ABUNDANCE, POPULATION TREND, AND DISTRIBUTION OF MARBLED MURRELETS AND KITTLITZ'S MURRELETS IN GLACIER BAY NATIONAL PARK

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ABSTRACT

We replicated an at-sea survey in Glacier Bay three times during 3-9 July 2009 to get current population estimates of Marbled Murrelets (*Brachyramphus marmoratus*) and Kittlitz's Murrelets (*B. brevirostris*), compare them with 1993 levels, and map spatial patterns of abundance. In 2009, there were 27,266 Marbled Murrelets, and 5,317 Kittlitz's Murrelets in Glacier Bay. This area is an important population center for both species, accounting for about 20% of the estimated global population of Kittlitz's Murrelets, and about 10% of the estimated statewide population of Marbled Murrelets.

The on-water density of Kittlitz's Murrelets increased from 2.07 to 3.55 birds per km^2 between 1993 and 2009, but the difference was not significant ($p = 0.13$). The on-water density of Marbled Murrelets decreased from 23.4 to 19.7 birds per km^2, but this difference was also not significant ($p = 0.45$). Of nearly 7,000 murrelets counted on 3 surveys in 2009, 80.0% were Marbled Murrelets, 15.7% were Kittlitz's Murrelets and 4.3% were unidentified. Approximately 9.2% of murrelets counted were flying.

The highest densities of Kittlitz's Murrelets were in the upper west and east arms of Glacier Bay, mostly near waters with a strong glacial influence. However, Kittlitz's Murrelets occur widely throughout the Bay, including concentrations in areas with little glacial influence. Murrelets were more dispersed in 2009. The most consistent "hot spot" for murrelets (especially Marbled

Murrelets) in 2009 was Beardslee Channel. During certain times of day and stages of tide, this area attracts thousands of murrelets, many of which are commuting from beyond Glacier Bay.

Murrelets showed a clear distribution pattern with respect to shore. Both species underutilize the 0-300 m zone relative to availability, and preferred waters further from shore. Marbled Murrelets preferred waters 600-900 meters from shore. Kittlitz's Murrelets preferred waters 600-1500 meters from shore. Because murrelet density varies with distance to shore, we recommend transects be oriented perpendicular to shore, or zig-zag to sample the range of densities. Straight-line transects can be replicated precisely, and are superior to a meander line.

Keywords: Marbled Murrelet, *Brachyramphus marmoratus*, Kittlitz's Murrelet, *Brachyramphus brevirostris*, Glacier Bay, Southeast Alaska, monitoring, trends, distribution

INTRODUCTION

Glacier Bay is a major population center for both Marbled Murrelets (*Brachyramphus marmoratus*) and Kittlitz's Murrelets (*B. brevirostris*). Both are identified as species of conservation concern throughout all, or portions of, their range. The Kittlitz's Murrelet is currently a candidate for range-wide listing under the Endangered Species Act (ESA). The Marbled Murrelet is listed as threatened in the lower 48 states under ESA, and is listed as threatened under the equivalent Canadian law (Species at Risk Act), but is not listed in Alaska.

The main basis for concern, in both cases, is presumed declines in populations from historic levels. For Marbled Murrelets, the loss of important old-growth forest habitat for nesting was a significant factor in the listing decision. Because population declines form the basis for the conservation concerns, it is important that the population abundance and trend data be reevaluated and updated as new surveys are conducted. The surveys conducted in Alaska to date have been designed with different objectives, different sampling designs, and different methods. These differences vary from study area to study area, and within individual study areas.

In Glacier Bay, bay-wide surveys (including the present study) have been conducted in 10 different years since 1991. These surveys include very different designs, from 90% coastal

(1991) to 96% offshore (1993, 2009), from a sample area of 300 km^2 (1999) to a sample area of 18 km^2 (2008), from surveys with no unidentified murrelets (1993) to surveys with 59% unidentified murrelets (2000), and from surveys with randomized sampling (2007), to surveys with quasi-systematic sampling designs (1993, 1999-2003, 2009).

Making sense of such variable surveys is difficult. Depending on which years you include or exclude, and whether one makes adjustments for those differences or not, trends vary. This is not a criticism of prior efforts. With the exception of the 1993, 2007, and 2009 surveys in Glacier Bay, the principle target species were not *Brachyramphus* murrelets; and objectives were geared toward multi-species inventory rather than monitoring. In this light, it is not surprising that the survey designs are so different, and the results so variable.

In planning this study, we chose to repeat the 1993 survey because it was (a) the second-earliest survey in the time series, and (b) the first to use strait-line transects with known start and end points, so exact replication was possible. We repeated this survey in 2009, using the same survey design, similar vessels, and similar methods used in 1993. The designer of the 1993 survey, John Lindell, participated on both the 1993 and 2009 efforts to ensure consistency and comparability.

This survey comparison does not address what may have occurred with populations prior to 1993, nor does it speak to inter-annual variation over that 16-year time period. But because precise replication is possible, and the span of time is large, it should be possible to identify major declines that may have occurred in this important population center. By replicating the survey multiple times in a week-long period, we also will learn how distribution and abundance patterns shift, and how confidence in the results is affected by survey replication.

This work provides a basis for increasing our understanding of past population trends in Glacier Bay, as well as providing information on current population abundance and distribution for these species. We hope it provides a useful foundation for designing a powerful, forward-looking monitoring program for murrelets in Glacier Bay.

METHODS

Sampling Design—In 2009, we replicated transects established by the USFWS in 1993 (Figure 1). The 1993 survey consisted of 37 transect segments, totaling 270.53 linear km. Strips were 300 m wide, equaling a sample area of 81.16 km^2. The start and end waypoints of the series are shown in Table 1. The same transects were resurveyed in 2009; however, a new wilderness boundary in upper Muir Inlet restricted motorized access, and required shortening transect 428 by 2.5 km. The total sample area of 37 transects in 2009 was 80.41 km^2. All comparisons between 1993 and 2009 murrelet populations are based on these 37 common transects.

Four additional transects were added in 2009 to increase coverage in the Bay (Table 2). We added a single transect in Tarr Inlet, and three new transects in Wachusset Inlet, following the zig-zag pattern of the 1993 survey (Figure 1). With these added transects, the vessels traversed 299.39 km, and sampled 89.82 km^2. This expanded survey was used to derive a mean population estimate for Glacier Bay in 2009, and was used in mapping patterns of murrelet abundance in Glacier Bay. Transect 4161, near the mouth of Johns Hopkins Inlet, was added by the *Gravina* crew to document an aggregation of Kittlitz's Murrelets in that area (Figure 1). Because of this bias, it was not used in population estimates, trend estimates, or maps of relative abundance.

Survey Methods— Methods used in the 2009 surveys were similar to those used in 1993 (see Lindell, 2005). Surveys were conducted from two large displacement vessels. The *MV Sierra*, a 10.7 m vessel, conducted one complete survey from 3-9 July. The *MV Gravina*, a 15.9 m vessel, conducted two complete surveys from 3-6 July and 7-9 July.

For each transect, crews recorded the start time and end time, sea conditions (glassy, ripples, wavelets, small waves), precipitation (none, drizzle, rain), cloud cover (clear, partly cloudy, overcast), and visibility (excellent, good, fair, poor). Transects were discontinued if sea state was greater than "small waves", or visibility was rated poor (due to low light, glare, drizzle, or sea conditions).

On the *MV Gravina*, two observers and a recorder counted birds from seated positions on the cabin top, with their viewing height approximately 4.5 meters above the waterline. This mimicked the height, and location, of the observers on the *MV Curlew* during the 1993 survey.

On the *MV Sierra* a single observer and a recorder counted from a standing position on the bow deck, with eye height approximately 3 meters above the waterline.

Observers counted all murrelets sitting on the water within 150 m on either side of the transect centerline (total strip width = 300 m). The *Gravina* traveled at 8-9 knots during surveys, with two persons counting birds. Each observer was responsible for birds on their side of the center line, but communication was permitted to avoid missing or double counting birds near the line. The Sierra traveled at 6-7 knots, with a single observer counting birds within 150 m on either side of the centerline. Recorders on both vessels helped with bird spotting, bird identification, and recorded GPS locations for all birds detected in the strip.

Observers in 2009 counted only murrelets. Observers in the1993 survey counted all bird species, but murrelets had priority. In 1993, when a multitude of birds made counting difficult, the non-murrelet species were ignored (J. Lindell, personal communication). The proportion of murrelets missed was deemed low (1%), and was consistent between the 1993 and 2009 surveys (J. Lindell, personal communication).

Accuracy-- The effort an observer makes to identify a bird to species can vary. If observers are not given specific goals with respect to murrelet identification rates, it becomes easy to simply label murrelets as "unidentified." In other Glacier Bay surveys, over half of the murrelets were classified as unidentified in some years. On the other hand, if every murrelet has to be identified to species, there is a natural tendency to default to the most common species (in this case, Marbled Murrelets) when the observer does not get a good look.

In the 1993 surveys, observers were instructed to identify every bird to species, using their best judgment in every case. In the 2009 surveys, observers were instructed to strive for 90-95% identification rates. To assist them in achieving this goal, we used experienced surveyors, conducted detailed ID training, slowed the vessel when viewing conditions were challenging (e.g., waves, dim lighting), and encouraged use of binoculars.

Accurate results depend on the observer's ability to locate the boundaries of a fixed-width strip accurately. In 2009, observers calibrated their estimates of a 150 m distance (the outer boundary of the strip) by estimating line-of-site distance to murrelets on the water, and checking their estimates against the true distance measured with a laser rangefinder. While this provides a useful check when the bird is counted directly abeam of the vessel, it cannot verify accuracy of "in" versus "out" calls when the bird is spotted ahead of the vessel. Observers communicated with each other on birds "near the line" to promote consistency and accuracy.

In addition to counting murrelets on the water, crews counted murrelets in flight that entered the survey window, which was defined as a space 150 m on either side of the centerline, and 150 m in front of the vessel. In 1993, flying birds were counted similarly (Lindell 2005).

Data Analyses— We summed the counts and divided by the total area sampled to obtain a mean density for the survey. In calculate confidence intervals, and test for significant differences, we subdivided our survey transects into 2 km-long segments. Although not strictly independent (Schneider 1990), binning of data into 1-10 km segments reduces or eliminates auto-correlation effects for many species (Piatt et al. 2007). Segments of 2 km length yield unbiased means, and intermediate coefficients of variation for Marbled Murrelets and Kittlitz's Murrelets (Drew et al. 2008).

Expansion Factor-- To compute population size we multiplied the mean density per km^2 by the total area surveyed (i.e., the marine waters of Glacier Bay). That area varies somewhat by source. Lindell (2005) used 1,252.8 km^2. Kirchhoff (2008) used 1,275.8 km^2. Piatt et al. (2007) used 1288.7 km^2. In this study, we used 1286.0 km^2 to extrapolate all measured densities, including those from the 1993 surveys.

Unidentified Birds-- Treatment of unidentified murrelets in a dataset can have a large influence on estimated population trends and abundance, especially when the percentage of unidentified birds varies widely from one survey to the next. Three approaches have been adopted by different authors to deal with unidentified murrelets: (1) use only known-identity birds in density and abundance estimates (Drew et al. 2008), (2) assign unidentified birds to species based on the ratio of Marbled Murrelets to Kittlitz's Murrelets in the known-ID birds (Kirchhoff 2008), or (3) use a non-linear model for predicting the best species assignment of unknown species (Kuletz et al. 2005).

Because the unidentified fraction of murrelets varies widely from year to year (e.g., 0-58% over Glacier Bay surveys), discarding these birds depresses population estimates for both Murrelet species. Because the proportion of unidentified birds in our 2009 survey was small (4%), the results are insensitive to how they are handled in the analysis. Still, we have chosen to allocate the small numbers of unidentified birds to species, based on species ratio in known-identity birds.

Flying Birds-- Strip transects assume no movement into or out of the strip while the count is being conducted. With flying birds, especially fast-flying birds like murrelets, continuous counts will lead to a substantial positive bias in density estimates (Kirchhoff 2008). We analyzed population trends using murrelets sitting on the water. To calculate total population size in 2009, we include counts of flying birds, as others have, so that the population estimates can be fairly compared to other areas/studies.

Spatial Analyses – We created density maps to visually depict the "hot-spots" for Marbled Murrelets and Kittlitz's Murrelets seen on the water during surveys in 2009 and 1993. We used the kernel density function (ESRI Spatial Analyst) with a 3 km search radius, reporting results in birds per square kilometer for each 25 m grid cell. The same density scales are used among all maps so they can be directly compared.

We also looked at the distribution of birds relative to the shoreline. Habitat was defined as a series of zones, each 300 meters wide and parallel to the shore (e.g., 0-300 m, 300-600 m, 600-900 m etc.). Habitat availability was measured as the area of each habitat type sampled in the survey. Habitat use was measured as the habitat the birds occurred in (GPS based) during the survey. The proportional use of a particular habitat, divided by its proportional availability, gives an index of habitat selection (positive values) or non-selection (negative values) (after Ivlev 1961).

RESULTS

Survey conditions-- Survey conditions in early July 2009 were very good. Less than 1% of the survey time had any precipitation. Sky conditions were clear (57%) or partly cloudy (43%). Seas were rated as glassy calm (28%) slight ripple (35%), small wavelets (25%), or occasional small white caps (12%). Visibility was very good, with 69% of transects rated as excellent, 20% rated as good, and 11% rated as fair. Consistent with the 1993 analysis (Lindell 2005), we assumed sea state and weather did not affect count accuracy, and all birds in the strip were detected.

Counts-- The sum of birds counted, by species, and by behavior (sitting or flying), for each of the 2009 surveys is shown in Table 3. In 2009, 96% of all murrelets seen were identified to species (Table 4). Because there was no allowance for unidentifiable birds in the 1993 survey, we suspect a slight positive bias in assignment to the more abundant Marbled Murrelets. If this is true, the 1993 density of Marbled Murrelets may be slightly overestimated, and the density of Kittlitz's Murrelets may be slightly underestimated.

The number of sitting Marbled Murrelets counted on the *Gravina's* first survey was a little over half the number counted on the second survey (Table 3). The difference was largely due to counts on three transects in the lower bay, which showed 5.5 times more Marbled Murrelets in the second survey than the first. Counts in lower Glacier Bay tend to be more variable, depending on time of day and tide, because thousands of murrelets can be attracted here from outside the bay (Kirchhoff 2008).

Population Density— In 2009, Marbled Murrelets (flying and sitting) occurred at an average density of 21.2 birds per km^2 across the three surveys, while Kittlitz's Murrelets occurred at an average density of 4.1 birds per km^2 across the three surveys. These density figures are based on the 41-transect series, including Wachusset Inlet and Tarr Inlet.

Population Abundance— Extrapolating the density estimates for Marbled and Kittlitz's Murrelets across the surface area of Glacier Bay yields population abundance figures of 27,266 Marbled Murrelets and 5,317 Kittlitz's Murrelets in the bay. There are small differences in population estimates depending on whether one extrapolated from the 37-transect survey or the 41-transect survey. For a point estimate of abundance, we used the 41-transect survey because the greater coverage is more representative of Glacier Bay as a whole.

The most recently published estimate (May 2009) for Kittlitz's Murrelets indicates an Alaska population of 19,578 and a global population of 24,678 (USFWS 2009). Therefore, the mean population estimate of 5,317 Kittlitz's Murrelets in Glacier Bay represents 27% of the entire Alaska population and 22% of the global population. Piatt et al. (2007) projected a 2006 population of 271,182 *Brachyramphus* murrelets in Alaska. The 27,266 Marbled Murrelets found in Glacier Bay, in 2009, represent about 10% of that total. These comparisons underscore the importance of Glacier Bay as a major population center for both species.

Population Change— Observed on-water densities, and extrapolated population sizes, for Marbled and Kittlitz's Murrelets in 1993 and 2009 are shown in Table 5. The observed on-water density of Marbled Murrelets decreased from 1993 to 2009, but not significantly ($P = 0.453$) (Figure 2). The observed on-water density of Kittlitz's Murrelets increased from 1993 to 2009, but not significantly ($P = 0.132$) (Figure 3). Type II errors (concluding no difference when one truly exists) are always a concern, but we are mostly concerned about being able to detect major declines, not minor fluctuations. We can say with some confidence, based on these results, that neither Marbled Murrelets nor Kittlitz's Murrelets have undergone a large population change since 1993.

Use versus Availability— The proportional availability and use of different nearshore zones is shown in Table 6. The zig-zag survey design (Figure 1) allocated 4% of sampling effort to the closest-to-shore stratum (0-300 m). While this is not optimal for species that use this nearshore zone extensively, it is the optimal allocation for Kittlitz's Murrelet (Drew et al. 2008:17).

Nearshore Distribution-- Murrelets showed a strong and consistent pattern of distribution with respect to the shore. Both species made little use of the nearshore zone (0-300 m from shore), especially Kittlitz's Murrelets. Both preferred to forage and rest further offshore, with Marbled Murrelets preferring a band 600-900 meters from shore (Figure 4), and Kittlitz's Murrelets preferring a band 600-1500 meters from shore (Figure 5). This is consistent with other surveys that show Marbled and Kittlitz's Murrelets prefer deeper waters (Drew et al. 2008:83), and Kittlitz's Murrelets being found further offshore than Marbled Murrelets (Robards et al. 2002).

Because murrelets exhibit a pattern of avoidance and preference for different offshore zones, a transect line that runs strictly parallel to shore, and samples only 1 zone, will be biased. The direction and magnitude of that bias will depend on how far offshore the transect line is, and whether it falls in a little used or heavily used habitat. If surveys are done for trend only, such a bias is acceptable, as long as the distribution of birds doesn't shift from year to year. If the distribution shifts, of if distance offshore varies, trend estimation is confounded.

Bay-wide Spatial Distribution—In general, the highest densities of Marbled Murrelets were found in the lower Glacier Bay. The highest densities of Kittlitz's Murrelets were found in both upper arms of Glacier Bay, as well as the lower bay (Figure 6). Although Kittlitz's Murrelets occur at their highest densities in glacially-influenced waters, they can be encountered anywhere in the bay. The hotspots for both species vary somewhat from survey to survey, but there are notable differences between the 1993 survey and the average pattern for the 2009 survey (Figures 7 and 8). The very high murrelet densities in lower Muir Inlet in 1993 were less obvious in 2009 (Figure 9).

Kittlitz's Murrelets were more highly aggregated in 1993 than in 2009. The coefficient of variation (CV) is a mean-adjusted measure of variance among the transect segments (CV = standard deviation/mean). It can be looked at as a measure of how "clumped" the counts of birds are across the surveyed segments. Kittlitz's Murrelets were more aggregated in 1993 (CV = 4.9) than in 2009 (CV = 2.5). Between species, we found Kittlitz's Murrelet were more clumped in their distribution (CV = 3.1) than Marbled Murrelets (CV = 2.0). This result might be expected given the smaller numbers of Kittlitz's Murrelets, and their affinity for marine areas with high glacial influence.

Although densities of murrelets changed substantially from one survey to the next in 2009 (Table 5), we found the distribution to be fairly consistent among surveys (Figures 10 and 11). Marbled

Murrelets are consistently widespread in the bay (Figure 10), whereas Kittlitz's Murrelets are consistently low in the middle bay and lower west arm (Figure 11). Because the time frame of this study is short (9 days), these density maps do not represent summer-long distribution. Other studies have documented substantial shifts in distribution from month to month within the bay (Romano et al. 2004).

DISCUSSION

Population Trend-- The results of this survey suggest that both Marbled Murrelets and Kittlitz's Murrelets are abundant in Glacier Bay, and that their populations have been relatively stable since 1993. We would be more confident in this conclusion if we had more than 2 survey years of data. However, trends have been cited for several Alaska study areas based on 2 surveys-years of data (Piatt et al. 2007), and because the 2009 surveys were replicated 3 times, the 2009 results are relatively robust.

This period of population stability, after 1993, may have been preceded by a large population decline. Drew and Piatt (2008) found densities of Kittlitz's Murrelets in 1991 were 7 times higher than in 1999. Up until now, we have supposed that murrelet populations crashed sometime within an 8 year time span (1991-1999)(Drew et al. 2007, Drew and Piatt 2008). The results of this study allow us to narrow the timing of the decline. If it is real, the bulk of the decline occurred before the 1993 survey, most likely in the winter of 1991 and 1992.

If murrelets truly declined 80-90 percent in 2 years (or even 8 years), we are challenged to answer why. Murrelets, like all seabirds, are relatively long-lived; and poor nesting success over a few years can not result in an 80% decline in the population. Direct adult mortality is necessarily implicated. Habitat conditions changed little during that short interval, and would not add significant adult mortality in any case. Gill-net fishing, which can cause adult mortality through by-catch, has never occurred in Glacier Bay or surrounding waters. Avian predators, like Bald Eagles (*Haliaeetus leucocephalus*), may kill some birds, but it is difficult to imagine them killing tens of thousands of murrelets in a few years, and then stopping. The only agents that might cause a decline of this severity, and suddenness, include a large oil spill, mass starvation (perhaps during the flightless molt), or disease. There is no independent evidence to suggest these things occurred.

That a population crash went unnoticed, or that a cause can not be easily identified, does not mean it did not occur. But it does invite questions about whether the decline is real, or an artifact of an anomalous bird distribution, or measurement errors in one or more surveys. Given the many factors that can affect survey results, and the fact that a single high count drives much of the decline in both species, we believe the latter explanation deserves more attention.

Nearshore Distribution—Murrelets may be considered a “nearshore” seabird, but they are not functionally tied to shallow water, or benthic food resources. Both Marbled and Kittlitz’s Murrelets forage over relatively deep water compared to other waterbirds in Glacier Bay (Drew et al. 2008). In our study, we found the birds only lightly used the nearshore zone, and preferred waters 500-1500 meters offshore.

Other studies have found similar results. In California, the peak density of Marbled Murrelets occurs 800 m offshore (Ralph and Miller 1995). In Stephen’s Passage, in Southeast Alaska, the peak density of Marbled Murrelets occurs 1000 m offshore (ADF&G unpublished data). In British Columbia, peak densities are approximately 300 m offshore in Trevor Channel (Burger 1995), and 600 m offshore along southwest Vancouver Island (Wong et al. 2008). The exact shape of these murrelet distribution patterns reflects, in part, the abundance and availability of food resources in these different areas.

But other factors come into play as well. These birds are exposed to predation, especially by aerial predators such as the Bald Eagle. They must balance the need to acquire sufficient food for themselves and their chicks, while avoiding being killed. Because the majority of a murrelet’s daily activity budget is allocated to non-foraging activity (Henkel et al. 2003), we suspect their typical distribution is heavily influenced by the need to reduce exposure to predation risk. Logically, that risk increases with proximity to shore.

The oceanographic conditions that drive forage abundance and availability are not static, but change over time (Gaston 2004, Etherington et al. 2007). Not surprisingly, we see this spatial and temporal variability reflected in the shifting distribution of murrelets in Glacier Bay. In 2007, *Brachyramphus* murrelet abundance peaked 200-400 m from shore (Kirchhoff 2008). In 2009, they showed stronger preference for waters 600-900 m from shore. In 1999, Marbled Murrelets were most abundant on coastal transects (< 200 m from shore); and the next year, they were more abundant on offshore transects (> 200 m from shore) (Robards et al. 2002).

Murrelet density increases as one moves progressively outward from the shore, peaking somewhere between 300-1000 m generally. The steepness and magnitude of this density gradient varies from place to place, and from time to time. Survey lines that run parallel to the shore make it impossible to know if two density estimates differ because (a) surveys were run different distances from shore (b) surveys were run the same distance from shore, but murrelet distribution shifted between years, or (c) the population truly changed. When a density gradient exists, the population should be sampled with the lines *parallel* to that gradient (Buckland et al. 2001), (i.e., perpendicular to shore). Alternatively, the gradient can be sampled with zig-zag lines, or at randomized distances to shore, so that the entire gradient is sampled. The latter approach is the one used to monitor Marbled Murrelets in the Northwest Forest Plan (Raphael et al. 2007)

Large-scale (bay-wide) Distribution-- Marbled Murrelets are relatively abundant and widespread in Glacier Bay. Kittlitz's Murrelets are much more rare, and localized in their distribution. For Kittlitz's Murrelets especially, the density returned on any annual survey is heavily dependent on whether one or more transect lines intersects a cluster of birds. In 1993, for example, over 50% of the Kittlitz's murrelets were counted on 1.5% of the survey area. One way of improving the efficiency, and power, of the surveys is to stratify your sampling effort. Placing more effort in strata where Kittlitz's Murrelets are more likely to occur will potentially increase the precision of your estimate without increasing time and cost. The advantage of various stratification designs is well covered by Drew et al. (2008), and won't be discussed further here.

Temporal Variation-- For the sake of discussion, we raise the question of whether the birds in Glacier Bay really reflect a "population" in the sense that it is closed to significant emigration and immigration within a breeding season, and that the same birds (or same fraction of the global population) return to Glacier Bay from one summer to the next. We know from flyway counts in Icy Strait, and at the mouth of Glacier Bay that thousands of murrelets are flying into lower Glacier Bay in the morning, and leaving this area in the evening (Kirchhoff 2008). Whether this daily influx of "day-use" birds is constant throughout the summer, or year to year, is not known.

Similarly, when forage resources are low, birds may abandon breeding efforts early, or altogether, and move out of Glacier Bay. In those circumstances, low densities in Glacier Bay would reflect a redistribution of birds, not a population decline. More research is needed to understand these large-scale temporal and spatial patterns, and their potential effect on survey trends.

Implications for Future Surveys--One of the most important findings of this study is that surveys conducted in the nearshore stratum (0-300 m) are sampling habitat that is lightly-used by both species, and so counts will be low. Similar conclusions have been reached by Kirchhoff (2008) and Drew et al. (2008). Slight, unintended shifts in the survey track of even a few hundred meters further from shore can change the density estimate by several hundred percent (Kirchhoff 2008). Survey tracks that "follow" the shore never follow the shore exactly, and no two shoreline surveys are ever the same. For that reason, we recommend that survey transects always be straight lines, with known start and end points. Ideally, these start and end points are programmed into an auto-pilot steering system so tracks can be replicated exactly, and steerage is independent of the observer with respect to birds ahead.

Most surveys of murrelets in Alaska are based on a single survey conducted during the breeding season. Sometimes those surveys are conducted on the same date, and sometimes they are weeks, or even months different. This introduces unhelpful variance, because populations change as breeding birds come off nests sometime in mid summer. Moreover, nesting is asynchronous, and the peak of incubation may shift year to year. For this reason, we recommend surveys be conducted within the same 2-3 week time window each year. The time interval selected should coincide with the summer period when the survey coefficient of variation is lowest. In Glacier

Bay, and nearby Icy Strait, that period is late June to mid July (Kirchhoff and Lindell, unpublished data).

In this study, we found that in two bay-wide surveys, conducted with the same vessel and crew just 3 days apart, returned differences in density estimates of > 50 percent. This variability may be due to an influx of birds, or it may reflect normal sampling variance. Because of high between-survey differences within a narrow time period, we recommend replicating the survey 1 or more times to achieve a robust, representative estimate of true density.

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LITERATURE CITED

Buckland, S.T., D.R. Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers, and L. Thomas. 2001. Introduction to distance sampling, estimating abundance of biological populations. Oxford University Press, New York. 432pp.

Burger A.E. 1995. marine distribution, abundance and habitats of Marbled Murrelets in British Columbia. Pages 295-312 in: Ralph, C.J, G.L. Hunt, M.G. Raphael, and J.F. Piatt, eds. Ecology and conservation of the Marbled Murrelet. USDA Forest Service, Pacific Southwest Research Station, Gen. Tech Rep. PSW-GTR-152

Drew, G.S., J.F. Piatt, and J.L. Bodkin. 2007. et al. 2007. Population status and trends of marine birds and mammals in Glacier Bay National Park, in J.F. Piatt and S.M. Gende, eds., Proceedings of the Fourth Glacier Bay and Science Symposium, October 26-28, 2004. U.S. Geological Survey Scientific Investigations report 2007-5047, p. 120-132.

______, and J.F. Piatt. 2008. Using geographic information systems to compare non-uniform marine bird surveys: detecting the decline of Kittlitz's Murrelet (*Brachyramphus brevirostris*) in Glacier Bay, Alaska. The Auk 125(1):178-182.

______, S.G. Speckman, J.F. Piatt, J.M. Burgos, and J.L. Bodkin. 2008. Survey design considerations for monitoring marine predator populations in Glacier Bay, Alaska: results and post-hoc analysis of surveys conducted 1999-2003. Administrative Report., U.S. Department of the Interior, U.S. Geological Survey., prepared in cooperation with the National Park Service.

Etherington, L.L., P.N. Hooge, E.R. Hooge, and D.F. Hill. 2007. Oceanography of Glacier bay, Alaska: implications for Biological patterns in a Glacial Fjord Estuary. Estuaries and Coasts 30(6):927-944.

Gaston, A.J. 2004. Seabirds, a Natural History. Yale University Press. New haven, CT., 222 pp.

Henkel, L.A., E.E. Burkett, and J.Y.Takekawa, 2003. At-sea asctivity and diving behavior of a radio-tagged Marbled Murrelet in central California. Waterbirds 26(4)9-12.

Ivlev, V.S. 1961. Experimental ecology of the feeding of fishes. Yale University Press, New Haven CN.

Kirchhoff, M.D. 2008. Methodological considerations for at-sea monitoring of Brachyramphus murrelets in Glacier Bay, Alaska. Final Report, Feb. 2008. Alaska Department Of Fish and Game. Juneau. 73pp.

Kuletz, K.K., B. Manly, C. Nations, and D. Irons. 2005. Declines in Kittlitz's and Marbled Murrelets in Prince William Sound, Alaska: dealing with uncertainty. Appendix in: Kuletz, K.K., 2005. Foraging behavior and productivity of a non-colonial seabird, the Marbled Murrelet (*Brachyramphus marmoratus*), relative to prey and habitat. PhD. dissertation. University of Victoria, 195pp.

Lindell, J. 2005. Results of at-sea Brachyramphus murrelet surveys in Icy Strait and other selected areas of Southeast Alaska. USFWS Ecological Services, Juneau.

Piatt, J.F., K.J. Kuletz, A.E. Burger, S.A. Hatch, V.L. Friesen, T.P. Birt, M.L. Arimitsu, G.S. Drew, A,M.A. Harding, and K.S. Bixler. 2007. Status review of the Marbled Murrelet (*Brachyramphus marmoratus*) in Alaska and British Columbia. U.S. Geological Survey Open-File Report 2006-1387, 285p.

Ralph, C.J and S.L. Miller. 1995. Offshore population estimates of Marbled Murrelets in California. Pp. 353-360, in: Ralph, C.J, G.L. Hunt, M.G. Raphael, and J.F. Piatt, eds. Ecology and conservation of the Marbled Murrelet. USDA Forest Service, Pacific Southwest Research Station, Gen. Tech Rep. PSW-GTR-152

Raphael, M.G, J. Baldwin, G.A. Falxa, M.H. Huff, M. Lance, S.L. Miller, S.F. Pearson, C.J. Ralph, C. Strong, and C. Thompson. 2007. Regional Population Monitoring of the Marbled Murrelet: Field and Analytical Methods. PNW GTR-716

Robards**,** M., G. Drew, J. Piatt, P. Hooge, J.M. Anson, A. Abookire, S. Speckman and J. Bodkin. 2002. Glacier Bay small schooling fish project. U.S. Geological Survey, Alaska Science Center. Final Report. 154 pages.

Romano, M.D., M.L. Arimitsu, J.F. Piatt, A.A. Agness, nd G.S. Drew. 2004. At-sea density and distribution of Kittlitz's Murrelets and marbled Murrelets in Glacier Bay, Alaska, Summer 2003. U.S. geological Survey, Alaska Science Center, Anchorage. Annual Report to U.S. national park Service, Glacier Bay National Park and Preserve.

Schneider, D.C. 1990. Spatial autocorrelation in marine birds: Polar Biology, V. 8, P. 89-97.

USFWSa. 2009. Species Assessment and Listing Priority Assignment Form. May 2009. US Fish and Wildlife Service, Ecological Services, Anchorage. 38 pp.

Wong, S.N.P., R.A. Ronconi, A.E. Burger, and B. Hanson. Marine distribution and behavior of juvenile and adult marbled murrelets off southwest Vancouver island, British Columbia: applications for monitoring. The Condor 110:306-315.

TABLES

Table 1. Transect start and end points for the 1993 Glacier Bay surveys. Latitude and Longitude readings are NAD 27. Transects are “named” with the lower (start) waypoint number.

Transect ID	Latitude Start	Longitude Start	Latitude End	Longitude End	Length
400	58.3792	135.9333	58.4450	136.0617	10.06
401	58.4450	136.0617	58.4567	136.0417	1.43
402	58.4567	136.0417	58.4956	136.0417	4.31
403	58.4956	136.0417	58.5442	136.1344	7.64
404	58.5442	136.1344	58.5850	136.0000	9.02
405	58.5850	136.0000	58.6258	136.1333	8.95
406	58.6258	136.1333	58.6767	136.0783	6.48
407	58.6767	136.0783	58.6767	136.2200	8.18
408	58.6767	136.2200	58.7481	136.2200	7.93
409	58.7481	136.2200	58.7481	136.4283	12.04
410	58.7481	136.4283	58.8167	136.4283	7.63
411	58.8167	136.4283	58.8167	136.5317	5.94
412	58.8167	136.5317	58.9156	136.5317	10.98
413	58.9156	136.5317	58.8633	136.7033	11.44
414	58.8633	136.7033	58.9069	136.7539	5.65
415	58.9069	136.7539	58.8825	136.8369	5.49
416	58.8825	136.8369	58.9536	136.9150	9.09
418	58.7342	136.3583	58.6819	136.3317	6.00
419	58.6819	136.3317	58.5950	136.4983	13.65
421	58.6819	136.3317	58.7217	136.1044	13.83
422	58.7217	136.1044	58.8089	136.1247	9.76
423	58.8089	136.1247	58.8411	136.0628	5.06
424	58.8411	136.0628	58.8867	136.1100	5.74
425	58.8867	136.1100	58.9117	136.0617	3.93
426	58.9117	136.0617	58.9567	136.1483	7.05
427	58.9567	136.1483	58.9850	136.1167	3.63
428	58.9850	136.1167	59.0683	136.2100	10.25
430	58.8089	136.1247	58.6967	136.0011	14.35
431	58.6967	136.0011	58.6911	136.0117	0.86
432	8.6911	136.0117	58.5978	135.9097	12.58
433	58.5978	135.9097	58.6289	136.0111	7.21
434	58.6289	136.0111	58.5617	136.0108	7.46
435	58.5617	136.0108	58.5133	135.9572	6.21
436	58.5133	135.9572	58.4917	135.9983	3.39
437	58.4917	135.9983	58.5050	136.0417	2.92
438	58.5050	136.0417	58.4683	136.0417	4.07
439	58.4683	136.0417	58.4364	135.9317	7.32

Table 2. Additional transect lines were added in July 2009 to obtain better coverage of Glacier Bay, including one transect in Tarr Inlet (4171) and three transects in Wachusset Inlet (4291-4293). These four survey lines were not included in comparisons of 1993 and 2009 survey results. The original (1993) end waypoint for transect 428 fell beyond the wilderness water boundary in upper Muir Inlet and could not be reached in 2009. This waypoint was relocated to the wilderness boundary, and resulted in transect 428 being shortened by 2.5 km in 2009.

TRANSECT ID	LATITUDE START	LONGITUDE START	LATITUDE END	LONGITUDE END	LENGTH
428	58.9850	136.1167	59.0450	136.1850	7.75
4171	58.9675	136.9133	59.0517	137.0558	12.40
4291	58.9417	136.1400	58.9233	136.2600	7.18
4292	58.9233	136.2600	58.9582	136.3867	8.23
4293	58.9582	136.3867	58.9880	136.4083	3.55

Table 3. Sums of birds seen on 41 transects in each of three surveys conducted in 2009.

SURVEY VESSEL	MAMU SITTING	KIMU SITTING	UNID SITTING	MAMU FLYING	KIMU FLYING	UNID FLYING
Sierra	1367	336	157	231	42	49
Gravina 1	1287	298	35	126	4	14
Gravina 2	2426	401	39	155	12	8
MEAN	1693	345	77	171	19	24

Table 4. Percent of murrelets that were unidentified, flying, and identified as Kittlitz's Murrelets during summer, 1993 and 2009. Results are for the 37-transect set.

SURVEY YEAR	SURVEY VESSEL	MURRELETS UNIDENTIFIED	MURRELETS FLYING	% IDENTIFIED AS KITTLITZ'S
1993	Curlew	0.0%	29.8%	7.2%
2009a	Sierra	8.5%	15.0%	13.4%
2009b	Gravina 1	3.0%	8.9%	17.5%
2009c	Gravina 2	1.3%	5.9%	12.9%

Table 5. A comparison of density and population size of Marbled Murrelets (MAMU) and Kittlitz's Murrelets (KIMU) *on the water* in 1993 and 2009. Unidentified murrelets (N=179) were allocated 14% to KIMU and 87% to MAMU consistent with the species ratio in positively identified birds (N = 6,616). Comparisons are based on the 37-transect set (replicated three times in 2009).

SPECIES	SURVEY YEAR	NUMBER OF TRANSECTS	DENSITY (BIRDS/KM^2)	POPULATION SIZE
MAMU	**1993**	37 x 1	23.36	30,042
	2009	37 x 3	19.66	25,288
KIMU	**1993**	37 x 1	2.07	2,657
	2009	37 x 3	3.55	4,570

Table 6. Distribution of survey effort and habitat use by Marbled Murrelets (MAMU) and Kittlitz's Murrelets (KIMU) relative to the shore. Use statistics are for birds recorded on the water over three surveys (41 transects/survey).

DISTANCE FROM SHORE (M)	% AVAILABLE AS HABITAT	% OF USE BY MAMU (N = 5,080)	% OF USE BY KIMU (N = 1,035)
0-300	0.04	0.03	0.02
300-600	0.16	0.16	0.15
600-900	0.18	0.27	0.25
900-1500	0.20	0.22	0.20
1500-1800	0.13	0.10	0.15
1800-2100	0.08	0.07	0.09
>2100	0.06	0.06	0.04

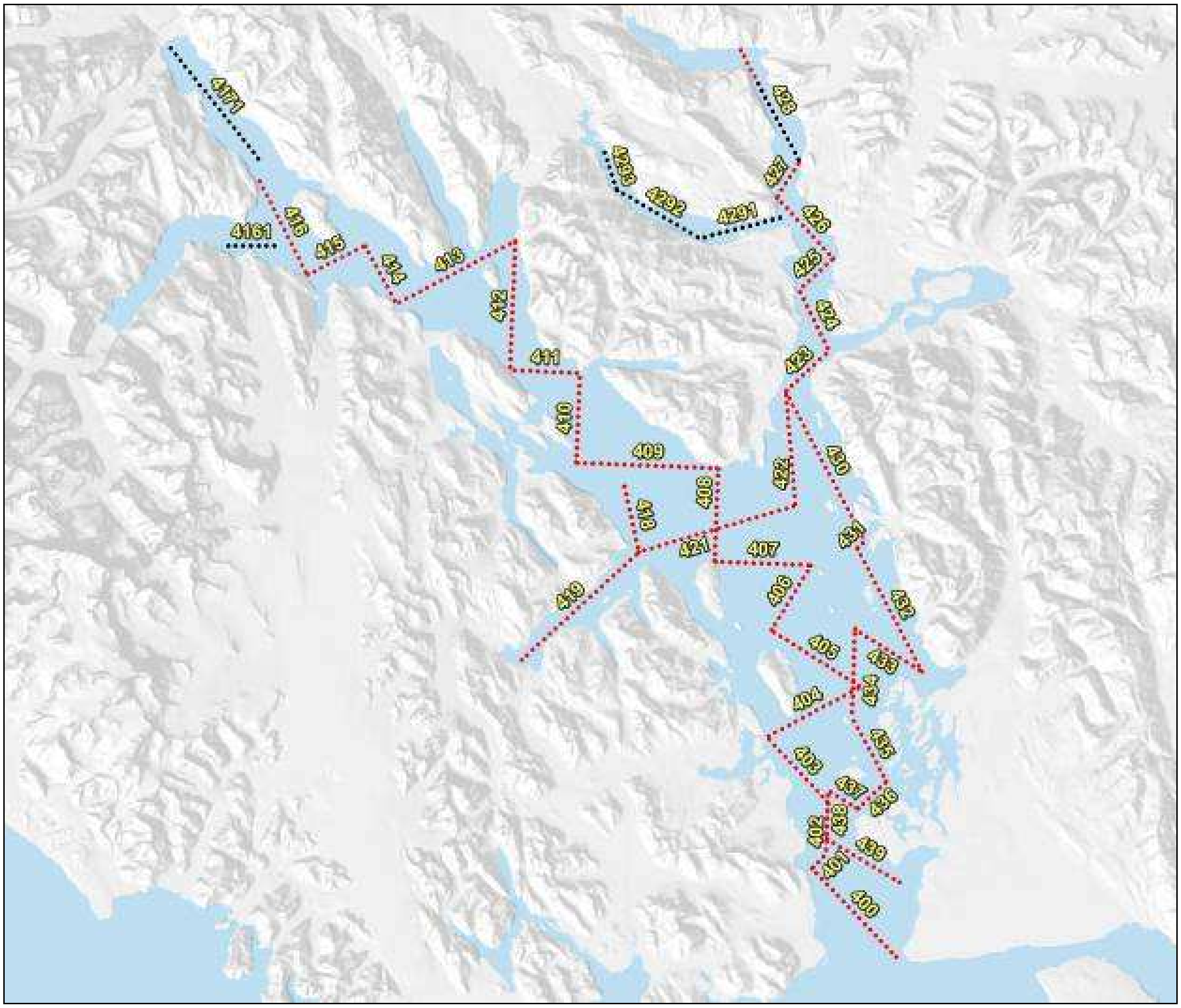

Figure 1. Locations of 42 at-sea transects in Glacier Bay. The red lines are transects surveyed in both 1993 and 2009. The black lines, with four-digit numbers, are transects added in 2009. These added transects were not used when comparing densities between years. Transect 428, in northern Muir Inlet, was surveyed both years, but the northernmost portion (in red) could not be reached in 2009 due to a Wilderness boundary. Transect 4161, near the mouth of Johns Hopkins Inlet, was added by the *Gravina* crew to document an aggregation of Kittlitz's Murrelets in that area. Because of this bias, it was not used in population estimates, trend estimates, or maps of relative abundance.

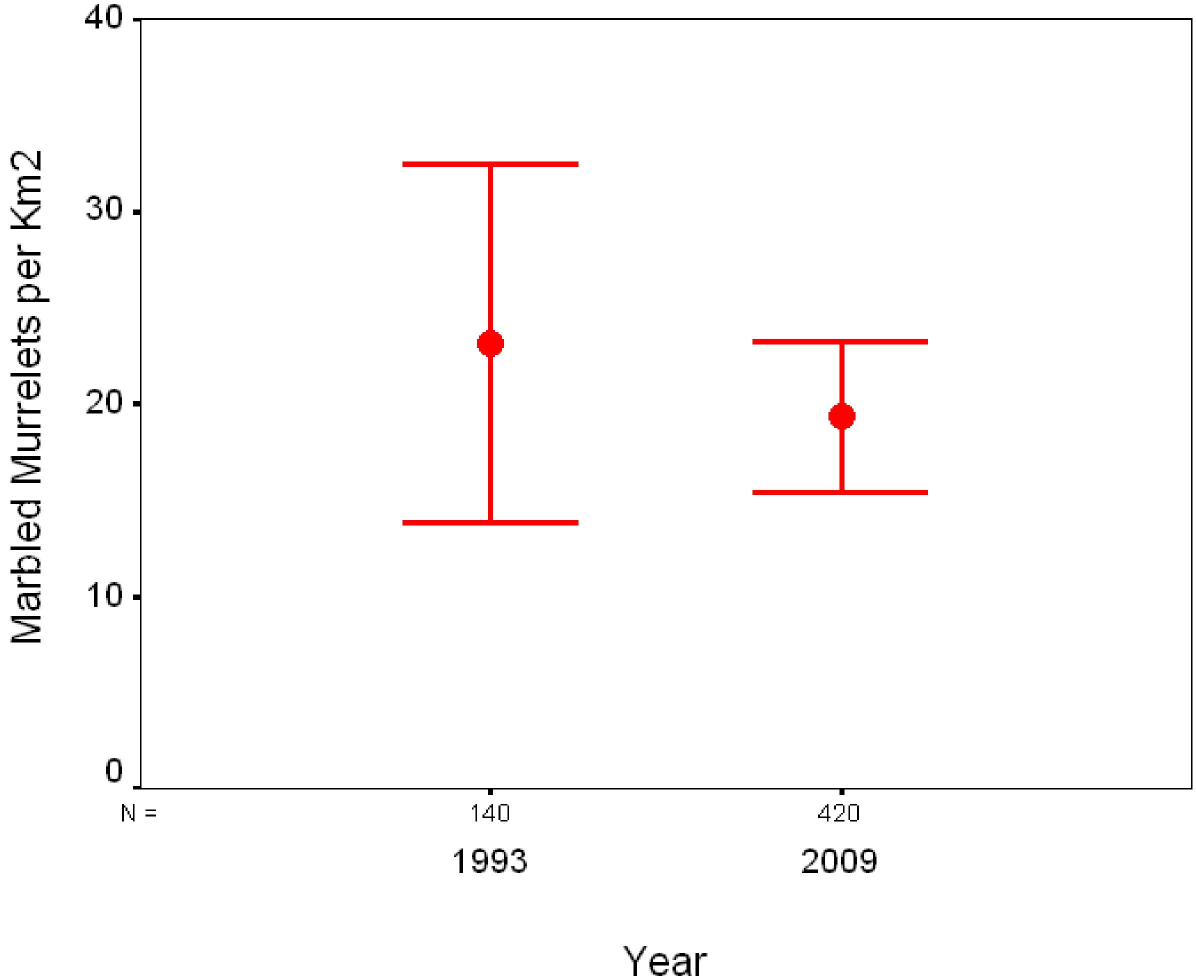

Figure 2. Mean density and 95% Confidence Intervals for Marbled Murrelets in Glacier Bay in 1993 and 2009. The 37 transects shown in Figure 1 were subdivided into 2 km long segments, yielding 120 sample units in 1993, and 420 sample units (from three surveys) in 2009.

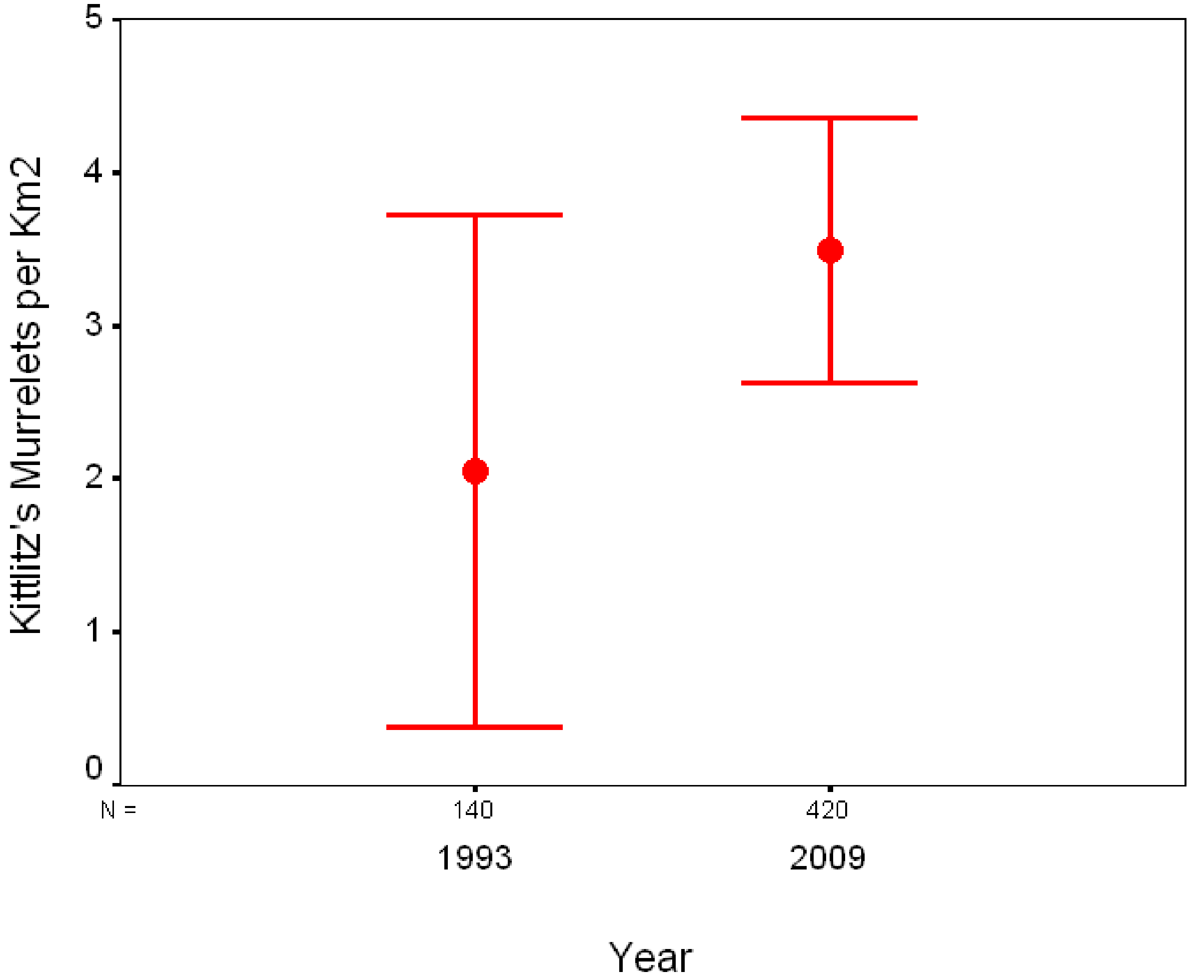

Figure 3. Mean density and 95% Confidence Intervals for Kittlitz's Murrelets in Glacier Bay in 1993 and 2009. The 37 transects shown in Figure 1 were subdivided into 2 km long segments, yielding 120 sample units in 1993, and 420 sample units (from three surveys) in 2009.

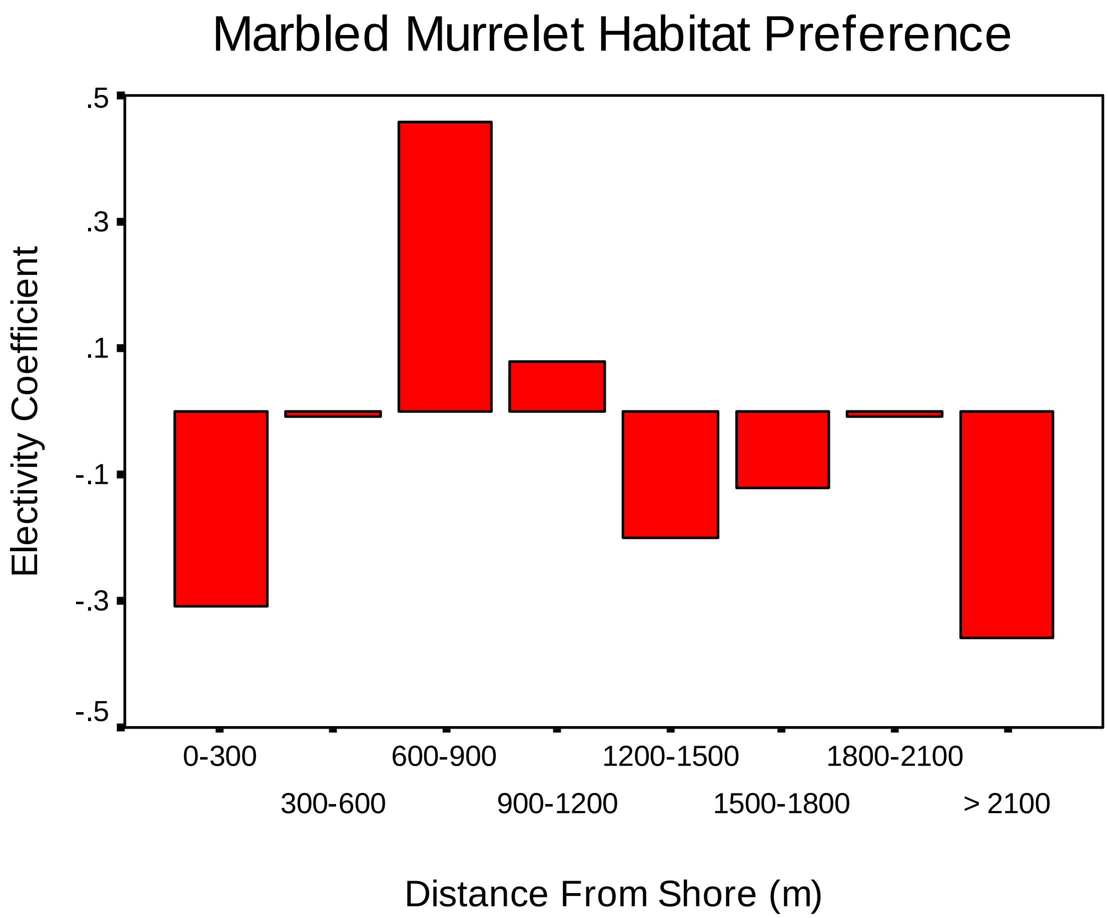

Figure 4. Marbled Murrelets do not select for waters within 300 m of shore, and selected for waters 600-900 m from shore. Waters beyond 1,200 m from shore are not selected (N = 5,080 Marbled Murrelets recorded over three surveys).

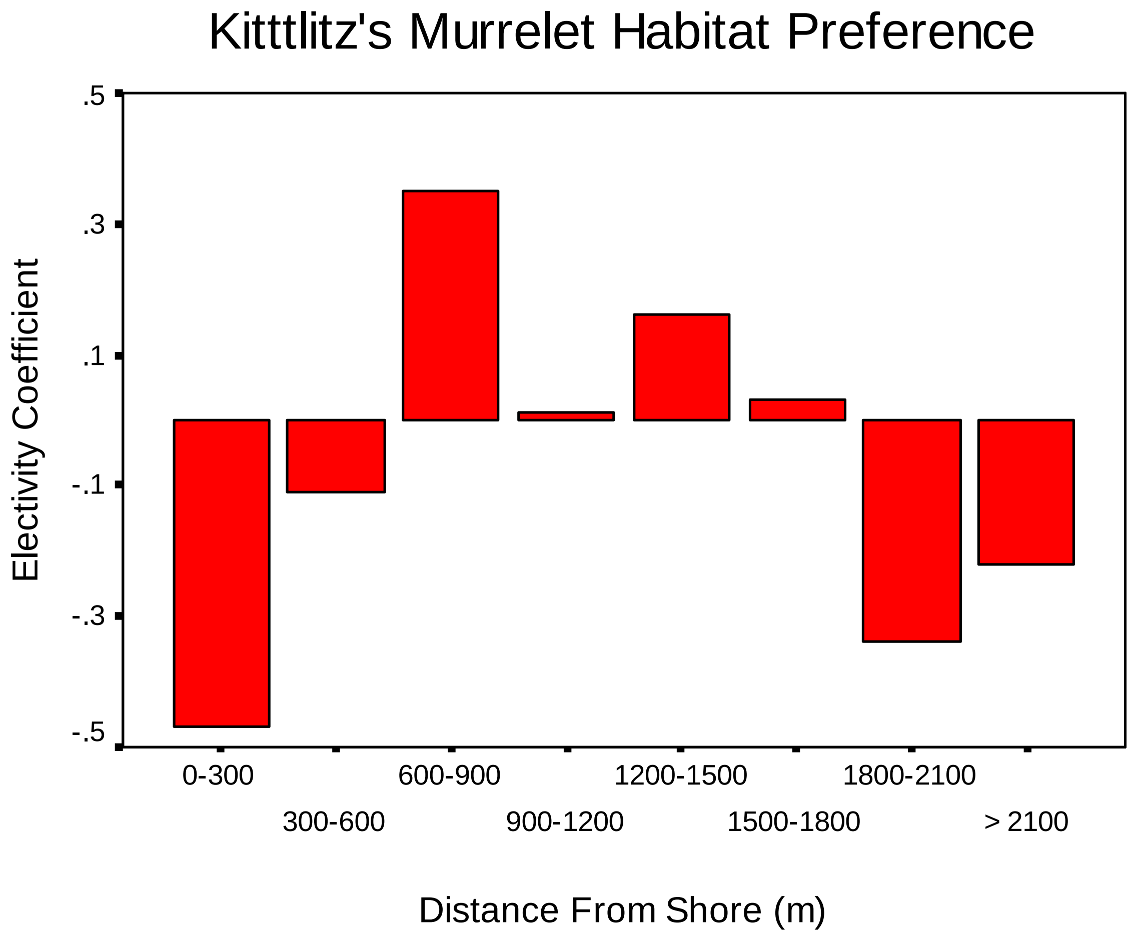

Figure 5. Kittlitz's Murrelets also do not select for waters within 300 m of the shore. Kittltiz's Murrelets tend to occur further offshore than Marbled Murrelets, with a preference for waters 600-900 offshore, and a less-strong preference for 1200-1500 m offshore. Waters beyond 1800 m from shore are not selected. (N = 1,035 Kittlitz's Murrelets recorded over three surveys)

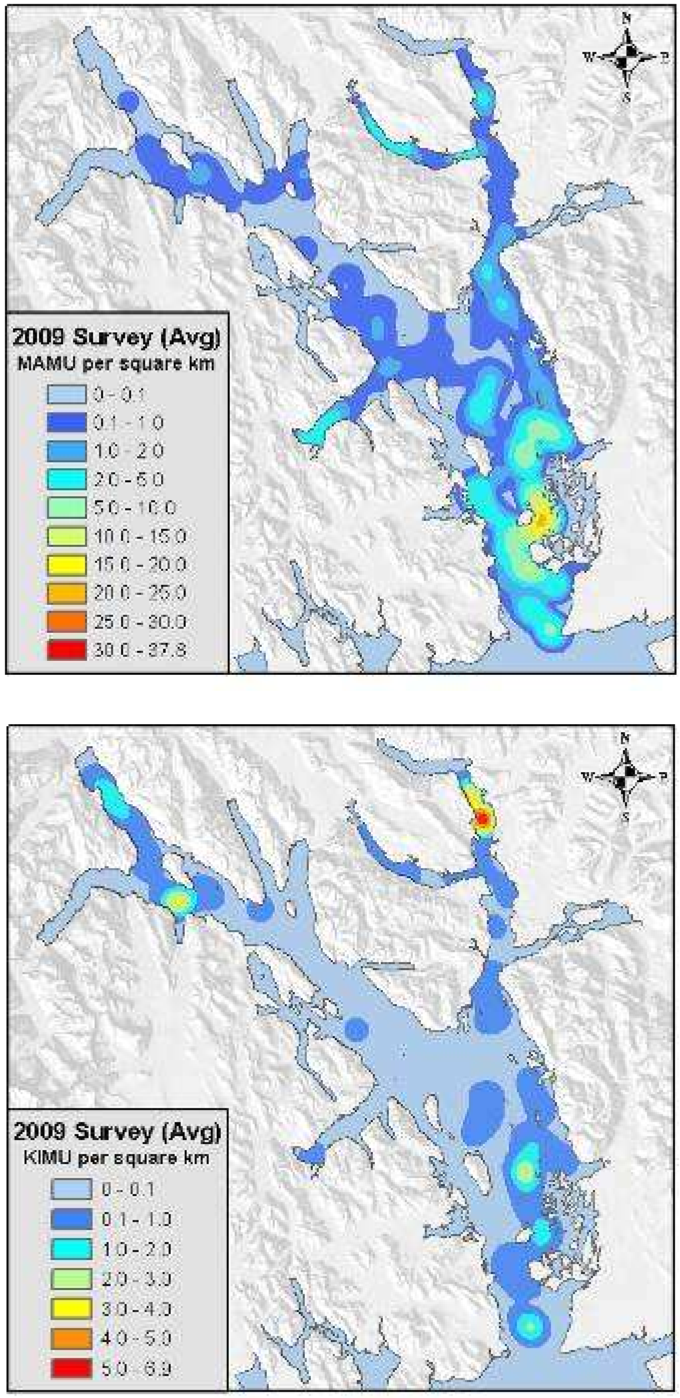

Figure 6. Comparative distribution of Marbled Murrelets (top) and Kittlitz's Murrelets (bottom) in Glacier Bay, 2009. Results reflect average of three replicate surveys. Small bays were not surveyed (see Figure 1).

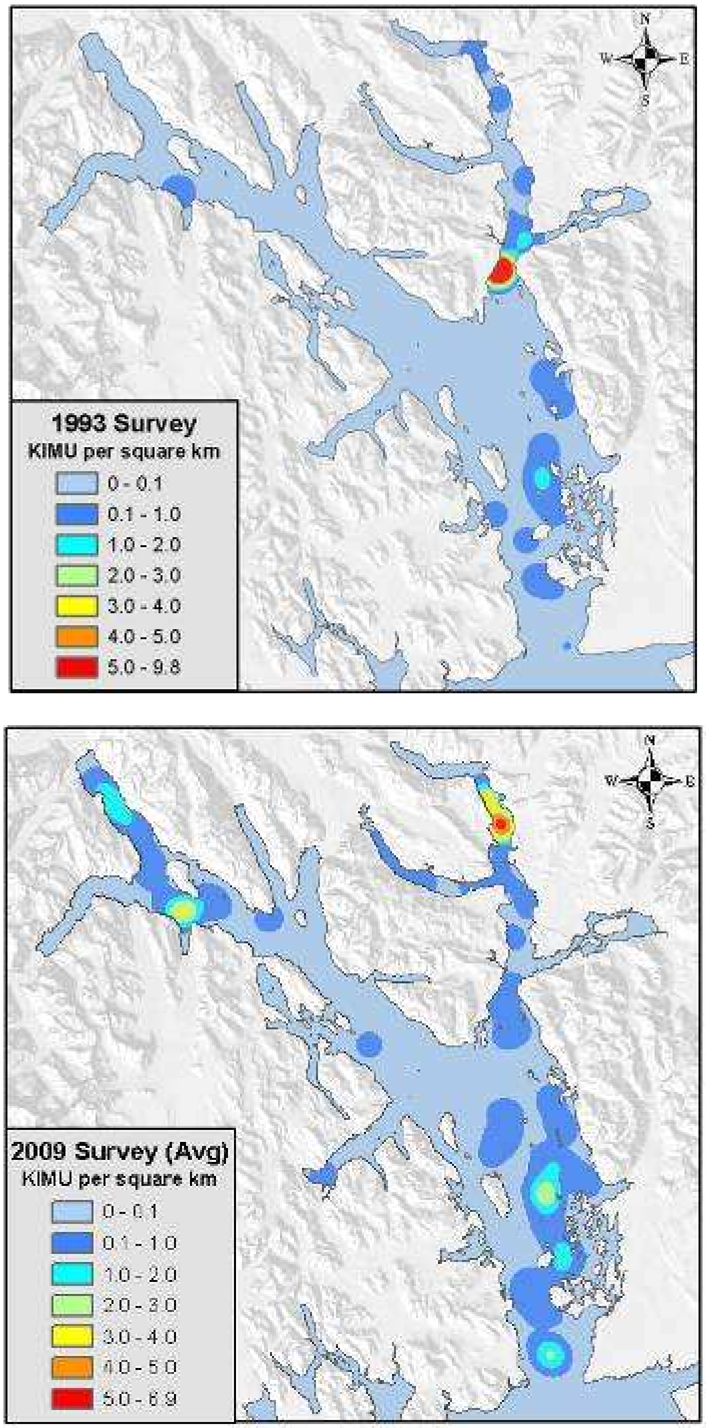

Figure 7. Comparative distribution of Kittlitz's Murrelets in Glacier Bay in 1993 (top) and 2009 (bottom). Survey coverage was expanded into Tarr and Wachusset Inlets in 2009 (see Figure 1).

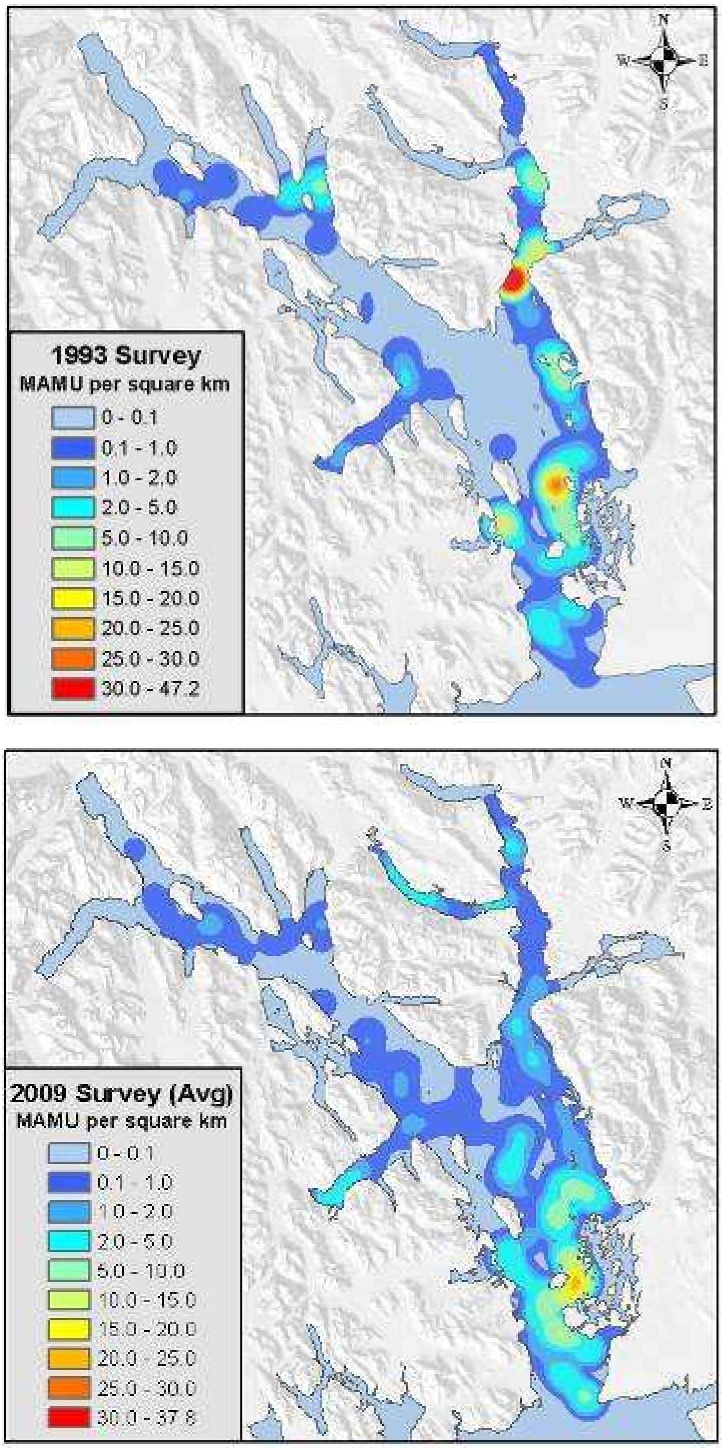

Figure 8. Comparative distribution of Marbled Murrelets in Glacier Bay in 1993 (top) and 2009 (bottom). Survey coverage was expanded into Tarr and Wachusset Inlets in 2009 (see Figure 1).

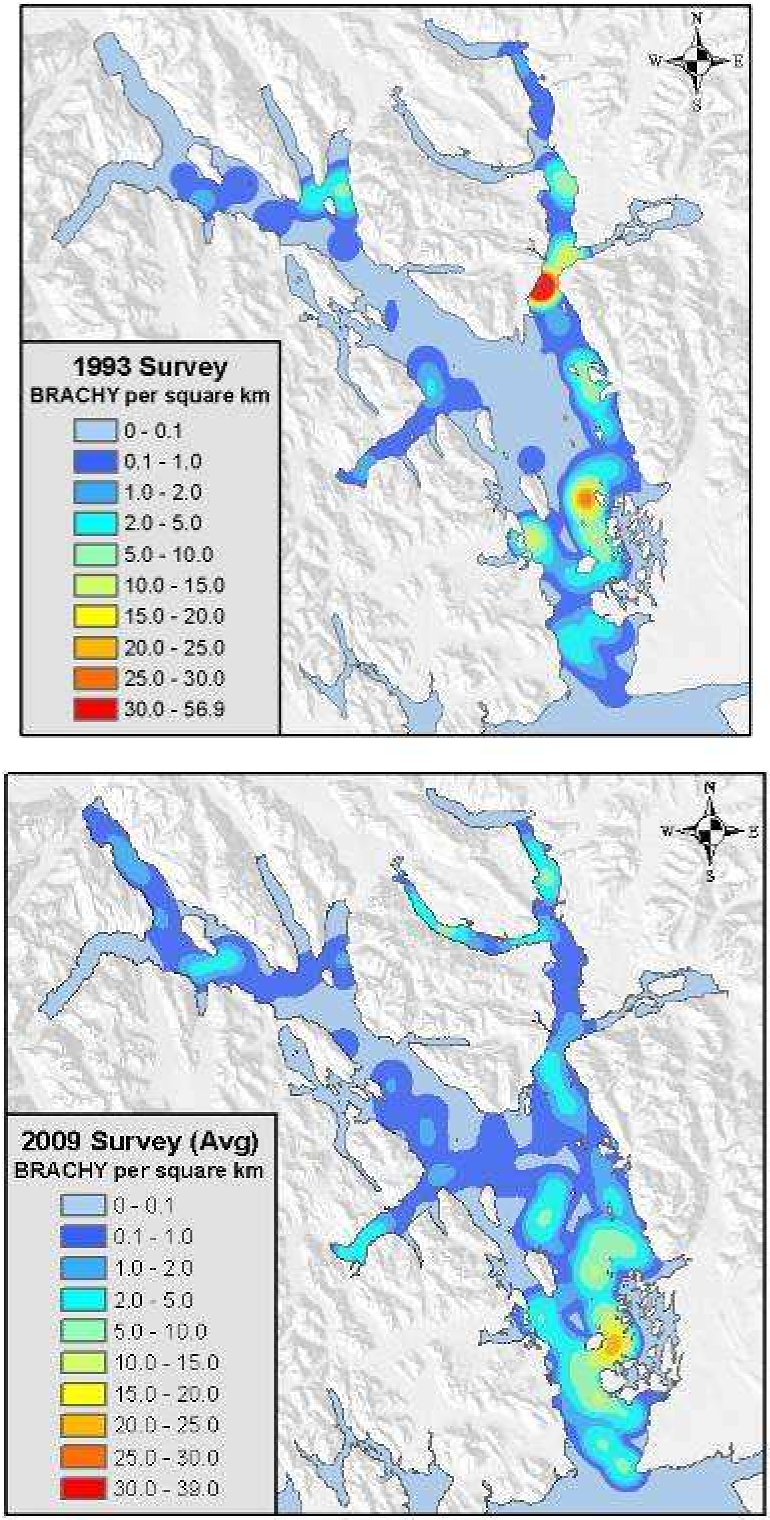

Figure 9. Comparative distribution of *Brachyramphus* Murrelets in Glacier Bay in 1993 (top) and 2009 (bottom). Survey coverage was expanded into Tarr and Wachusset Inlets in 2009 (see Figure 1).

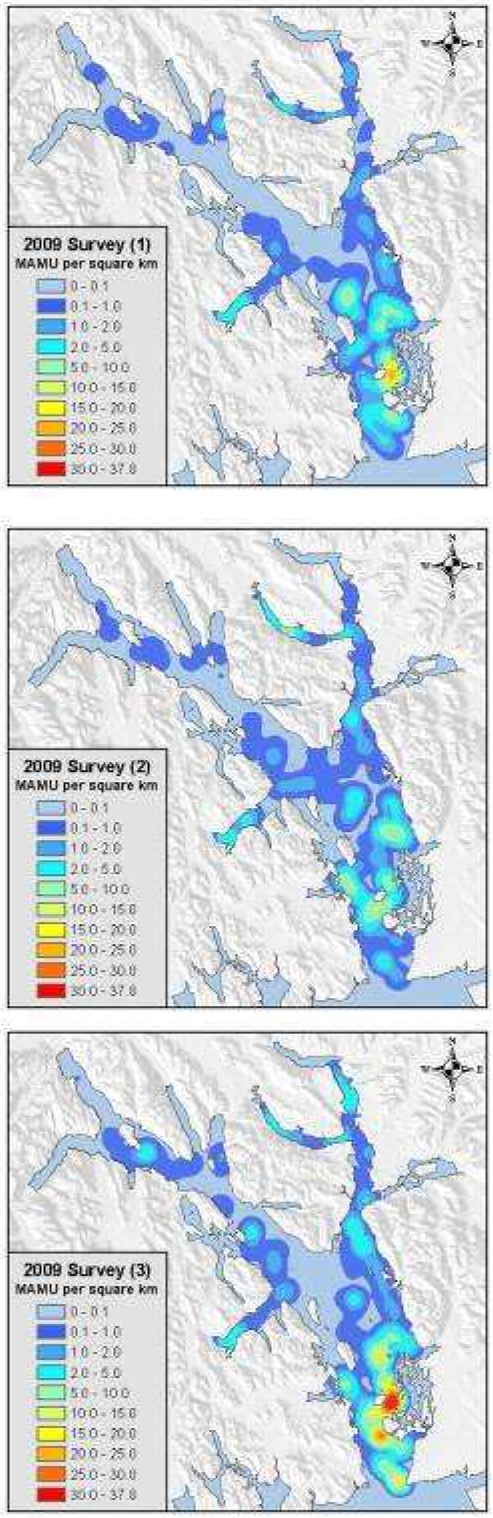

Figure 10. Survey to survey variance in density and distribution of Marbled Murrelets during three surveys conducted 3-9 July 2009.

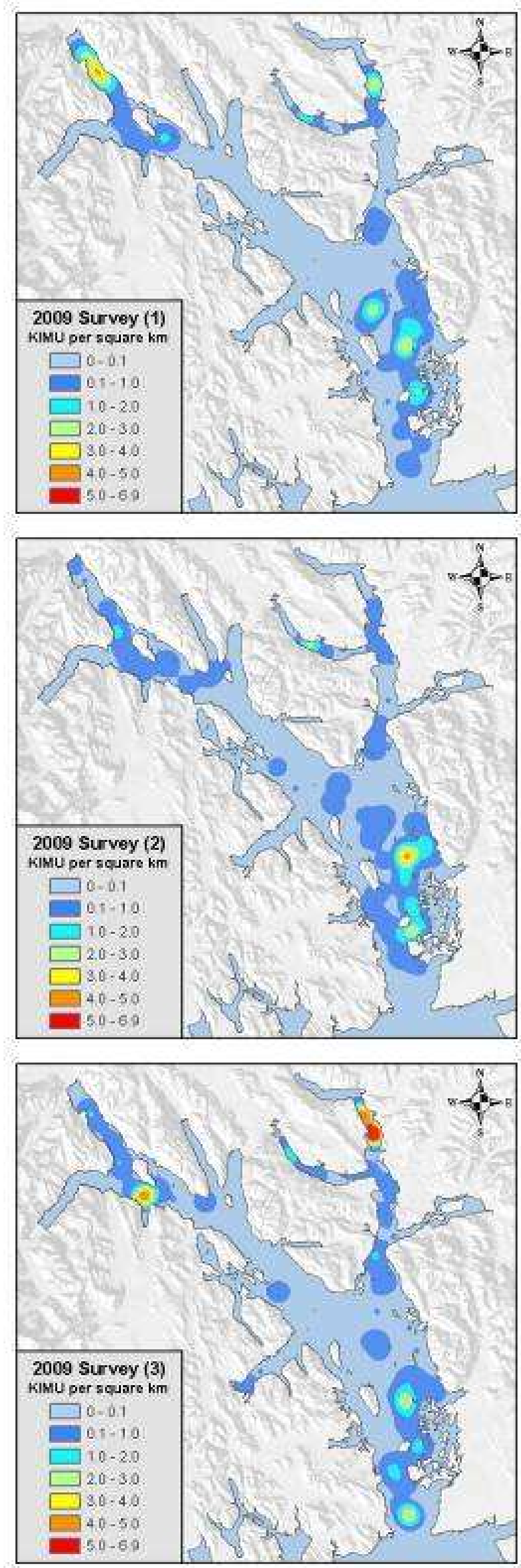

Figure 11. Survey to survey variance in density and distribution of Kittlitz's Murrelets during three surveys conducted 3-9 July 2009.