ALASKA DEPARTMENT OF FISH AND GAME
DIVISION OF WILDLIFE CONSERVATION
PO Box 115526
Juneau, AK 99811-5526

Alaska Department of Fish and Game
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Project Title: Field testing alternative survey methods for monitoring marbled murrelet populations in Southeast Alaska

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I. PROBLEM OR NEED THAT PROMPTED THIS RESEARCH

The marbled murrelet (Brachyramphus marmoratus) is currently listed as a threatened species in California, Oregon, Washington, and British Columbia, but is relatively abundant in Alaska, where an estimated 91% of the world's population exists (McShane et al. 2004). Given the national spotlight on this species, and the obvious importance of Southeast Alaska to the bird's future, relatively few resources have been devoted to monitoring marbled murrelets in this region. Estimates of the Alaska population were driven in large part by a single at-sea survey conducted by the USFWS in 1994, which placed the population of Brachyramphus spp. in Southeast Alaska at 687,061 (+201,162) (Agler et al. 1998). By these estimates, Southeast Alaska alone contains approximately 65% of the world's marbled murrelets, making it the geographic and demographic center of the bird's range. It is worth noting, however, that the total population estimate was derived from a 0.8% sample of the bird's marine habitat (Agler at al. 1998). Additional localized at-sea surveys were conducted by the USFS and the USFWS in the early 1990's (ref. DeGange 1996), but few of these have been repeated. The only marbled murrelet dataset that spans >3 years is from Glacier Bay National Park, where marbled murrelets declined by 75% between 1991 and 1999/2000 – a rate of decline of 17.5% per year (Piatt and Kuletz 2005). We do not know if the broader population in Southeast Alaska has followed this Glacier Bay trend.

Although information on the current status and trend of marbled murrelets in Southeast Alaska is desperately needed, the best approach for surveying and monitoring this species has not been determined. A region-wide survey comparable to the 1994 USFWS at-sea survey would provide valuable management data, however large-scale randomized surveys are expensive, and funding has been lacking to conduct this work. The cost of marine survey efforts is only one consideration. Agencies must also consider whether to repeat prior survey protocols exactly, for maximum comparability, or switch to alternate methods which may be more accurate, more precise, and less costly. For example, new distance-sampling techniques model detectability as a function of distance, and generally return a more accurate, more precise estimate than the standard fixed-width strip surveys that were employed in Alaska in the past, with only minimal additional effort (Burnham et al. 1985, Thomson et al. 1998, Becker et al. 1997). Staying with old methods improves power retrospectively, while switching to more precise or more accurate techniques improves power prospectively. Management agencies in the Pacific Northwest deliberated for several years over this question before settling on new survey protocols (Beissinger et al. 1999, USDA 2001, Bentivoglio et al. 2002).

Alaska traditionally used fixed-width strip transects for vessel-based surveys. Other murrelet monitoring methods include vessel-based line transects, aerial strip transects, variable area transects (Parker 1979, Engeman et al 2005), “flyway counts” (VanVliet 1993) which are conducted in daylight without the aid of radar, and radar surveys (Burger 1997). It is worth emphasizing that neither radar counts nor flyway counts will provide an estimate of population size. Without knowing what proportion of the population we are counting, the sample counts can not be extrapolated to a larger population. The counts merely represent an index of activity which we assume is correlated with population size.

This study will determine which of the survey methods described above provide the greatest power to detect trends for a given amount of money, time, and effort. Since almost nothing is known about the types of habitats/landscapes favored by marbled murrelets for nesting, this study also will correlate marbled murrelets population indices with physiographic and vegetative attributes at the watershed scale.

II. REVIEW OF PRIOR RESEARCH AND STUDIES IN PROGRESS ON THE PROBLEM OR NEED

Alaska has primarily used fixed-width strip transects for vessel-based surveys. This is partially due to historical precedence. It is also partially due to the fact that in Alaska, large-scale surveys often census all bird species encountered, as well as marine mammals. When populations are dense, as they sometimes are in Alaska, there is insufficient time to collect necessary distance measures (K. Kuletz, personal communication). Hamer (1997) found that multi-species surveys lead to a negative bias for Marbled Murrelets and other small birds.

High-frequency surveillance radar is a tool that allows birds to be reliably detected in darkness and other low-visibility conditions. Radar also provides the option to map flight path, flight speed, and if desired, save data from the CRT screen to CD or other storage media. Extensive testing in British Columbia and the Pacific Northwest has shown radar to be effective for detecting marbled murrelets, with higher detection rates and greater precision than audio-visual methods (Hamer et al 1995, Burger 1997, Cooper et al 2001). In addition to monitoring population trend, researchers have found useful correlations between marbled murrelet numbers and upland habitat attributes, such as forest area, forest type, tree size, fragmentation indices, and topography (e.g., Burger 2001, Cullen 2002, Steventon and Holmes, 2002).

If radar is to be used effectively as a monitoring tool, it should be located where topography funnels birds into narrow, discrete flight paths (Cooper and Hamer 2000), and ideally, where the birds from several watersheds funnel past the monitoring site (Drever and Kaiser 1999). As counts per unit time increase, and precision increases, we realize increased power to detect trends (Thompson et al. 1998). Our goal will be to situate radar stations where they will consistently track the largest possible number of birds per hour.

Flyway counts consist of 10-20 minute counts of marbled murrelets in flight over water (Kirchhoff, in prep). The counts, made with a spotting scope, are conducted during daylight hours, ideally between 5 and 10 AM. Flyway counts are most effective when terrain funnels large numbers of birds through waterways that are less than 3 km across. For waterways > 3 km, an unknown proportion of birds flying in the distant band likely go undetected. In Southeast Alaska, we know from radio-tagged birds that Marbled Murrelets can make long flights 1 or more times per day between nesting and foraging sites (x = 78 km, + 27 km) (Whitworth et al. 2000). Other observers in Southeast Alaska, conducting visual counts from stationary points in the post-dawn hours, have detected hundreds to > 1,000 murrelets per hour flying to and from foraging and nesting areas (Van Vliet 1993, McAllister, unpublished data). Such mass movements along predictable flyways provide an ideal opportunity for population monitoring. As with radar surveys, flyway surveys provide an index of abundance (not a population estimate). Depending on how stable and uniform these surveys are over time (within day and within season), they can be a useful tool for monitoring population trends in Marbled Murrelets.

The purpose of this study is to (1) compare line transects, strip transects, and variable area transects for measuring Marbled Murrelet densities, (2) assess variations in marbled murrelet numbers across the region and relate to upland habitat attributes, and (3) develop a protocol for future Marbled Murrelet monitoring surveys that will maximize the statistical power to detect trends while minimizing cost.

III. APPROACHES USED AND FINDINGS RELATED TO THE OBJECTIVES AND TO PROBLEM OR NEED

OBJECTIVE 1: Evaluate the strengths and weaknesses of alternative survey protocols to monitor trends in marbled murrelet populations in Southeast Alaska. Merit shall be reflected in statistical power to detect trends versus relative cost, including equipment, manpower, and time.

We conducted surveys using flyway counts, strip transects, and line transects in Glacier Bay and Icy Strait during this reporting period. We documented temporal and spatial patterns of abundance and variability, and used that information to recommend survey protocols that yielded the highest power to detect population trends. For at-sea surveys, line transects are superior to strip transects; and surveys conducted in July have lower variability, and higher power to detect trends, than surveys conducted in June or August. Observer bias with respect to distance estimation was low. For flyway surveys, activity appears closely tied to time of day and stage of tide. Surveys conducted between 0500 and 0900, and between 1800 and 2200, capture the peaks of Murrelet flyway activity. More detail on methods and results are included under the Job/Activity statements that follow. A progress report is in review.

From 9-13 July, 2007, flyway surveys were conducted from the western shore of Young Island, at Sitakaday Narrows in lower Glacier Bay. Alternating 2-person crews conducted 15 minute flyway surveys every half hour from sunrise to sunset. At the start of each survey, the observer recorded his or her name, the date, time of day, stage of tide, scope and power setting, cloud cover (%), ceiling height, precipitation, sea state, and visibility. A digital timer/alarm was used to mark the 15 minute survey period. A multiple tally counter was used to keep count of *Brachyramphus* murrelets going in (northbound) and going out (southbound) through the narrows. Surveys were discontinued when visibility declined to “poor” (half or more of the distance not viewable) due to fog, rain, shimmer, or low light.

Over 108 surveys, we counted an average of 331 murrelets per 15 minute survey (SE = 32.8) flying North into Glacier Bay. Birds arrived in two main pulses, mid morning and mid day, with the highest peak at mid-day (1300 hrs) averaging over 700 birds per 15 minute survey. The lulls between those two incoming pulses were balanced by two pulses of birds flying south, out of the Bay. Over 108 surveys, the mean number of birds counted (in plus out) was 521 per survey (SE = 30.13). The coefficient of variation for total number of birds (north and south) was low, at 0.06.

Tides appear to strongly influence the timing of these pulses. Birds moved in and out of the Bay counter to the direction of tidal flow. The daily peak count of incoming birds occurred 1.5 hours after high tide (x = 97 minutes, SE=6.6, N=4). As the tide ebbs, large volumes of water from Glacier Bay flow through this constriction, creating strong currents and tide rips. It was not uncommon to see many murrelets, and other seabirds (including thousands of Northern Phalaropes [*Phalaropus lobatus*]) actively foraging there.

The maximum number of birds coming into the Bay occurred during moderate stages of ebbing tides (1.5-2 hours past high); and the maximum number of birds flying out of the Bay coincided with maximum flooding tidal volume (3-4 hours past low tide). Because significantly more murrelets are entering the Bay than leaving it during our daylight surveys, the difference is presumably leaving Glacier Bay sometime during the evening hours, after the last survey is conducted. Marbled Murrelets in Port Snettisham show a similar diurnal movement pattern (ADF&G, unpubl. data).

Between June 27 and June 30, 2008, we conducted 15-minute flyway surveys at Pt. Adolphus in Icy Strait. Surveys were conducted on the hour, every hour, starting at 0500 and ending at 2200. Similar weather and environmental variables were recorded as in Glacier Bay (see above). The temporal pattern of activity differed from Glacier Bay (in 2007) in that the highest counts occurred just after dawn, and tapered off through the morning. Incoming birds (flying westward) past Pt. Adolphus were much more numerous than eastbound birds in the evening hours, which suggests a significant proportion of the population is flying east after dusk.

We had insufficient replicates in either location to test for effect of scope, magnification, observer, and weather. The final report will combine surveys at point Adolphus from before July 1 with those after July 1 to examine effects of covariates on counts.

We conducted 367 accuracy trials from 8-15 July 2007. A trial consisted of an observer making a distance estimate to a Marbled Murrelet sitting on the water, followed by a measurement of the true distance using a laser rangefinder. The true distance to the bird in these trials ranged from 15-242 m, with a mean of 94.8 m (SD = 46.3). We trained and tested 6 observers for this exercise. Mean error overall was -2.6 m, and mean percent error was -2.1%. The absolute error ranged from 9.4-15.8 m by observer, and averaged 13.9 m across observers. Although absolute error was relatively high, the under-estimates largely cancelled out the over-estimates, and a slight (2%) underestimate in distance estimation resulted. This will bias strip transects approximately 4% low because the underestimate applies to both sides of the strip. In contrast, if distances are underestimated in line transects, there will be a positive bias in the density estimate. The best way to control for this is to adjust distance estimates for individual observers, based on these trials, and re-compute the density estimates.

We conducted 293 accuracy trials with 4 observers from 30 May-30 June 2008. A trial consisted of an observer making a distance estimate to a Marbled Murrelet sitting on the water, followed by a measurement of the true distance using a laser rangefinder. The true distance to the bird in these trials ranged from 20-300 m, with a mean distance of 101.8 m (SD = 46.3). The mean error (for all observers) was 0.62 meters. The mean percent error was 3.0 percent. The mean absolute error (16.5 m). For individual observers, the mean error ranged from -1.59 to 4.50; the mean percent error ranged from 0.4 % to 7.4 %, and the mean absolute error ranged from 12.1 to 21.8 m. Although there was a degree of error in all the distance estimates, those errors tended to cancel one another out over time, with the net percent error being very low. On this basis we decided no adjustment were necessary in counts based on observer.

From 9-15 July, 2007, we conducted simultaneous line and strip transects in Glacier Bay. We randomly selected 48 transect throughout the non-wilderness waters of the Bay, with lines running from mid-channel to the nearest shore. The observers switched duties after each transect, so observer effects were cancelled out. Line transects returned substantially higher population densities, and lower coefficients of variation, than strip transects. Line transects returned population estimates of 31, 318 Marbled Murrelets and 4,207 Kittlitz's Murrelets on the water. If both line and strip transects return unbiased estimates of murrelet abundance, simultaneous surveys of the same transect lines should yield similar results. In this study, line transects returned a population estimate for *Brachyramphus* murrelets that was 33 % higher than strip transects. Based on line transects, the number of *Brachyramphus* murrelets on the water was 36,627, with Marbled Murrelets numbering 31,318 and Kittlitz's Murrelets numbering 4,299. Coefficients of variation were 0.18 and 0.38 for the 2 species respectively

Although it is commonly assumed that no birds are missed within the width of a strip transect, some birds are inevitably missed, especially when seas are rough. The maximum detection distance from the centerline was 218 m, and the effective strip width was 97 m. The CV for the population *Brachyramphus* murrelet population estimate was 17 %, which is a little more than half the CV for strip counts on the same lines.

From May 30-June 31, 2008, we completed 3 surveys of the western half of Icy Strait. The survey consisted of 14 transect segments, and duplicated the survey tracks of John Lindell (USFWS 1993). Survey protocols were the same for these Icy Strait surveys in 2008 as they were for Glacier Bay in 2007. The data from these surveys has been entered and the strip transect data analyzed.

OBJECTIVE 2. Assess spatial variation in marbled murrelet numbers between watersheds and across the region and relate to upland and marine habitat attributes.

We underestimated the logistical difficulties, costs, and personnel required to accomplish this job as planned. We scaled this job back, and completed surveys in a smaller geographic area (Icy Strait). The distribution and abundance of murrelets was related to physiographic and oceanographic habitat features. The work was done with a single 8 person crew, working from the ADF&G research vessel, *Iyoukeen*. The results of this work are described in section V below.

IV. MANAGEMENT IMPLICATIONS

Evaluating the strengths and weaknesses of different monitoring methods will allow ADF&G or other agencies to design more accurate, more precise, and cost effective protocols. By understanding the inland distribution and habitat relationships of marbled murrelets, the US Forest Service will be able to target old-growth conservation measures effectively, both in Alaska and in the lower 48.

V. SUMMARY OF WORK COMPLETED ON JOBS FOR LAST SEGMENT PERIOD ONLY (July 1, 2009 – June 30, 2009)

There was no activity on Objective 1 jobs during the last segment period.

JOB/ACTIVITY 2A: <u>Survey murrelets using different methods at multiple watersheds in Southeast Alaska.</u>

Study Area
Icy Strait is the major East-West waterway connecting offshore waters with inside waters in northern Southeast Alaska. It is bounded by Chatham Strait to the east, Cross Sound to the west, Chichagof Island to the south, and the mainland to the north. Of particular interest was the portion of Icy Strait that receives the cold, highly-mixed, nutrient-rich waters from Glacier Bay (C, in Figure 1). This marine area, bounded by Point Adolphus to the east and Lemesurier Island to the west, features a massive, v-shaped submarine sill, or moraine that was deposited by the Glacier Bay ice sheet centuries ago. This submarine sill figures prominently in the unique oceanography and productivity of this locale (Etherington et al 2007).

Methods
<u>At-Sea Surveys</u>
Surveys in 2008 were conducted in western Icy Strait (B in Figure 1). Surveys of the Icy Strait Sill area followed the same survey routes and protocols established by Lindell (2005) and referenced by Piatt et al (2007) (Figure 2). Two observers counted from the bow deck of a 26-foot aluminum vessel traveling 5-15 knots. We slowed the vessel when encountering large numbers of birds in order to satisfy the assumptions of the survey protocols (e.g., 100% of birds counted within the strip, or on the line). We would also slow when humpback whales were observed, and stop when our respective courses appeared likely to intersect.

One observer counted all murrelets detected on the water within a 100-m wide strip on either side of the vessel. The second observer recorded the angle and the estimated distance to every murrelet detected on the water (with no distance limit). A third observer recorded data, and collected GPS readings (some surveys). Observers rotated duties after each transect to eliminate observer-related bias. A fourth crewmember was dedicated to navigating and steering the vessel, and did not participate in the surveys. Surveys were discontinued when seas showed whitecaps (0.5-1.0 m), or rain and fog limited visibility. Data on time of day, stage of tide, and weather conditions were recorded for each transect segment.

If a bird was seen sitting on the water, or was observed o take off from the water, it was recorded as a sitting bird. Observers counted flying birds using a “snapshot” method. The area surveyed in each snapshot was the width of the transect (200 m), times the distance to the bird (or birds) when they entered the transect space. The distance forward was unconstrained, but in most cases < 500 m. Once that initial group of flying birds was counted, no other flying birds would be tallied until the vessel had reached the end of the prior snapshot area (i.e., that point on the water where the prior bird(s) entered). This method avoided the need to record zero counts, and keep track of a series of rolling survey ”windows” in front of the vessel.

Observers were trained to estimate distances accurately by periodic testing. This was done by having observers estimate distance to single murrelet sitting on the water, and having the true distance determined with a laser range finder. Observers were told the true distance after each test and their improvement on successive tests recorded. Differences were recorded as mean difference, mean absolute difference, and mean percent difference for the daily trials. Computed densities were not adjusted based on these tests.

Observers on the bow conducted strip and line transects independently for later comparison (e.g., Kirchhoff 2008). Earlier surveys did not use a snapshot technique for tallying flying birds, but instead, counted birds continuously whenever they passed over a moving window 200-300 meters in front of the boat. Because these flying birds are traveling very fast relative to the boat, continuous counts of this nature significantly overestimate the number of flying birds (Kirchhoff 2008). The densities cited in this report refer to birds sitting on the water.

In western Icy Strait (Figure 1, Area B), we surveyed 6 straight-line transects that ran from Elfin Cove to Point Adolphus. These segments are named for the waters they transit, including Cross Sound, South Inian Pass, Idaho Inlet Mouth, South Pass, Mud Bay, and Point Adolphus (Figure 3). Because we ran these transects at higher speed (20-25 knots), the strip width was reduced to 50 m on either side of the vessel to ensure the assumption of 100% detection. We only counted birds sitting on the water. Otherwise, protocols for these surveys were the same as strip surveys in eastern Icy Strait.

Results

Distribution of Birds in Icy Strait

The large majority of murrelets in Icy Strait are found over the Icy Strait sill, between Point Adolphus and Lemesurier Island. Over the course of 15 complete surveys between 1993 and 1999, the area between Point Adolphus and Lemesurier Island (representing 29.8% the sample area) contained 80 percent of all sitting birds counted (Lindell 2005).

Piatt et al. (2007) also noted high use of this area, but suggested it was a recent phenomenon, and that the bird’s distribution had contracted significantly over time. When one examines the proportion of bird using the Icy Bay sill area across all surveys, from 1993 to 1999, there is no evidence of the population contracting (Figure 4). With the exception of the June 1993 survey, no survey found less than 65% of the total *Brachyramphus* murrelet population on the waters between Lemesurier Island and Point Adolphus.

In 2008, we completed 7 surveys of the Icy Bay sill area between 31 May and 8 August. The first survey used the original transect lines from Lindell (2005). For subsequent surveys, we broke the longer north-south transects into smaller segments of approximately equal length (14 segments in all) (Figure 2). The highest densities in this area were recorded in the center (over the shallow sill), along the shore of Chichagof Island, and along the eastern shore of Lemesurier Island (Figure 5). These areas all experience upwelling and fronts that predictably attract foraging birds (as well as whales and sea lions). In comparison, the lowest densities were consistently in the northeast quadrant (segments 2 and 3), near Pleasant Island and the mainland. Thermographs of sea surface temperature show that Glacier Bay outflow has little influence on sea surface temperature in this area (Figure 1). All Kittlitz's Murrelets (*B. brevirostris*) identified in these surveys (19 birds) occurred in Icy Strait off Point Carolus, near the Mouth of Glacier Bay.

Between Cross Sound and Point Adolphus (Figure 1, Area B), we conducted 28 surveys between 27 June and 10 August. Due to conflicting demands, 11% of the 168 possible survey segments were not completed. In those cases, I substituted the segment mean (all surveys) for the corresponding missing value. These surveys reveal an increase in the density of *Brachyramphus* murrelets going from Cross Sound towards Point Adolphus (Table 1).

The results confirm there are substantially higher murrelet densities in western Icy Strait, especially between Lemesurier Island and Point Adlophus (the Icy Strait sill). The relatively high murrelet densities coincide very closely with the colder, nutrient-rich waters that are brought to the surface by the bathymetry at the mouth of Glacier Bay (Figure 6).

<u>Variation Within Summer</u>

Because the survey tracks and methods used in the central Icy Strait area in 2008 were identical to those used by Lindell (2005), I combined his 1993-1999 data with the 2008 data to analyze variation in murrelet attendance throughout the summer (N=22 surveys).

There was an apparent decrease in density during June (Figure 7), which would be expected, assuming some proportion of adult birds are off the water sitting on nests. The monthly means, however, were not significantly different (Anova, $P = 0.59$, $df = 22$). The monthly coefficients of variation showed July to be the least variable, and June to be the most variable month (Table 1). On this evidence, surveys conducted during July would have the greatest power to detect population trends in central Icy Strait.

Although monthly differences are convenient to reference, there is no reason to expect that months are biologically meaningful to the birds. It is more likely that if density changes over the summer, it changes based on some linear or curvilinear relationship. Accordingly, I looked at how bird densities changed in Icy Strait as a function of Julian Date throughout the summer, and found a weak curvilinear relationship that shows bird numbers in Icy Strait increase gradually through early summer, peak during the last 2 weeks of July, and then decrease through mid August (Figure 8).

Acknowledgements

Many people contributed to the success of this job. ADF&G staff working on the project included P. Harper, J. Koehler, M. Rabe, D. Rabe, and S. Wright. Volunteers working on the project included D. Albert, P. Kirchhoff, E. Hill, B. Koehler, R. Posey, Z. Posey. I thank the University of Alaska, Southeast, and ADF&G for allowing me to offer a 4-credit field course in Marine Ornithology that featured this field study. Students enrolled in that class were: J. Brown, K. Burkinshaw, T. Cullison, K. Jackson and C. Mounce. Jack Hodges (USFWS) provided valuable assistance with the data analysis, and G. Drew (USGS) generously provided data from USGS surveys in Icy Strait.

VI. PUBLICATIONS

The following manuscripts are in preparation by Matt Kirchhoff and will be submitted for publication by June, 2010:

<u>Near-shore Distribution of Marbled Murrelets: Implications for Population Survey Design</u> (Kirchhoff)

This paper will describe the population density gradient that exists in the near-shore (<1 km) marine environment. This pattern has implications for survey designs because meandering survey routes that "follow the shore" are difficult to replicate (imprecise) and susceptible to significant bias.

<u>Status and Trends in Marbled Murrelet Populations in Southeast Alaska</u> (Kirchhoff, Lindell, Kissling, and Hodges)

This paper will reanalyze historic survey data from Glacier Bay and Icy Strait, and update it with new data collected by ADF&G in 2007 and 2008. It will include an analysis of temporal variation throughout the breeding season, inter-annual variation in spatial distribution, and revise estimated rates of population change for both Marbled and Kittlitz's Murrelets.

<u>Large-scale Activity Patterns of Marbled Murrelets in Southeast Alaska</u> (Kirchhoff and Koehler)

This paper will describe large-scale movements of Marbled Murrelets, in time and in space, as documented using flyway count data from Port Snettisham, Taku Inlet, and Icy Strait. These data describe regular long-distance movements of Murrelets on a daily, seasonal, and inter-annual basis. They have implications for the timing and spatial scale of future monitoring efforts.

<u>Assessing Potential Causes of Declining Murrelet Populations in Southeast Alaska</u> (Kirchhoff and Day) (Day's involvement is not confirmed)

This paper will discuss how population trend data (job 1b) can provide insight into contributing sources of mortality, including juvenile versus adult mortality, and chronic versus episodic mortality. This analysis can sharpen our focus on the true drivers in Murrelet population declines, and eliminate others as trivial.

<u>A Field Comparison of Fixed Strip and Line Transect Methods for Surveying *Brachyramphus* Murrelets</u> (Kirchhoff)

This paper compares the accuracy and precision of two common at-sea survey methods that were employed simultaneously on surveys in Glacier Bay. The ease, efficiency, precision, and statistical power of the two methods will be compared.

<u>A Convenient, Unbiased Method for Tallying Flying Murrelets on At-sea Surveys</u> (Kirchhoff and Hodges) (Hodges involvement is not confirmed)

Murrelet surveys in Alaska have been inconsistent in how flying birds are tallied, with the fraction of flying birds ranging from 5-75%. Continuous counts of flying birds will result in estimates that are biased high. This paper proposes a new, unbiased method for estimating the density of flying birds that can be easily incorporated into existing protocols (either line or strip surveys).

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VII. APPENDIX

Tables

Table 1. Mean density of Brachyramphus murrelets sitting on the water in Western Icy Strait, between Cross Sound and Point Adolphus, June 27-August 10, 2008.

AREA	N SURVEYS	MEAN BIRDS/KM2	STANDARD DEVIATION
Cross Sound	28	53.7	55.0
Inian Pass	28	39.7	44.8
Idaho Inlet	28	83.6	74.5
South Pass	28	89.0	87.6
Mud Bay	28	130.4	114.8
Point Adolphus	28	171.2	114.9
Total	168	94.6	90.5

Table 2. Mean monthly density of Brachyramphus murrelets on the water in central Icy Strait (Lemesurier Island to Point Adolphus) during all years (1993-99, 2008).

MONTH	N SURVEYS	MEAN BIRDS/KM^2	STANDARD DEVIATION	COEFF. OF VARIATION
May	1	57.7	na	na
June	8	49.0	25.4	0.518
July	4	63.5	18.8	0.296
August	10	62.9	21.2	0.337
Total	23	59.9	22.0	0.380

List of Figures

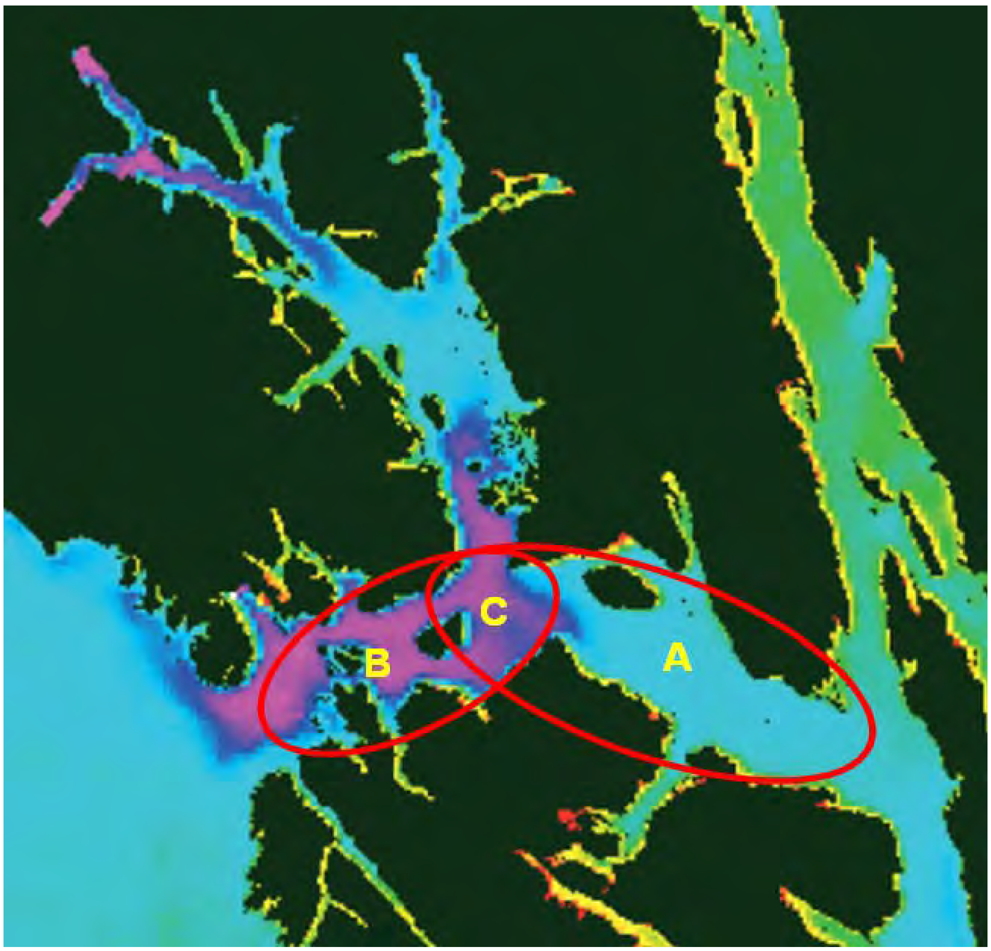

Figure 1. Cold, nutrient rich waters (shown in purple) from the deep basins of Glacier Bay flow are brought to the surface by submarine moraines in the lower Bay and Icy Strait. Eastern Icy Strait, marked as A, was surveyed 1993-2003. Western Icy Strait, marked as B, was surveyed in 2008. The overlapping central area, marked as C, was surveyed in all years. Base map shows mean sea surface temperatures from late May through mid September, 1985-2000 (N=26 images, flood stage) (Douglas 2001).

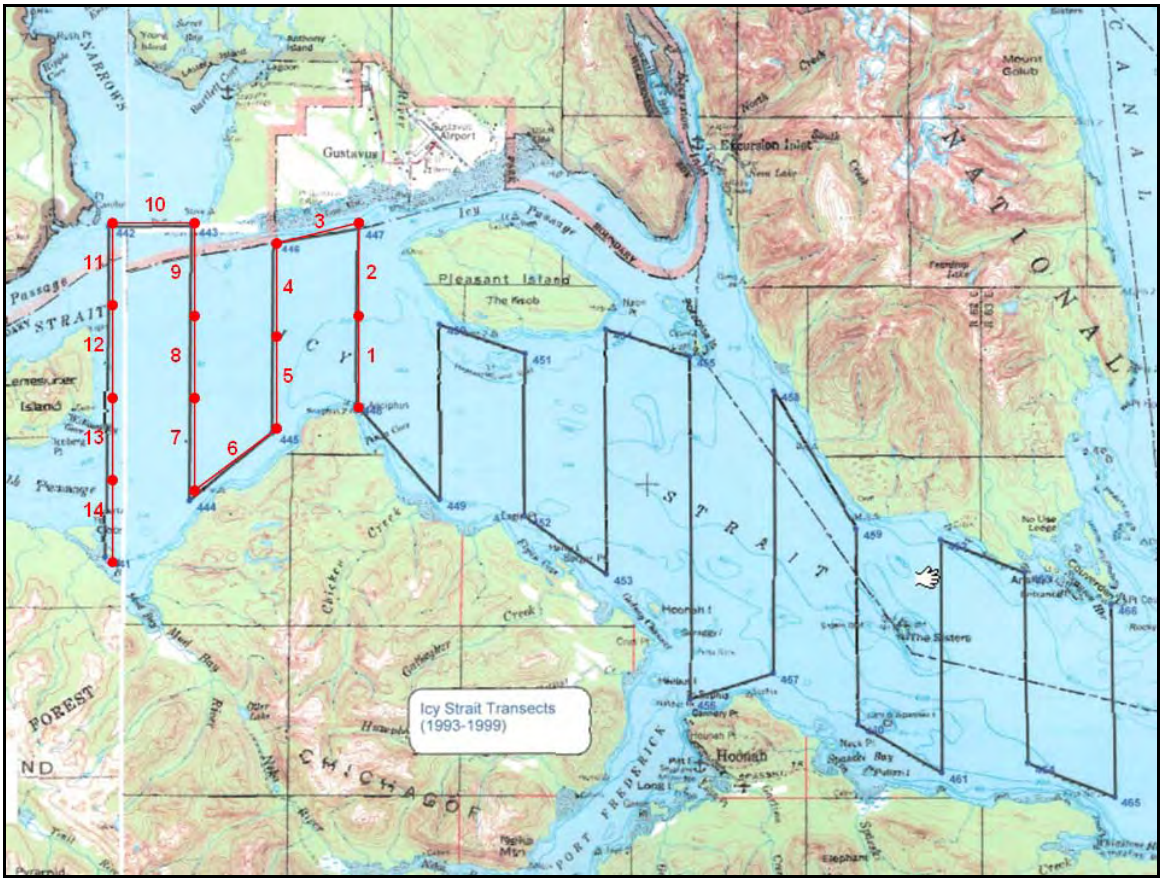

Figure 2. The transect routes surveyed by Lindell (2005) are shown in black. Overlain, in red, are the transect routes surveyed in this study. These red transects sample the productive Icy Strait Sill, an area of concentrated murrelet use. From 1993-1999, 80 % of all murrelets recorded in Icy Strait were found in this area.

Figure 3. Six survey segments in western Icy Strait, including 2 in the Icy Strait sill area (outlined in red).

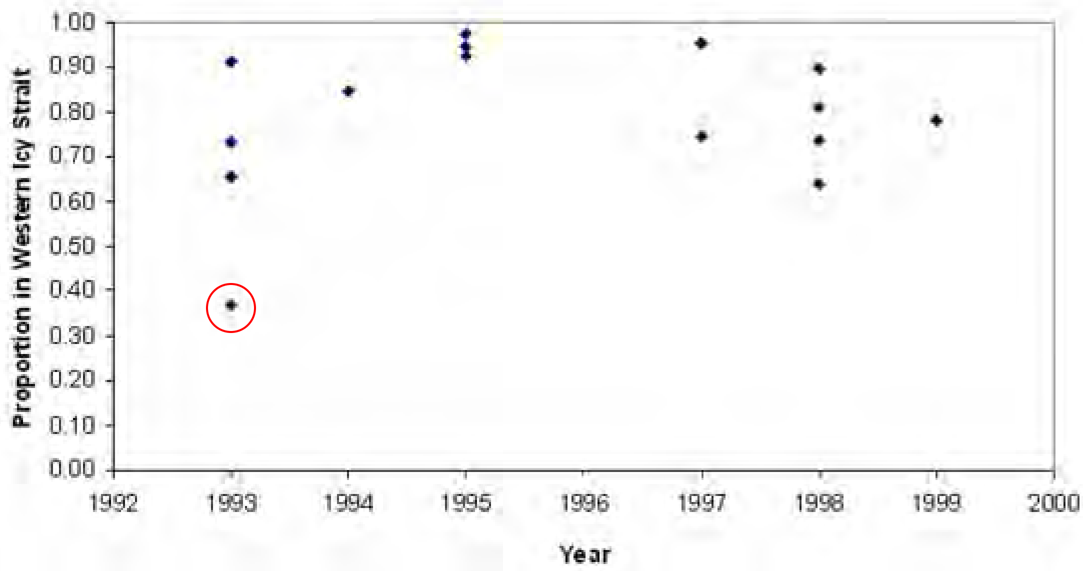

Figure 4. Eighty percent of birds observed in surveys of Icy Strait are found between Point Adolphus and Lemesurier Island. Although the proportion varies from survey to survey, there was no significant trend from 1993 to 1999. One survey in June, 1993, (circled) stands out as different.

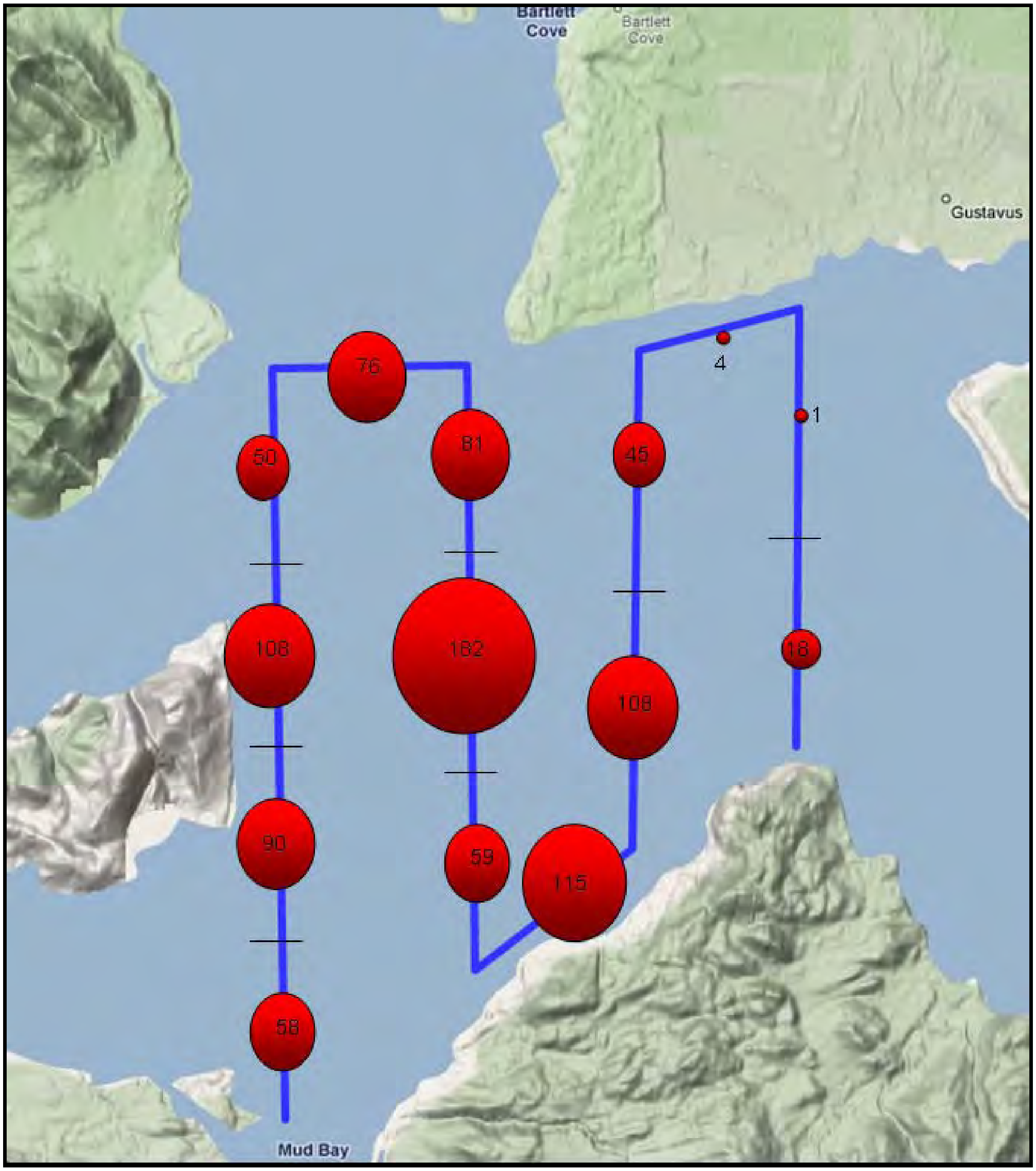

Figure 5. Distribution of Brachyramphus murrelets in central Icy Strait during summer, 2008. Numbers signify mean density in murrelets per km^2 on the water (N = 6 surveys, 12 June – 8 August).

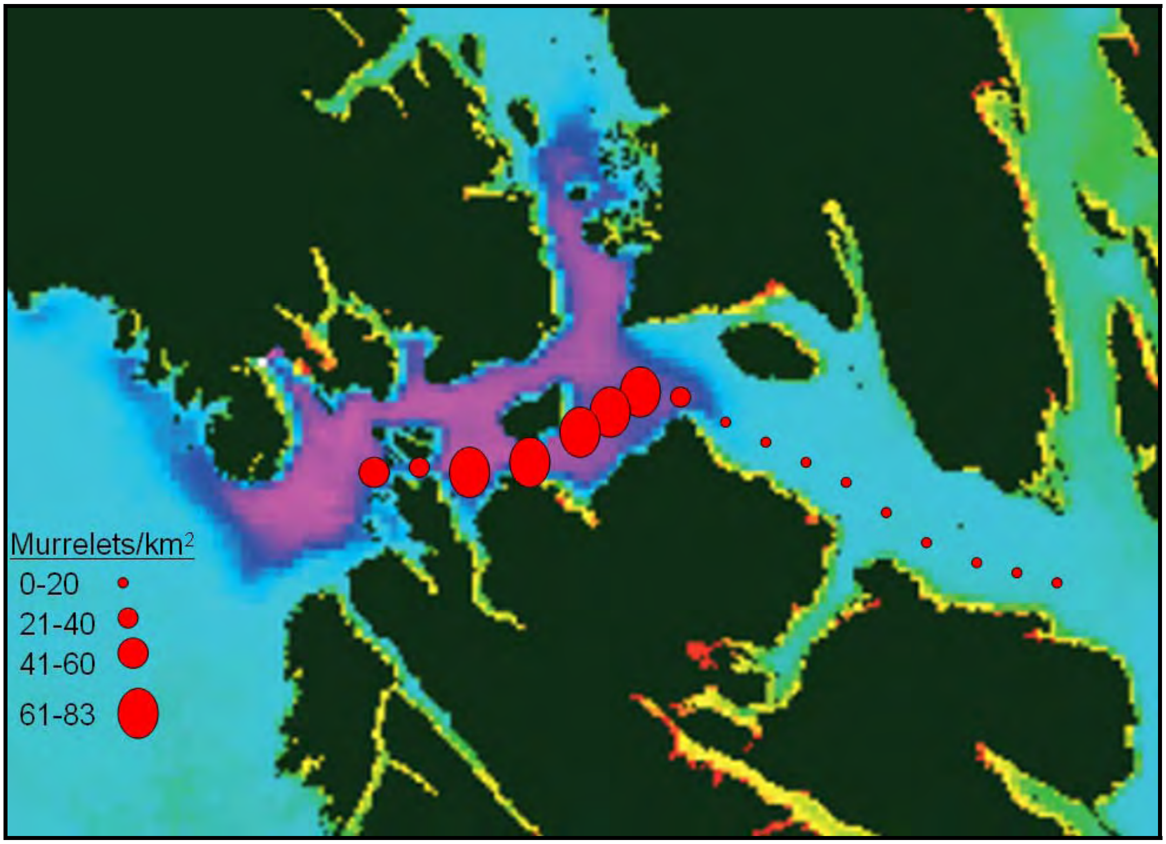

Figure 6.Relative density of Brachyramphus murrelets in Icy Strait, overlain on a base map showing mean Sea Surface Temperature (colder temperatures are purple) (Douglas 2001). Mean densities for all points, except the 4 westernmost, are calculated from north-south crossing transects. Density on the four western points (Cross Sound, S. Inian Pass, Idaho Inlet, South Pass) were adjusted for a methods difference (see text) to make this spatial comparison valid.

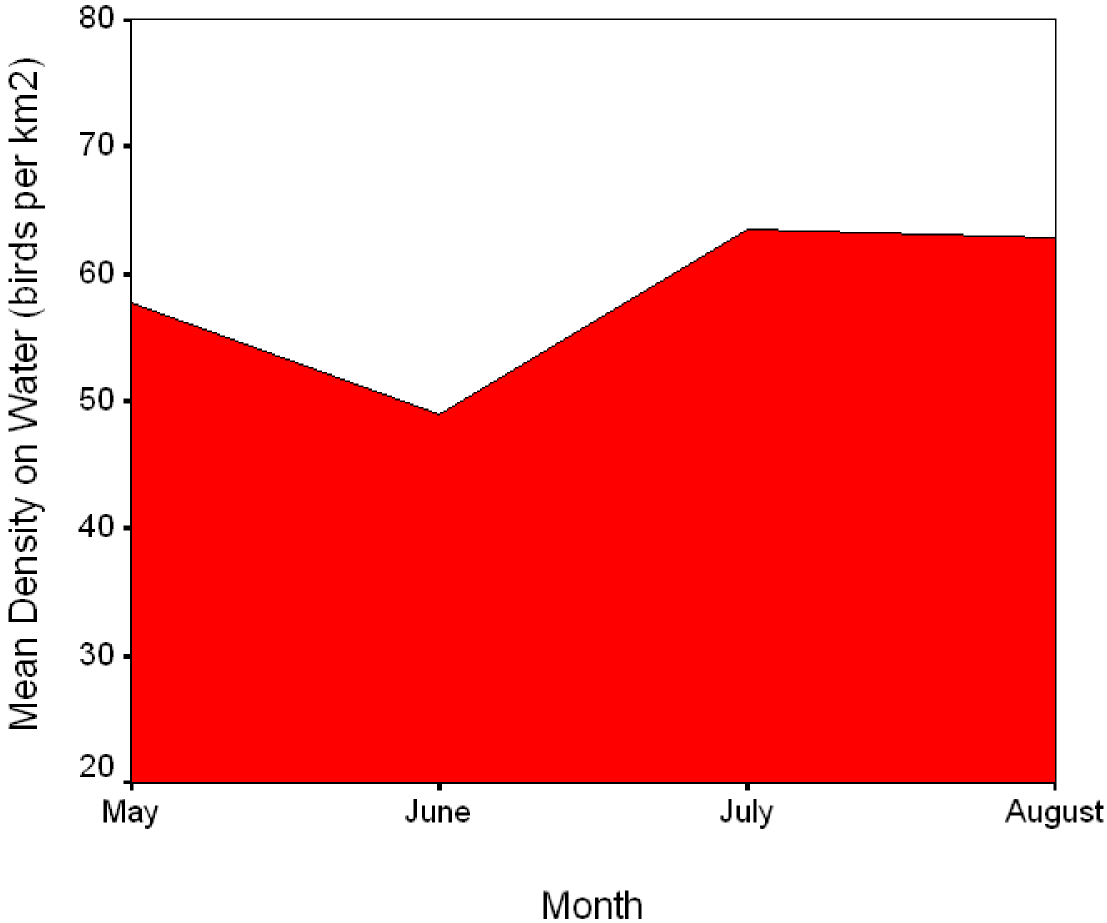

Figure 7. Mean density of Brachyramphus murrelets on the water in central Icy Strait , by month, during summer. The lower numbers in June probably reflect the absence of adult birds who are on the nest incubating eggs. The monthly means are not significantly different (ANOVA P = 0.59, df = 22).

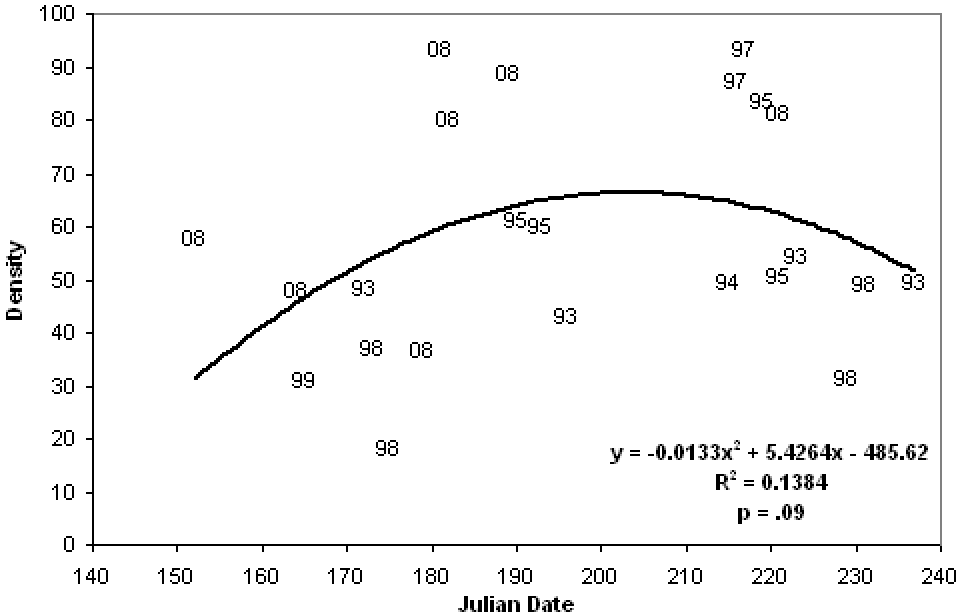

Figure 8. Change in density of Brachyramphus murrelets on the water (birds/km2) throughout the summer in central Icy Strait. The regression equation is marginally significant (P = 0.09).