STATUS AND DISTRIBUTION OF THE KITTLITZ'S MURRELET *BRACHYRAMPHUS BREVIROSTRIS* IN KENAI FJORDS, ALASKA

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SUMMARY

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The Kittlitz's Murrelet *Brachyramphus brevirostris* is a candidate species for listing under the US *Endangered Species Act* because of its apparent declines within core population areas of coastal Alaska. During the summers of 2006–2008, we conducted surveys in marine waters adjacent to Kenai Fjords National Park, Alaska, to estimate the current population size of Kittlitz's and Marbled murrelets *B. marmoratus* and examine seasonal variability in distribution within coastal fjords. We also evaluated historical data to estimate trend. Based on an average of point estimates, we find the recent population (95% CI) of Kittlitz's Murrelet to be 716 (353–1080) individuals, that of Marbled Murrelet to be 6690 (5427–7953) individuals, and all *Brachyramphus* murrelets combined to number 8186 (6978–9393) birds. Within-season density estimates showed Kittlitz's Murrelets generally increased between June and July, but dispersed rapidly by August, while Marbled Murrelets generally increased throughout the summer. Trends in Kittlitz's and Marbled murrelet populations were difficult to assess with confidence. Methods for counting or sampling murrelets varied in early decades of study, while in later years there is uncertainty due to highly variable counts among years, which may be due in part to timing of surveys relative to the spring bloom in coastal waters of the Gulf of Alaska.

Key words: Alaska, *Brachyramphus brevirostris*, Kittlitz's Murrelet, distribution and abundance, Kenai Fjords, population trend, status

INTRODUCTION

The Kittlitz's Murrelet *Brachyramphus brevirostris* is a non-colonial, diving seabird of the Alcidae family. Its breeding range is limited to coastal Alaska and the Russian Far East, where it nests inland on talus slopes in glacial alpine areas or on unvegetated mountain slopes in deglaciated areas (Day *et al*. 1999). The species' strong association with glaciated or recently deglaciated habitats, and its highly aggregated distribution at sea, suggest vulnerability to large-scale disturbance of nesting and foraging habitats from global warming (Piatt *et al*. 1990, Kuletz *et al*. 2003). Localized threats include commercial fishing (bycatch), oil spills, and vessel traffic (Romano *et al*. 2007, Agness *et al*. 2008).

The closely related Marbled Murrelet *B. marmoratus* breeds from central California to southern Alaska and the Aleutian Islands, usually nesting in old-growth coniferous forests (Nelson 1997). Like other alcids, *Brachyramphus* murrelets (hereafter, murrelets) feed on small schooling fish and invertebrates, have a long life span, and delay reproduction until they are several years old (Nelson 1997, Day *et al*. 1999). Both species are of management concern due to population declines in core breeding areas (Piatt *et al*. 2007, US Fish and Wildlife Service 2010).

The two species of murrelet co-occur in Alaska, although the Marbled Murrelet uses a wider range of coastal habitats than Kittlitz's Murrelet. Kittlitz's Murrelets are associated with strong tidal currents (Kissling *et al*. 2007) and prefer glacial-affected, nearshore and highly turbid marine waters (Day *et al*. 2003). The availability of near-surface prey within the turbid glacial plumes (Weslawski *et al*. 2000, Abookire *et al*. 2002, Arimitsu 2009) may explain the preference of Kittlitz's Murrelets for this type of habitat. Marbled Murrelets are more closely tied to shoreline habitats, and they are often associated with areas of upwelling near marine sills, mouths of bays or eddies (Piatt *et al.* 2007). In the Kenai Fjords region of Alaska, Marbled Murrelets prefer shallow, ice-free waters over other habitat types (Arimitsu 2009).

The cryptic and solitary breeding habits of murrelets make it necessary to census the birds at sea in Alaska. Previous surveys for marine birds were conducted along coastal areas of the Kenai Peninsula between 1976 and 2008 (Bailey 1977, Nishimoto & Rice 1987, Bailey & Rice 1989, Van Pelt & Piatt 2003). However, the estimation of population trends for murrelets is hampered by varying proportions of unidentified murrelets (i.e. murrelets not identified to species; Piatt *et al*. 2007, Appendix J), and high variance in counts due to biological and physical factors that affect their movements and abundance at sea (Speckman *et al*. 2000, Piatt *et al*. 2007).

Our main objectives were: (1) to describe the at-sea distribution and abundance of Kittlitz's Murrelet in the coastal areas of Kenai Fjords National Park during 3 years (2006–2008) in which we conducted extensive surveys, and (2) to examine historical data and determine whether any inferences can be made regarding population trends of Kittlitz's Murrelet in Kenai Fjords. Although Marbled Murrelets differ from Kittlitz's Murrelets in density and distribution within the study area, the overlap in habitat use and difficulties of identification required data to be collected on both species. Therefore, we present information on both murrelet species, focusing our attention on the less common Kittlitz's Murrelet.

STUDY AREA AND METHODS

The study area, approximately 620 km^2 in size, encompassed the coastal area of Kenai Fjords National Park in southcentral Alaska (Fig.1). The region features steep coastal mountains, a convoluted shoreline, numerous islands and tidewater glaciers. Shallow marine sills mark submerged glacier termini and separate deep ocean basins in the inner and outer fjords. The outer fjords are exposed to the oceanic conditions of the Gulf of Alaska, while the inner fjords are estuarine, as they are influenced by runoff from glaciers extending from the Harding Icefield.

Survey design and protocol

In 2006–2008, we conducted coast-wide surveys in the middle of the expected breeding season (27 June–15 July) using a systematic survey design; we also surveyed a subset of transects located in areas of high Kittlitz's Murrelet density in the early (31 May–8 June) and late (31 July–13 August) breeding seasons (Table 1, Fig. 1; Day 1996). Transects in the eastern arm of Nuka Bay were not sampled during every survey period because of weather and other logistical constraints (Table 1).

Based on previous work in our study area showing that Kittlitz's Murrelet density and distribution vary in relation to marine sills and distance to shorelines (Van Pelt & Piatt 2003), we chose four survey strata *a priori*: coastal (<200 m from shore) and offshore (>200 m from shore) areas in the inner (north of marine sills) and outer fjords (south of marine sills). We created coastal transects by dividing the coastline into 4 km segments using GIS software (ESRI Inc., ArcMap, ver. 9.3, Redlands, California). We defined offshore transects as parallel lines running from east to west, spaced every 0.93 km (30" of latitude), within each major bay along the Kenai Fjords coast (Fig. 1). From a random starting point, we systematically selected one of every three coastal segments and one offshore line every 3.7 km (2' of latitude) for inclusion in the survey. Because historical surveys indicated that Kittlitz's Murrelet distribution was generally restricted to the upper sections of Aialik Bay and to the Northwestern Lagoon (Van Pelt & Piatt 2003), we increased coverage by spacing offshore transects every 1.8 km (1' of latitude) in those two areas (Fig. 1).

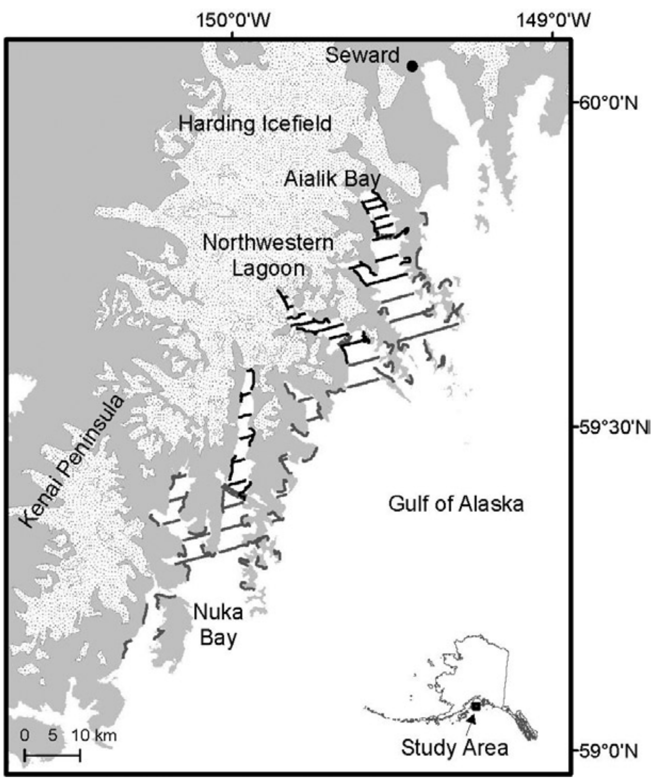

Fig. 1. Map of the study area and 2006–2008 coastwide survey transects (gray and black lines) in Kenai Fjords, Alaska. Supplementing the standard July transects, the subset of transects in areas important to murrelets (black lines) were also surveyed during the early (June) and late (August) season. Glaciers are represented by gray stippling, and the positions of prominent sills separating the inner and outer fjords are shown by dashed lines.

We conducted surveys following Gould & Forsell (1989), with modifications for working in coastal nearshore waters from small boats (Agler *et al.* 1998) and for counting flying birds continuously (Raphael *et al.* 2007). We used line transect sampling in all three years, estimating perpendicular distance to murrelets to the nearest meter within 100 m forward and to either side of the transect line in 2006 and 2007, and to a maximum of 150 m forward and 300 m lateral to the transect line in 2008. Before each survey, observers completed training in distance estimation and identification that involved a combination of rangefinders on fixed objects and bird-sized buoys strung at known distances on a line towed behind the vessel. In addition, throughout the survey, we used rangefinders to calibrate distance estimation. We conducted surveys primarily in a 4.8 m Naiad rigid inflatable boat, but in 2007 and 2008 the 15.3 m seiner M/V *Alaskan Gyre* was used to survey more exposed locations or to accommodate concurrent measurement of marine habitat (Arimitsu 2009). We conducted shoreline transects approximately 100–150 m from shore or in the shallowest navigable waters, depending on the vessel size. Ground speed while conducting surveys was generally between 9 and 22 km/h, although survey crews slowed the vessel as needed to confirm the identification of murrelets.

We counted all birds and mammals and identified them to species whenever possible. We assigned a behavior code to birds sighted on the water or flying within the transect. We recorded juvenile murrelets when they could be positively identified. We recorded all sightings using a real-time computer data-entry system (dLOG-CE, v1.5.0, Glenn Ford Consulting, Portland, Oregon) that logged sightings, with their position coordinates, continuously. We constantly monitored weather conditions and sea state, and we ceased surveys if wave height exceeded 0.5 m.

Data analysis

Distribution and abundance

We calculated annual population estimates of Kittlitz's, Marbled and all *Brachyramphus* murrelets combined in the program DISTANCE (Thomas *et al.* 2010), using line transect methods for birds on the water and strip transect methods for flying birds. We separated the analyses by behavior because flying birds were more conspicuous than birds on the water, and we therefore assumed that all flying birds were detected to a maximum distance of 100 m. We estimated detection functions for all *Brachyramphus* murrelets combined because we lacked sufficient detections for robust single-species models, and we expected detection functions to be similar for both species. We considered candidate models using uniform, halfnormal and hazard-rate keys with cosine, polynomial or Hermite adjustment terms. We selected the most parsimonious models on the basis of χ^2 goodness-of-fit tests and minimum second-order Akaike Information Criterion corrected for small sample sizes (AIC_c) values. Following Kissling *et al.* (2007), we assumed the probability of detection on coastal transects was the same as that of the offshore transects, at 100 m in the respective stratum (inner and outer fjords). In 2006 and 2007 we fitted detection functions

TABLE 1
Survey effort used for estimation of within-season density and coastwide population estimates of *Brachyramphus* murrelets, and percent of murrelet observations allocated to species, Kenai Fjords, Alaska[a]

Year	Dates	Survey period[b]	Stratum	No. of transects	Length surveyed (km)	Area surveyed (km^2)	% of total area surveyed	% KIMU	% MAMU	% UNMU
2006	31 May–2 Jun	Early	Coastal	16	64.4	12.9	29.3	32.1	66.0	1.9
			Offshore	20	60.4	12.1	7.0	13.5	83.3	3.1
			Total	36	124.8	25.0	11.5	23.3	74.3	2.5
	27 Jun–5 Jul	Middle	Outer Coastal	49	212.9	42.6	26.4	2.3	90.9	6.8
			Outer Offshore	24	100.9	20.2	6.3	0.0	91.0	9.0
			Inner Offshore	16	44.6	8.9	8.7	35.5	58.6	5.9
			Inner Coastal	11	43.0	8.6	29.6	0.3	98.5	1.1
			Total	100	401.4	80.3	13.1	8.4	88.8	2.8
	31 Jul–13 Aug	Late	Coastal	10	39.6	7.9	26.3	3.7	92.5	3.7
			Offshore	15	54.2	10.8	9.1	3.0	90.9	6.1
			Total	25	93.8	18.8	12.6	3.5	92.0	4.6
2007	1–8 Jun	Early	Coastal	15	59.5	11.9	27.0	5.7	91.9	2.4
			Offshore	18	57.5	11.5	6.7	19.5	71.4	9.0
			Total	33	117.0	23.4	10.8	10.6	84.7	4.7
	25–29 Jun	Middle	Outer Coastal	43	187.0	37.4	23.2	0.5	93.3	6.3
			Outer Offshore	21	85.7	17.1	5.3	1.0	91.3	7.7
			Inner Offshore	16	42.9	8.6	8.3	27.3	68.7	4.0
			Inner Coastal	10	37.2	7.4	25.6	5.2	87.0	7.8
			Total	90	352.8	70.6	11.5	6.5	86.9	6.5
	31 Jul–4 Aug	Late	Coastal	17	66.6	13.3	30.3	1.9	96.2	1.9
			Offshore	20	56.3	11.3	6.5	8.2	81.5	10.3
			Total	37	122.9	24.6	11.4	3.5	92.5	4.0
2008	4–8 Jun	Early	Coastal	11	42.1	8.4	28.0	11.2	85.5	3.3
			Offshore	14	45.6	9.1	7.6	21.7	69.6	8.7
			Total	25	87.7	17.5	11.7	13.5	82.0	4.5
	5–15 Jul	Middle	Outer Coastal	49	206.9	41.4	25.7	0.1	86.1	13.8
			Outer Offshore	24	88.9	17.8	5.5	0.0	84.1	15.9
			Inner Offshore	15	36.3	7.3	7.0	30.6	50.0	19.4
			Inner Coastal	11	42.5	8.5	29.3	6.6	82.2	11.2
			Total	99	374.6	74.9	12.2	5.5	80.9	13.6
	7–10 Aug	Late	Coastal	12	47.5	9.5	31.5	1.6	93.2	5.2
			Offshore	15	48.4	9.7	8.1	4.8	92.0	3.2
			Total	27	95.9	19.2	12.8	2.6	92.8	4.6

[a] Kittlitz's Murrelets (KIMU), Marbled Murrelets (MAMU) and unidentified murrelets (UNMU) within 100 m.
[b] Early- and late-season transects in the east arm of Nuka Bay were sampled as weather allowed.

using a truncation distance of 100 m (i.e. the maximum distance for which birds were counted). Because we counted birds to a greater maximum distance in 2008, we fitted the 2008 detection functions for offshore observations (inner and outer fjord) to a maximum distance of 290 m (Fig. 2). We then integrated the detection functions from 0–100 m, recalculated the detection probabilities at 100 m, applied those probabilities to the encounter rate and group size by species, and calculated variance by the Delta method (Seber 1982). We estimated densities of flying birds per stratum using a uniform key and cosine adjustment, the total number of flying birds having been summed for each transect. For each of four geographic strata, we calculated variances empirically, using the mean group size, and determined within-stratum confidence intervals using a non-parametric bootstrap (Efron & Tibshirani 1986). For each behavior (i.e. on water, flying) we calculated density as the mean of stratum density weighted by stratum area, and population size as the sum of stratum density multiplied by stratum area. We assumed independence between observations, and therefore summed behavior-specific estimates of population size and variance to estimate total population size and variance (Cochran 1977). We calculated log-based confidence intervals for the annual population estimates (Buckland *et al.* 2001). We did not incorporate unidentified murrelets into the annual population estimates of Kittlitz's and Marbled murrelets because of uncertainty in separating prorated counts (number of birds by transect, as described below) from the sample units (number of groups or clusters) used for coastwide population estimates of birds on the water. The uncertainty stemmed from our inability to assume uniform distributions of both murrelet species throughout the study area. Therefore, we present *minimum* population estimates of Kittlitz's and Marbled murrelets identified to species, and unqualified estimates of all murrelets combined in each year of our study.

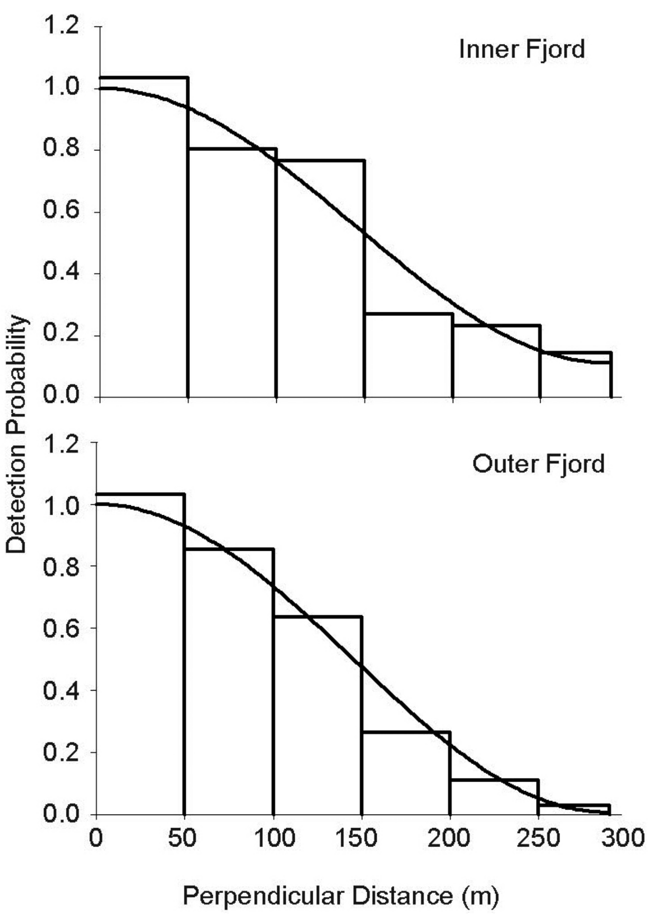

Fig. 2. Fitted detection functions for *Brachyramphus* murrelets in the inner fjord (top) and outer fjord (bottom), from data on sighting distances in 2008, Kenai Fjords, Alaska.

We estimated within-season densities for a subset of transects repeated during each survey period in areas important to murrelets (Fig. 1, Table 1). For each survey, we estimated a detection function for all *Brachyramphus* murrelets on offshore transects (inner fjords only, where the subset of transects was located), and we used the resulting effective strip half-width (ESW) to correct stratified (coastal versus offshore) density estimates for imperfect detection across the 200 m width of the strip. We adjusted raw counts by allocating unidentified birds *pro rata*, using the ratio of Kittlitz's and Marbled murrelets positively identified within 100 m of either side of the boat on a transect-by-transect basis. After summing the count of birds by transect, and setting a single-interval distance at the ESW for offshore transects, we computed stratified density estimates using a uniform key and cosine adjustment in the program DISTANCE. Finally, we calculated within-season densities from the prorated counts of Kittlitz's and Marbled Murrelets.

There are several sources of error associated with boat-based surveys (Gould & Forsell 1989, Agler *et al.* 1998, Piatt *et al.* 2007). First, counting flying birds continuously overestimates density because the targets move faster than the survey platform, meaning more birds fly over the survey area than are present at one instant in time (Tasker *et al.* 1984). Some species are attracted to ships (e.g. Laridae and Diomedeidae species), and this behavior can result in double-counting of individuals during surveys. However, murrelets are not known for ship-following behavior (Tasker *et al.* 1984), and we have never observed such behavior in our work. We therefore assumed that double-counting of flying murrelets was not an issue in our dataset. Flying birds were usually <5% of observations for both murrelet species, and we analyzed them separately for coastwide population estimates. Second, the overlap in distribution, variable weather and observation conditions, and the inherent difficulty of distinguishing the two murrelet species contribute to variation in the proportion of birds that can be identified to species (Piatt *et al.* 2007). For historical counts and our within-season estimates of density, we present prorated data that include murrelets not identified to species. Third, strip transect results are biased low when the assumption of 100% detection across the strip is not met (Ronconi & Burger 2009), although sighting models can be used to counter the effect when line transect methodology is incorporated (Buckland *et al.* 2001, Ronconi & Burger 2009). Furthermore, while the most important assumption behind line transect methods is that all birds on the transect line are detected, Lukacs *et al.* (2010) tested this assumption for Kittlitz's Murrelet in Icy Bay and concluded that non-detection on the transect line as a result of diving behavior was minimal (i.e. a probability $P < 0.03$). Our survey conditions and protocol were similar, so we likely met this critical assumption (Kissling *et al.* 2011). We incorporated detection functions from line transect methods to improve accuracy in our density and population estimates and to account for variation in detection probabilities as a result of observers, survey conditions and platforms. Finally, densities of murrelets may vary with perpendicular distance from the shoreline (Piatt *et al.* 2011). This can influence detection functions derived from shoreline transects because birds are less likely to be found at greater distances on the shore-side of the vessel. We modified estimates in the coastal stratum by using detection functions from offshore transects to account for this.

We examined murrelet distribution using a kernel density estimator in R (ver. 2.10.1, R Development Core Team 2009). We pooled point data, weighted by group size and sampling intensity, for all murrelets identified to species across years. We chose bandwidth following Sheather & Jones (1991) and applied edge correction.

Population change over time

For trend estimation, we evaluated the usefulness and reliability of historical survey data collected in Kenai Fjords (Bailey 1976, Nishimoto & Rice 1987, Bailey & Rice 1989, Van Pelt & Piatt 2003). Important to note is that the earliest efforts were not targeted for *Brachyramphus* murrelets specifically. In 1976, Bailey (1976) conducted a straightforward month-long survey of the entire nearshore area, subdivided into 11 geographic units extending from Gore Point to Cape Resurrection. In 1986, Nishimoto & Rice (1987) resurveyed the whole nearshore area and further subdivided the coastline into ~150 smaller survey subunits. In 1989, Bailey & Rice (1989) covered a randomly selected subset of the subunits established by Nishimoto & Rice (1987). To maximize comparison with past results, while reducing the cost of a whole-shoreline survey, the subset of transects selected in 1989 was repeated in 2002 (Van Pelt & Piatt 2003). Because we surveyed a completely different set of shoreline transects in 2006–2008, we do not make direct comparisons with earlier surveys (1976–2002).

Comparison of past surveys (1976–2002) was further complicated by differences in survey methods, platforms and sampling protocols (Table 2). Observers on the first two surveys (1976 and 1986) counted all birds observed without defining a survey strip width. In contrast, observers recorded all birds within survey strips 200 m and 300 m wide in 1989 and 2002, respectively. In addition, survey platforms varied from 4.3 m inflatable boats to 12.8 m vessels, and the proportion of murrelets identified to species ranged from 0% to 62% across all four surveys (Table 2). Because of these data limitations, we chose to compare an index of counts that could be standardized by effort and, accordingly, we used data only from the random subset of shoreline segments surveyed in 1986 (i.e. reduced from the whole-shoreline survey) and repeated in 1989 and 2002. We excluded 1976 data because we could not separate distinct survey areas from the broader geographical subunits described by Bailey (1976). To account for the large proportion (12%–51%) of unidentified birds in 1986–2002 surveys, we assigned unidentified birds to species using the ratio of identified birds within subareas (1986 and 1989) or by transect (2002). To standardize survey effort, we assumed observers in 1986 did not detect birds beyond 100 m on either side of the inflatable skiff used as a survey platform—probably a reasonable assumption given the decrease in detections farther from the transect typical of small-boat surveys with a single observer (Becker *et al*. 1997, Evans Mack *et al*. 2002, Ronconi & Burger 2009). We also assumed that the length of transects in 1986 and 1989 was the same as in 2002 (for which GPS data are available)—also a reasonable assumption because the goal of the 2002 survey was to repeat the earlier surveys. We calculated density from prorated counts per subunit, divided by area surveyed, and used a ratio estimator to estimate mean density and variance among subunits. Given the variability in murrelet density over recent surveys, and the fact that a robust trend analysis would include more years of data (Kissling *et al*. 2007, Drew *et al*. 2008), it was not appropriate to calculate a trend from the three years of data (1986, 1989 and 2002). We therefore calculated the percent change in mean density of both murrelet species between surveys (1986 versus 1989 and 1989 versus 2002).

RESULTS

Distribution and abundance

In 2006–2008, we observed a total of 6389 murrelets on surveys, including 6.4% Kittlitz's Murrelets, 87.5% Marbled Murrelets and 6.6% unidentified *Brachyramphus* murrelets. Mid-season coastwide transects sampled 11.5%–13.1% of the total area (Table 1), while early-, middle- and late-season surveys (subset of transects) sampled 10.8%–12.8% of the total area.

Based on a point average (95% CI) of mid-season, coastwide population estimates from 3 years (Table 3), we estimated local populations to be 716 (353–1080) Kittlitz's Murrelets (minimum), 6690 (5427–7953) Marbled Murrelets (minimum), and 8186 (6978–9393) total *Brachyramphus* murrelets. Annual population estimates for both species were lower in 2007 compared to 2006, while Kittlitz's Murrelet numbers were highest in 2006 and Marbled Murrelet numbers were highest in 2008 (Table 3).

TABLE 2
Comparison of methods used during historical shoreline surveys for marine birds along the Kenai Peninsula, Alaska, 1976–2002

Year	Survey dates	Distance (m) from shore	Linear km surveyed	Survey platform and length (m)[a]	% unidentified murrelets	Survey type
1976[b]	19 Jun–14 Jul	~100	1038	12.8 m vessel, 4.3 m inflatable	0	Whole shoreline, strip width unspecified
1986[c]	27 Jun–7 Jul	100	1038	4.7 m inflatable, 9.6 m vessel	25	Repeated whole shoreline, strip width unspecified
1989[d]	27 Jun–7 Jul	100	317	9.6 m vessel, 4.7 m inflatable	51	Random sample of shoreline, strip transects 200 m wide
2002[e]	3–13 Jul	150	316[f]	12.8 m vessel	12	Repeated random sample of shorelines, strip transects 300 m wide

[a] Where more than one survey platform was used, the primary survey vessel is listed first.
[b] Bailey 1976
[c] Nishimoto & Rice 1987
[d] Bailey & Rice 1989
[e] Van Pelt & Piatt 2003
[f] A total of 554 km of transect were surveyed in 2002, but only 316 km overlapped with previous surveys.

Within-season density estimates in areas important to murrelets varied by species over the course of the breeding season (Fig. 3). Average densities (with 95% CI) of Kittlitz's Murrelet were 2.91 (1.71–4.11) birds/km^2 in the early season, 2.85 (0.95–4.76) birds/km^2 in the mid-season and 1.18 (0.59–1.77) birds/km^2 in the late season (Fig. 3a). Highest variability in Kittlitz's Murrelet density occurred in the mid-season surveys, and lowest variability occurred during the late-season surveys.

Marbled Murrelet densities (95% CI) averaged 14.33 (10.85–17.82) birds/km^2 in the early season, 16.46 (12.08–20.85) birds/km^2 in the mid-season and 35.31 (27.63–42.98) birds/km^2 in the late season (Fig. 3b). Highest variability in Marbled Murrelet density occurred during the late-season surveys, and lowest variability occurred during the early-season surveys.

Kittlitz's Murrelet distribution was more restricted to the upper fjords than Marbled Murrelet distribution (Fig. 4). The greatest concentration of Kittlitz's Murrelet was found in waters adjacent to tidewater glaciers in upper Aialik Bay, Northwestern Lagoon and the eastern arm of Nuka Bay. Marbled Murrelets were more widely distributed within the fjords, although they generally were not found in the more exposed coastal waters.

Population change over time

After prorating by species and standardizing by effort, density estimates of Kittlitz's Murrelet suggested a 55% increase between 1986 and 1989, and a 90% decrease between 1989 and 2002 (Fig. 5). In contrast, Marbled Murrelet density increased by 12% between 1986 and 1989, and by 103% between 1989 and 2002.

DISCUSSION

Distribution and abundance

Year-over-year variability in local attendance of murrelets at sea may result in part from phytoplankton blooms that determine trophic

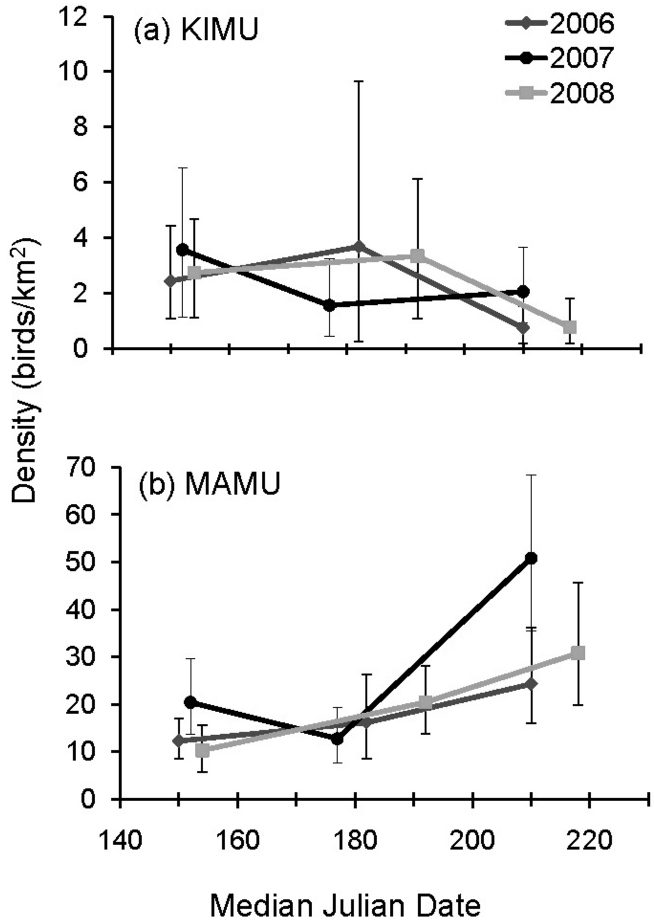

Fig. 3. Within-season density estimates and 95% confidence intervals by median Julian date for (a) Kittlitz's (KIMU) and (b) Marbled (MAMU) murrelets identified on transects repeated three times annually in Kenai Fjords National Park, Alaska, 2006–2008.

TABLE 3
Population estimates (N), confidence intervals (CI) and coefficients of variation (CV,%) for Kittlitz's Murrelet (KIMU), Marbled Murrelet (MAMU) and all *Brachyramphus* murrelets combined (BRMU) counted on coastwide surveys in Kenai Fjords, Alaska, 2006–2008[a,b]

Year	Behavior	KIMU		MAMU		BRMU	
		N (95% CI)	CV	N (95% CI)	CV	N (95% CI)	CV
2006	Water	740 (268–2042)	55.7	6082 (4416–8376)	16.4	6930 (4737–10 136)	19.6
	Flying	185 (63–539)	67.6	336 (184–614)	31.5	656 (409–1052)	24.4
	Both[b]	925 (393–2179)	45.9	6418 (4730–8709)	15.6	7586 (5344–10 768)	18.0
2007	Water	407 (239–694)	27.8	3460 (2228–5373)	22.7	4224 (2915–6121)	19.1
	Flying	16 (4–61)	77.4	159 (59–367)	44.7	200 (99–402)	36.8
	Both[b]	423 (252–709)	26.8	3619 (2371–5524)	21.8	4424 (3099–6315)	18.3
2008	Water	801 (359–1785)	42.7	9945 (7485–13 213)	14.6	12 160 (10 015–14 764)	10.0
	Flying	0	0.0	88 (32–240)	54.7	387 (196–763)	35.7
	Both[b]	801 (359–1785)	42.7	10 033 (7569–13 299)	14.4	12 547 (10 383–15 162)	9.7

[a] Estimates of Kittlitz's and Marbled murrelets based on identified birds only.
[b] Estimate incorporates line transect estimates for birds on the water and strip transect (200 m) estimates for birds flying.

dynamics at lower levels. Speckman *et al.* (2000) demonstrated that interannual variability in Marbled Murrelet abundance, apparent nesting phenology and chick production were related to differences in marine production and ocean climate among years. The variation in Kittlitz's Murrelet population estimates during 2006–2008 may have been due to anomalous oceanographic conditions and a possible delay in the onset of breeding in 2007, and this is supported by the observed fluctuations in within-season density during that year (Fig. 3a). Within-season density patterns show that a late-season influx of Marbled Murrelets was coincident with the departure of Kittlitz's Murrelets from the fjords, which may also provide insight into historical counts along the Kenai Peninsula.

Changes in the number of Kittlitz's Murrelets in Kenai Fjords were concordant with surveys in Kachemak Bay (~200 km northwest of Kenai Fjords; Kuletz *et al.* 2011b), Prince William Sound (~150 km east of Kenai Fjords; Kuletz *et al.* 2011a) and Icy Bay (~450 km southeast of Kenai Fjords; Kissling *et al.* 2011). Population surveys in Kenai Fjords and Kachemak Bay indicated an influx of Kittlitz's Murrelets to those areas in 2006. Although Prince William Sound estimates were higher than those earlier in the decade (Kuletz *et al.* 2011a), abundance was low in all survey areas in 2007 compared with

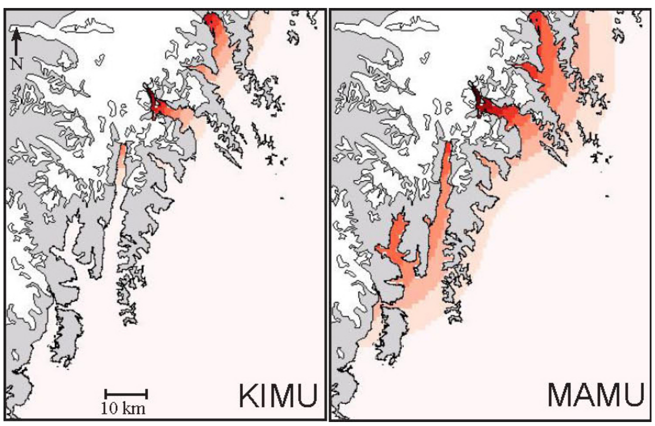

Fig. 4. Kittlitz's (KIMU) and Marbled (MAMU) murrelet distributions in Kenai Fjords, 2006–2008. Point intensity, weighted by group size and survey effort, was derived from all observations of murrelets identified to species in mid-season coastwide surveys (kernel density estimator). Darker shades of red indicate higher point intensity. Glaciers shown in white.

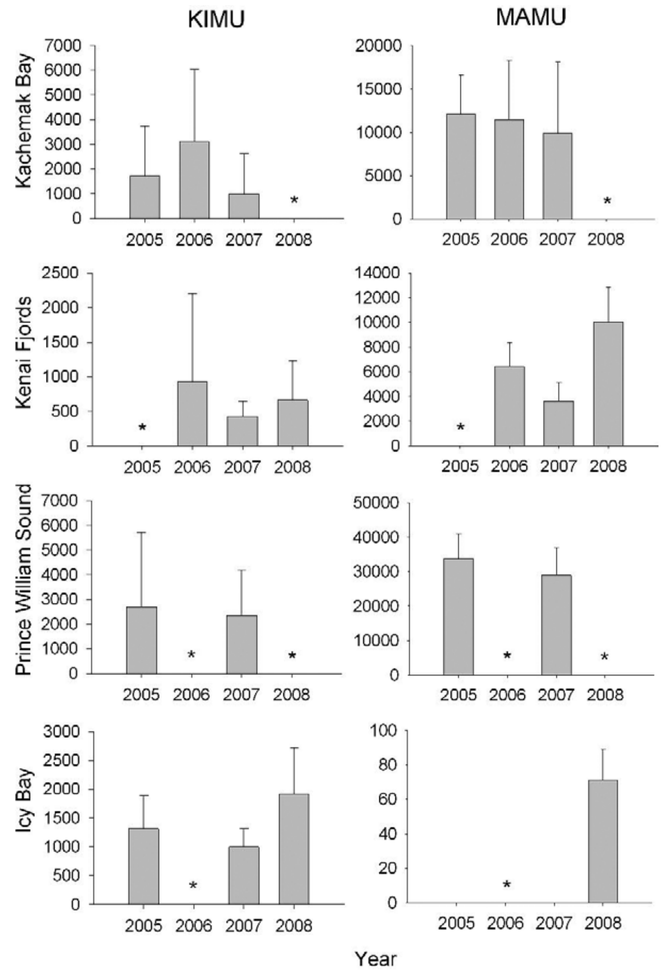

Fig. 6. Kittlitz's Murrelet (KIMU) and Marbled Murrelet (MAMU) population estimates (n ± 95% CI) in four areas in the Gulf of Alaska with overlapping years of survey effort. Population estimates from Kachemak Bay (~200 km west of Kenai Fjords; Kuletz *et al*. 2011b), Prince William Sound (~ 150 km east of Kenai Fjords; Kuletz *et al*. 2011a) and Icy Bay (~ 450 km east of Kenai Fjords; Kissling *et al*. 2011) are detailed in this volume. An asterisk (*) indicates no yearly survey was conducted.

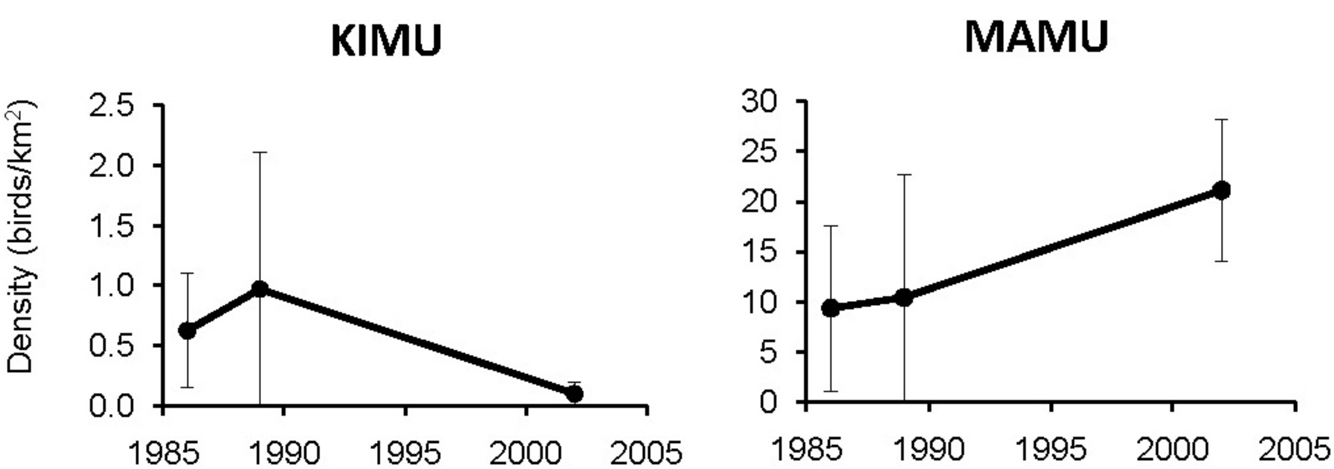

Fig. 5. Change in density (± 95% CI) of Kittlitz's (KIMU) and Marbled (MAMU) murrelets on historical shoreline transects along the Kenai Peninsula, 1986–2002. Calculations use GPS data from 2002 and assume identical survey lengths in other years.

other years (Fig. 6). The influx of Kittlitz's Murrelets in Kachemak Bay during 2006 was confined to the outer bay, and birds may have come from Lower Cook Inlet populations (Kuletz *et al.* 2008). In Kenai Fjords, Kittlitz's and Marbled murrelets exhibited similar fluctuations in abundance between 2006 and 2007, which suggests that interannual variability had a common cause in both species.

As 2007 was an anomalous year oceanographically in the Gulf of Alaska (Hopcroft *et al*. 2010, Janout *et al*. 2010), we believe that regional oceanography played a role in the low abundance of murrelets at sea during our mid-season surveys that year. Spring and summer temperature and salinity profiles along the Gulf of Alaska shelf adjacent to Kenai Fjords fell outside the long-term average in May 2007, with cooler temperatures throughout the water column and higher salinity at the surface (Janout *et al*. 2010). Higher salinity and lower stratification in the upper 50 m in May 2007 than in 2006 and 2008 indicate there was less freshwater runoff from snow melt, and these unusual oceanographic conditions corresponded to a delayed spring bloom along the shelf adjacent to Kenai Fjords (Hopcroft *et al*. 2010). On the other hand, the median date of 2007 surveys in Kenai Fjords was five days earlier than in 2006 and 15 days earlier than 2008 (Table 1), and it has been shown that murrelet densities increase from late June to early July (Romano *et al*. 2004, Stephensen 2009, Piatt *et al*. 2011). The cause of that pattern is unknown, but it may arise from fluctuations in breeding effort (many nonbreeding birds remaining offshore and moving between foraging areas), pulses of recruiting birds from previously successful years of reproduction, or pulses of subadult birds prospecting near breeding grounds.

Within-season density patterns of both murrelet species differed in 2007 compared with 2006 and 2008 (Fig. 3). The highest density of Kittlitz's Murrelet occurred on late-season surveys in 2007, when no juveniles were sighted in coastal areas, and we observed several birds holding fish (an indication of chick-rearing). These observations suggest there was a delay in the onset of breeding during that year. Higher densities of Kittlitz's and Marbled murrelets occurred during late-season surveys in 2007, perhaps because of higher chlorophyll *a* concentrations, a proxy for primary production, within the fjords in August than in June 2007 (Arimitsu 2009), and a stronger fall bloom (Hopcroft *et al*. 2010) that affected prey availability later in the season.

As in Marbled Murrelets (Speckman *et al.* 2000), variation in Kittlitz's Murrelet densities through the breeding period may be strongly related to nesting phenology. However, differences in post-breeding dispersal between species may also contribute to within-season variability in murrelet density in Kenai Fjords and elsewhere. Bailey (1927) and Wik (1968) noted that Kittlitz's Murrelet density in glaciated fjords peaked in mid-summer and rapidly declined by late summer, a pattern later confirmed quantitatively (e.g. Romano *et al.* 2004, Stephensen 2009). In a "normal" year, Kittlitz's Murrelets arrive in April–May, increase in numbers between June and July, and apparently leave the area shortly after chicks fledge in late July and early August. In contrast, Marbled Murrelets increase through the summer, with very high densities (24–50 birds/km^2) observed in some areas during late July and August (Romano *et al.* 2004, this study).

Van Pelt & Piatt (2003) estimated there were 509 (SE 359) Kittlitz's Murrelets and 9554 (SE 1347) Marbled Murrelets along the Kenai Peninsula in 2002. Although it is impossible to know with certainty the breeding stage of birds surveyed in 2002, there is evidence for early or productive nesting of murrelets that year—three experienced observers recorded 17 juvenile Marbled Murrelets and 3 juvenile Kittlitz's Murrelets from 7–12 July 2002 (Van Pelt & Piatt, unpublished data). Likewise, chlorophyll *a* concentrations in May 2002 were higher than the long-term average along the Seward Line (Fig. 4), which suggests the timing of the spring bloom was earlier than normal. Although murrelets nest asynchronously and the timing of peak fledging may vary, at-sea surveys in Prince William Sound and Lower Cook Inlet suggest peak fledging occurs during the first two weeks of August (Kuletz & Kendall 1998, Kuletz *et al*. 2008).

Population change over time

Differences in survey methods over time, few years of survey effort and low population numbers made it difficult to assess trends in the Kittlitz's Murrelet breeding population in Kenai Fjords. The lack of a defined strip width in the early years would have tended to inflate population estimates in comparison with the strip transect approach (1989 and 2002), owing to detection of murrelets beyond the strip width. This is especially true in 1976, when surveys were conducted by two observers from a larger primary vessel, rather than by one observer from an inflatable skiff as in 1986. Differing strip widths in 1989 and 2002 could be another source of variation (Table 2)—the use of a larger vessel and wider strip in 2002 would have tended to increase the 2002 counts compared with the 1989 counts. The 1989/2002 subset of transects was not ideal for Kittlitz's Murrelet population estimation because it missed some key glacial habitat where Kittlitz's Murrelets were likely to be found. Furthermore, during the 1976 survey, all *Brachyramphus* murrelets were recorded as either Marbled or Kittlitz's murrelets, and the proportion of murrelets identified only to genus varied among the 1986, 1989 and 2002 surveys (Table 2). To account for these issues, we excluded some years of data, and conservatively standardized effort for a common set of coastal transects.

The best information available suggests a decrease in Kittlitz's Murrelet density in nearshore areas of Kenai Fjords between 1989 and 2002. Although we recognize there is much uncertainty (due to few years of data), the magnitude of the change is similar to observed changes in Kittlitz's Murrelet in similar habitats within southern coastal Alaska over the same time period (Kuletz *et al.* 2011a, Kuletz *et al.* 2011b, Piatt *et al.* 2011). More recent (2006–2008) information suggests, however, that Kittlitz's Murrelet numbers fluctuated considerably in years sampled after 1989. Furthermore, within-season patterns in Kenai Fjords and Glacier Bay suggest that Marbled Murrelet density tends to increase, whereas Kittlitz's Murrelet density tends to decline on surveys conducted in late July and August (Romano *et al.* 2004, Stephensen 2009, Fig. 3). A strong spring phytoplankton bloom in 2002 may have prompted earlier than normal nesting phenology that year. That possibility, and the contrasting changes in density of Kittlitz's and Marbled murrelets late in the season, may partly explain why Kittlitz's Murrelets decreased and Marbled Murrelets increased between 1989 and 2002, despite the fact that the timing of surveys differed by less than a week.

Survey methods

We used a combination of strip and line transect methods to allow maximum comparability with historical surveys and to estimate population size of *Brachyramphus* murrelets more accurately. Strip transects underestimate marine bird population size when observers are unable to detect every bird within the strip (Buckland *et al.* 2001)—for example, if sighting probability declines with increasing distance from the survey vessel. Line transect methods account for variation in detection probabilities using perpendicular distance to detected birds from the transect line and other covariates, if desired. The population estimates presented here differ slightly from those reported in Arimitsu *et al.* (2010) because we used a greater truncation distance to fit 2008 detection functions (Fig. 2). We believe the updated estimates presented here are more accurate.

Survey design for murrelets in coastal Alaska presents several issues, such as how to deal with unidentified birds, how best to survey species with highly clumped distributions and when to conduct surveys. The use of highly trained and experienced observers lowers the uncertainty associated with unidentified birds. Strip transects have traditionally been used for marine bird surveys in Alaska (e.g. Agler *et al.* 1999, Piatt *et al.* 2007), and bias associated with the inability to detect all birds within the strip can be corrected with detection functions to define an effective strip width (Ronconi & Burger 2009). Timing of population surveys in Kenai Fjords has targeted the presumed dates of highest abundance of murrelets at sea. If nesting phenology is linked to bloom dynamics; that is, if nests are initiated earlier in years with earlier blooms and *vice versa*, then bloom dynamics should be used to inform the timing of surveys in order to minimize variability in assessing trends. This could be accomplished using a long-established oceanographic dataset for the Gulf of Alaska (the Seward Line; Hopcroft *et al.* 2010), or remote sensing if the protocol is discontinued. We believe a standard survey protocol across Alaska will be critical to understanding population trends of Kittlitz's Murrelets over time, and will ultimately aid in sound management of this species across its range.

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