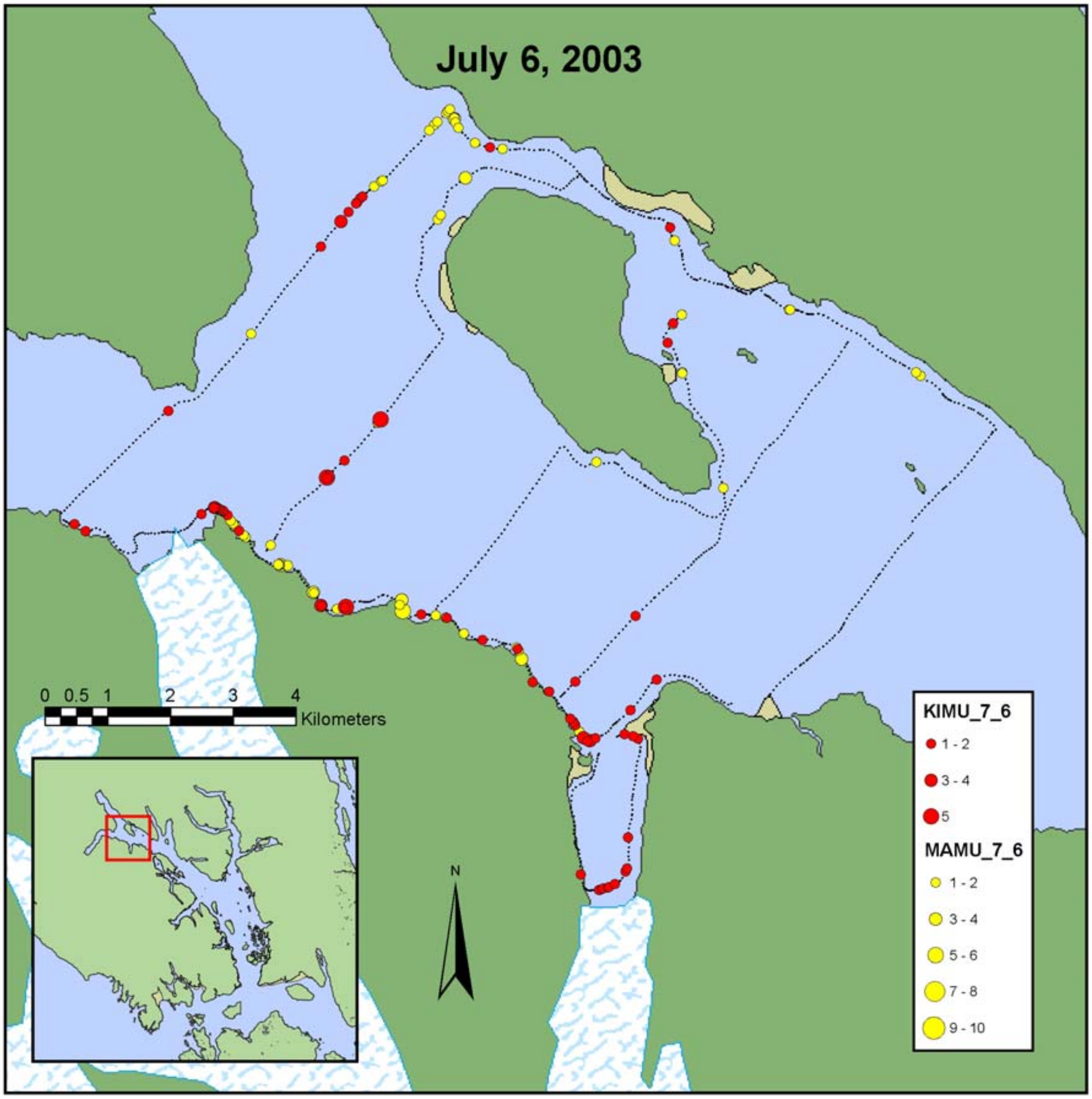

Figure 11d. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the Upper West Arm area of Glacier Bay National Park during a survey conducted on July 6, 2003. Black lines indicate survey track. The survey was conducted aboard the *MV Predator*.

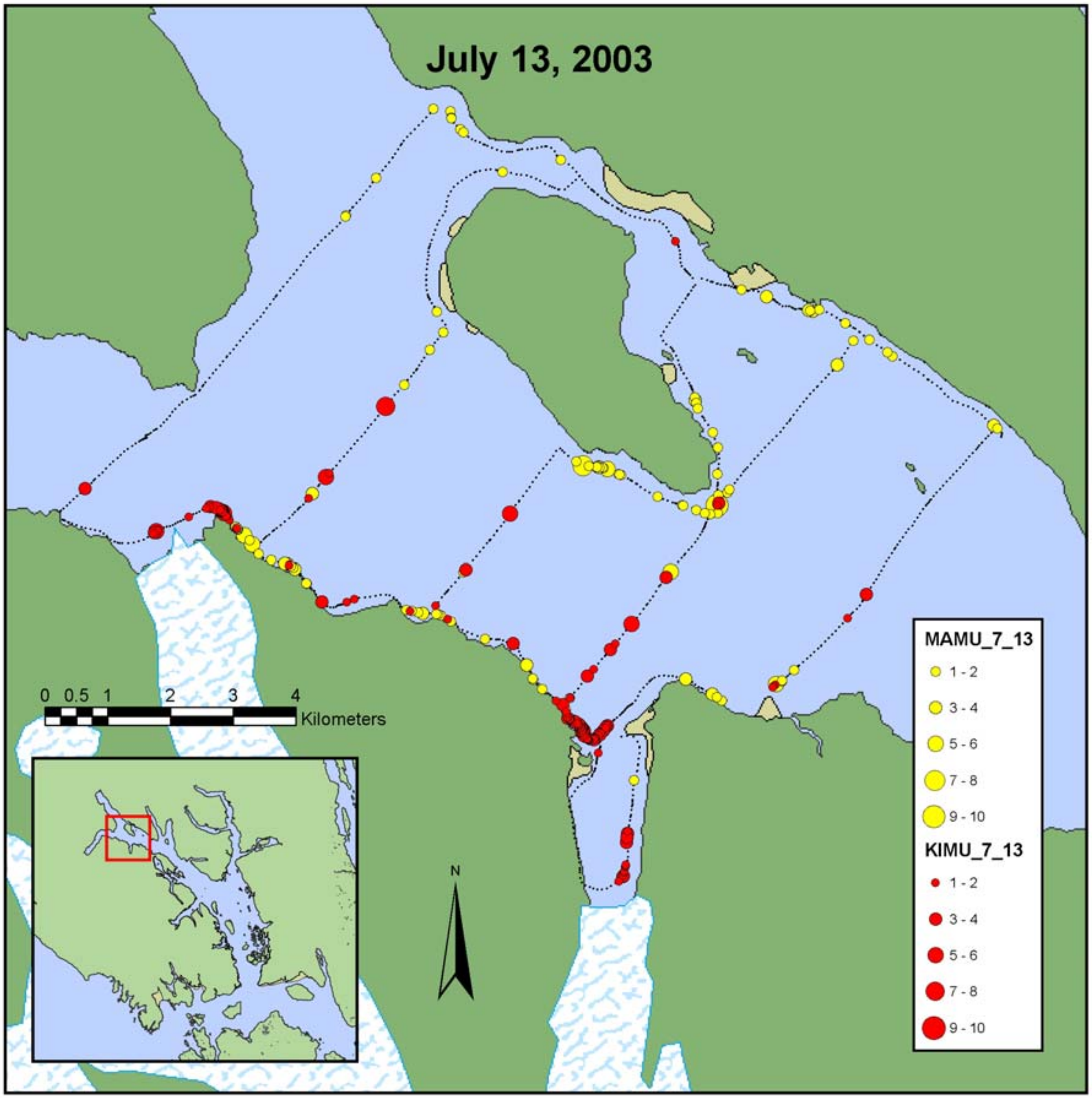

Figure 11e. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the Upper West Arm area of Glacier Bay National Park during a survey conducted on July 13, 2003. Black lines indicate survey track. The survey was conducted aboard the *MV Predator*.

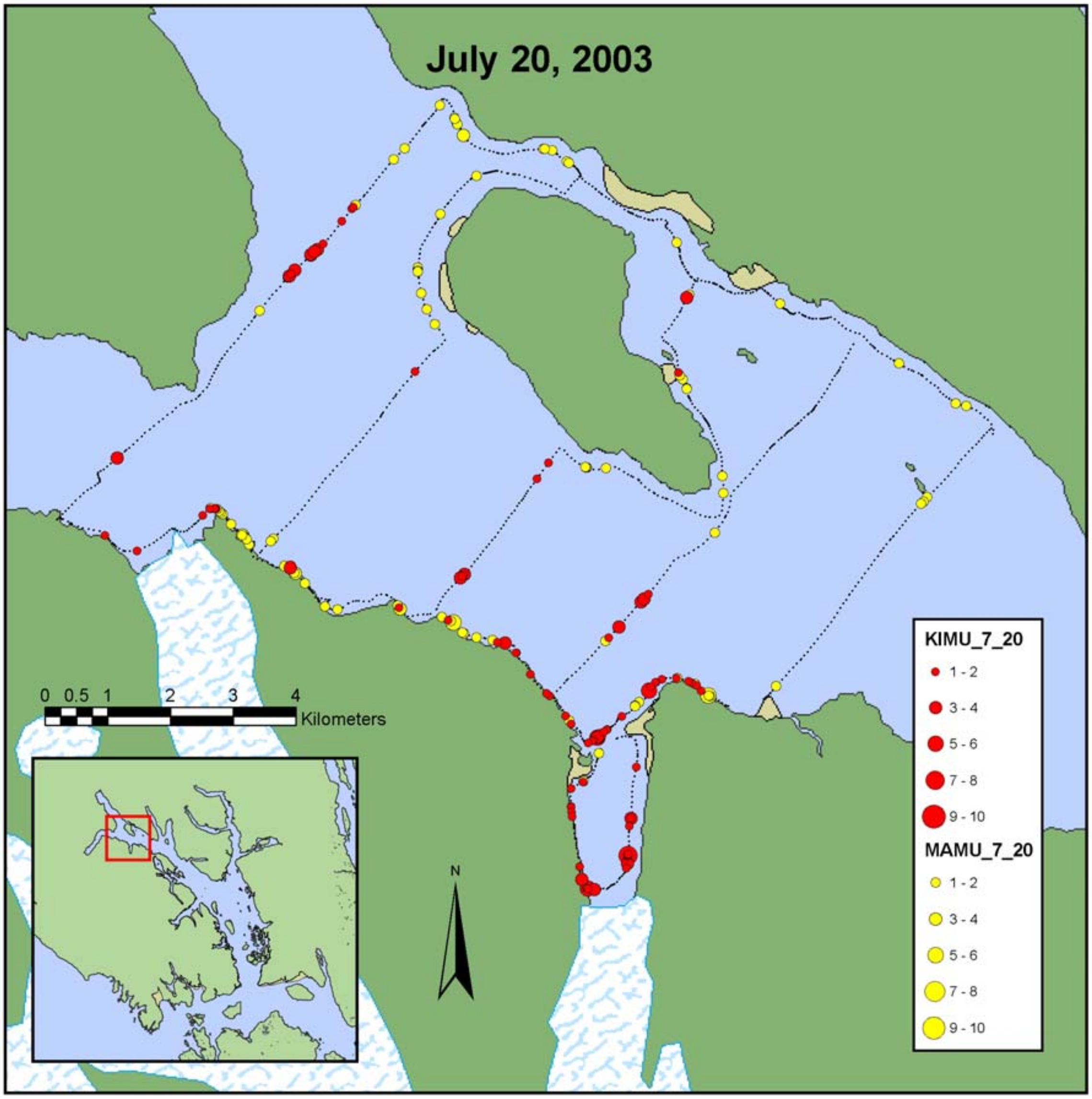

Figure 11f. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the Upper West Arm area of Glacier Bay National Park during a survey conducted on July 20, 2003. Black lines indicate survey track. The survey was conducted aboard the *MV Predator*.

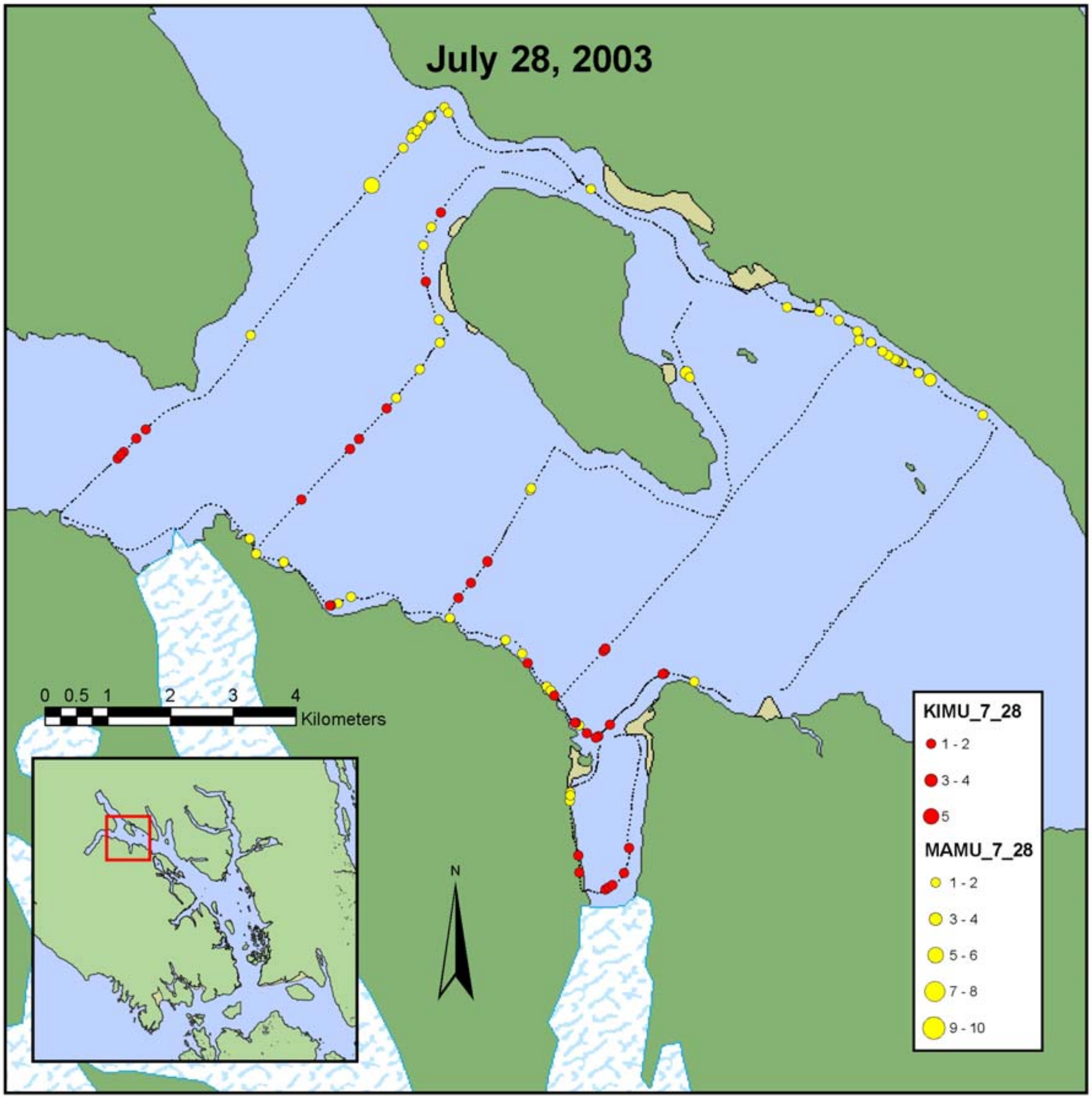

Figure 11g. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the Upper West Arm area of Glacier Bay National Park during a survey conducted on July 28, 2003. Black lines indicate survey track. The survey was conducted aboard the *MV Predator*.

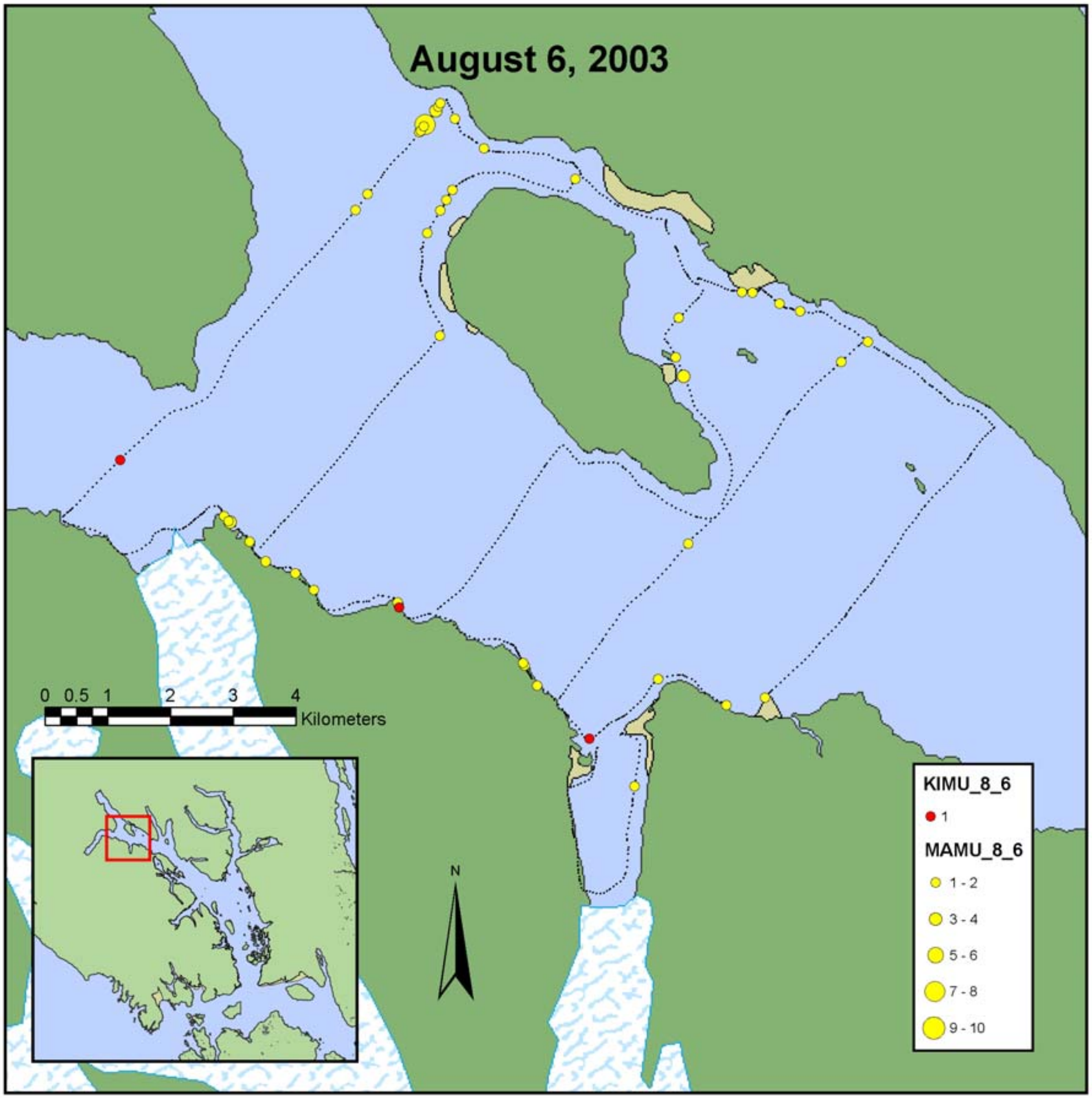

Figure 11h. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the Upper West Arm area of Glacier Bay National Park during a survey conducted on August 6, 2003. Black lines indicate survey track. The survey was conducted aboard the *MV Predator*.

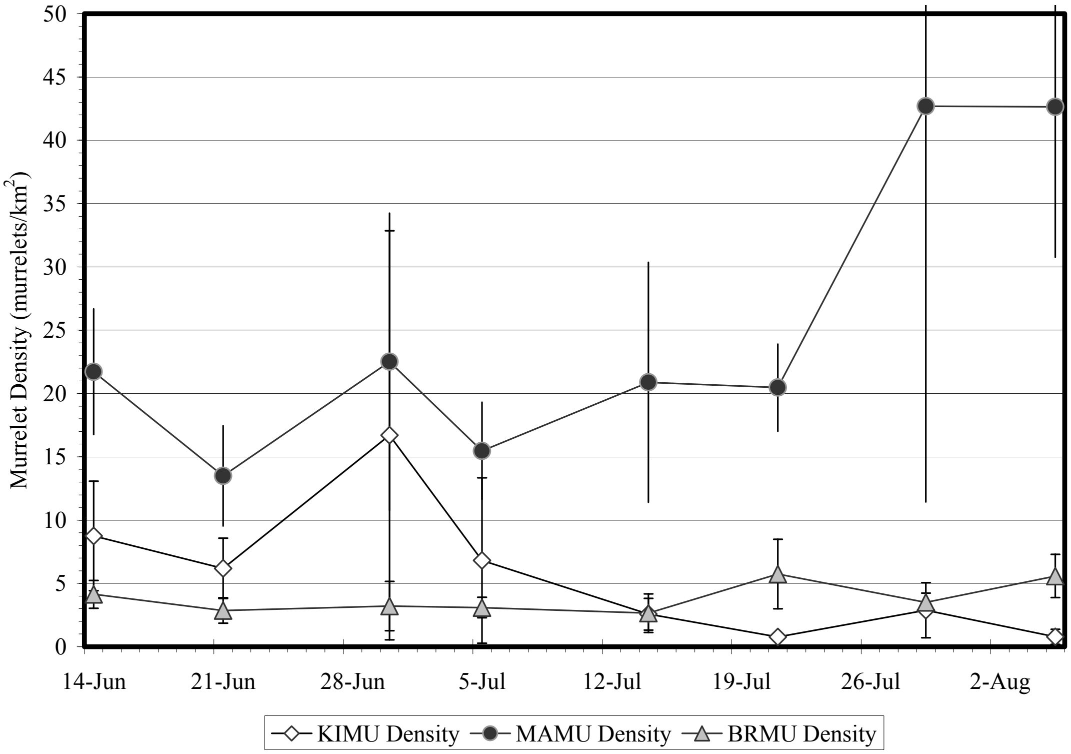

Figure 12. Density (birds/km^2; ± 1 SE) of Kittlitz's Murrelets (KIMU), Marbled Murrelets (MAMU), and unidentified murrelets (BRMU), in the Muir Inlet Entrance area of Glacier Bay National Park. Surveys were conducted weekly (mean = 7.4 days) from June 16 to August 5, 2003.

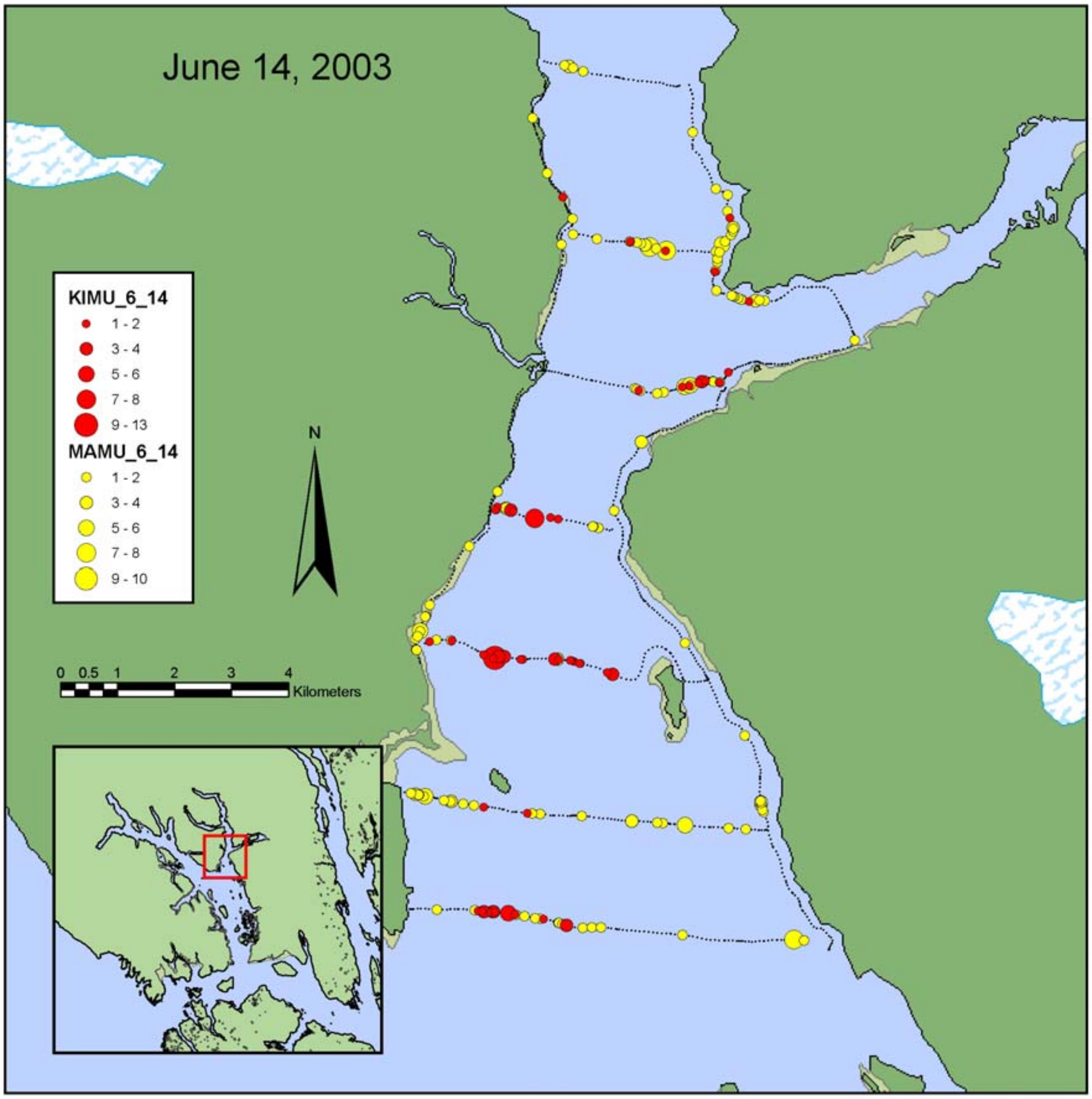

Figure 13a. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the Muir Inlet Entrance area of Glacier Bay National Park during a survey conducted on June 14, 2003. Black lines indicate survey track. The survey was conducted aboard the *MV Predator*.

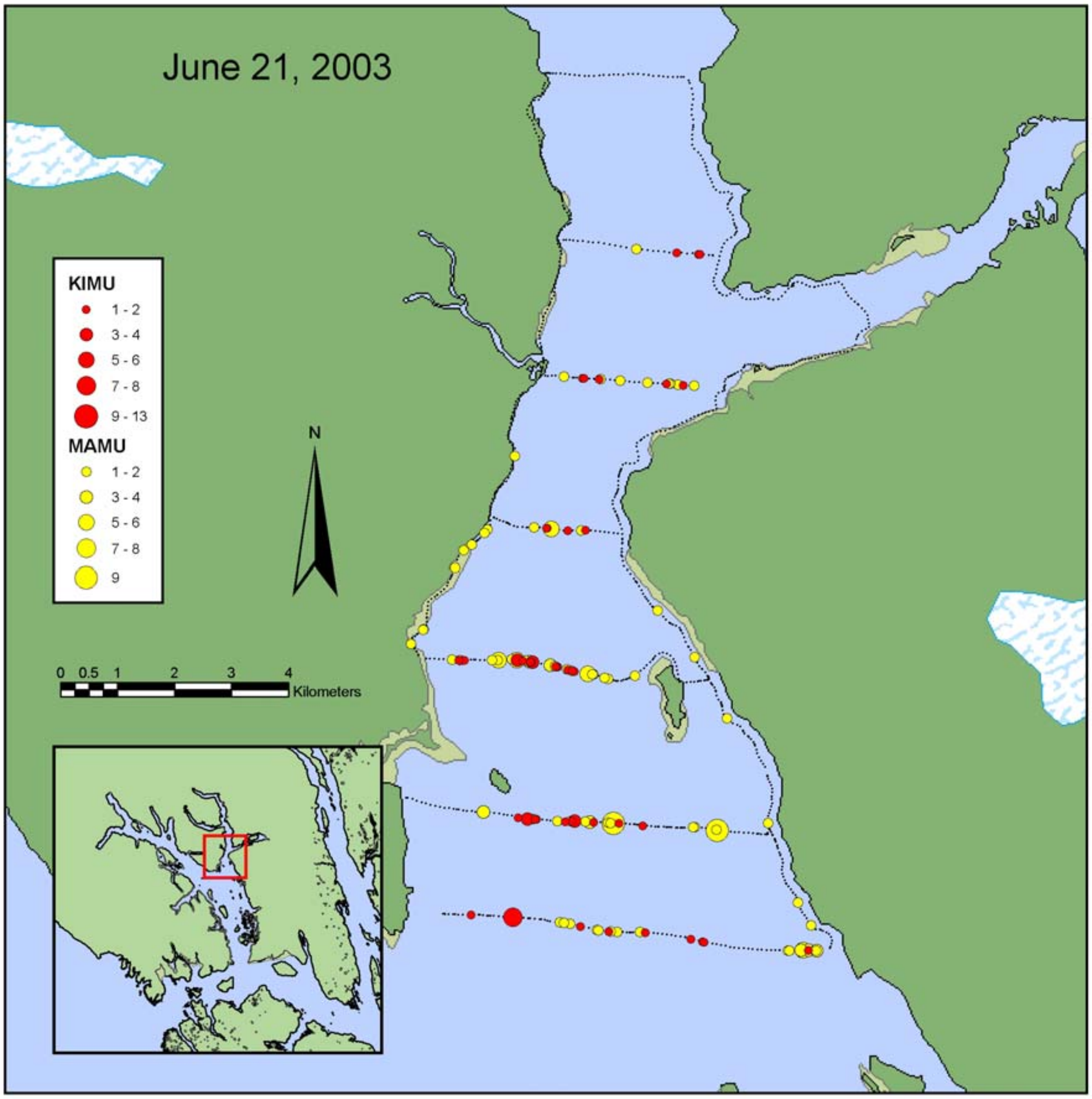

Figure 13b. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the Muir Inlet Entrance area of Glacier Bay National Park during a survey conducted on June 21, 2003. Black lines indicate survey track. The survey was conducted aboard the *MV Predator*.

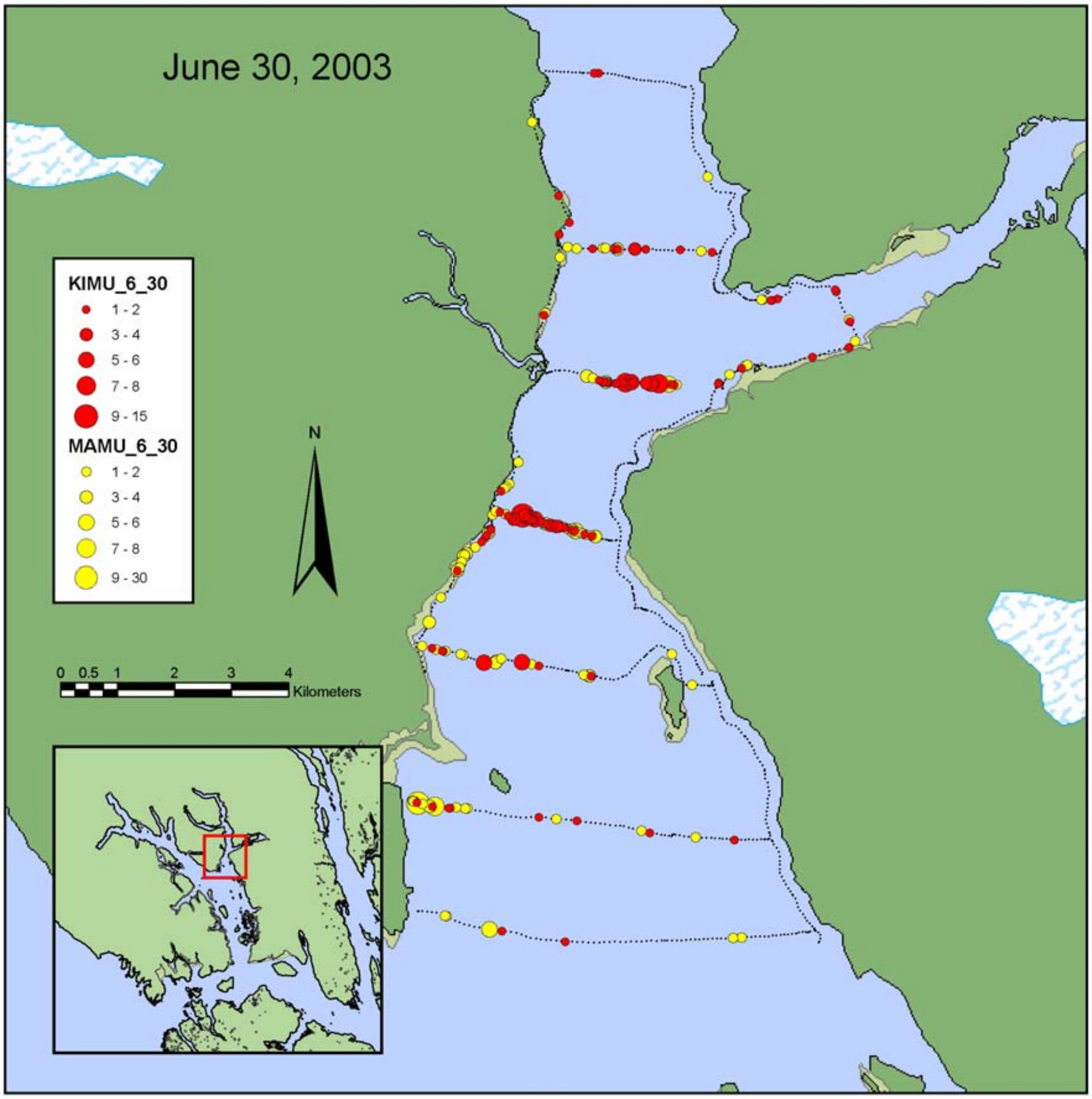

Figure 13c. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the Muir Inlet Entrance area of Glacier Bay National Park during a survey conducted on June 30, 2003. Black lines indicate survey track. The survey was conducted aboard the *MV Predator*.

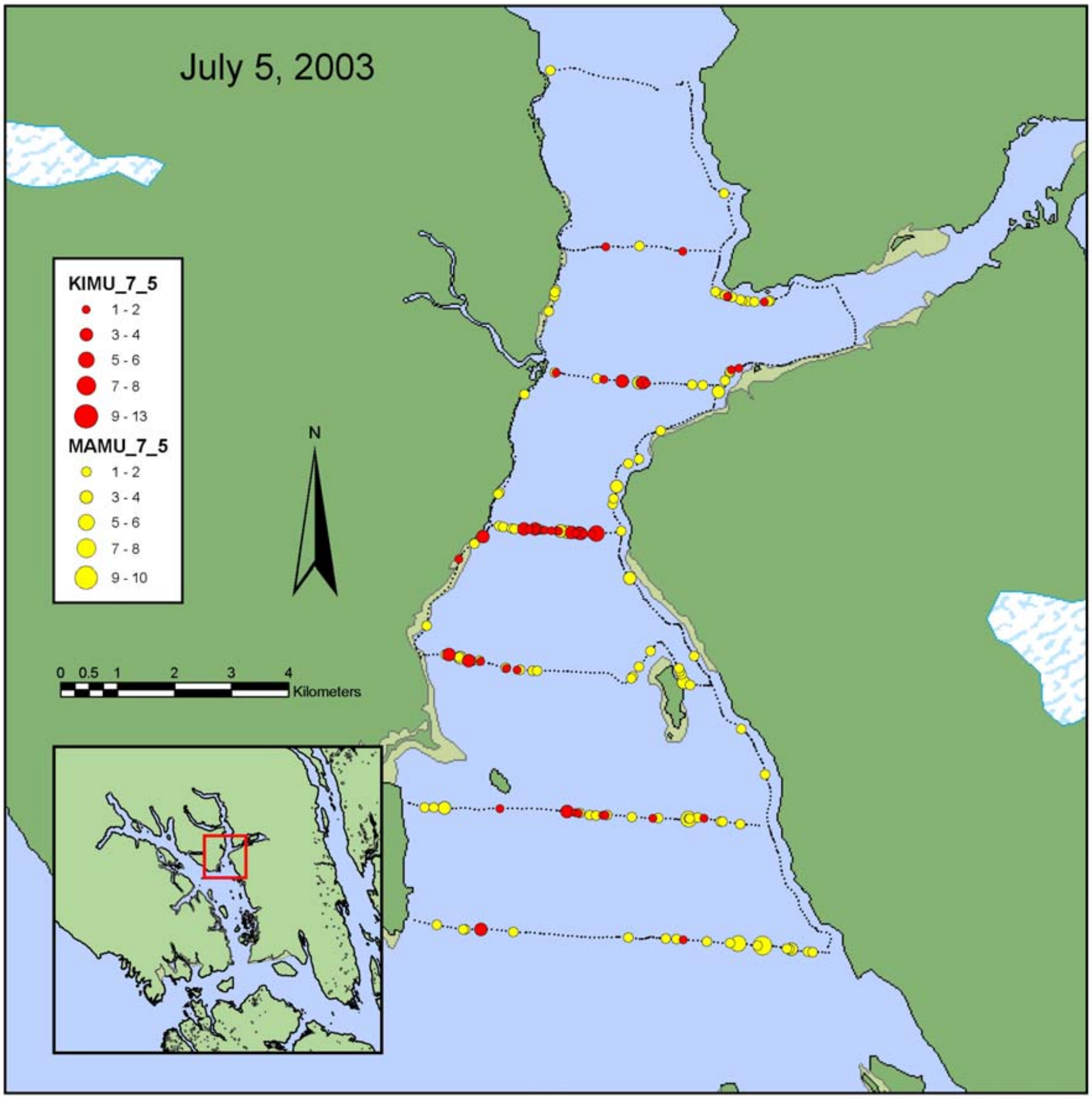

Figure 13d. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the Muir Inlet Entrance area of Glacier Bay National Park during a survey conducted on July 5, 2003. Black lines indicate survey track. The survey was conducted aboard the *MV Predator*.

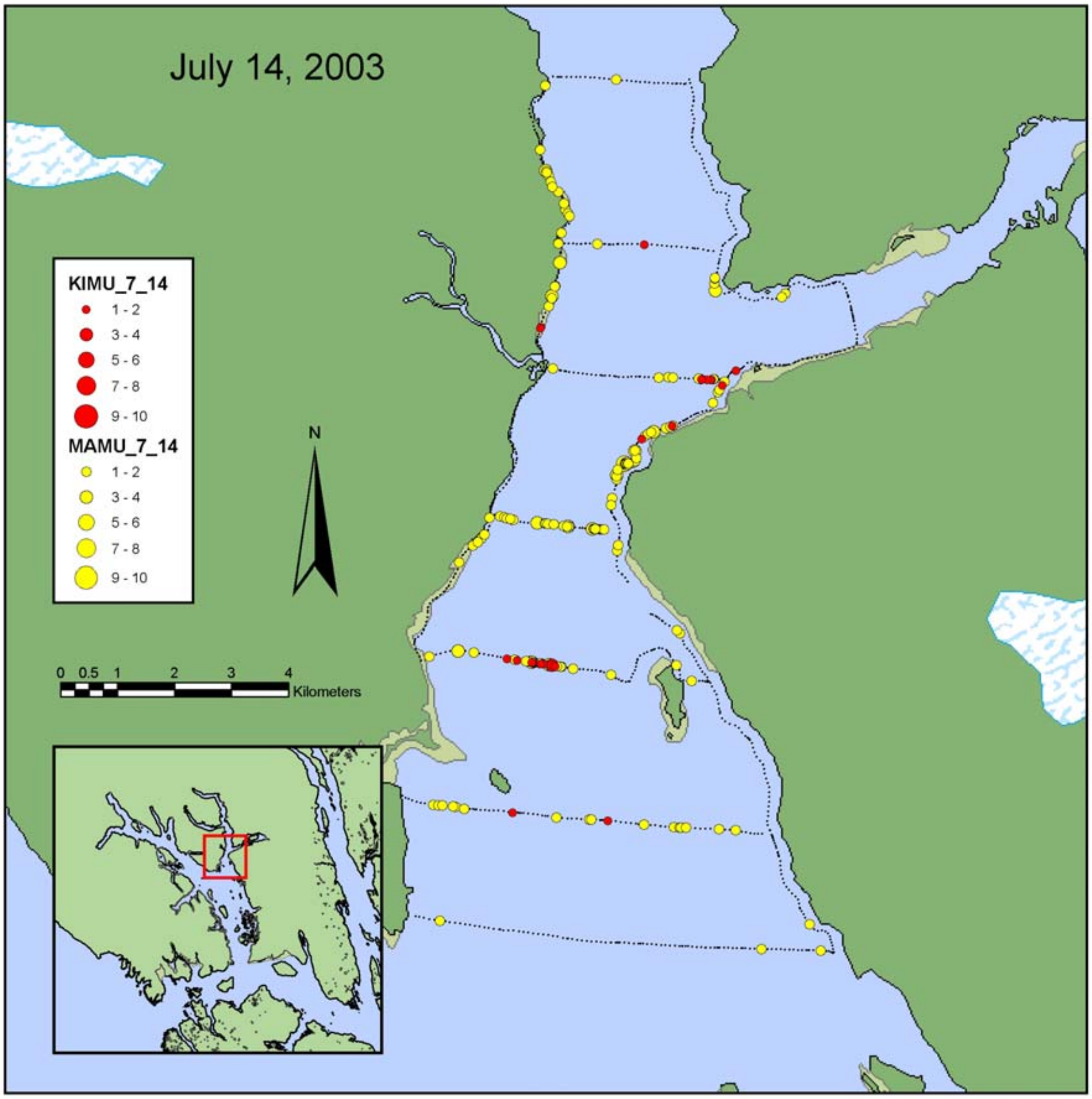

Figure 13e. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the Muir Inlet Entrance area of Glacier Bay National Park during a survey conducted on July 14, 2003. Black lines indicate survey track. The survey was conducted aboard the *MV Predator*.

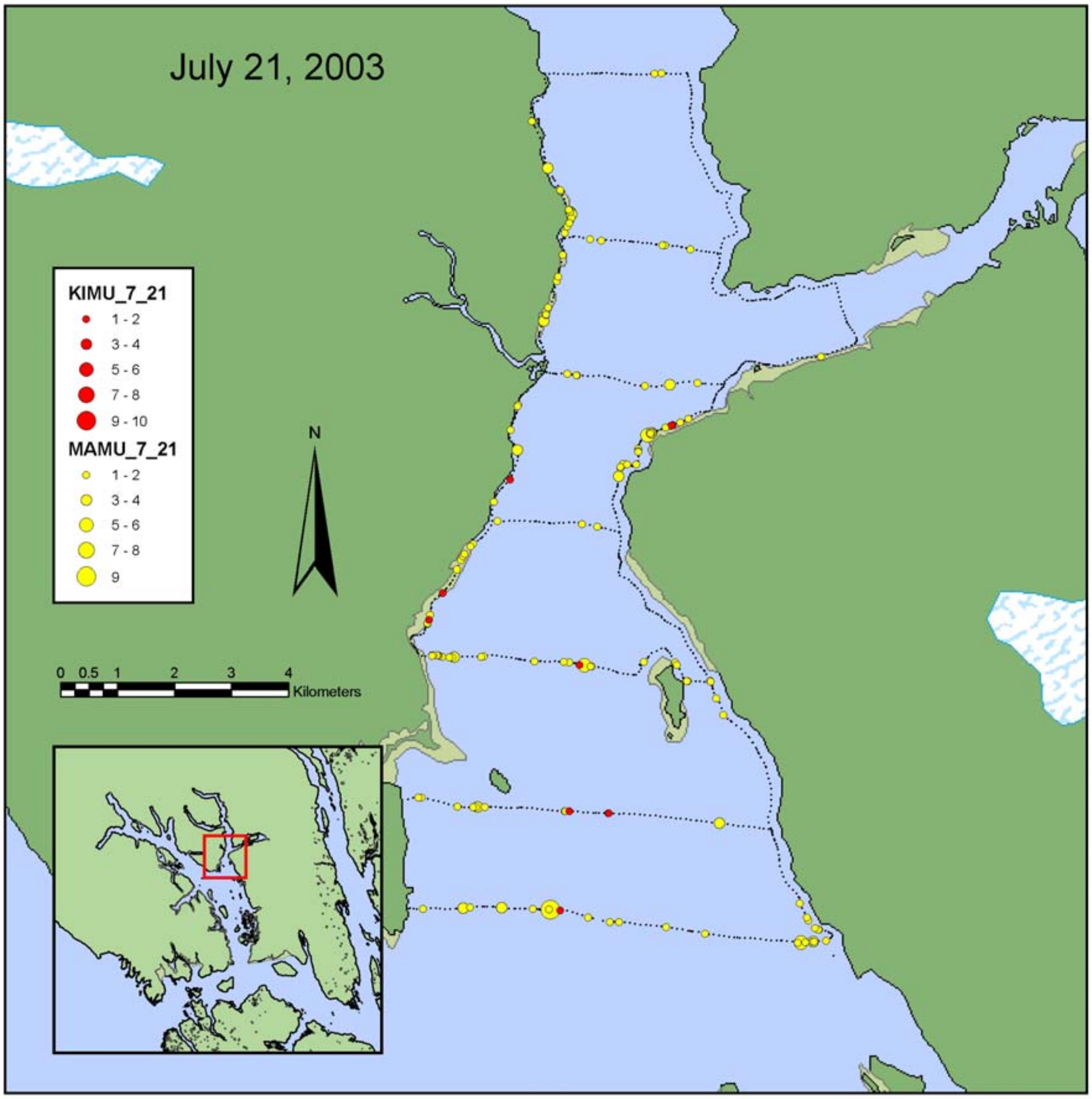

Figure 13f. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the Muir Inlet Entrance area of Glacier Bay National Park during a survey conducted on July 21, 2003. Black lines indicate survey track. The survey was conducted aboard the *MV Predator*.

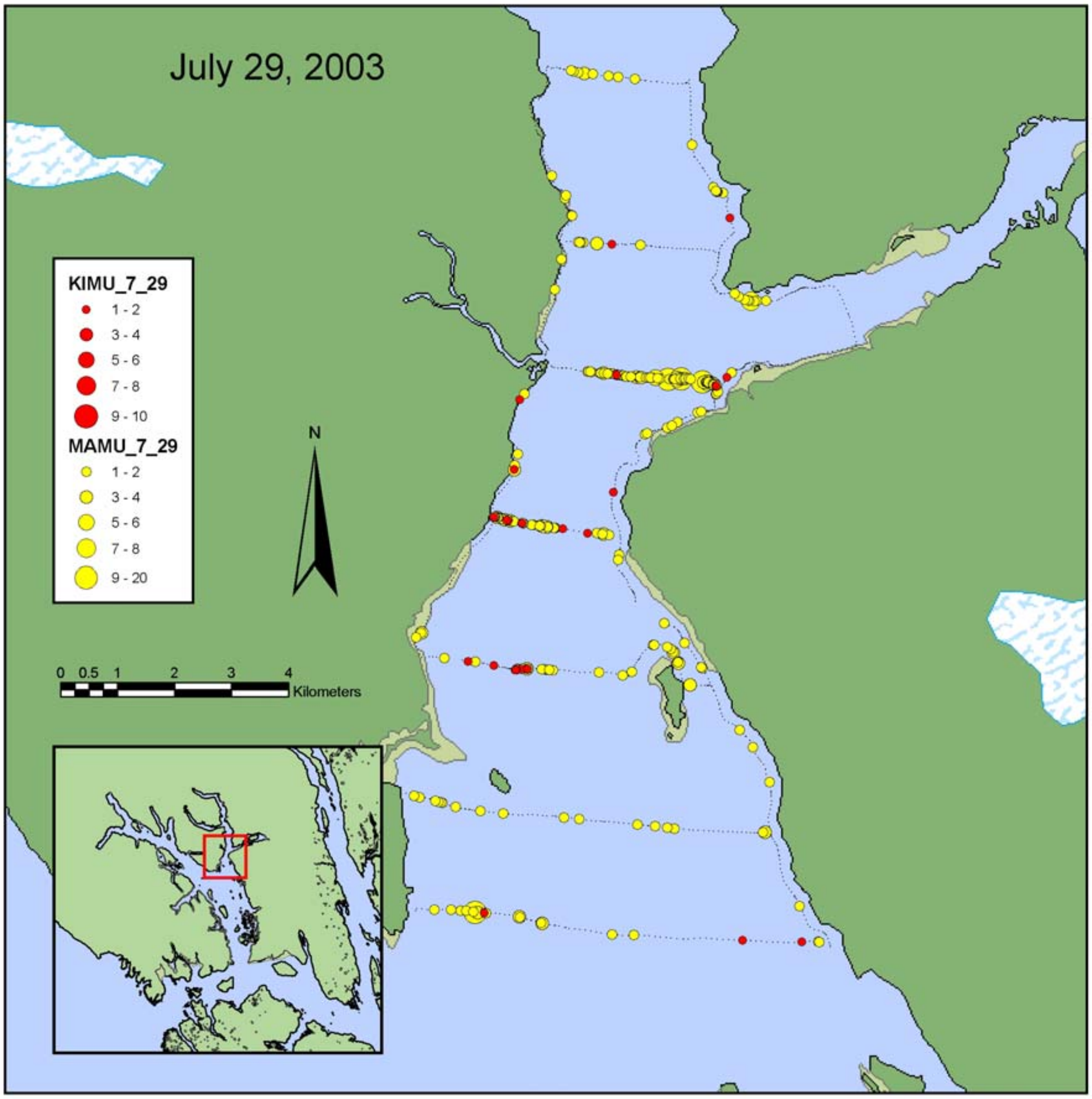

Figure 13g. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the Muir Inlet Entrance area of Glacier Bay National Park during a survey conducted on July 29, 2003. Black lines indicate survey track. The survey was conducted aboard the *MV Predator*.

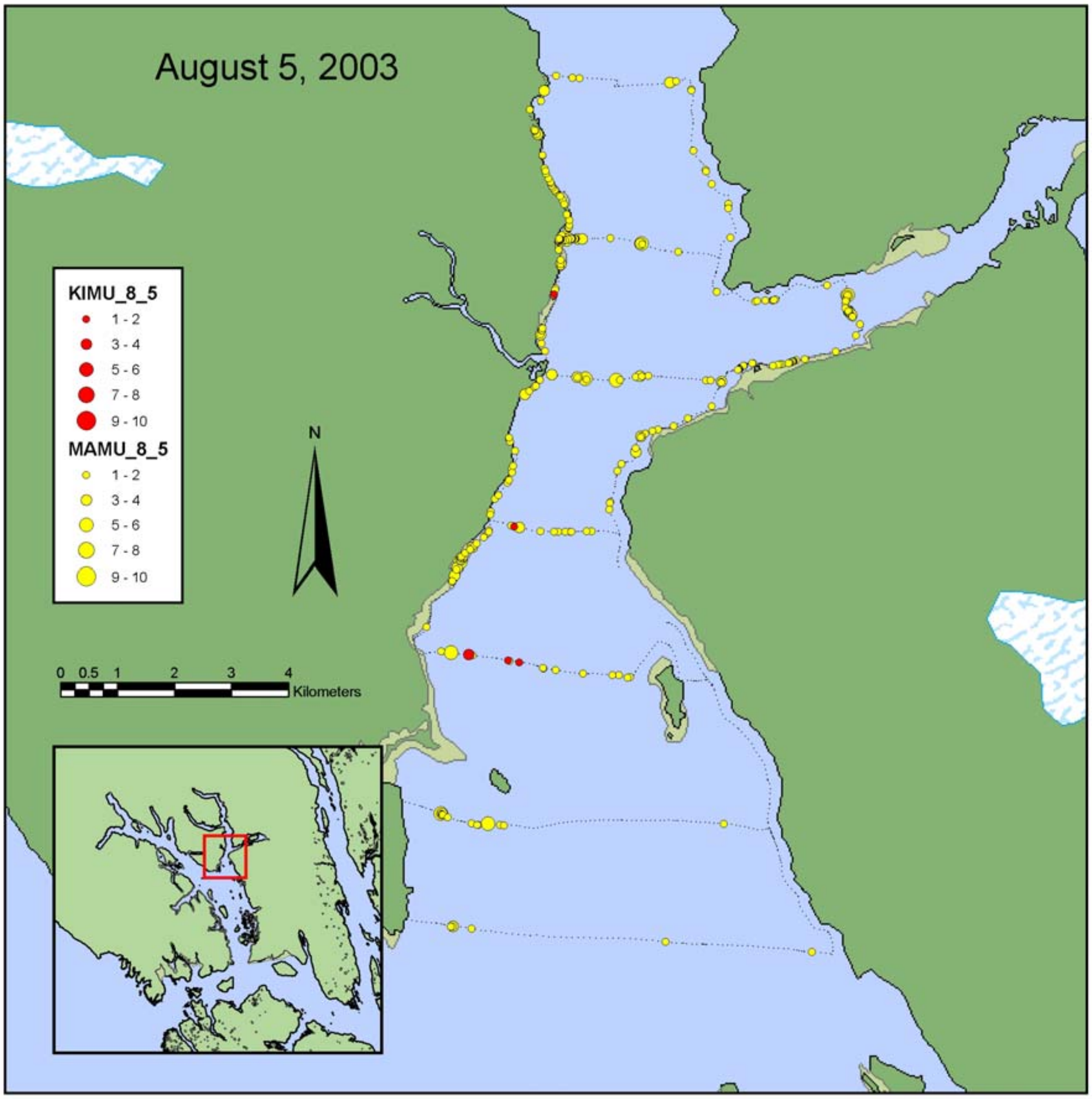

Figure 13h. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the Muir Inlet Entrance area of Glacier Bay National Park during a survey conducted on August 5, 2003. Black lines indicate survey track. The survey was conducted aboard the *MV Lutris II*.

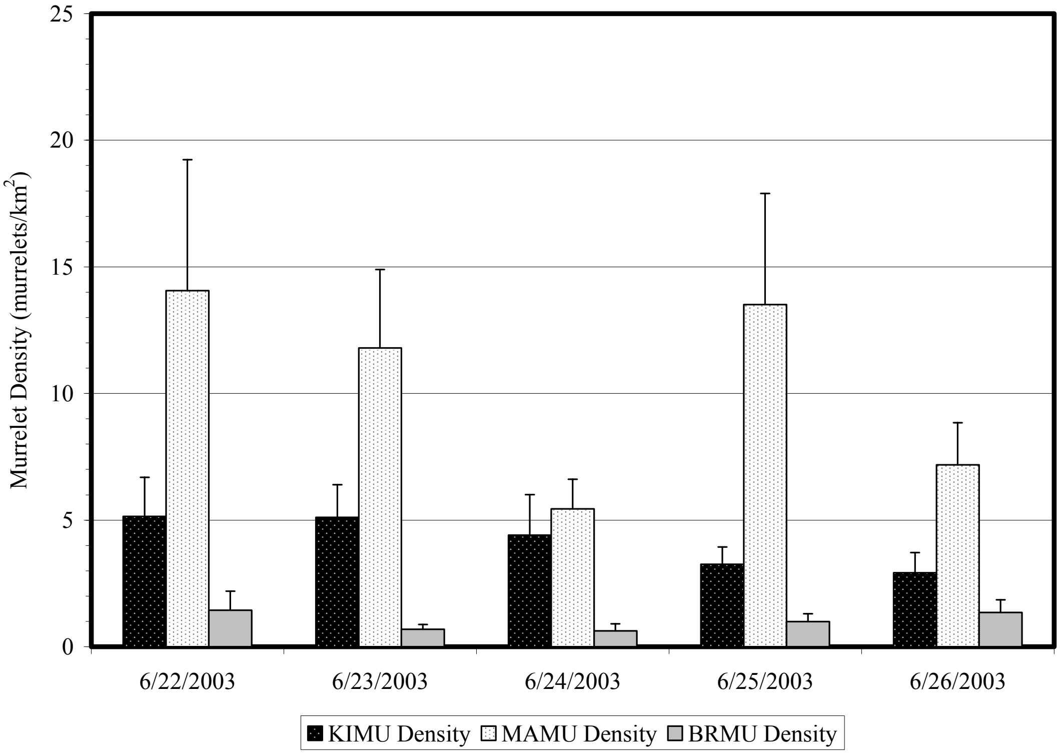

Figure 14. Density (birds/km^2, + 1 SE) of Kittlitz's Murrelets (KIMU), Marbled Murrelets (MAMU), and unidentified murrelets (BRMU), in the Upper West Arm area of Glacier Bay National Park. Surveys were conducted daily from June 22 through June 26, 2003.

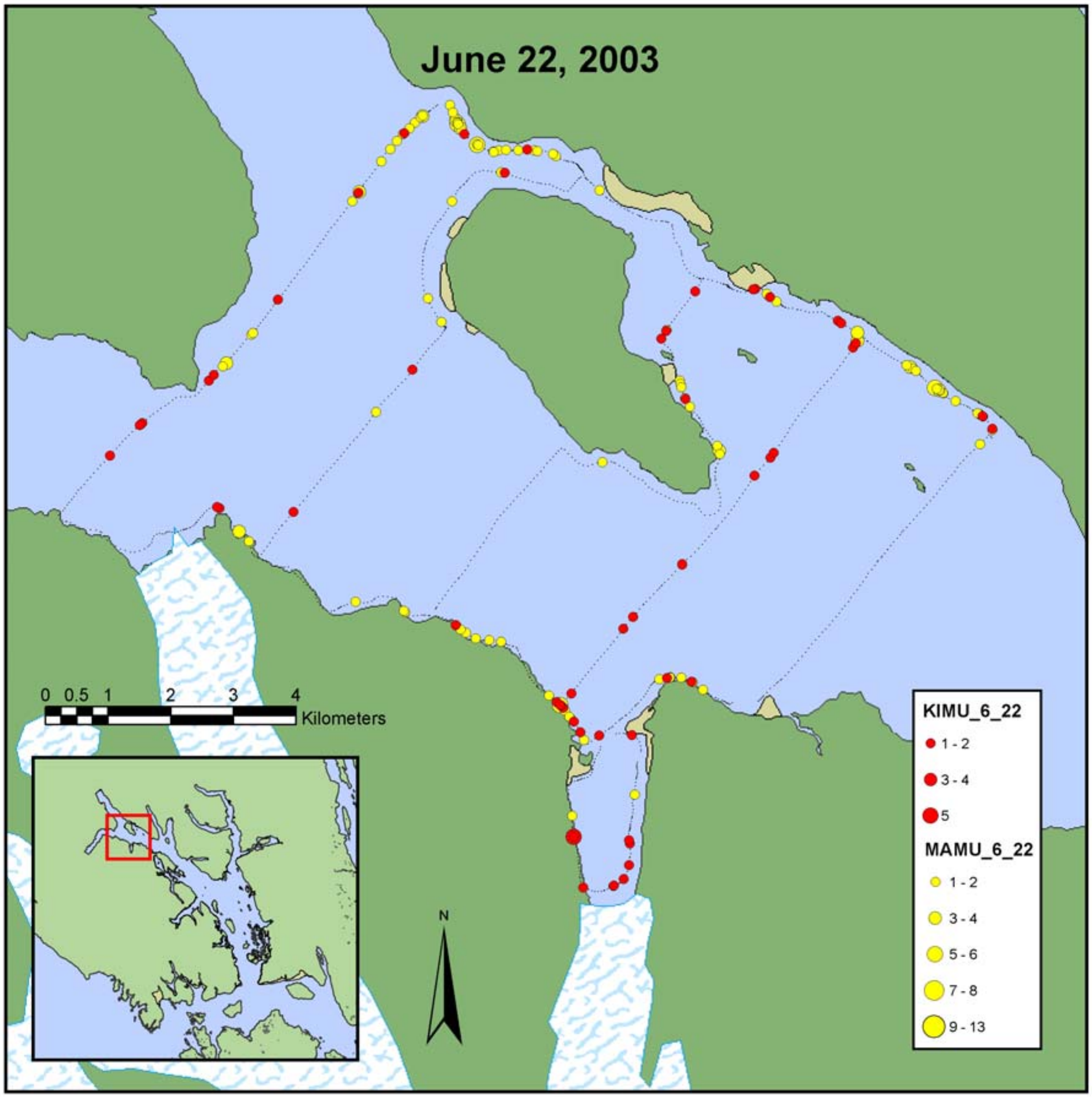

Figure 15a. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the Upper West Arm area of Glacier Bay National Park during the June 22, 2003 survey. Black lines indicate survey track. The survey was conducted aboard the *MV Predator*.

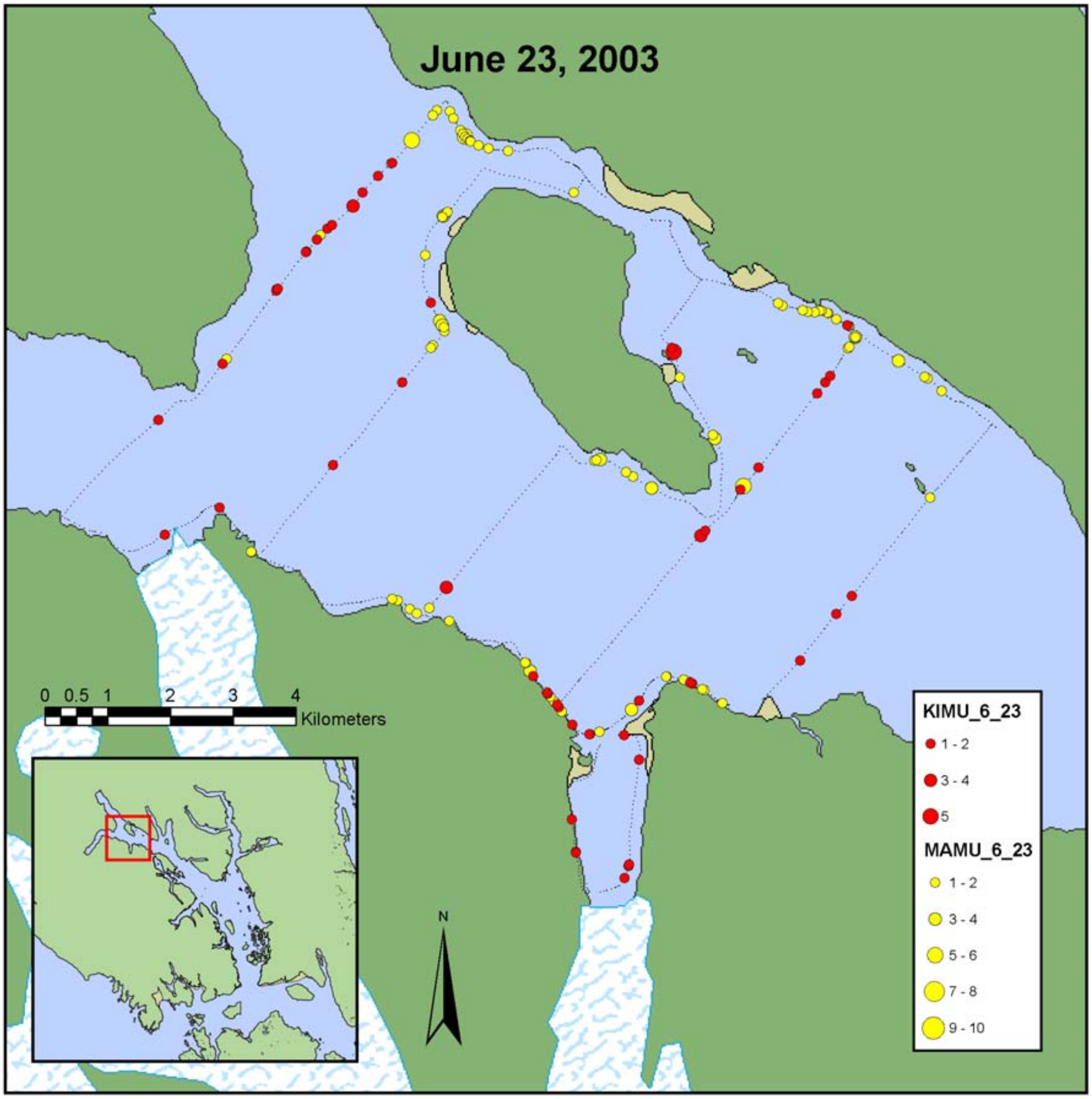

Figure 15b. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the Upper West Arm area of Glacier Bay National Park during the June 23, 2003 survey. Black lines indicate survey track. The survey was conducted aboard the *MV Predator*.

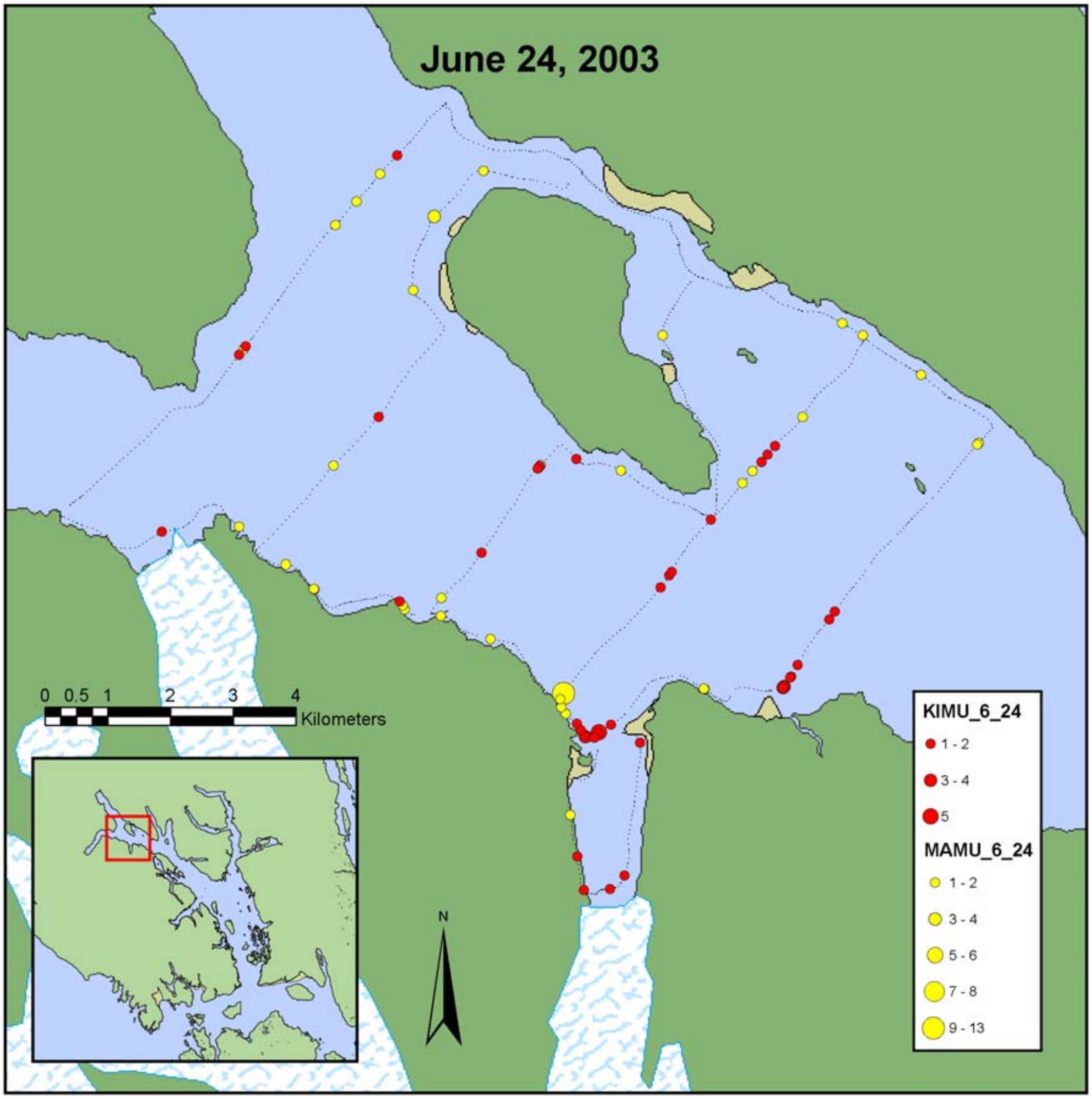

Figure 15c. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the Upper West Arm area of Glacier Bay National Park during the June 24, 2003 survey. Black lines indicate survey track. The survey was conducted aboard the *MV Predator*.

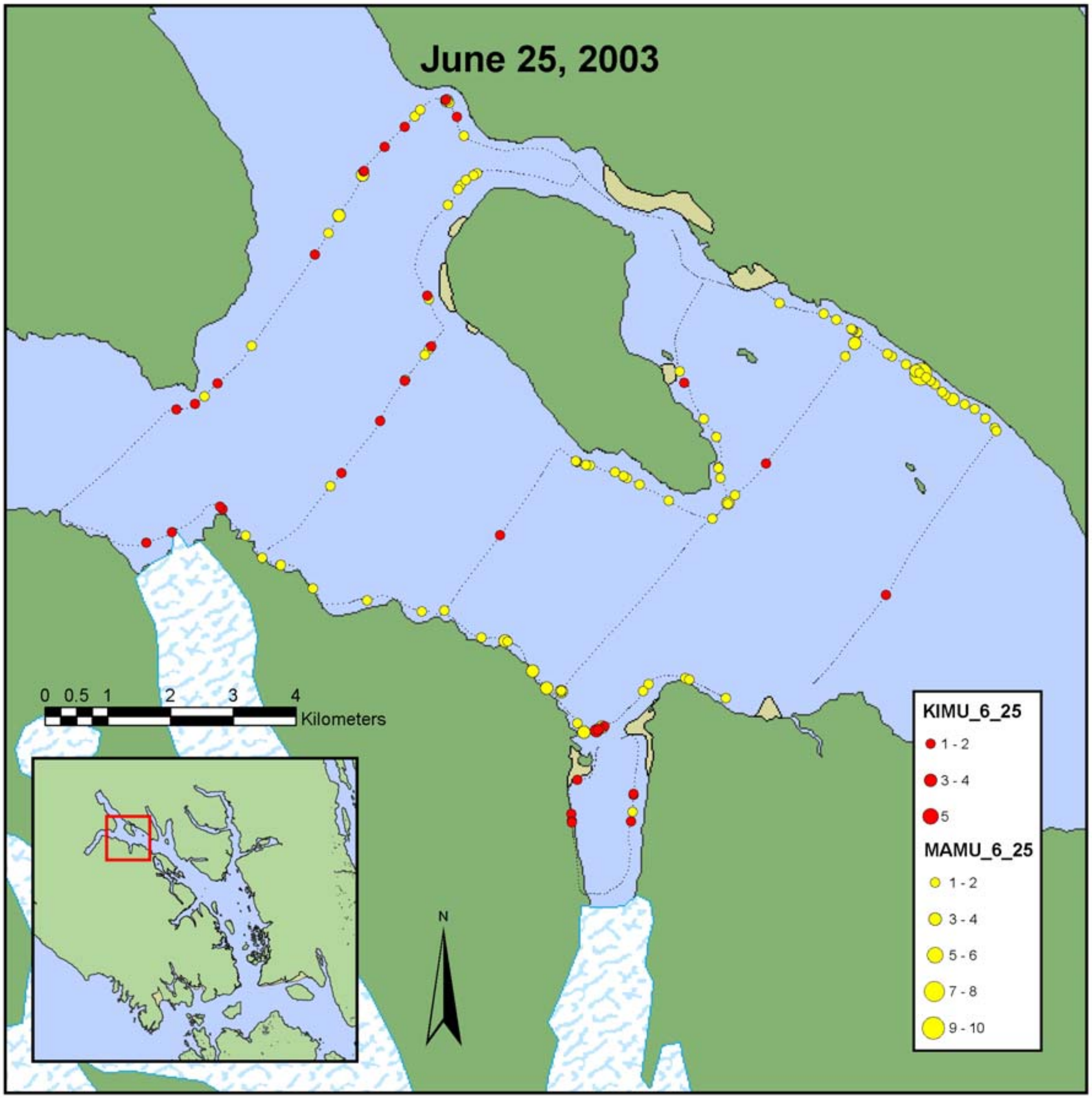

Figure 15d. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the Upper West Arm area of Glacier Bay National Park during the June 25, 2003 survey. Black lines indicate survey track. The survey was conducted aboard the *MV Predator*.

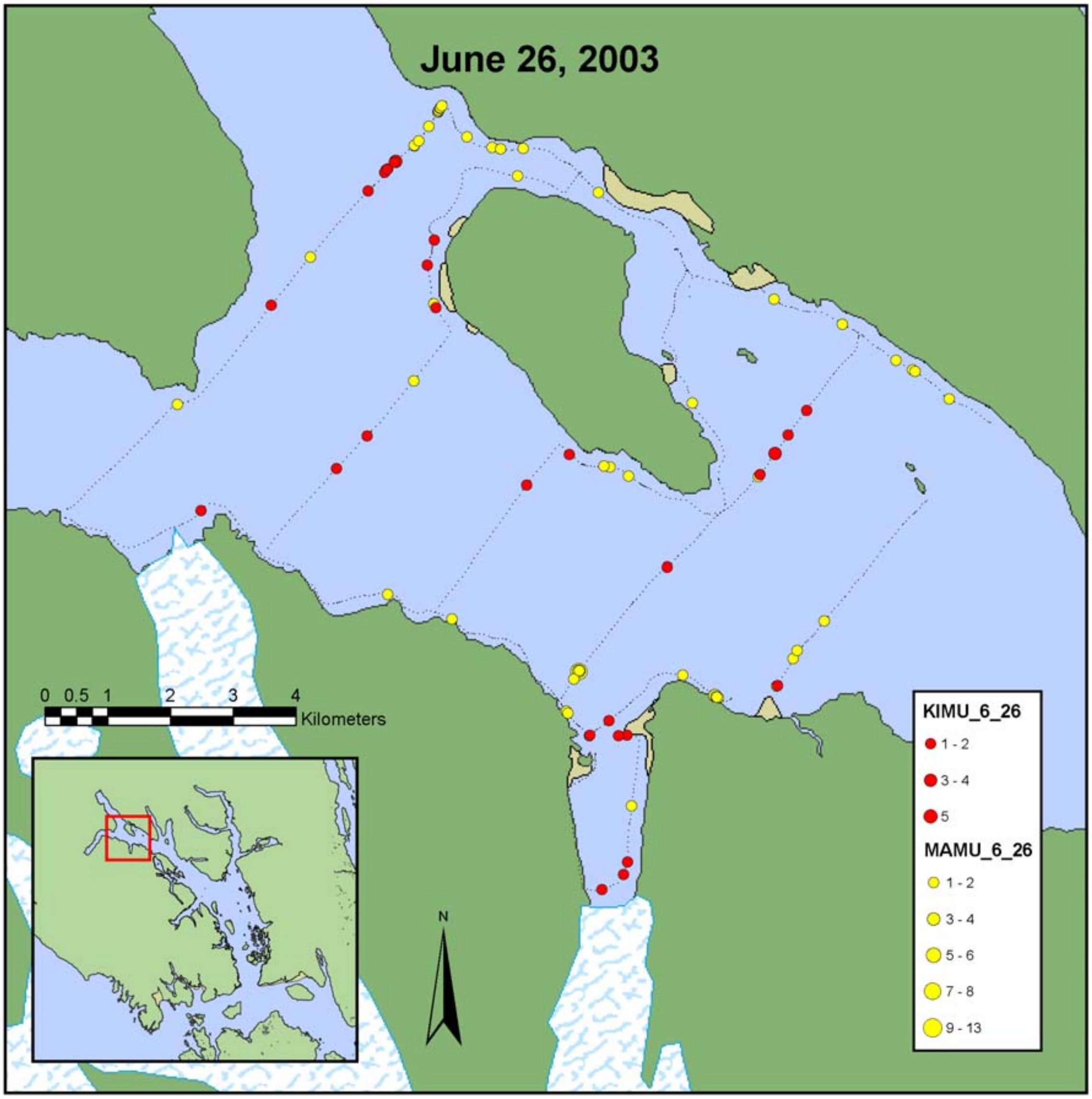

Figure 15e. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) sightings in the Upper West Arm area of Glacier Bay National Park during the June 26, 2003 survey. Black lines indicate survey track. The survey was conducted aboard the *MV Predator*.

Appendix 1. Kittlitz's Murrelet photographs.

A group of six Kittlitz's Murrelets and one Marbled Murrelet (black arrow)*,* in Reid Inlet, Glacier Bay National Park, Alaska (photographed on June 8, 2003).

Two Kittlitz's Murrelets in Reid Inlet, Glacier Bay National Park, Alaska (photographed on June 8, 2003).

Appendix 2. Techniques For Sampling the Forage Fish Prey of Kittlitz's Murrelet

INTRODUCTION

Kittlitz's murrelet feeding ecology is poorly known. To date only one study, conducted in Prince William Sound, has been dedicated to describing the foraging habits of Kittlitz's murrelets in Alaska (Day and Nigro 2000). Findings suggest Kittlitz's murrelets in Alaska tend to forage in glacial waters and they prefer the shallow waters of nearshore areas during the summer. They are pursuit divers and acquire prey underwater. Diet items include forage fishes such as capelin (*Mallotus villosus*), Pacific sandlance (*Ammodytes hexapterus*), Pacific herring (*Clupea palasii*), Pacific sandfish (*Trichodon trichodon*) and walleye pollock (*Theragra chalcogramma*) (Day et al. 1999). Kittlitz's murrelets are also known to feed on macrozooplankton such as euphausiids (*Thysanoessa inermis* and *T. raschii*) (Day et al. 1999).

In recent years, several studies related to marine fish have been conducted in Glacier Bay (Arimitsu et al. 2003; Robards et al. 2003). Dense aggregations of fish, measured with hydroacoustic and trawl surveys, were generally composed of forage fishes like capelin, Pacific herring and walleye pollock or euphausiids. In addition, the largest concentrations of acoustic fish sign were found in the shallow, nearshore areas of the bay with more than 50% of the forage biomass occurring at depths less than 35 m (Arimitsu et al. 2003; Robards et al. 2003).

The species composition and abundance of available prey may contribute to patterns of Kittlitz's murrelet distribution in Glacier Bay. In 2003 we sampled a variety of fishing techniques to form a strategy that would aid in describing Kittlitz's Murrelet feeding ecology. Our goal was to determine the most efficient methods for collecting forage fish in habitats used by Kittlitz's Murrelets in Glacier Bay.

METHODS

Sampling occurred in Glacier Bay between July 19 and August 8, 2003. The five fishing methods we employed were beach seine, dip net, cast net, vertical gill net and horizontal gill net. Fishing sites were selected based on gear type as described below.

Beach seine

The beach seine was deployed from a 4.8m rigid hull inflatable skiff at suitable beaches near known Kittlitz's Murrelet foraging areas. Suitable beaches for beach seining have wave action less than 30 cm, enough shoreline slope to safely land the skiff, and substrate type smaller than cobble. We used a beach seine that was 36.6 m long, 2.4 m deep at the mid-point, and tapered to 0.5 m deep at the wings. Mesh dimensions were 6 mm stretch nylon at the center and 28 mm stretch nylon at the wings. The net was set from the skiff about 30 m from shore, and pulled onto the beach by two or three people.

Dip Net and Cast Net

We used a dip net and cast net to target fish schools beneath feeding flocks of gulls and murrelets. The smelt dip net had 10 mm nylon mesh and a 3 m retractable pole. The cast net had a 3 m radius, 5 mm mesh and a 6 m draw cord. We counted the number of birds feeding as we approached the flock with a skiff, and positioned the boat in the center of the birds. The school of fish, seen from the surface, was collected either with a swipe of the dip net or a throw of the cast net.

Vertical Gill Net

We explored the efficiency of a vertical net system designed for variable current situations (Hansson 1988). The net had three removable panels which could be adjusted for different depths. Each panel was constructed from a 3.2 m tube of 1.9 cm diameter PVC and a 10 m x 3.2 m curtain of 1.9 cm stretched monofilament. The bottom panel was weighted with lead line strung through the PVC. We also weighted one end with a 7 kg lead weight attached to a 7 kg anchor. At the other end of the lower PVC tube we attached a 3 kg weight, which helped to keep the net vertical but allowed one side of the net to swing in the current. We also attached large buoys to each end of the PVC tube on the surface for floatation, and a crab buoy on sinking line to the anchor to aid in retrieving the net. We set this net in 13-24 m of water in variable tide and current conditions.

Horizontal Gill Net

A 65 m, multi-paneled surface gill net was used to test the efficiency of capturing schooling fishes. The panels were 15.2 m wide by 3.1 m deep, and stretched mesh sizes were 1.9 cm, 2.5 cm, 3.2 cm, and 3.8 cm. We attached 7 kg anchors to each end of the net and allowed it to soak for seven hours to assure proper anchoring through low and high tide. We also set this net drift to test the ease of deployment and retrieval.

Processing the Catch

For all fishing methods, we measured fork lengths of up to 50 individuals from each species. We estimated the number of fish in large catches by counting the number of fish in a subsample and approximating the proportion of the total catch in the subsample. Most fish were returned to the water immediately to minimize mortality. For the purposes of this study, we designated forage fish as larval fishes and pelagic schooling fish species less than 160 mm in length. Benthic species and fish larger than 160 mm were considered to be non-forage fishes.

RESULTS AND DISCUSSION

We collected a total of 8822 fish from 23 species (Table 1). Our efforts included 20 beach seine sets at 13 locations, four attempts with the dip net and three successful throws of the cast net. We also deployed the vertical gill net five times and the horizontal gill net two times. The total soak time for the gill nets was 1024 minutes.

Table 1. Capture method, number of sets in which the species was collected, and forage species designation for each species collected in Glacier Bay during 2003.

Species Common Name (Scientific Name)	Capture Method*	No. of Sets	Forage Species
Armorhead sculpin (*Gymnocanthus galeatus)*	1	1	N
Buffalo sculpin (*Enophrys bison)*	1	1	N
Capelin (*Mallotus villosus)*	1,2	12	Y
Crescent gunnel (*Pholis laeta)*	1	2	N
Dolly Varden (*Salvelinus malma)*	1,4	4	N
Frog sculpin (*Myoxocephalus stelleri)*	1	1	N
Great sculpin (*Myoxocephalus polyacanthocephalus)*	1	13	N
Larval prickleback [Stichaeidae (family)]	1	1	Y
Larval smelt [Osmeridae (family)]	1	1	Y
Pacific cod (*Gadus macrocephalus)*	1	1	Y
Pacific herring (*Clupea pallasi)*	1,2,3	13	Y
Pacific sand lance (*Ammodytes hexapterus)*	1,2,3	11	Y
Pacific staghorn sculpin (*Leptocottus armatus)*	1	1	N
Pink salmon (*Oncorhynchus gorbuscha)*	1,4	4	N
Red Irish lord (*Hemilepidotus hemilepidotus)*	1	2	N
Rock greenling (*Hexagrammos lagocephalus)*	1	1	N
Rock sole (*Lepidopsetta sp.)*	1	2	N
Sculpin [Cottidae (family)]	1	1	N
Silver Salmon (*Oncorhynchus kisutch)*	4	1	N
Silver spotted sculpin (*Blepsias cirrhosus)*	1	1	N
Snake prickleback (*Lumpenus sagitta)*	1	4	N
Southern rock sole (*Lepidopsetta bilineata)*	1	1	N
Starry flounder (*Platichthys stellatus)*	1	1	N

* 1=Beach Seine, 2=Dip Net, 3=Cast Net, 4=Gill Net

We collected 70% of the season's catch with a beach seine. The beach seine catch was composed of 95% forage and 5% non-forage fishes. We collected 28% of the total catch with a dip net. All of the dip net catch was potential Kittlitz's Murrelet forage. Less than 2% of the total catch was collected with a cast net and all of the cast net catch was

Kittlitz's Murrelet forage. Less than 1% of the total catch was collected with the gill nets. We did not catch forage fish with the gill net (Fig. 1).

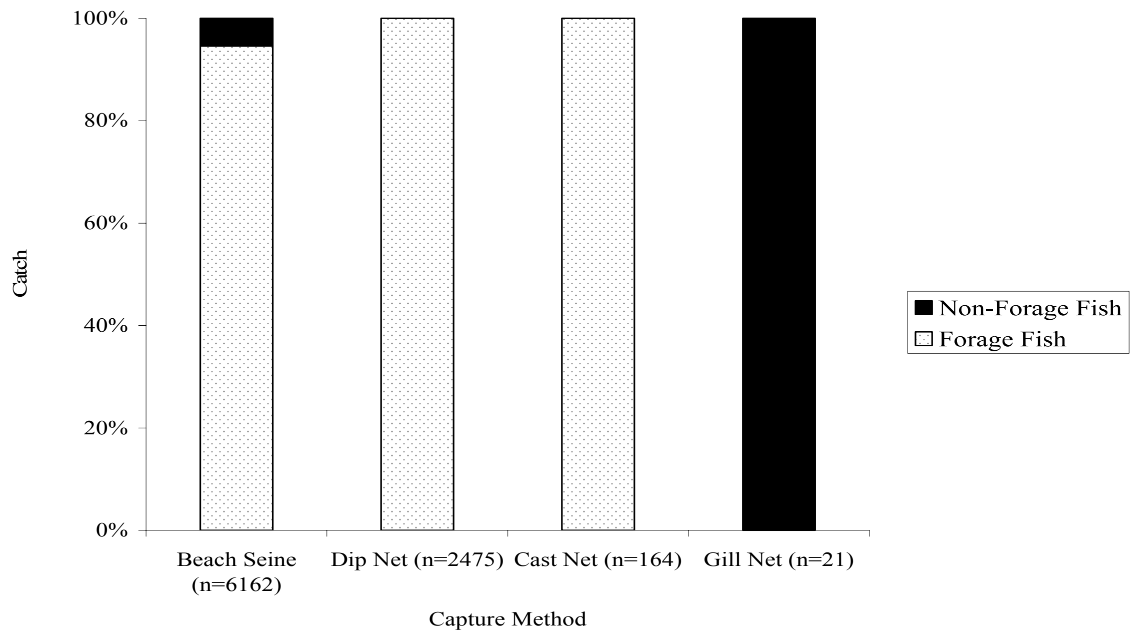

Figure 1. Proportion of each method's catch comprised of forage and non-forage fishes. Forage fishes are pelagic schooling fish species less than 160 mm in length including larval fish. Non-forage fishes are benthic fish species or fish that were greater than 160 mm in length.

Comparison of Methods

We collected fish near foraging Kittlitz's Murrelets with three beach seine sets at two locations, and with two attempts with the dip net. Beach seines and dip nets may have been more successful than other methods due to the ease and speed of deployment from a skiff. These methods have proven to be useful for collecting nearshore and surface schools of fish from a small boat.

We found the cast net to be less effective than the beach seine or dip net at collecting forage fish in murrelet foraging areas. Even with considerable practice, the technique for deploying the cast net was never mastered. From a skiff, we found it difficult to throw the cast net with enough loft to spread open completely before hitting the water. However, from a larger vessel the cast net method may be useful because more draft would allow time for the net to open.

Table 2. Species composition and average fork length (mm) for forage fish collected with a beach seine or dip net near feeding Kittlitz's murrelets.

Species	Fork length (mm)
Pacific herring	34.9 ± 3.0
capelin	105.5 ± 15.5
Pacific sandlance	82.4 ± 9.3

The gill nets were the least effective way to catch fish suitable as murrelet prey. One of the main problems with both the vertical and horizontal gill nets was mesh size. Our 1.9 cm mesh panel, the smallest mesh size available from U.S. manufacturers, collected mostly larger than forage-sized salmonids. In addition, our inability to assess depth for anchoring the gill nets from a skiff limited the efficiency of the nets in tide or current. Though we could obtain custom nets with smaller mesh size and a hand held depth meter, the costs outweigh the benefits of this method at this time.

Direct Sampling of Kittlitz's Murrelet Prey

On July 24, 2003 we observed a mixed-species feeding flock including three Kittlitz's Murrelets, two Pigeon Guillemots (*Cepphus columba*) and five Arctic Terns (*Sterna paradisaea*) foraging within 50 m of shore. We collected 138 capelin with a beach seine set at this site. Five of these were larva (average fork length = 36.4 ± 4.8 mm) and 133 were spawning adults (average fork length = 108.3 ± 7.8 mm). A subsample (n=10) contained 80% males in spawning condition and 20% ripe or spent females.

Capelin spawning grounds in Reid Inlet and throughout the bay may represent a predictable, high-quality food source for Kittlitz's Murrelets. Capelin may be a particularly important forage species for Kittlitz's Murrelets in Glacier Bay because spawning occurs nearshore during the critical breeding season. Concentrations of Kittlitz's Murrelets were recorded on transect during the nearshore survey at the capelin spawn site in Reid Inlet on July 20, 2003. Capelin in spawning condition were also collected at the same beach in July of 2000 (Arimitsu and Piatt, *in prep*), which implies annual spawning at this site.

We also collected forage fish near feeding Kittlitz's Murrelets, Marbled Murrelets, humpback whales (*Megaptera novaeangliae),* and Glaucous-winged Gulls (*Larus glaucescens*) on the west shore of Muir Inlet opposite Adam's inlet and in the Beardslee channel. Tight, sphere-shaped schools of sandlance were observed from the surface near the feeding flocks in both locations. In the Beardslee Channel we also caught mixed schools of capelin and sandlance. Larval Pacific herring were collected in Muir Inlet (Table 2), though it is likely that the larval fish were not the preferred forage in the presence of schooling sandlance.

Furthermore, opportunistic sightings of Kittlitz's Murrelets holding fish may give insight into they type of fish they prefer to eat or feed to young. We observed Kittlitz's Murrelets holding capelin or sandlance at Lamplugh Glacier, Reid Inlet, the mouth of Adam's Inlet and the Beardslee Channel.

CONCLUSIONS

Information on the feeding habits of Kittlitz's Murrelets is necessary to identify the causes for the species' decline. One of the biggest challenges to obtaining this information is capturing their prey. We were successful in collecting Pacific herring, capelin and Pacific sandlance with beach seines and a dip net. Another way we can opportunistically obtain species composition data is by recording fish-holding behavior. These methods, in addition to hydroacoustic and trawl surveys will be useful in describing the largely unknown foraging ecology of Kittlitz's Murrelets.

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