STATUS AND TREND OF THE KITTLITZ'S MURRELET *BRACHYRAMPHUS BREVIROSTRIS* IN GLACIER BAY, ALASKA

JOHN F. PIATT[1], MAYUMI ARIMITSU[2], GARY DREW[1], ERICA N. MADISON[1], JAMES BODKIN[1] & MARC D. ROMANO[1,3]

[1]*US Geological Survey, Alaska Science Center, 4210 University Drive, Anchorage, Alaska, 99503, USA (jpiatt@usgs.gov)*
[2]*US Geological Survey, Alaska Science Center, 3100 National Park Road, Juneau, Alaska, 99801, USA*
[3]*Current address: NOAA Fisheries, Protected Resource Division, 1201 Lloyd Boulevard, Suite 1100, Portland, Oregon, 97232, USA*

Received 7 May 2010, accepted 17 May 2011

SUMMARY

PIATT, J.F., ARIMITSU, M., DREW, G., MADISON, E.N., BODKIN, J. & ROMANO, M.D. 2011. Status and trend of the Kittlitz's Murrelet *Brachyramphus brevirostris* in Glacier Bay, Alaska. *Marine Ornithology* 39: 65–75.

We conducted standardized surveys for marine birds in Glacier Bay in seven years between 1991 and 2008. From our most recent survey, a combination of line- and strip-transect methods completed in 2008, we estimated that 4981 (95% CI 1293–8670) Kittlitz's Murrelets *Brachyramphus brevirostris* resided in Glacier Bay during the month of June, together with 12 195 (5607–18 783) Marbled Murrelets *B. marmoratus*. When counts were prorated to assign unidentified *Brachyramphus* murrelets to species, population estimates increased to 5641 Kittlitz's Murrelets and 13 810 Marbled Murrelets. Our surveys of bird numbers in Glacier Bay between 1991 and 2008 revealed that Kittlitz's Murrelet declined by ≥85% during this period. Trend analysis suggested a rate of decline between -10.7% and -14.4% per year. No direct human impacts (e.g., bycatch, oil pollution, vessel disturbance) in our study area could fully account for a decline of this magnitude. Widespread declines of *Brachyramphus* murrelets and Harbor Seals *Phoca vitulina* in the Gulf of Alaska during the 1980s–1990s suggest large-scale influences on these marine predators, perhaps related to climate-mediated cycles in food supply. Other natural factors that may impact Glacier Bay populations include predation by avian and terrestrial predators, widespread glacial retreat and its effect on nesting and foraging habitats, and competition for food with marine predators whose abundance in Glacier Bay has increased markedly in recent years (Humpback Whales *Megaptera novaeangliae* and Steller Sea Lions *Eumetopias jubatus*).

Keywords: Alaska, Glacier Bay, seabird, *Brachyramphus brevirostris*, Kittlitz's Murrelet, distribution and abundance, population trend, deglaciation, global warming

INTRODUCTION

Glacier Bay has long been known to harbor significant populations of Kittlitz's Murrelet *Brachyramphus brevirostris*. Grinnell (1910) noted: "One of the more surprising results of the 1907 Alexander Expedition's explorations was the discovery of large numbers of the Kittlitz's Murrelet on the waters of Glacier Bay." During July, Dixon (in Grinnell 1910) "saw at least five hundred of these gray murrelets in one flock. They were feeding in the channels among the numerous islands that lie near the mouth of the bay"—referring probably to Beardslee Channel, where large concentrations of Kittlitz's Murrelets are still found. Early surveys in the upper reaches of the bay and in proximity to tidewater glaciers were infrequent because of heavy ice, but those that were conducted revealed that Kittlitz's Murrelet and the closely related Marbled Murrelet *B. marmoratus* were distributed throughout the bay and that Kittlitz's Murrelets, in particular, were concentrated in the vicinity of tidewater glaciers (Bailey 1927, Wik & Streveler 1967).

Many naturalists' accounts of murrelets in Glacier Bay followed the Alexander Expedition (e.g. Gabrielson & Lincoln 1959, Wik & Streveler 1967), but no quantitative surveys were undertaken before the late 1980s, when Bevins (1987) initiated baseline surveys of marine birds in the Beardslee Islands. The latter surveys, conducted repeatedly from about May to September in each year 1987–1991, revealed marked seasonal cycles in abundance of murrelets in the Beardslee Islands, with peaks in mid- to late July (Duncan & Climo 1991). However, a systematic, bay-wide survey of marine birds was not conducted until the early 1990s, when Piatt *et al.* (1991) surveyed most of the shoreline and a portion of the offshore waters of Glacier Bay. This was followed by a survey of offshore waters in 1993 (Lindell 2005). For five years, 1999 to 2003, extensive surveys of the entire bay were conducted (Robards *et al.* 2003, Drew & Piatt 2008, Drew *et al.* 2008), and in 2008 the same workers sub-sampled about 25% of the transects used in 1999–2003. In a previous analysis, we compared a spatially matched set of transects from 1991 and 1999/2000 and found that Kittlitz's Murrelet had declined by 83% between surveys (Drew & Piatt 2008). In 2007, Kirchhoff (2008) designed and tested a new protocol for surveying Kittlitz's Murrelet, and Kirchhoff *et al.* (2010) resurveyed offshore waters of Glacier Bay in 2009 following methods used by Lindell (2005). In 2009–2010, the Southeast Alaska Inventory and Monitoring Program adopted a new set of transects and survey protocol for long-term monitoring of Kittlitz's Murrelets (Hoekman *et al.* 2011a).

In this paper, we summarize survey data for Kittlitz's and Marbled murrelets collected in Glacier Bay from 1991 to 2008. Our primary objectives were to calculate population size using data from our most recent survey (2008) and to estimate the trend of Kittlitz's Murrelet in Glacier Bay. To ensure comparability across years and reliable estimates of trend, we used only survey data for which we were directly responsible in 1991, 1999–2003 and 2008. Our surveys employed the same data collection protocols (multi-species strip surveys of birds flying and on the water) and similar sample designs (systematic shoreline and offshore transects initiated in June).

STUDY AREA

Glacier Bay is a Y-shaped glacial fjord in southeastern Alaska that stretches over 100 km northwestward from its mouth on Icy Strait (Fig. 1). The bay forms the core area of Glacier Bay National Park, which also extends to the outer coast and the Gulf of Alaska. Glacier Bay is fed by numerous glacier-melt rivers and contains eight tidewater glaciers in its upper reaches. Filled by ice as recently as 230 years ago, the bay's rapid glacial retreat since the end of the Little Ice Age has left all but its upper arms ice-free, and glacial melting continues today at an accelerated pace (Larsen *et al*. 2005). The marine ecosystem of Glacier Bay is complex and characterized by strong environmental gradients from its entrance on Icy Strait to the head of its two branching arms (Etherington *et al*. 2007). The two inner arms forming the head of the bay are strongly influenced by input of cold, fresh water from tidewater glaciers, silt-laden glacial river runoff, and rainfall. The main bay features deep channels carved by glaciers, shallow sills and narrow passes around islands. Near the mouth of the bay, strong tidal currents mix estuarine waters with deep water from the Gulf of Alaska (Hill *et al*. 2009).

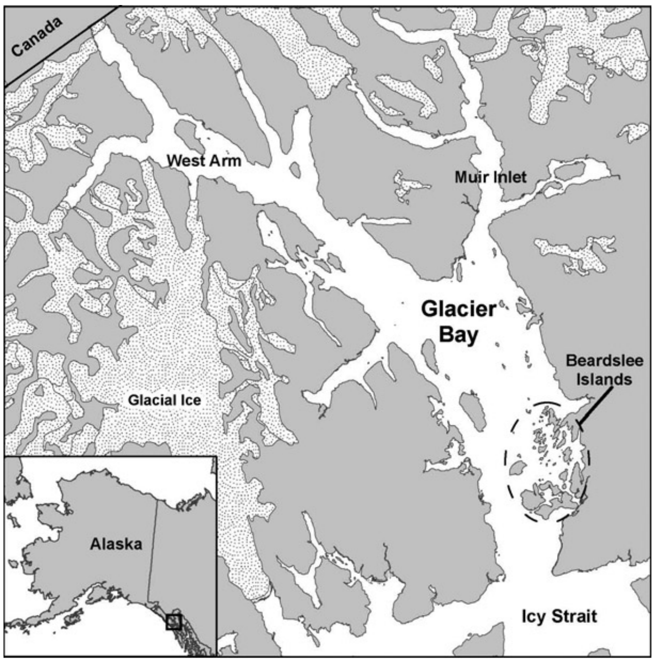

Fig. 1. Glacier Bay study area in southeastern Alaska.

METHODS

Survey design and protocols

Surveys in 1991

In 1991, we surveyed Glacier Bay to collect baseline data on Marbled and Kittlitz's murrelets, as well as other marine birds and mammals (Piatt *et al.* 1991). We used a 5 m skiff to survey 648 linear km of shoreline (Fig. 2a), about 60% of the total linear shoreline of Glacier Bay. The survey included 152 transects averaging 4.3 km in length (range 0.9–12.0 km), and 76 linear km of offshore waters on 21 opportunistic offshore transects averaging 3.6 km in length (range 1.6–3.6 km). Following Klowsiewski & Laing (1994), we defined shoreline transects as those conducted parallel to and within 100 m of shore (except where prevented by navigation hazards), and offshore transects as those located in open water >200 m from the shore and generally perpendicular to it (Fig. 2a). As these surveys were conducted before commercial availability of GPS equipment, we chose transect start and stop points that coincided with prominent features such as river-mouths, rocks and headlands (Gould & Forsell 1989). In total, we surveyed 145 km^2, or about 11.5% of the total surface area (1258 km^2) of Glacier Bay (Table 1). The majority of surveys (75%) and murrelet observations (77%) occurred during a concerted survey effort from 14–29 June, while the remainder of transects were surveyed 1–15 July. The median date of survey (when 50% of transects were completed) was 18 June (Table 1).

We used standard census protocols developed for small-boat surveys in Prince William Sound following the *Exxon Valdez* oil spill (Klowsiewski & Laing 1994, Agler *et al.* 1998), which in turn had been modified slightly from standard protocols for ship-based surveys of marine birds (Gould & Forsell 1989; see below).

TABLE 1
Historical surveys for seabirds in Glacier Bay used for analysis of status and trends of Kittlitz's Murrelet

Year	Timing and sampling effort[a]						Observations[b]					
	Median date	No. of transects	km of transects	km2 surveye[d]	% shoreline	% offshore	BRMU	MAMU	KIMU	UNMU	% UNMU	Total KIMU[c]
1991	18 June	173	724	145	40.0	1.6	8474	4353	883	3238	38	1672
1999	18 June	110	1139	316	61.6	12.5	5972	3630	505	1837	31	885
2000	19 June	109	1169	270	55.9	9.6	3879	1211	399	2269	59	965
2001	18 June	105	1176	276	56.1	10.1	4545	2664	546	1335	29	779
2002	10 June	109	1219	259	54.3	8.9	3302	2186	323	793	24	441
2003	12 June	109	1165	263	52.9	9.9	3300	2168	405	727	21	524
2008	24 June	35	295	59	11.3	2.4	601	421	116	64	11	126

[a] % shoreline = percentage of total (323 km^2) shoreline habitat (<300 m from shore) that was sampled; % offshore = percentage of total (935 km^2) offshore habitat (>300 m) that was sampled.
[b] BRMU, all murrelets combined; MAMU, Marbled Murrelet; KIMU, Kittlitz's Murrelet; UNMU, unidentified *Brachyramphus* murrelet.
[c] Total KIMU = sum of KIMU and prorated KIMU from unidentified murrelets.

Observers viewed birds from ~1.5 m above the water, and two observers were on duty during all surveys. Observations were recorded continuously on tape recorders and transcribed later. Binoculars were used to aid in location and identification of species. Swimming birds and mammals within 100 m on either side and 200 m forward of the boat were identified to species (if possible) or genus. Flying birds were counted continuously (e.g. Agler *et al.* 1998) rather than in periodic scans (e.g. Gould & Forsell 1989). All observers were trained in survey methods and species identification, including field marks of Kittlitz's and Marbled murrelets, and we frequently calibrated our estimates of distance to shore and transect width by pulling a float at 100 m behind the vessel. For more details on methods, see Gould & Forsell 1989, Klosiewski & Laing 1994, Agler *et al.* 1998, and Robards *et al.* 2003.

Surveys in 1999-2003, and 2008

Beginning in 1999, we collected data on shoreline transects and on offshore transects positioned 4.6 km (2.5 nautical miles) apart and perpendicular to the shoreline in Glacier Bay (Fig. 2a). As in 1991, shoreline transects ran parallel to the shore at a distance of 100–150 m depending on vessel size (see below), while offshore transects were in open waters >200–300 m from shore depending on vessel size (Fig. 2a). In 1999-2003 we surveyed more than 250 km^2, or 20-25%, of the bay's surface area, of which 35% was offshore habitat (Table 1, Fig. 2a,b). All surveys were conducted during 7–26 June, with median dates from mid- to late June (Table 1). Methods of data collection were as described above for surveys in 1991, with one difference: over several years of study (1999–2003), we used multiple survey vessels, often 2–3 vessels at the same time, to reduce the time required to survey the entire bay. Observers on the *R/V Pandalus* (22 m length, 3.4 m viewing height, 300 m transect width), *R/V Alaskan Gyre* (16 m, 3.7 m, 300 m, respectively) and *M/V Capelin* (12 m, 2.5 m, 300 m, respectively) counted and identified birds and mammals within 150 m on either side and 150 m forward of the boat. Owing to a lower viewing elevation, we used a transect width of 100 m on either side and 100 m forward of three additional smaller vessels—the *M/V Lutris II*, (9 m, 2 m, 200 m, respectively), *R/V David Grey* (10 m, 2 m, 200 m, respectively) and *R/V Sigma-t* (9 m, 2 m, 200 m, respectively). Thus, while the total linear distance surveyed varied little (<6.5%) among years, the area surveyed varied by up to 12% (Table 1), reflecting a different combination of survey vessels in each year. The use of different transect widths is recommended when using survey platforms with different viewing heights and distances (Gould & Forsell 1989). Results are standardized by calculating murrelet densities (birds observed / area surveyed) for comparison among areas or years (Gould & Forsell 1989, Tasker *et al.* 1984).

As in 1991, observers were trained in protocols, distance estimation and murrelet species identification before surveys began. We calibrated distance estimates repeatedly during surveys, using radar, range-meters and/or a float towed behind the vessel. We did not conduct surveys when seas exceeded 1 m. Bird and mammal sightings were recorded directly into a real-time data-entry system (dLOG; Glenn Ford Consulting, Portland, Oregon) that plotted sighting positions continuously using GPS coordinates. In 1999–2000 (before US government removal of GPS "selective availability"), GPS locations were obtained from a Rockwell Precision Lightweight Global-positioning Receiver, which had a horizontal accuracy of ±10 m. In 2001–2008, we used commercial GPS units with similar positional accuracy.

During 23–26 June 2008, we surveyed a subset (about 25%, by length) of transects surveyed in 1999–2003 (Fig. 2b). This was the same track used for sampling Glacier Bay during winter months (Drew *et al.* 2008), with a similar ratio of shoreline to offshore sampling completed as in 1999–2003 (Table 1). We used methods described above to count birds from the *R/V Sigma-t*. To improve accuracy and test the assumption of perfect detection within the strip transect, we also estimated the perpendicular distance (m) from the transect line to all *Brachyramphus* murrelets observed (maximum distance = 300 m; Buckland *et al.* 2001). Again, all observers were experienced in identification of murrelets, estimating distances, and line transect methodology. We used rangefinders to calibrate distance estimates before and throughout surveys each day, and observers attempted to maximize detection probability on the transect line (Buckland *et al.* 2001, Lukacs *et al.* 2010). Line transect methods were employed only for murrelets, and not for other marine birds and mammals observed on these surveys.

Data analysis

Stratification

Surveys in 1999–2003 were designed to show the distribution of all marine birds in Glacier Bay with respect to environmental characteristics (Robards *et al.* 2003) and thus included shoreline transects and a grid of offshore transects that crisscrossed the bay (Fig. 2a,b). In a previous analysis of *Brachyramphus* murrelet trends in Glacier Bay (data for Marbled, Kittlitz's and unidentified murrelets combined, but dominated by Marbled Murrelets), sampling strata were combined, as there was no significant difference between *Brachyramphus* murrelet densities on shoreline and offshore transects (Piatt *et al.* 2007). Before using the same data to assess population trends of Kittlitz's Murrelet, we examined the distribution of Kittlitz's Murrelets across shoreline and offshore habitats to judge whether we should separate the strata. For offshore transects, we assigned each Kittlitz's Murrelet recorded during 1999–2003 to a 100 m wide bin (e.g. 100–200 m, 200–300 m, 300–400 m, etc.) starting at 100 m from the shoreline of Glacier Bay and moving offshore as far as possible within the bay (maximum 4300 m; ArcGIS, v9.3). We then calculated the area of each bin and the density of murrelets in each bin. Density in the 0–100 m bin was estimated from shoreline transect data only (Fig. 3).

Over the 5-year period (1999–2003), we surveyed 5800 linear km of transects, including 908 km^2 of shoreline habitat (containing 900 birds) and 476 km^2 of offshore habitat (containing 1278 birds). Density of Kittlitz's Murrelet (birds/km^2) was consistently low within the first 300 m from shore, increased rapidly between 400 and 700 m, reached a plateau of threefold greater densities at about 800 m offshore, and remained variably high up to 4000 m from shore (Fig. 3). The overall 1999–2003 average density of Kittlitz's Murrelet (6.60 birds/km^2) in offshore habitat (>300 m from shore) was significantly higher (t = -4.97, P < 0.0001; two-tailed test assuming unequal variances) than density (1.60 birds/km^2) in shoreline habitat (<300 m from shore). The contribution of each distance stratum to total bay area was greatest near shore and fell rapidly with distance (Fig. 3). Thus, despite low densities, a substantial fraction (~10%) of the Kittlitz's Murrelet population may be found within 300 m of shore. Taken together, these results provided strong support for stratifying population estimates into shoreline (<300 m) and offshore strata (>300 m) to obtain a more accurate estimate of overall population size in Glacier Bay (Table 2).

Estimating current population size

We estimated population size of Kittlitz's Murrelet using data collected on our most recent survey (2008) in Glacier Bay, the only survey in which we used both strip-transect (200 m strip, 100 m on either side of the transect line) and line-transect (Buckland *et al.* 2001) methods of data collection. We estimated densities of flying birds (strip transects) and birds on the water (line transects) separately for each stratum (shoreline and offshore) in the program DISTANCE (v6.0; Thomas *et al.* 2010). Flying birds were analyzed separately using strip-transect methods because they were more conspicuous and more likely to be detected on transect than birds on the water, and it is more difficult to estimate distances to fast-moving targets accurately. For flying birds, we assumed perfect detection across the strip width, used birds per transect as samples, and applied a uniform key with a cosine adjustment following Buckland *et al.* (2001). To fit a detection function for birds on the water, we binned observations into 20 m intervals and estimated cluster size (number of birds sighted within 3 m of each other) as the mean of all clusters. To ensure an appropriate number of detections

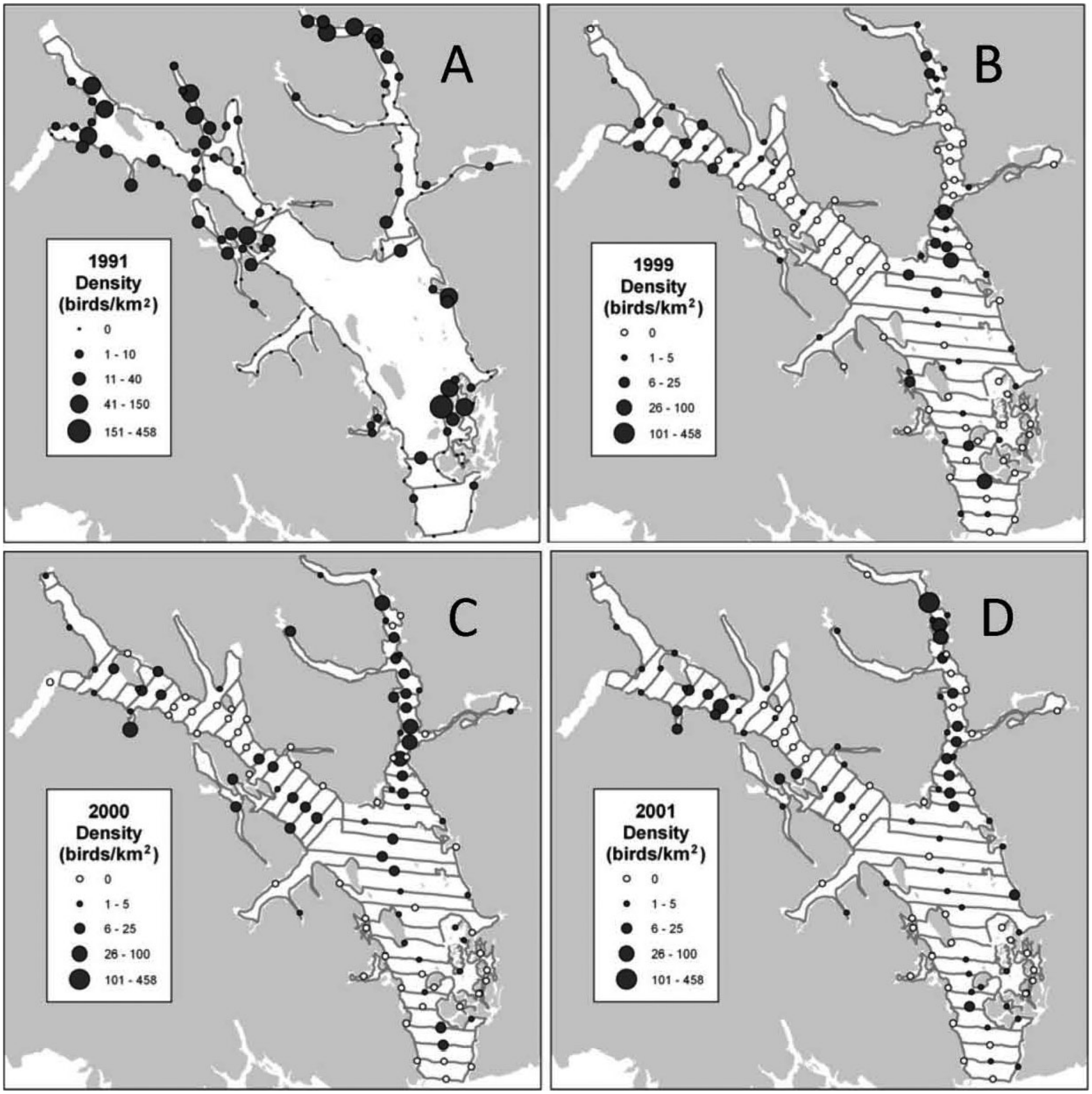

Fig. 2. (a) Density (birds/km^2) of Kittlitz's Murrelet on surveys conducted in Glacier Bay, Alaska, during: (A) 1991, (B) 1999, (C) 2000 and (D) 2001. Dark lines along coast and offshore indicate survey routes. Panels (A)–(D) indicate (with common density scales) the average density per transect at the mid-point of each transect (i.e. dots do not correspond to spatial location of individual birds).

for sighting models (a minimum of 60–80 detections per species), we used a global detection function for each species rather than a separate detection function for each stratum. Candidate sighting models included uniform and half-normal adjustments with cosine, polynomial and Hermite adjustment terms. Variance was estimated empirically, and 95% confidence intervals (CI) were estimated using nonparametric bootstrap estimates. Using Akaike's Information Criterion, we selected a half-normal key with cosine adjustment model for Kittlitz's and *Brachramphus* murrelets, and a uniform key with polynomial adjustment model for Marbled Murrelets. The data indicated a decline in detections with increasing distance from the transect line for Kittlitz's and *Brachyramphus* murrelets, but a uniform detection probability for Marbled Murrelets during the 2008 Glacier Bay survey. Because we did not identify any murrelets to species beyond 180 m, we truncated the data at that distance. The effective strip width for murrelets, counted out to a maximum distance of 180 m, was 100 m (95% CI 87–115 m).

We obtained our final population estimates (Table 3) of murrelet populations in Glacier Bay (1258 km^2) by summing stratum

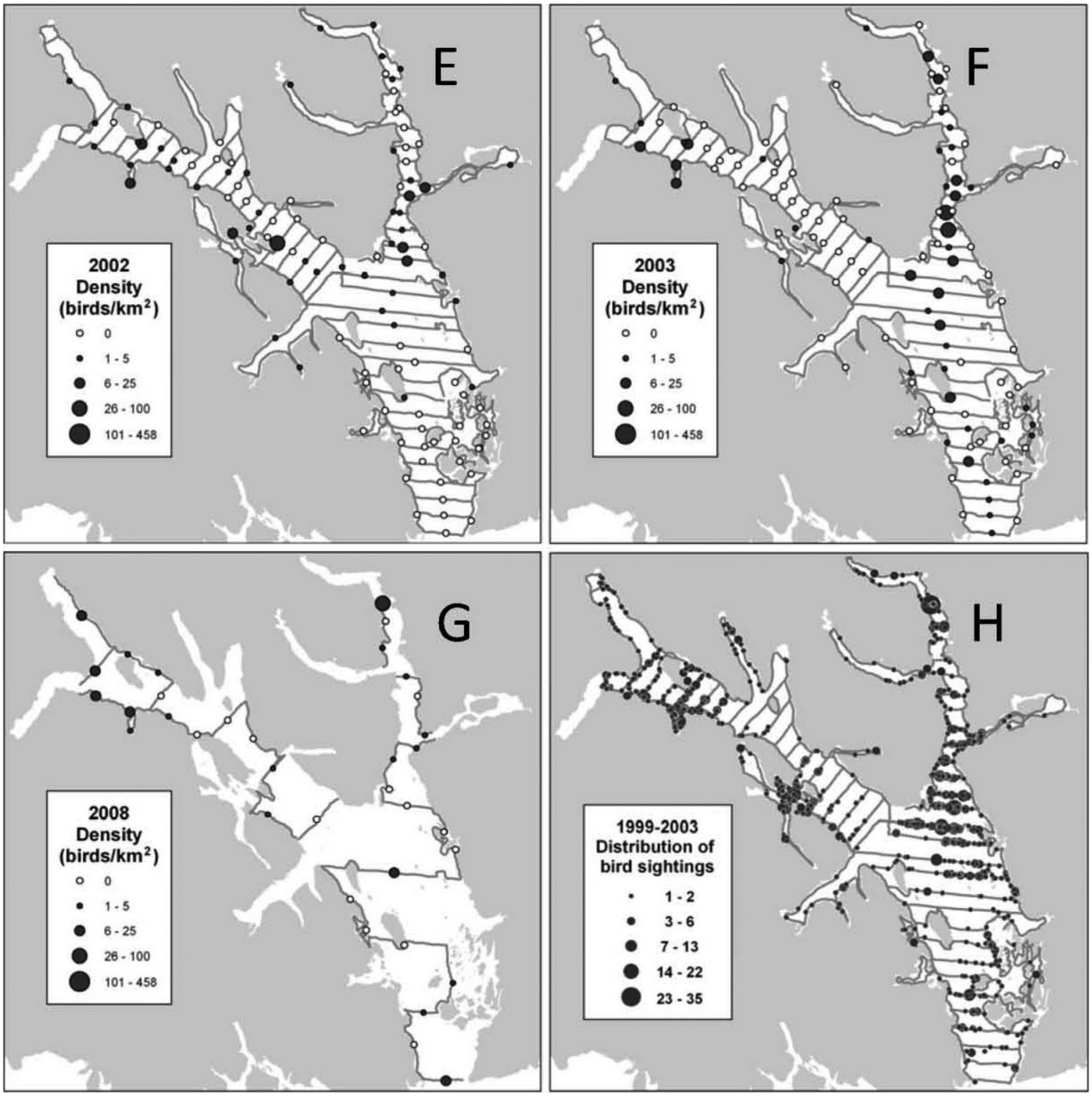

Fig. 2. (b) Density (birds/km^2) of Kittlitz's Murrelet on surveys conducted in Glacier Bay, Alaska, during: (E) 2002, (F) 2003 and (G) 2008; and (H) the distribution of all Kittlitz's Murrelet sightings in 1999–2003 combined. Dark lines along coast and offshore indicate survey routes. Panels (E)–(G) indicate (with common density scales) the average density per transect at the mid-point of each transect (i.e. dots do not correspond to spatial location of individual birds), whereas panel (H) plots flock sightings along each transect, not average densities.

estimates (weighted by stratum area) of flying birds and birds on the water (assuming independence of the two estimates). We performed these calculations using a uniform key with a cosine adjustment following Buckland *et al.* (2001) and estimated variance empirically with a nonparametric bootstrap procedure. We then adjusted estimates to include unidentified murrelets observed on the survey (see below). We did not prorate unidentified murrelets before generating 2008 population estimates, because the program DISTANCE uses cluster as the sample unit, and there was no subset of identified birds in each cluster to furnish a ratio for prorating unidentified clusters (in contrast to strip estimates, see below).

Prorating unidentified birds for trend analysis

Identification of *Brachyramphus* murrelets in the field can be difficult, even for experienced observers. On our surveys, about 30% of murrelets were categorized as unidentified *Brachyramphus* (range 11–59%, Table 1). Over time, the proportion of unclassified birds declined because of improved knowledge of murrelet plumages, better identification keys and better training (Table 1). To evaluate trends in populations, we had to remove the effect of varying identification rates by prorating unidentified murrelets to species.

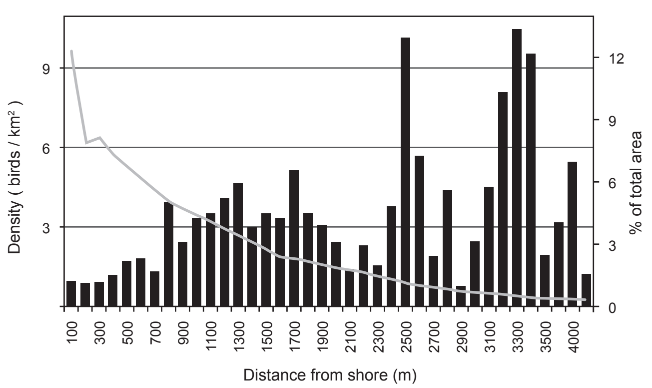

Fig. 3. Density (birds/km²) of Kittlitz's Murrelets (bars) versus distance from shore on transects in Glacier Bay, Alaska (data averaged over five years, 1999–2003). Line indicates the percentage of total marine area of Glacier Bay found within each distance bin (e.g. 12.4% of bay area found in the 0–100 m bin, 7.9% in the 100–200 m bin, etc.).

We prorated unidentified murrelets on a transect-by-transect basis to estimate total numbers of each species on surveys (Calambodikis & Barlow 2004):

$$M_{A(Total)} = \sum_{i=1}^{n} \left[M_{At} + U_t \left(\frac{M_{At}}{M_{At} + M_{Bt}} \right) \right]$$

where M = number of murrelets of species A or B and U is unidentified murrelets observed on transect t, and M_{Total} is summed over all n transects. This proration assumes the two murrelet species are equally easy to identify. We have not noticed any bias in our ability to identify one species over the other, and Hoekman *et al.* (2011b) also give qualitative support for this assumption. In any case, the assumption is necessary in the absence of quantitative data on the relative ease of identification (Gerrodette & Forcada 2005).

Estimating population trend

Because all data collected before 2008 were collected using strip-transect methods, we used a ratio estimator on prorated bird densities to calculate population estimates of Kittlitz's Murrelet for trend analysis (Cochrane 1977; Table 2). Density (birds/km²) of Kittlitz's Murrelet in each survey (year) was calculated as the ratio of prorated total murrelets observed to total area surveyed in each of two strata, shoreline and offshore (Cochran 1977). The total population of Glacier Bay was estimated by extrapolation from the ratio estimator of density in each stratum to its total area (shoreline = 323 km²; offshore = 935 km²) and summed for the whole bay (1258 km²).

A bootstrap procedure was used to estimate the variance of the density estimate for each survey. We assumed the variance in the sample was equivalent to the variance of the population, and we resampled the original data with replacement (Manly 1997). The bootstrap procedure was conducted separately for each survey and stratum. Simulated samples were equal in size to the original. The ratio estimator of density (total murrelets observed to total area surveyed) was calculated for each resampled dataset. These steps were repeated 2000 times, and the mean, standard deviation, variance and percentile CIs were calculated for the 2000 bootstrap

TABLE 2
Density and population estimates of Kittlitz's Murrelet in two strata of Glacier Bay, 1991–2008

Year	Coastal strata[a]		Offshore strata[b]		Glacier Bay total
	Density, birds/km²	N (95% CI[c])	Density, birds/km²	N (95% CI[c])	N (95% CI[c])
1991	9.08	2937 (1912–4127)	32.81	30 675 (5002–76 404)	33 612 (7882–79 472)
1999	1.20	389 (222–582)	5.50	5147 (2665–8086)	5536 (3060–8460)
2000	2.43	787 (444–1216)	5.88	5502 (3790–7855)	6289 (4511–8659)
2001	2.01	651 (392–977)	4.37	4084 (2709–6140)	4735 (3282–6803)
2002	1.60	517 (253–820)	1.93	1808 (738–3491)	2325 (1203–4037)
2003	0.59	191 (75–337)	4.50	4204 (2647–5896)	4394 (2826–6089)
2008	1.40	454 (134–846)	3.35	3130 (858–5436)	3583 (1271–5884)

[a] <300 m from shore.
[b] >300 m offshore.
[c] Bootstrapped 95% confidence limits for Kittlitz's Murrelets, including prorated birds.

ratios. Bias was calculated for each survey as the difference between the bootstrap mean and the observed ratio of totals. Bias was insignificant, being less than 2% in all comparisons.

We calculated a trend estimate of Kittlitz's Murrelet population size from 1991 to 2008 for each stratum and for the whole bay using weighted linear regression analysis. In doing so, we took the natural log of murrelet densities to make the variances independent of the means, and we weighted values by the inverse of estimated variance of log-transformed density (Sokal & Rohlf 1981).

RESULTS

Population size

Based on our most recent survey (2008), we estimated a minimum of 4981 (95% CI 1293–8670) Kittlitz's Murrelets, 12 195 (5607–18 783) Marbled Murrelets and a total of 19 451 (9605–29 297) *Brachyramphus* murrelets (including 2275 unidentified murrelets) in Glacier Bay at the time of the survey (Table 3). When we prorated the unidentified *Brachyramphus* murrelets (11.7% of total), we estimated that 5641 Kittlitz's and 13 810 Marbled murrelets occupied Glacier Bay in late June 2008.

Population trend

Kittlitz's Murrelet numbers declined by 85% in shoreline habitat and by 90% in offshore habitat between 1991 and 2008 (Table 2). Combined data indicated a bay-wide population decline of 89%. Trend analysis of shoreline transects was robust owing to good sampling effort in all years of study (Table 1) and to relatively low variances of population estimates within years (Fig. 4). Linear regression analysis of log-transformed densities in the shoreline strata, weighted by the inverse of the bootstrap variance, indicated a significant decline over time ($F = 16.40$, $P < 0.0098$, $r^2 = 0.77$), at a rate of -14.4% per year. The decline may have leveled off by 2008 (Fig. 4), and if 2008 data are excluded from analysis, the rate of decline from 1991 to 2003 was 16.2% per year ($F = 19.54$, $P < 0.0115$, $r^2 = 0.83$). Comparison of offshore transects was less robust owing to smaller sample sizes, especially in 1991 and 2008 (Table 1), yet weighted linear regression of log-transformed densities in the offshore stratum indicated a marginally significant decline over time ($F = 5.35$, $P < 0.0686$, $r^2 = 0.52$), at a rate of -10.6% per year. The offshore data also suggest that the decline had leveled off by 2008 (Fig. 4), and, if we exclude the 2008 data, the rate of decline from 1991 to 2003 was 13.8% per year ($F = 5.69$, $P < 0.074$, $r^2 = 0.59$). Weighted linear regression of log-transformed totals for both strata combined indicates a marginally significant decline from 1991 to 2008 in the bay-wide population ($F = 6.44$, $P < 0.0520$, $r^2 = 0.56$), at a rate of -10.7% per year.

DISCUSSION

Population size

Drew *et al.* (2008) analyzed the same 5-year (1999–2003) dataset reported here, stratified into shoreline and offshore estimates, and estimated a population (5-year mean) of 3042 (95% CI 1303) Kittlitz's Murrelets. Our 2008 estimate of 4981 birds (95% CI 1293–8670) was made from data collected using line transect methods, however, and is considered more accurate because it accounts for undetected birds on transect (e.g. Raphael *et al.* 2007, Kirchhoff 2008, Ronconi & Burger 2009). After prorating and including unidentified murrelets, our analysis suggests 5641 Kittlitz's Murrelets occupied Glacier Bay in 2008. This is approximately 1.35 times higher than our estimate from strip transects (Table 2), and similar to the ratio (1.33) of line to strip estimates noted by Kirchhoff (2008) in his study of methods for surveying Kittlitz's Murrelet in Glacier Bay. Our estimate is within the range of unpublished estimates calculated for Kittlitz's Murrelet in Glacier Bay during 2007 (4229, 95% CI 2092–8943; Kirchhoff 2008) and 2009 (5317, 95% CI 2812–6155; Kirchhoff *et al.* 2010), but considerably lower than an unpublished

TABLE 3
Density and population estimates for murrelets in Glacier Bay from a survey conducted on 23–26 June 2008[a,b]

Species	Method	Behavior	Density, birds/km^2 (95% CI)	Coefficient of variation	N (95% CI)	Coefficient of variation
KIMU	Line	On water	3.93 (1.14–6.91)	38.2	4923 (1426–8654)	38.2
	Strip	Flying	0.05 (0–0.18)	103.8	58 (0–220)	103.8
	Combined	On water + Flying	3.98 (1.04–6.92)	37.8	4981 (1293–8670)	37.8
MAMU	Line	On water	8.22 (4.38–14.40)	32.2	10 291 (5487–18 024)	31.0
	Strip	Flying	1.52 (0.45–3.58)	56.2	1904 (565–4482)	56.2
	Combined	On water + Flying	9.74 (4.29–15.19)	28.5	12 195 (5607–18 783)	27.6
BRMU	Line	On water	13.61 (7.00–22.55)	28.5	17 041 (8427–23 221)	24.4
	Strip	Flying	1.92 (0.55–4.54)	53.2	2410 (694–5690)	53.2
	Combined	On water + Flying	15.53 (7.67–23.39)	25.8	19 451 (9605–29 297)	25.8
KIMU	Prorated	On water + Flying			5641	
MAMU	Prorated	On water + Flying			13 810	

[a] Line-transect methods used for birds on the water, strip-transect methods used for flying birds; these were combined to improve the overall accuracy of population estimates.

[b] Estimates stratified by coastal and offshore areas; densities calculated as the mean of stratum estimates weighted by the area of the stratum.

estimate (14 503, SE 1479) from sampling of predominantly high-density areas of the bay during mid-July (Hoekman *et al.* 2011a). All of these recent surveys employed different protocols, sampling designs, sampling efforts and assumptions than ours, and it was beyond the scope of this paper to consider the effects of methodological variations on population estimates. We simply advocate caution in promoting any one population estimate over another and note that the largest number of Kittlitz's Murrelets ever identified positively was in 1991 (n = 883 birds). Despite increasing identification rates, and regardless of effort or protocol, less than a few hundred birds have been identified positively on any survey since 2003. On the whole, however, population estimates suggest that Glacier Bay hosts a relatively large population of Kittlitz's Murrelet, perhaps 20–25% of the total Alaska population (US Fish and Wildlife Service 2010).

Our 2008 estimate of *Brachyramphus* murrelets, although not strictly comparable with historical estimates because we used line transect methods to estimate numbers, was 19 451 (95% CI 9605–29 297)—about 20% higher than the *Brachyramphus* murrelet population (16 178 95% CI 12 851–20 070) estimated in Glacier Bay during 2003 (Piatt *et al.* 2007). Again, this difference is somewhat less than we would expect from the differing efficiencies of line- and strip-transect methods (i.e. we would expect closer to a 35% difference), and therefore suggests that populations have not really changed much between 2003 and 2008. A recent survey found a Marbled Murrelet population of 67 259 (SE 5854) birds in 2010 (Hoekman *et al.* 2011a), but as this effort employed very different protocols and sampling design from all previous efforts, it is unclear how to compare it with earlier estimates (see below).

Our estimates of population size of Kittlitz's Murrelet are conservative. We chose to sample populations in mid- to late June, when murrelet counts are lower than later in the summer but tend to be less variable and also provide the best index of the breeding component of the population (Jones 1992, Speckman *et al.* 2000). Numbers of birds on the water increase in early to mid-July and may rapidly diminish in late July (Bevins 1987, Duncan & Climo 1991, Romano *et al.* 2004, Stephensen 2009). There is presumably large-scale movement of populations during that month. Because the exact timing of movement varies considerably from year to year, it adds uncertainty to the interpretation of counts from one year to the next. While some of the increase in birds on the water in July must represent post-incubating breeding birds, it almost certainly includes significant numbers of nonbreeding and subadult birds that typically return to natal sites during late incubation and increase to a peak during chick-rearing (Jones 1992). It may also include large numbers of daily immigrants that enter and exit Glacier Bay to forage on its rich food supplies (Whitworth *et al.* 2000). For example, Kirchhoff (2008) estimated that one-third of the Marbled Murrelet population during July was actually composed of daily immigrants from outside the bay. For these reasons, and because counts of alcids (including murrelets) are usually less variable during incubation than during chick-rearing and tend to comprise the breeding component of the population (Piatt *et al.* 1990, Jones 1992, Speckman *et al.* 2000, Romano *et al.* 2004, Arimitsu *et al*. 2011), we continue to advocate for monitoring population trends of *Brachyramphus* murrelets in mid-June.

Population trend

For our analysis, we compared data collected using the same protocols and overlapping sample designs in each year. With respect to data collection protocols, we used standardized methods recommended for strip-transect surveys of seabirds (Gould & Forsell 1989, Klowsiewski & Laing 1994, Agler *et al.* 1998). Details are given in Methods, but we emphasize here that all surveys consisted of a multi-species census of all birds (on water and flying) in a strip of pre-defined width by at least two experienced and trained observers who calibrated transect strip boundaries regularly. With respect to sample design, we collected most data at the same time each year (mid- to late June) and always sampled the shoreline of Glacier Bay. The offshore habitat was sampled opportunistically and less extensively in 1991 compared with systematic sampling in subsequent years, creating the only significant discrepancy in overall survey design among years. In our analysis, we compensated for that discrepancy with a separate analysis of shoreline and offshore data, use of bootstrapping methods to analyze variance in population estimates, and use of variance-weighted regression to evaluate trends.

Given these considerations and the data at hand, we are confident that Kittlitz's Murrelet numbers in Glacier Bay declined by 85-90% between 1991 and 2008. This corroborates an earlier analysis of spatially matched shoreline transects conducted in 1991 versus 1999/2000, which indicated that the population had declined by 83% over that time period (Drew & Piatt 2008). While we fitted a linear model to the log-transformed data (Fig. 4), this actually represents a curvilinear decrease in population size over time and implies a constant rate of decline, through at least the mid-2000s. It is possible that declines actually occurred more rapidly over one or a few years in the 1990s, but our data did not permit us to test other models.

Statistically, we found a highly significant and negative linear trend (-14.4% per year in log-transformed population data) in the

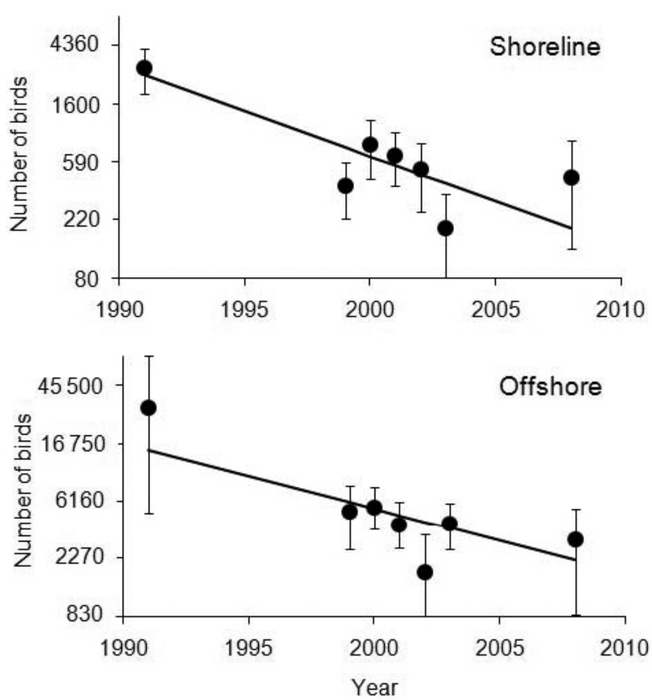

Fig. 4. Population size (±95% CI) and trend of Kittlitz's Murrelets in shoreline habitat (upper graph) and offshore habitat (lower graph) of Glacier Bay, Alaska, between 1991 and 2008. Line is best-fit regression of data weighted by the inverse of the estimated variance.

most comparable data obtained in shoreline habitat (Fig. 4), and a marginally significant and negative linear trend (-10.6% per year) in data from offshore habitat. These results are consistent with prior analysis of trends in *Brachyramphus* murrelet populations in Glacier Bay from 1991 to 2003 (-11.8% per year) and a wholly separate trend analysis of 12 surveys conducted in nearby Icy Strait (Fig. 1) between 1993 and 2003, which revealed a 70% decline in murrelet populations at a rate of -12.7% per year (Piatt *et al*. 2007).

It appears that Kittlitz's Murrelet declines leveled off after 2002–2003 in both habitats, but this can only be confirmed with further surveys. There is evidence that some Marbled Murrelet population declines elsewhere in Alaska and British Columbia also leveled off in the mid-2000s, perhaps in response to climate-related physical changes (e.g. winds, temperatures) that may have pervasive biological effects on marine forage fish and the higher predators that feed on them (Springer *et al*. 2007, Arimitsu *et al*. 2008, Womble *et al*. 2010).

We recognize that our conclusions about population trend rest heavily on one year of the survey data (1991) that show much greater Kittlitz's Murrelet densities than in all subsequent years. We do not believe there was any bias in the survey protocols used in 1991 that could have led to systematic over-counting of birds and mammals (e.g. from errors in estimating transect width, distance from shore or estimating group size). If there were, we should have found that densities of all marine species in 1991 were about 10-fold greater than in the 2000s. On the contrary, of more than 30 common species of birds and mammals observed on surveys in Glacier Bay, only Kittlitz's and Marbled murrelets and Harbor Seals *Phoca vitulina* exhibited significant declines, while a few other taxa (e.g. Sea Otter *Enhydra lutris*, Humpback Whale *Megaptera novaeangliae*) increased (Robards *et al.* 2003, Piatt *et al.* 2007, Drew *et al.* 2008). The magnitude of changes that we detected in populations of these taxa have been corroborated by independent studies (Esslinger & Bodkin 2009, Womble *et al.* 2010), which increases confidence that our survey accurately reflects population trends of murrelets. Alternatively, Kittlitz's Murrelet populations could have been extraordinarily high in 1991 because of massive immigration. Because we know of no precedent for such an influx, nor any population source for such a large number of murrelets, we view this as a weak alternative hypothesis.

We did not include a few surveys conducted by other investigators in our trend analysis. Lindell (2005) conducted ship-based surveys in offshore waters of Glacier Bay during June 1993. He used standardized protocols (Gould & Forsell 1989) for conducting surveys, and we previously included his counts in an analysis of population trends of *Brachyramphus* murrelets in Glacier Bay (Piatt *et al.* 2007). Although his data are useful for evaluating the *Brachyramphus* genus, we are at a loss to interpret his data on *Brachyramphus* murrelets identified to the species level. He reported 0% unidentified murrelets on his survey, and this seems an improbable result. In seven surveys, our teams of experienced and trained observers regularly could not identify ~30% of murrelets to species (Table 1). Kirchhoff *et al.* (2010) reported that the protocol used by Lindell (2005) in 1993 required observers to identify all murrelets to species using their best judgment in the field, which likely led observers to place uncertain identifications more frequently into the more common Marbled Murrelet category (Kirchhoff *et al*. 2010). Of all murrelets identified in offshore waters on our surveys, 24.6% (SD 6.4%) were Kittlitz's Murrelet, whereas Lindell (2005) reported that Kittlitz's Murrelets comprised only 7.2% of murrelet observations. Again, this is well outside expected levels of variability, and therefore we chose not to include the Lindell data in our trend analysis. Including his results would not have changed the conclusion that Kittlitz's Murrelets had declined by about 85-90% in Glacier Bay between 1991 and 2008, but would have suggested that the decline had occurred more rapidly in the early 1990s.

We also chose not to include offshore surveys conducted in 2007 (Kirchhoff 2008) and 2009 (Kirchhoff *et al.* 2010). Both surveys were done in July, sampled offshore waters primarily, and targeted *Brachyramphus* murrelets only. All else being equal, these protocols would generate higher population estimates than ours (Kirchhoff 2008, Kirchhoff *et al.* 2010). Similarly, the *Brachyramphus* survey conducted in 2010 by Hoekman *et al.* (2011a) employed very different protocols and sampling design than any previous survey, and was conducted in mid-July. As those authors stressed, "effects of differences in methods on abundance estimates cannot be fully resolved." We agree, and we therefore opted to exclude the 2010 surveys from our analysis of population trend.

Are the reported trends plausible?

The magnitude and rate of declines for Kittlitz's Murrelet in Glacier Bay are not unusual compared to the range observed in other seabirds in Alaska (Dragoo *et al.* 2006) nor beyond the range predicted for the Marbled Murrelet in Alaska (Piatt *et al.* 2007). In Glacier Bay and elsewhere in Alaska and British Columbia, populations of *Brachyramphus* (mostly Marbled) murrelets may have declined by 70% during the past few decades (Piatt *et al.* 2007). There have been parallel changes in marine mammal populations as well, including a rapid decline in stocks of Steller Sea Lions *Eumetopias jubatus* (-16% per year in 1980s and 1990s) and Harbor Seals (-7% per year during 1980s and early 1990s) in parts of the Gulf of Alaska and Bering Sea (Springer *et al.* 2007). In Glacier Bay, Harbor Seals declined by more than 60% during the 1990s (Mathews & Pendleton 2006). In fact, the seals' decline mirrors that of Kittlitz's Murrelet in Glacier Bay, amounting to -12.4% per year on terrestrial haul-outs since the early 1990s (Womble *et al.* 2010).

All such population changes are unlikely to be tied to any one factor, but whatever the cause or causes, they illustrate that rapid, large-scale population changes in higher marine vertebrates *do* occur. There is vigorous debate and widespread disagreement about how these wildlife populations are regulated in Alaska (Springer *et al.* 2007). A number of human activities are known to have a negative influence on Kittlitz's Murrelet populations, including bycatch of birds in fishing gear, oil pollution, competition from commercial fisheries and vessel disturbance (Kuletz *et al.* 2003, US Fish and Wildlife Service 2010). To the extent we are describing trends of resident, breeding birds in Glacier Bay, however, there is little evidence that any of those factors have a strong influence on birds in summer (Piatt *et al.* 2007, Agness *et al.* 2008).

Several natural factors could be having direct or indirect negative effects on murrelets. These include predation, glacial retreat, climate change and its effect on marine food supplies, and competition for food. We have little quantitative data with which to assess the numerical impact of predation on Kittlitz's Murrelet, but it is a pervasive source of adult mortality in Icy Bay (M. Kissling, unpublished data) and could be an important factor in regulating the population (Sinclair *et al.* 1998, Parrish *et al.* 2001). Rapid glacial recession and reduction in the number of tidewater glaciers in Glacier Bay during recent decades could have led to a direct reduction of icy foraging/breeding habitat used by seals and murrelets during summer (Mathews & Pendleton 2006, Kuletz *et al.* 2003), or an indirect effect on all marine predators by altering the availability of cold-water forage species (Arimitsu *et al.* 2008). A major climate regime shift in the North Pacific during the late 1970s altered marine fish communities dramatically in the Gulf of Alaska, and this was reflected in widespread changes in diets of murrelets and other seabirds (Francis *et al.* 1998, Anderson & Piatt 1999). Compounding this problem, populations of Humpback Whales and Steller Sea Lions in Glacier Bay increased dramatically (55% and 485%, respectively) during this same period, and it appears those species may be competing with Harbor Seals and murrelets for shared prey resources (Womble *et al.* 2010). Continued surveys of the marine predator community in Glacier Bay are needed to assess Kittlitz's Murrelet populations in respect to glacial recession, marine climate change and associated fluctuations in food supply and competing predators.

ACKNOWLEDGEMENTS

Most of the survey work presented was funded by the US Geological Survey (Natural Resources Preservation Program), USGS Alaska Science Center, and Glacier Bay National Park. Thanks to all Park staff for their support over the years, in particular Lisa Climo, Mary Beth Moss, Mary Kralovec, Rusty Yerxa and Lewis Sharman, who provided advice, encouragement and logistic support. We sincerely thank boat captains Jim de la Bruere, Greg Snedgen and Justin Smith for long hours at the helm, as well as for aiding with logistics and research aboard the *Alaskan Gyre, David Grey,* and *Capelin*. We acknowledge the crew of the RV *Pandalus*, who crossed the Gulf of Alaska from Homer to aid in research during 1999. Numerous people assisted in our field efforts, including Alisa Abookire, Alison Agness, Brenda Ballachey, Tim Bowden, Beth Brindle, Chola Dick, Janene Driscoll, Dan Esler, George Esslinger, Patricia Gaines, Jennifer De Groot, Philip and Elizabeth Hooge, Kim Kloecker, Kathy Kuletz, Mike Litzow, Aileen Miller, Jennifer Mondragon, Dan Monson, Jon Schroeder, Martin Schultz, Emily Scott, Chad Soiseth, Suzann Speckman and Jim Taggart. We are grateful to Shay Howlin of WEST Inc., for assistance with statistical analyses of trend data. This manuscript benefited greatly from reviews by Laura MacFarlane-Tranquilla, Joel Reynolds and Michelle Kissling. Any use of trade, product or firm names in this publication is for descriptive purposes only and does not imply endorsement by the US government.

REFERENCES

AGLER, B.A., KENDALL, S.J. & IRONS, D.B. 1998. Abundance and distribution of Marbled and Kittlitz's murrelets in southcentral and Southeast Alaska. *Condor* 100: 254-265.

AGNESS, A.M., PIATT, J.F., HA, J.C. & VAN BLARICOM, G.R. 2008. Effects of vessel activity on the near-shore ecology of Kittlitz's Murrelets *(Brachyramphus brevirostris)* in Glacier Bay, Alaska. *Auk* 125: 346-353.

ANDERSON, P.J. & PIATT, J.F. 1999. Community reorganization in the Gulf of Alaska following ocean climate regime shift. *Marine Ecology Progress Series* 189: 117-123.

ARIMITSU, M.L., PIATT, J.F., LITZOW, M.A., ABOOKIRE, A.A., ROMANO, M.D. & ROBARDS, M.D. 2008. Distribution and spawning dynamics of capelin (*Mallotus villosus*) in Glacier Bay, Alaska: a cold water refugium. *Fisheries Oceanography* 17: 137-146.

ARIMITSU, M.L., PIATT, J.F., ROMANO, M.D. & VAN PELT, T.I. 2011. Status and distribution of the Kittlitz's Murrelet *Brachyramphus brevirostris* in Kenai Fjords, Alaska. *Marine Ornithology* 39: 13–22.

BAILEY, A.M. 1927. Notes on the birds of southeastern Alaska. *Auk* 44: 1-23.

BEVINS, J. 1987. Beardslee Island bird and mammal baseline survey [unpublished report]. Gustavus, AK: National Park Service, Glacier Bay National Park and Preserve.

BUCKLAND, S.T., ANDERSON, D.R., BURNHAM, K.P., LAAKE, J.L., BORCHERS, D.L. & THOMAS, L.J. 2001. Introduction to distance sampling: estimating abundance of biological populations. Oxford: Oxford University Press.

CALAMBOKIDIS, J. & BARLOW, J. 2004. Abundance of blue and humpback whales in the eastern North Pacific estimated by capture-recapture and line-transect methods. *Marine Mammal Science* 20: 63-85.

COCHRAN, W.G. 1977. Sampling techniques. New York: John Wiley and Sons.

DRAGOO, D.E., BYRD, G.V. & IRONS, D.B. 2006. Breeding status, population trends and diets of seabirds in Alaska, 2003 [unpublished report]. Homer, AK: US Fish and Wildlife Service.

DREW, G.S. & PIATT, J.F. 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. *Auk* 125: 178-182.

DREW, G.S., SPECKMAN, S., PIATT, J.F., BURGOS, J.M. & BODKIN, J.L. 2008. Survey design considerations for monitoring marine predator populations in Glacier Bay, Alaska: results and post-hoc analyses of surveys conducted in 1999-2003 [unpublished report]. Reston, VA: US Geological Survey.

DUNCAN T. & CLIMO, L. 1991. Beardslee Island bird and mammal survey [unpublished report]. Gustavus, AK: National Park Service, Glacier Bay National Park.

ESSLINGER, G.G. & BODKIN, J.L. 2009. Status and trends of sea otter populations in Southeast Alaska, 1969-2003. Scientific Investigations Report 2009-5045. Anchorage, AK: US Geological Survey.

ETHERINGTON, L.L., HOOGE, P.N., HOOGE, E.R. & HILL, D.F. 2007. Oceanography of Glacier Bay, Alaska: implications for biological patterns in a glacial fjord estuary. *Estuaries and Coasts* 30: 927-944.

FRANCIS, R.C., HARE, S.R., HOLLOWED, A.B. & WOOSTER, W.S. 1998. Effects of interdecadal climate variability on the oceanic ecosystems of the NE Pacific. *Fisheries Oceanography* 7: 1-21.

GABRIELSON, I.N. & LINCOLN, F.C. 1959. The birds of Alaska. Pennsylvania, PA, & Washington, DC: Stackpole Company & Wildlife Management Institute.

GERRODETTE, T. & FORCADA, J. 2005. Non-recovery of two spotted and spinner dolphin populations in the eastern tropical Pacific Ocean. *Marine Ecology Progress Series* 291: 1-21.

GOULD, P.J. & FORSELL, D.J. 1989. Techniques for shipboard surveys of marine birds. Technical Report 25. Washington, DC: US Fish and Wildlife Service.

GRINELL, J.G. 1910. Birds and mammals of the 1907 Alexander expedition to southeastern Alaska. *University of California Publications in Zoology* 5: 171-264.

HILL, D.F., CIAVOLA, S.J., ETHERINGTON, L.L. & KLAAR, M.J. 2009. Estimation of freshwater runoff into Glacier Bay, Alaska and incorporation into a tidal circulation model. *Estuarine and Coastal Shelf Science* 82: 95-107.

HOEKMAN, S.T., MOYNAHAN, B.J. & LINDBERG, M.S. 2011a. Monitoring Kittlitz's Murrelets in Glacier Bay National Park: 2010 annual report. Natural Resource Technical Report NPS/SEAN/NRTR—2011/441. Fort Collins, CO: National Park Service.

HOEKMAN, S.T., MOYNAHAN, B.J., LINDBERG, M.S., SHARMAN, L.S. & JOHNSON, W.F. 2011b. Line transect surveys for murrelets: accounting for incomplete detection and identification. *Marine Ornithology* 39: 35–44.

JONES, I.L. 1992. Colony attendance of Least Auklets at St. Paul Island, Alaska: implications for population monitoring. *Condor* 94: 93-100.

KIRCHHOFF, M.D. 2008. Methodological considerations for at-sea monitoring of *Brachyramphus* murrelets in Glacier Bay, Alaska [unpublished report]. Douglas, AK: Alaska Department of Fish and Game.

KIRCHHOFF, M.D., SMITH, M. & WRIGHT, S. 2010. Abundance, population trend, and distribution of Marbled Murrelets and Kittlitz's Murrelets in Glacier Bay National Park [unpublished report]. Anchorage, AK: Audubon Alaska.

KLOSIEWSKI, S.P. & LAING, K.K. 1994. Marine bird populations of Prince William Sound, Alaska, before and after the *Exxon Valdez* oil spill. Natural Resource and Damage Assessment Bird Study No. 2. Anchorage, AK: US Fish and Wildlife Service.

KULETZ, K.J., STEPHENSEN, S.W., IRONS, D.B., LABUNSKI, E.A. & BRENNEMAN, K.M. 2003. Changes in distribution and abundance of Kittlitz's Murrelets (*Brachyramphus brevirostris*) relative to glacial recession in Prince William Sound, Alaska. *Marine Ornithology* 31: 133-140.

LARSEN, C.F., MOTYKA, R.J., FREYMUELLER, J.T., ECHELMEYER, K.A. & IRVINS, E.R. 2005. Rapid viscoelastic uplift in Southeast Alaska caused by post-Little Ice Age glacial retreat. *Earth and Planetary Science Letters* 237: 548-560.

LINDELL, J.R. 2005. Results of at-sea *Brachyramphus* murrelet surveys in Icy Strait and other selected areas of Southeast Alaska, 1993-1999 [unpublished report]. Juneau, AK: US Fish and Wildlife Service.

LUKACS, P.M., KISSLING, M.L., REID, M., GENDE, S.M. & LEWIS, S.B. 2010. Testing assumptions of distance sampling of a pelagic seabird. *Condor* 112: 455-459.

MANLY, B.F.J. 2007. Randomization, bootstrap and Monte Carlo methods in biology, third edition. Boca Raton, FL: Chapman and Hall/CRC.

MATHEWS, E.A. & PENDLETON, G.W. 2006. Declines in harbor seal (*Phoca vitulina*) numbers in Glacier Bay National Park, Alaska 1992-2002. *Marine Mammal Science* 22: 167-189.

PARRISH, J.K., MARVIER, M. & PAINE, R.T. 2001. Direct and indirect effects: interactions between Bald Eagles and Common Murres. *Ecological Applications* 11: 1858-1869.

PIATT, J.F., KULETZ, K.J., BURGER, A.E., HATCH, S.A., FRIESEN, V.L., BIRT, T.P., ARIMITSU, M.L., DREW, G.S., HARDING, A.M.A. & BIXLER, K.S. 2007. Status review of the Marbled Murrelet (*Brachyramphus marmoratus*) in Alaska and British Columbia. Open File Report 2006–1387. Reston, VA: US Geological Survey.

PIATT, J.F., ROBERTS, B.D. & HATCH, S.A. 1990. Colony attendance and population monitoring of Least and Crested auklets on St. Lawrence Island, Alaska. *Condor* 92: 109-116.

RAPHAEL, M.G., BALDWIN, J., FALXA, G.A., HUFF, M.H., LANCE, M., MILLER, S.L., PEARSON, S.F., RALPH, C.J., STRONG, C. & THOMPSON, C. 2007. Regional population monitoring of the Marbled Murrelet: field and analytical methods. General Technical Report PNW-GTR-716. Portland, OR: US Forest Service.

ROBARDS, M., DREW, G.S., PIATT, J.F., ANSON, J.M., ABOOKIRE, A., BODKIN, J.L., HOOGE, P. & SPECKMAN, S. 2003. Ecology of selected marine communities in Glacier Bay: zooplankton, forage fish, seabirds, and marine mammals [unpublished report]. Anchorage, AK: US Geological Survey.

ROMANO, M.D., ARIMITSU, M.L., PIATT, J.F., AGNESS, A.M. & DREW, G.S. 2004. At-sea density and distribution of Kittlitz's Murrelets (*Brachyramphus brevirostris*) and Marbled Murrelets (*Brachyramphus marmoratus*) in Glacier Bay, Alaska, summer 2003 [unpublished report]. Anchorage, AK: US Geological Survey.

RONCONI, R.A. & BURGER, A.E. 2009. Estimating seabird densities from vessel transects: distance sampling and implications for strip transects. *Aquatic Biology* 4: 297-309.

SINCLAIR, A.R.E., PECH, R.P., DICKMAN, C.R., HIK, D., MAHON, P. & NEWSOME, A.E. 1998. Predicting effects of predation on conservation of endangered prey. *Conservation Biology* 12: 564-575.

SOKAL, R.R. & ROHLF, F.J. 1981. Biometry. New York: W.H. Freeman.

SPECKMAN, S.G., SPRINGER, A.M., PIATT, J.F. & THOMAS, D.L. 2000. Temporal variability in abundance of Marbled Murrelets at sea in Southeast Alaska. *Waterbirds* 23: 364-377.

SPRINGER, A.M., IVERSON, S.J. & BODKIN, J.L. 2007. Long-term change: marine mammal populations. In: Spies, R. (Ed). Long-term ecological change in the Gulf of Alaska. Amsterdam: Elsevier Press. pp. 352-378.

STEPHENSEN, S.W. 2009. Habitat selection by Kittlitz's and Marbled murrelets in Harriman Fjord, Prince William Sound, Alaska [M.S. thesis]. Anchorage, AK: University of Alaska Anchorage.

TASKER, M.L., JONES, P.H., DIXON, T. & BLAKE, B.F. 1984. Counting seabirds at sea from ships: a review of methods employed and a suggestion for a standardized approach. *Auk* 101: 567-577.

THOMAS, L.T., BUCKLAND, S.T., REXSTAD, E.A., LAAKE, J.L., STRINDBERG, S., HEDLEY, S.L., BISHOP, J.R.B., MARQUES, T.A. & BURNHAM, K.P. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology* 47: 5-14.

US FISH AND WILDLIFE SERVICE. 2010. Status assessment and listing priority assignment form for Kittlitz's Murrelet. Anchorage, AK: US Fish and Wildlife Service.

WHITWORTH, D.L., NELSON, S.K., NEWMAN, S.H., VAN VLIET, G.B. & SMITH, W.P. 2000. Foraging distances of radio-marked Marbled Murrelets from inland areas in Southeast Alaska. *Condor* 102: 452-456.

WIK, D. & STREVELER, G.P. 1967. Birds of Glacier Bay National Monument [unpublished report]. Glacier Bay, AK: National Park Service.

WOMBLE, J.N., PENDLETON, G.W., MATHEWS, E.A., BLUNDELL, G.M., BOOL, N.M. & GENDE, S.M. 2010. Harbor seal (*Phoca vitulina richardii*) decline continues in the rapidly changing landscape of Glacier Bay National Park, Alaska 1992-2008. *Marine Mammal Science* 26: 686-697.