DISTRIBUTION, POPULATION STATUS AND TRENDS OF KITTLITZ'S MURRELET *BRACHYRAMPHUS BREVIROSTRIS* IN LOWER COOK INLET AND KACHEMAK BAY, ALASKA

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SUMMARY

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Lower Cook Inlet (LCI) in south-central Alaska is unusual among the breeding areas of Kittlitz's Murrelet *Brachyramphus brevirostris* because of human impacts on the marine and terrestrial environments and because of the lack of tidewater glaciers. In LCI the Kittlitz's Murrelet co-exists with the more abundant Marbled Murrelet, which complicates abundance estimates because of the difficulty of species identification. We compared survey data for an area with overlapping coverage in LCI (Core area) in 1993 (June) and from 1996 to 1999 (July–early August). Within this LCI Core area, the surveys in 1996–1999 estimated ~1600 Kittlitz's Murrelets and ~17 000 Marbled Murrelets, including prorated unidentified murrelets. The Kittlitz's Murrelet population declined between 1993 and 1999 at 26% per annum (84% overall). Simultaneously, Marbled Murrelets declined by 12% per annum (56% overall), though the decline was not statistically significant. Declines were estimated conservatively because the 1993 survey was conducted in June, when both murrelet species are less abundant on the water. We also surveyed Kachemak Bay, a large embayment of LCI, during mid-summer (July) of 2005–2007 and estimated a population of 2047 Kittlitz's Murrelets (SD 1120, n = 3 years) residing primarily in the inner bay. Marbled Murrelets numbered 11 040 (SD 1306) and were found throughout the bay. On one transect set in inner Kachemak Bay, Kittlitz's Murrelet density in late summer (1–16 August) declined 7.5% per annum between 1988 and 2007 (n = 6 years), and Marbled Murrelet density increased 4.9% per annum. On two other transect sets in the inner bay, however, neither murrelet species showed a change in density between 1996 and 2007. Inner Kachemak Bay is a persistent hotspot for Kittlitz's Murrelet and may attract murrelets from LCI and beyond. We recommend monitoring murrelet populations in Kachemak Bay, although Kittlitz's Murrelets likely move between the main body of Cook Inlet and Kachemak Bay, and a complete LCI survey is needed to gauge regional population trends.

Key words: Kittlitz's Murrelet, *Brachyramphus brevirostris*, Marbled Murrelet, *Brachyramphus marmoratus*, Kachemak Bay, Lower Cook Inlet, habitat use, status and trends

INTRODUCTION

The Kittlitz's Murrelet *Brachyramphus brevirostris*, a relatively rare member of the family Alcidae, is found only in coastal Alaska and the Russian Far East. It is a diving seabird that feeds on fish, small crustacea and macrozooplankton. During the breeding season, Kittlitz's Murrelets tend to forage in waters with glacial outflow (Day *et al*. 1999). Consequently, they are found along the coastal areas of the northern Gulf of Alaska (GOA), where most of North America's coastal glaciers occur (Arendt *et al*. 2002). Throughout most of its range, the Kittlitz's Murrelet co-exists with the closely related and morphologically similar Marbled Murrelet *B. marmoratus*, a species that is declining in parts of Alaska (Piatt *et al*. 2007). Because of evidence of similar declines since the 1970s and 1980s, the Kittlitz's Murrelet became a candidate species for listing under the US *Endangered Species Act* in May 2004 (US Fish and Wildlife Service 2010). However, Kittlitz's and Marbled murrelets can be difficult to distinguish at sea. Some of the historical survey data has a high proportion of birds identified only to the *Brachyramphus* genus, which has complicated trend estimation and interpretation for both murrelet species, particularly the less common Kittlitz's Murrelet.

During the breeding season, Kittlitz's Murrelets are typically found in remote areas, often with floating brash ice, which are difficult to access. In contrast, Lower Cook Inlet (LCI), and adjacent Kachemak Bay (Kendall & Agler 1998), receive high levels of glacial outflow but do not have tidewater glaciers or floating ice in summer. Among all regions in Alaska where Kittlitz's Murrelets are found during the breeding season, Cook Inlet has the highest level of human activity. Most of Alaska's human population lives in the Cook Inlet drainage, and the region supports resource extraction, shipping and commercial fishing. These human activities overlay a background of long-term ecological change in the GOA (Piatt & Anderson 1996, Anderson & Piatt 1999, Litzow 2006).

In 1993, Agler *et al*. (1998) conducted the first comprehensive survey for *Brachyramphus* murrelets in LCI and identified this area as a major population center for both murrelet species. During that June survey, the estimated *Brachyramphus* murrelet population of LCI was ~58 000 birds, with a minimum of 3353 (CI = 1635–5071) identified Kittlitz's Murrelets. However, species identification rates were low; if unidentified *Brachyramphus* murrelets (hereafter unidentified murrelets) were apportioned based on the ratio of identified Kittlitz's to Marbled murrelets, up to 12 000 Kittlitz's Murrelets might have been in LCI during that survey (Kendall & Agler 1998). In addition to the 1993 survey, Piatt (2002) surveyed LCI between 1996 and 1999 as part of a seabird-fisheries study and, on a smaller scale and sometimes concurrently, Kachemak Bay was surveyed for seabirds in 1988–1990 (Kuletz 1996), 1996–1999 (Piatt 2002) and 2004–2007 (Kuletz *et al.* 2008).

In this paper, we summarize available data on the summer distribution and abundance of Kittlitz's Murrelet in LCI and Kachemak Bay. We examine trends of Kittlitz's and Marbled murrelets and all *Brachyramphus* murrelets combined (including unidentified birds) over two decades in portions of LCI and Kachemak Bay where comparable surveys were conducted.

STUDY AREA

Lower Cook Inlet

Cook Inlet is a large tidal estuary ~290 km long and 50–100 km wide, draining a watershed of ~100 000 km^2. Bathymetry is mainly shallow (<50 m), although the main channel deepens to 70–100 m. The inlet separates the Alaska Peninsula and the Kenai Peninsula in south-central Alaska (Fig. 1), and, although it does not have tidewater glaciers, the inlet is strongly influenced by drainage of four major rivers at its head and runoff from land-locked glaciers. The southern half of the inlet exchanges water with the GOA via the Alaska Coastal Current (ACC) flowing north along the eastern side of the inlet, while fresher, warmer, and more turbid water flows south along the west side (Burbank 1977, Speckman *et al. 2005).*

Kachemak Bay

Kachemak Bay is a tidal estuary at the southeastern entrance of Cook Inlet (Fig. 1) measuring ~80 km long and ~40 km wide at its mouth. Upwelled water from the GOA reaches the southern entrance of the bay via the ACC. Maximum tide range is 8 m (Schoch & Chenelot 2004). The bay is divided into two basins, referred to as the inner and outer bays, roughly separated by the 6 km long Homer Spit extending from the northern shore (Fig. 2). The outer bay is more directly influenced by the mixing of cold, saline waters from the LCI and ACC water entering from the south, and, relative to the inner bay, is characterized in summer by waters that are well-mixed, cold, saline and clear. The inner bay is characterized by higher surface water temperatures, low salinity, stratification and high turbidity (Schoch & Chenelot 2004, Speckman *et al.* 2005). The origins of the fresher, turbid waters on the surface are melting snow pack and glacial runoff from steep mountains along the southern shore as well as river runoff from the Fox River Delta at the bay head, flowing westward along low bluffs of the northern shore. Ten-year average monthly bottom water temperatures on the southern shore of the bay ranged from winter lows of 1.1 °C to summer highs of 12.1 °C (Okkonen *et al.* 2007). During our surveys in 2004–2007, sea surface temperatures (SST) ranged from 4.7 °C in April to 16.4 °C in August (Kuletz *et al.* 2008).

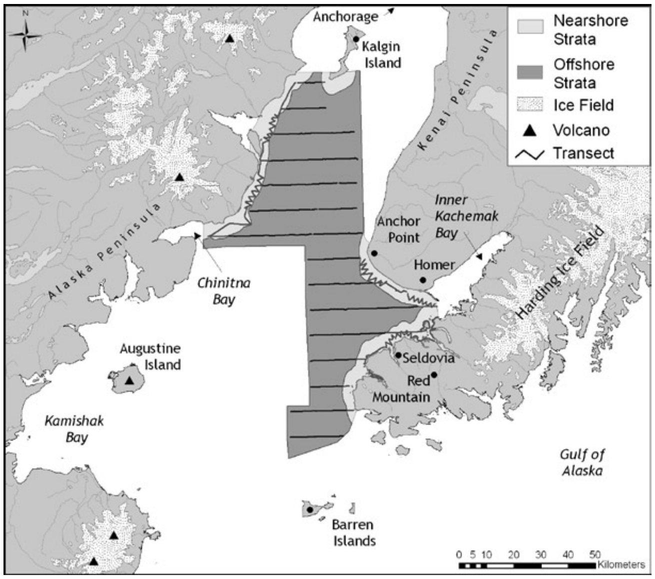


Fig. 1. Lower Cook Inlet Core study area, Alaska, showing overlapping coverage used to examine survey data for *Brachyramphus* murrelets collected from 1993 to 1999. Light gray designates the nearshore stratum; dark gray designates the offshore stratum. Transect lines (black) are those used during 1996–1999 surveys.

METHODS

Surveys in LCI and Kachemak Bay varied in design and used different terms for habitat strata and types of transects. In this paper, we distilled those terms into "shoreline" (≤0.2 km from shore), "nearshore" (0.2–6.0 km from shore) and "offshore" (>6.0 km from shore) strata. While we include the shoreline stratum in a murrelet distribution map (Fig. 3), we do not include it in estimation of population size or trend of Kittlitz's Murrelet because there was no comparable stratum in the 1996–1999 surveys.

Lower Cook Inlet

Sampling design and protocol

The 1993 comprehensive survey of LCI was conducted on 7–23 June (Agler *et al.* 1998). The LCI surveys in 1996–1999 were conducted during July and August (Table 1). In 1993 the study area

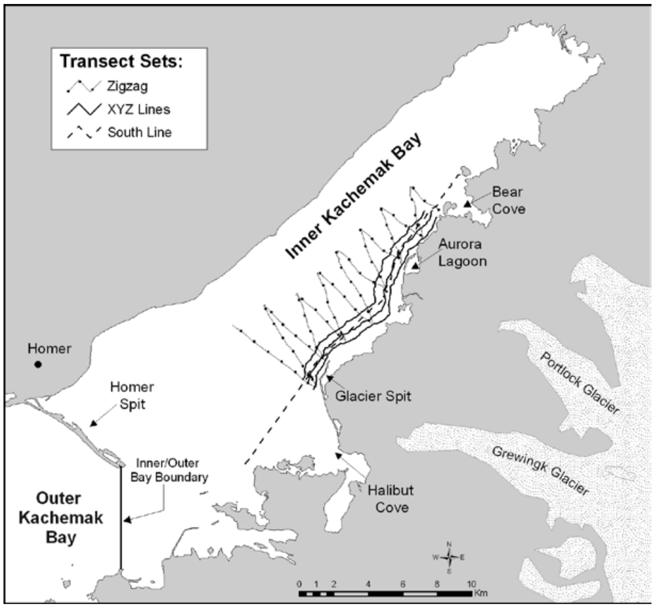


Fig. 2. Inner Kachemak Bay study area, Alaska, surveyed for Kittlitz's Murrelets in late summer (July 25–August 18) between 1988 and 2007. Three transect sets (examined independently for trends) are shown.

was divided into 3.7 km long blocks by latitude and longitude, and 411 transects were randomly selected. In blocks that intersected the shoreline (shoreline stratum), one transect paralleled that portion of shoreline (≤0.2 km from shore) that fell within the block. In blocks that did not touch shore, one edge of each block (usually the north-south edge) served as a transect in the offshore stratum. Length of transects averaged 4.3 km for shoreline and 3.5 km for offshore transects (Fig. 3; see Agler *et al*. 1995 for details).

The 1996–1999 surveys of LCI included marine waters on the southeastern side of the inlet extending to the Barren Islands (Figs. 1, 4). The nearshore stratum was based roughly on the bathymetric contours of LCI with waters typically <10 m deep, sometimes accessible only to smaller vessels (≤11 m in length), depending on tides. Nearshore transects followed the shoreline at approximately the 10 m depth contour and included zigzags extending up to 6 km from shore (Fig. 1). Depth in the offshore stratum was typically >10 m, making it accessible to larger vessels (≥11 m in length). Offshore transects were systematically spaced at ~9 km intervals, running east-west across the inlet.

All LCI surveys followed standard strip-transect survey methodology (Gould & Forsell 1989, Klosiewski & Laing 1994) with some differences in platform and protocol (Table 1). Three 8 m boats, each with two observers and one driver, were used in the 1993 surveys (Agler *et al*. 1995). In 1996–1999, a single vessel, ranging from 11 m (for shallow waters) to 36 m, was employed at any one time, with two observers and one driver. Vessels traveled at 10–15 km/hr (6–8 knots), and observers scanned each side and ahead of the vessel, with transect width dependent on vessel size and platform height (Table 1). Observers used binoculars for species identification, and all birds and mammals within the transect boundaries were recorded, including bird behavior (on water, flying) and plumage classes (e.g. hatch-year birds). *Brachyramphus* murrelets were either identified to species or recorded as unidentified murrelets. We did not conduct surveys from 8 m vessels when wave height was >0.6 m or from larger vessels when wave height was >1.0 m. In 1993, observers counted flying birds continuously, whereas in 1996–1999, observers used instantaneous scans to count flying birds (Gould & Forsell 1989). Because of this difference, we omitted flying birds from population estimates and trend analyses.

Data analysis

In estimating trends of Kittlitz's and Marbled murrelets in LCI, our primary concern was whether there had been a decline in population. A conservative approach was to compare densities of murrelets in June 1993 surveys to densities in July–early August on the 1996–1999 surveys. *Brachyramphus* murrelets are typically found at sea in much lower densities in June than in July and early August (Kuletz & Kendall 1998, Speckman *et al*. 2004, Kuletz *et al*. 2008), presumably because many birds are incubating eggs and because nonbreeders are absent during early summer. Hence, our trend estimates of Kittlitz's and Marbled murrelets in LCI should be interpreted as minimum changes in population size. To render data sets spatially consistent between 1993 and 1996–1999, we used ArcGIS (v9.1, ESRI, Inc., Redlands, California) to overlay all years of sampling effort, and we defined the boundaries of shared sampling in all five years (hereafter referred to as the LCI Core; Fig. 1). We then extracted transects from each survey year that fell within those boundaries. The LCI Core covers 4813 km^2, primarily in the northwestern and southeastern regions of LCI (Fig. 1).

Within the LCI Core, we defined the nearshore stratum as 0.2–6.0 km from shore, based on the extent of the zigzag transects (Fig. 1), and we used ArcGIS to identify other transects or transect segments within this stratum. Transects surveyed in 1993 (Fig. 3) that intersected both strata could not be split between nearshore and offshore strata because observations along a transect were not geo-referenced; we therefore

TABLE 1

Survey effort, densities and proportion of identified *Brachyramphus* murrelets during at-sea surveys of the Lower Cook Inlet Core area, Alaska, 1993–1999[a]

Year	Dates	Survey coverage		Platform height, m	Transect strip width, m	Density (SE), birds/km^2		Total Core Area		Proportion of identified birds, %	
		Stratum	Distance, km			KIMU[b]	MAMU[b]	Total count	% identified to species	KIMU	MAMU
1993	7–23 June	Nearshore	122	0.5	200	0.60 (0.50)	4.18 (0.25)	680	18	36	64
		Offshore	346	0.5	200	1.16 (0.03)	6.97 (0.13)			26	74
1996	14–31 July	Nearshore	299	3.4	200	0.03 (0.01)	0.93 (0.05)	362	62	4	96
		Offshore	324	8.5	300	0.65 (0.04)	2.42 (0.16)			21	79
1997	19 July–8 Aug	Nearshore	313	2.4	300	0.29 (0.04)	5.96 (0.58)	1048	73	5	95
		Offshore	390	3.4	300	0.43 (0.06)	3.50 (0.29)			11	89
1998	21 July–12 Aug	Nearshore	330	2.4	300	0.04 (0.01)	5.77 (0.36)	979	88	1	99
		Offshore	388	3.4	300	0.26 (0.05)	3.20 (0.23)			8	92
1999	25 July–16 Aug	Nearshore	331	2.4	300	0.16 (0.02)	5.81 (0.57)	864	86	3	97
		Offshore	393	3.4	300	0.18 (0.02)	2.11 (0.19)			8	92

[a] Density estimates include prorated unidentified murrelets.

[b] KIMU = Kittlitz's Murrelets; MAMU = Marbled Murrelets.

included 1993 transects that lay >50% within 6.0 km of shore as part of the nearshore stratum. For surveys conducted in 1996–1999, we entered data directly into a computer using dLOG software (Glenn Ford Consulting, Portland, Oregon), which interfaced with a global positioning system and automatically marked positions every 20 s or when an observation was entered. Therefore, we were able to split the 1996–1999 transects into nearshore and offshore segments. The nearshore stratum thus includes selected transects surveyed in 1993 as well as transect segments and zigzags ≤6.0 km from shore surveyed in 1996–1999. All other transects and transect segments >6.0 km from shore were assigned to the offshore stratum.

We incorporated unidentified murrelets into estimates of population size, densities and trends of Kittlitz's and Marbled murrelets in the LCI Core area. We used data for all *Brachyramphus* murrelets to calculate the ratio of Kittlitz's to Marbled murrelets among identified birds, and we prorated the unidentified murrelets accordingly. We assumed no bias in species identification. On many of the transects during the early years, no murrelets were identified to species, therefore we summed all identified murrelets within a stratum (nearshore or offshore), and applied that ratio to the unidentified murrelets of a given transect. In 1993 a low proportion of murrelets was identified to species (18% within the LCI Core). Given the low identification rate, and a relatively high ratio of Kittlitz's to Marbled murrelets among identified birds that year (Table 1), we prorated unidentified murrelets in 1993 using the mean ratio of Kittlitz's to Marbled Murrelets from the 1996–1999 surveys (LCI Core), again by nearshore and offshore strata. We used all of the 1996–1999 data to derive an average species ratio to apply to 1993 because there was no justification for selecting a subset of years from the latter survey period. The survey crews during 1996–1999 had experienced murrelet observers, crew members were fairly consistent across years, protocols were identical, and observers achieved a higher rate of species identification (77% across all years). Under this approach, we assumed that the average ratio of Kittlitz's to Marbled murrelets in 1996–1999 was a good proxy for 1993.

We used transect densities (birds/km^2) to calculate a mean density and standard error (SE) for each stratum and survey. We then applied the densities to the total survey area (defined with ArcGIS; Fig. 1) and used a ratio estimator (Cochran 1977) to derive population estimates (and 95% CI) for each year. We used the log-transformed population estimates within the LCI Core to examine population trends in 1993–1999 with linear regression analysis, and we back-transformed slopes to derive estimated per annum growth or decay rates. We used an ANOVA to test for deviation of the slope from zero, with $P < 0.05$ as the significance level.

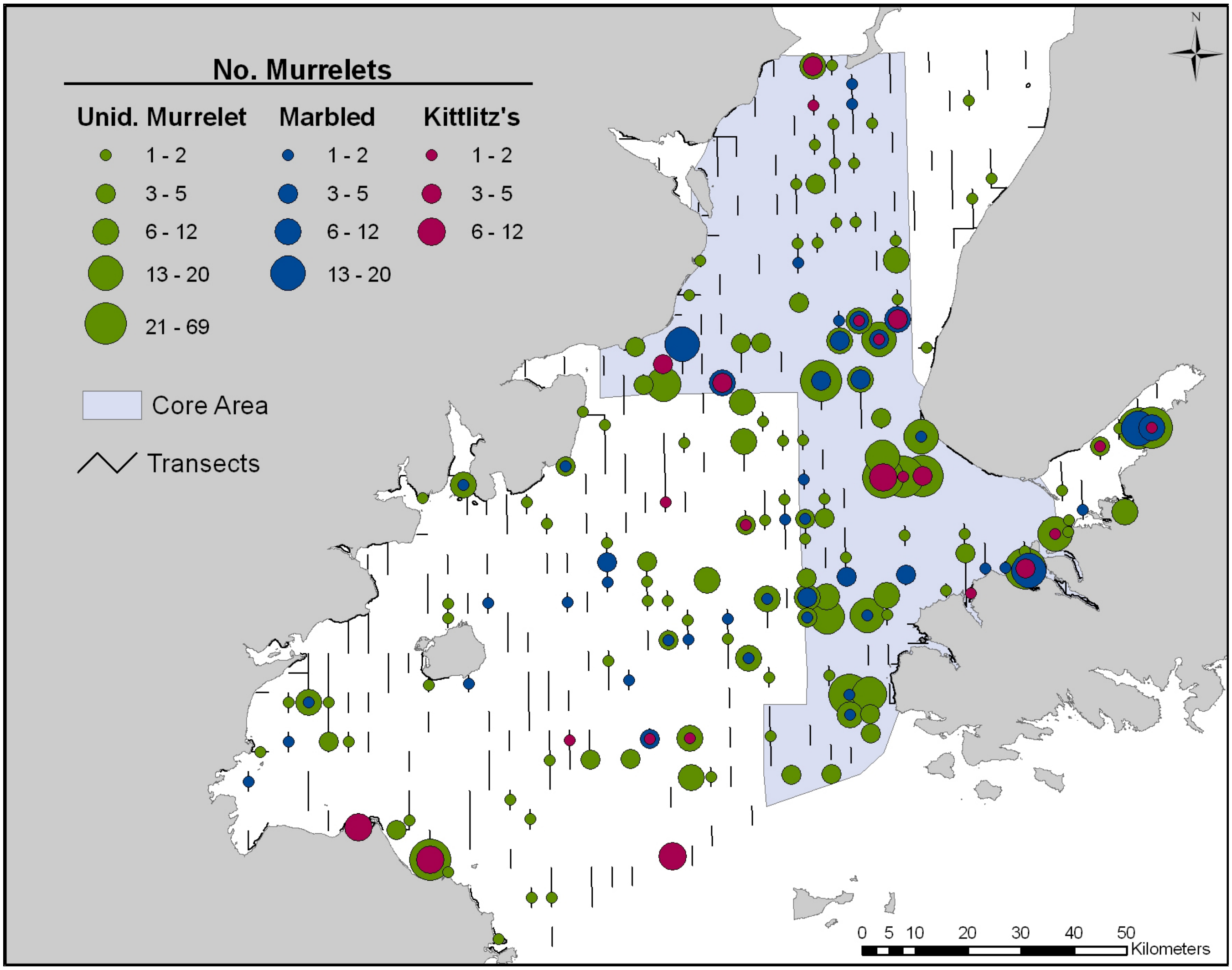


Fig. 3. Transects (black lines) in Lower Cook Inlet, Alaska surveyed for *Brachyramphus* murrelets on 7–23 June 1993. Graduated symbols are at the transect centroids.

Kachemak Bay

Sampling design and protocol

We conducted surveys in Kachemak Bay 18–26 July (mid-summer) in 2005–2007 to obtain estimates of peak murrelet abundance (Kuletz & Kendall 1998, Speckman *et al*. 2000, 2004). There were no historical surveys covering all portions of the bay during mid-summer for comparison. We established systematic transects at 4 km intervals (north-south longitude lines) throughout the bay (Fig. 5; following Agler *et al*. 1995). We did not include a shoreline stratum. The mid-summer survey was composed of 12 transects totaling ~188 km (38 km^2). It took 4–6 days to complete.

We examined trends in murrelet density in late summer (25 July–18 August) from 1988 to 2007. Late-summer transects followed the shoreline or zigzagged between shore and mid-bay (Fig. 2); topographic features delineated transect end points. The late-summer surveys were designed to calculate adult and juvenile murrelet ratios during the post-fledging period and thus were sited in areas of known murrelet concentrations (Kuletz & Piatt 1999). Because the late-summer transects were not randomly or systematically selected, the counts could not be used to estimate population size, but were appropriate to examine trends in murrelet densities (birds/km^2). Late-summer transects in the outer portion of Kachemak Bay were incorporated into the LCI Core analysis (Fig. 1), and, therefore, we examined late-summer murrelet trends using inner bay transects only. We analyzed survey data collected on three transect sets, defined as a single or group of independent survey lines; the sets overlapped, however, and were not independent. Within the inner bay, the "south line" set (between Bear Cove and Halibut Cove; Fig. 2) was surveyed

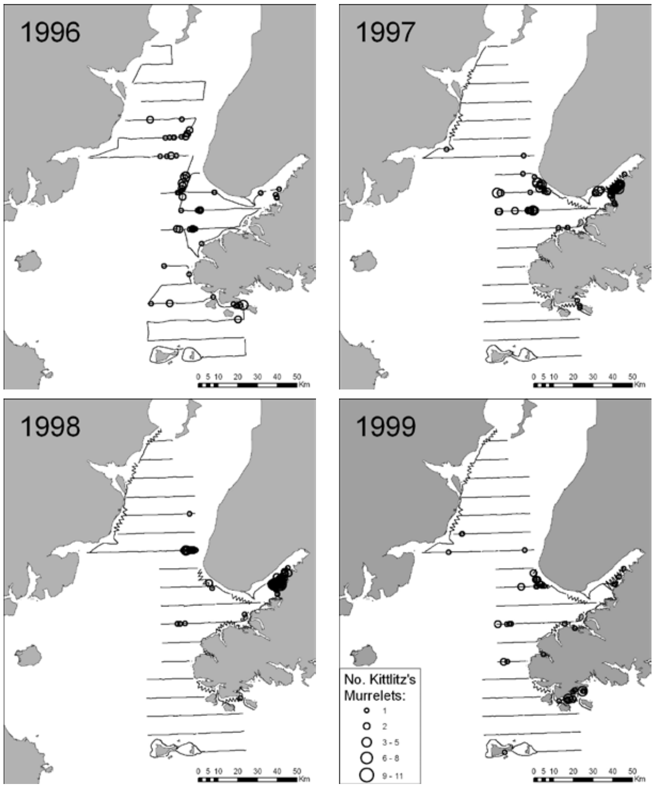


Fig. 4. Distribution of transects and Kittlitz's Murrelets observed on the water during surveys of Lower Cook Inlet, Alaska, 14 July–16 August, 1996–1999. The area surveyed extended beyond the LCI Core area used for trend analysis (see Fig. 1).

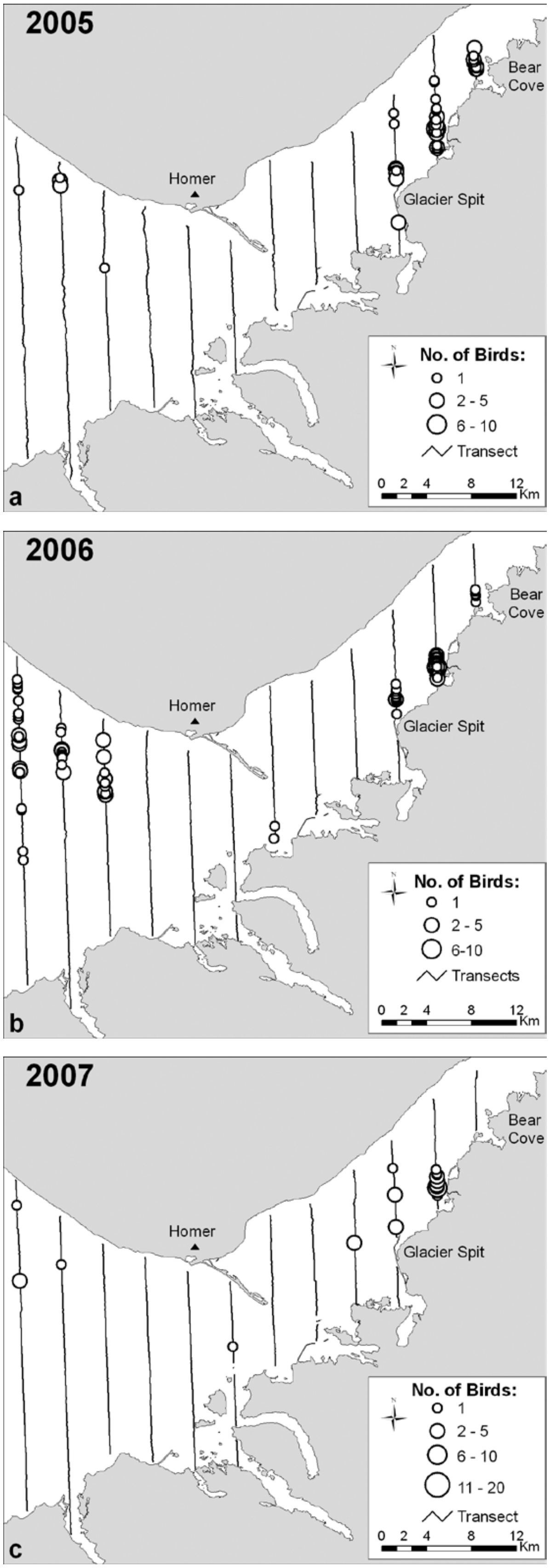


Fig. 5. Transects (black lines) for July surveys of *Brachyramphus* murrelets in Kachemak Bay, Alaska. The distribution of Kittlitz's Murrelets (open symbols) is shown for surveys conducted 18–26 July, 2005–2007.

in 1988, 1990 and 2004–2007 (n = 6 years; Fig. 2). The "zigzag" set was surveyed between 1996 and 2005 (n = 6 years) and the "xyz" set (three parallel lines) was surveyed between 1996 and 2007 (n = 7 years; Fig. 2). We used ArcGIS to map the locations of the historical (pre-1996) transect sets and uploaded them into the dLOG program to replicate the transects in 2004–2007 (see Kuletz *et al*. 2008 for details). Each late-summer transect set was sampled in a single day, with any replicates spaced 3–8 days apart within a year. If a set was surveyed more than once in the late-summer period, we used the annual mean density in final analyses.

In Kachemak Bay we surveyed from an 11 m vessel in 1996–1999 and from 8 m vessels in all other years. Thus, the observer platform was higher in 1996–1999 than in other years (Table 2). Starting in 1996 we entered data directly into a laptop computer (dLOG). Surveys were conducted using the same protocols as in LCI, with two observers and one driver recording all birds and mammals within the strip transect. As in LCI, flying birds were omitted from density calculations, with the exception of the south line, because we were unable to separate flying birds from those on the water in the 1988 and 1990 data. Because flying birds were always counted continuously in years when the south line was surveyed (1988, 1990, 2004–2007) total murrelet densities (flying and on water) were comparable across years, but densities from the south line were not comparable to densities from the other two transect sets.

Data analysis

To estimate population sizes for the entire bay in mid-summer, we used transect densities and a ratio estimator (Cochran 1977) extrapolated to the whole study area (816 km^2). We examined late summer trends for prorated densities of Kittlitz's and Marbled murrelets using log-transformed values and the same approach used to estimate LCI Core trends.

TABLE 2
Survey effort and counts of Kittlitz's and Marbled murrelets, Kachemak Bay, Alaska, 1988–2007[a,b]

Season	Year	Dates	Survey coverage		Platform height, m	Transect strip width, m	Density (SE), birds/km^2		Total count	% identified to species	% of identified birds	
			Transect	Distance, km			KIMU[c]	MAMU[c]			KIMU	MAMU
Mid-summer	2005	18–26 July	Systematic	188.2	0.5	200	2.5	14.8	736	89	14	86
	2006	18–26 July	Systematic	196.9	0.5	200	4.0	14.0	751	95	22	78
	2007	18–26 July	Systematic	193.0	0.5	200	1.4	12.2	570	92	10	90
Late summer	1988	1–16 Aug	SL	10.5	0.5	1000	54.3	19.5	774	35	74	26
	1990	1–16 Aug	SL	20.6	0.5	200	39.1	14.5	221	58	73	27
	2004	1–16 Aug	SL	20.6	0.5	200	4.8 (0.8)	49.6 (6.2)	227	93	9	91
	2005	1–16 Aug	SL	21.1	0.5	200	6.1 (0.6)	39.6 (15.9)	191	92	13	87
	2006	1–16 Aug	SL	20.6	0.5	200	34.8 (14.5)	37.2 (11.8)	304	95	48	52
	2007	1–16 Aug	SL	21.0	0.5	200	14.9	32.6	199	95	31	69
Late summer	1996	26 July–16 Aug	ZZ	61.0	8.5	300	0.2	12.3	228	96	1	99
	1997	26 July–16 Aug	ZZ	61.0	3.4	300	5.1	18.5	431	51	21	79
	1998	26 July–16 Aug	ZZ	61.9	3.4	300	11.8	26.7	715	75	31	69
	1999	26 July–16 Aug	ZZ	62.1	3.4	300	0.2	12.1	230	89	2	98
	2004	26 July–16 Aug	ZZ	65.3	0.5	200	1.8	23.6	331	81	7	93
	2005	26 July–16 Aug	ZZ	63.7	0.5	200	0.1	10.4	133	98	1	99
Late summer	1997	26 July–16 Aug	XYZ	40.4	2.4	300	26.2 (9.4)	61.8 (13.5)	1066	60	29	71
	1998	26 July–16 Aug	XYZ	39.6	2.4	300	22.8 (7.4)	48.7 (19.4)	850	87	32	68
	1999	26 July –16 Aug	XYZ	40.4	2.4	300	3.3 (2.1)	57.4 (21.5)	736	82	5	95
	2004	26 July–16 Aug	XYZ	40.9	0.5	200	4.2 (1.4)	60.6 (16.1)	1059	80	6	94
	2005	26 July–16 Aug	XYZ	40.4	0.5	200	6.2 (1.4)	36.6 (11.3)	692	93	15	85
	2006	26 July–16 Aug	XYZ	40.7	0.5	200	32.7 (5.4)	70.8 (29.5)	1681	98	32	68
	2007	26 July–16 Aug	XYZ	39.9	0.5	200	10.2 (57.2)	39.9 (13.1)	1199	97	20	80

[a] Mid-summer survey included 12 transects (Fig. 5); late-summer surveys included three transect sets—south line (SL), zigzag (ZZ) and three parallel lines (XYZ) (Fig. 2). Mean density (SE) shown for transect sets sampled more than once a year. Kilometers surveyed varied slightly for a given transect set because of changes in course due to tides or weather-related interruptions.

[b] Density estimates of both murrelet species include prorated unidentified murrelets.

[c] KIMU = Kittlitz's Murrelets; MAMU = Marbled Murrelets.

RESULTS

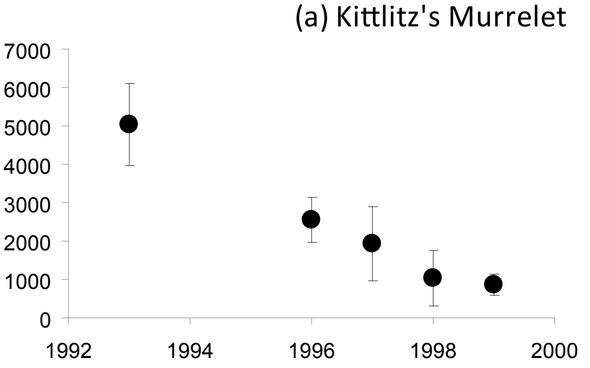
Lower Cook Inlet

Distribution in LCI

In all years, both species of *Brachyramphus* murrelets, especially Kittlitz's Murrelet, were most abundant in Kachemak Bay and along the eastern side of LCI, between the southern tip of the Kenai Peninsula and ~10 km north of Anchor Point (Figs. 1, 3, 4). Kittlitz's Murrelets and unidentified murrelets were encountered near the northern entrance to Chinitna Bay on the west side of LCI in 1993 (Figs. 1, 3), but few Kittlitz's Murrelets were found there in subsequent years (Fig. 4). In 1993, when the central and southwestern portions of LCI were surveyed, Kittlitz's Murrelets and groups of unidentified murrelets were found in high densities near the southwestern entrance to LCI, and unidentified and Marbled Murrelets were found in moderate densities in the central regions of LCI (Fig. 3).

Abundance and trends in LCI Core area

Within the LCI Core area, the majority (82%) of *Brachyramphus* murrelets observed in 1993 were unidentified, but identification rates improved substantially in subsequent years (Table 1). Between 1996 and 1999 we estimated an average 1592 (SD 787, 4-year mean) Kittlitz's Murrelets and an average 15 255 (SD 4086) Marbled Murrelets (Appendix 1). Between 1993 and 1999, *Brachyramphus* murrelets within the LCI Core area ranged from a high estimate of 36 084 birds in 1993 to a low estimate of 12 777 in 1996. For both murrelet species, estimates of population size peaked in 1993 and generally decreased thereafter (Fig. 6; Appendix 1). Kittlitz's Murrelets declined significantly ($r^2 = 0.96$, $F = 76.68$, $P < 0.01$) at 26.2% per annum between 1993 and 1999, for a total 84% decline over the 7-year period. Eliminating the 1993 survey, Kittlitz's Murrelets declined at a faster rate (32% per annum) between 1996 and 1999. Marbled Murrelets declined at 11.8% per annum from 1993 to 1999 for a total 56% decline, but the estimate in 1996 was low (Fig. 6) and the slope was not significant ($r^2 = 0.35$, $F = 0.62$, $P = 0.29$).


(a) Kittlitz's Murrelet

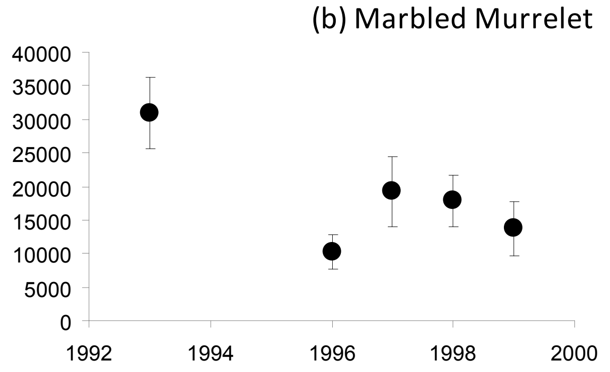

(b) Marbled Murrelet

Fig. 6. Murrelet population estimates (SE) for: (a) Kittlitz's Murrelet, and (b) Marbled Murrelet in the Lower Cook Inlet Core area, Alaska. The 1993 estimates for Kittlitz's and Marbled murrelets were apportioned unidentified murrelets using the average of 1996–1999 ratios of identified birds.

Kachemak Bay

Distribution in Kachemak Bay

Combining all three mid-summer surveys of Kachemak Bay, ~98% of Kittlitz's Murrelets were found within two high-density zones. A consistent hotspot was a ~75 km^2 area in the southern inner bay near Glacier Spit (Fig. 5). In 2006, we encountered high densities of Kittlitz's Murrelet in the northern outer bay (~128 km^2 area) in mid-summer, but few birds were observed in that area in 2005 and 2007.

Abundance and trends in Kachemak Bay

During the 2005–2007 mid-summer surveys, we counted 2057 *Brachyramphus* murrelets, with Kittlitz's Murrelets constituting 10–22% of identified murrelets, and unidentified murrelets constituting 5–11% of the total (mean 6.3%; Table 2). During the 2004–2007 late-summer surveys we counted 11 634 murrelets on

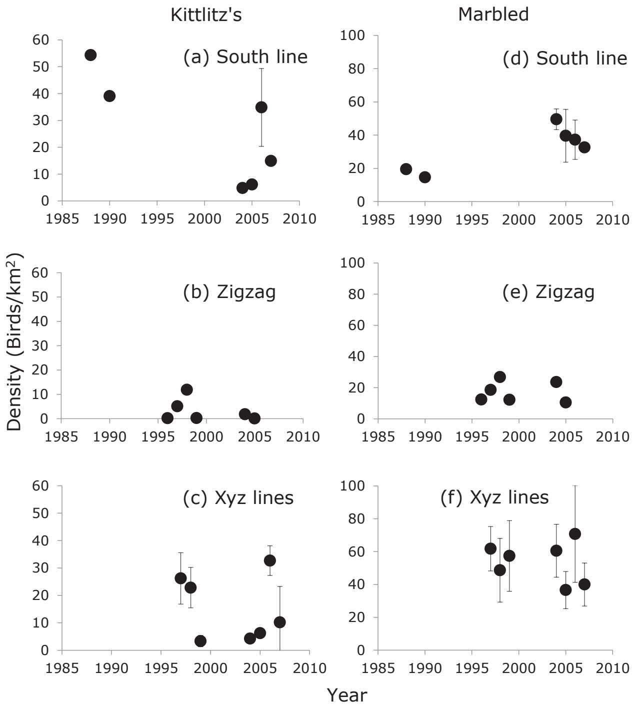


Fig. 7. Densities (SE for repeated surveys) of Kittlitz's Murrelet (left column) and Marbled Murrelet (right column), including prorated unidentified murrelets, in late summer surveys of inner Kachemak Bay, Alaska. The south line transect (a,d) was surveyed between 1988 and 2007, the zigzag (b,e) was surveyed between 1996 and 2006, and the xyz lines (c,f) were surveyed between 1996 and 2007.

transect, with Kittlitz's Murrelets constituting 1–32% of identified murrelets and unidentified murrelets constituting 2–20% of total murrelets (Table 2). Mid-summer population estimates of Kittlitz's Murrelet in Kachemak Bay in 2005–2007 averaged 2020 birds (SD 1108, n = 3 years), with the peak estimate in 2006 (Appendix 1). During the same surveys, we estimated an average of 11 060 (SD 1245) Marbled Murrelets, with the 2005 estimate being slightly higher than those in 2006. Total *Brachyramphus* murrelet numbers were highest in 2006.

During late-summer surveys in inner Kachemak Bay, Kittlitz's Murrelet densities on the south line transect set trended downward at 7.6% per annum between 1988 and 2007, but the slope of the regression was not significantly different from zero (r^2 = 0.44, F = 3.15, P = 0.15; Fig. 7a). We detected no trend in Kittlitz's Murrelet densities on the other two transect sets (zigzag and xyz lines) surveyed between 1996 and 2007 (Figs. 7b,c). Marbled Murrelet densities on the south line increased significantly at 4.9% per annum between 1988 and 2007 (r^2 = 0.78, F = 13.75, P = 0.02; Fig. 7d), but did not vary between 1996 and 2007 on the zigzag (Fig. 7e) or xyz lines (Fig. 7f).

DISCUSSION

Murrelet distribution

Our surveys consistently found the southeastern side of LCI and inner Kachemak Bay to be high-use "hotspots" for both Kittlitz's and Marbled murrelets, a pattern first described by Agler *et al*. (1998) and Kendall & Agler (1998). The LCI Core area captured most of the key areas in LCI used by Kittlitz's Murrelets, with the exception of Kamishak Bay (Fig. 1), where large numbers of Kittlitz's Murrelets were observed in 1993 (Fig. 3), and the central waters of LCI (southwest of the LCI Core boundaries), which had low but widespread numbers of Marbled and unidentified murrelets in 1993 (Fig. 3).

Although there are high murrelet densities in and around Kachemak Bay (Table 2), a substantial portion of the regional population of both species was found in the main body of LCI (Figs. 3,4). The distribution of Kittlitz's Murrelet in LCI differs from the usual pattern along the northern GOA coast (Kendall & Agler 1998). Kittlitz's Murrelets in LCI are more widely dispersed and more often found in offshore waters than they are in other areas, which may be owing partly to the generally shallow bathymetry of LCI (<50 m, but up to 100 m deep in the main channel). Kittlitz's Murrelets typically occupy protected bays and upper fjords in most regions where they are found, including Prince William Sound (Day *et al*. 2003, Kuletz *et al*. 2003), Kenai Fjords (Arimitsu *et al*. 2011), Glacier Bay (Piatt *et al*. 2011) and the "Lost Coast"' of southeastern Alaska (Kissling *et al*. 2011). To a more limited extent, Kachemak Bay serves a similar role within LCI.

The upwelling of cold, nutrient-rich waters into southern LCI results in a highly productive system (Speckman *et al*. 2005) that supports some of the largest seabird colonies of the northeastern GOA coast (Piatt 2002). This is especially true along the eastern side of LCI (Burbank 1977, Speckman *et al*. 2005), where we found the highest numbers of Kittlitz's Murrelet. In contrast, the western side of the inlet has low productivity because of enormous silt loads from Upper Cook Inlet (Speckman *et al*. 2005). However, near the southwestern entrance to LCI, the area between Augustine Island and Kamishak Bay (Fig. 1) occasionally receives nutrient-rich upwelled water from the GOA (Speckman *et al*. 2005), and that is where Kendall & Agler (1998) found Kittlitz's Murrelets in 1993 (Fig. 3).

Within Kachemak Bay, the most consistent foraging area for both murrelet species in summer lies between Glacier Spit and Bear Cove (Fig. 5), where ACC water meets glacial outflows. In late summer and fall, cold saline water from the ACC periodically enters Kachemak Bay at depth along the southern shore (Okkonen *et al*. 2007), resulting in local stratification, with a thin (<3 m) surface lens of turbid water covering clear water below (up to 60 m deep; Kuletz *et al*. 2008). In contrast, the north side of the inner bay is <20 m deep and turbid throughout the water column (Kuletz *et al*. 2008). We found few murrelets in the northern part of the inner bay in mid-summer (Fig. 5), and densities there were also low during late-summer surveys of the inner zigzag transect set (Figs. 7b,e). Cold, saline, clear water in the outer bay did not generally attract Kittlitz's Murrelets, with the exception of an irregular hotspot in outer Kachemak Bay in 2006 (Fig. 5). The hotspot was near a shallow bench 20–40 m deep, which in 2006 had turbid water at the surface and clear water below (Kuletz *et al*. 2008). Thus, in both the inner and outer bays, Kittlitz's Murrelet hotspots were found in stratified waters, with a lens of turbid water overlying clear water at depth.

In our study area, potential nesting habitat is found along the southern side of Kachemak Bay, at the southern end of the Kenai Peninsula, and along the west side of LCI, where Kittlitz's Murrelet nests have been found in uplands (Day *et al*. 1999). A Kittlitz's Murrelet nest found on Red Mountain (Fig. 1), outer Kachemak Bay (Piatt *et al*. 1999), was approximately 42 km from either the inner bay foraging hotspot or offshore feeding areas near Anchor Point in the northern outer bay. It remains unknown how far such nesters may travel to forage.

Murrelet abundance

Surveys in 1993 indicated that a sizeable portion of the world population of Kittlitz's Murrelet was found in LCI (Kendall & Agler 1998). More recently (July 2005–2007), the population in Kachemak Bay alone was ~2050 birds, or ~4–7% of the estimated global population of Kittlitz's Murrelet (30 900–56 000 birds, including ~11 000 in Russia; US Fish and Wildlife Service 2010). During the 2005–2007 July surveys, the inner basin of Kachemak Bay had mean densities of 3.44–6.83 birds/km^2 (Kuletz *et al*. 2008), similar to other high-density areas such as Icy Bay (Kissling *et al*. 2011), certain fjords of Prince William Sound (Kuletz *et al*. 2011) and Glacier Bay (Piatt *et al*. 2011). Adding the most recent (1999) population estimate from the LCI Core area (~900 birds) to the Kachemak Bay estimate, and assuming the two estimates are independent, we conclude that a minimum of 2950 Kittlitz's Murrelets, or ~5–9% of the world population, occupy Cook Inlet in summer. Although Marbled Murrelets were numerically dominant in LCI, their numbers constitute only ~4% of the world population of that species (cf. Piatt *et al*. 2007). A re-survey of the entire LCI would improve our understanding of the LCI contribution to the respective metapopulations of both murrelet species, particularly since the population estimates we present are based on a portion of LCI.

Murrelet counts at sea are likely influenced by interannual differences in environmental conditions. The high numbers of murrelets observed in LCI in 1993 (Fig. 6) correspond to unusually high numbers in Prince William Sound in the same year (Kuletz *et al*. 2011). In contrast, the 1996 *Brachyramphus* estimates were unusually low in both LCI and Prince William Sound, suggesting both populations responded to large-scale environmental factors. Similarly, the high numbers of Kittlitz's Murrelet in Kachemak Bay in 2006, relative to 2005 and 2007, mirrored high Kittlitz's Murrelet densities in Kenai Fjords in 2006 compared to 2007 (Arimitsu *et al*. 2011).

Murrelet population trends

Lower Cook Inlet

Within the LCI Core area, we found a significant decline in Kittlitz's Murrelet abundance but no significant change in Marbled Murrelet abundance. Comparing the 1993 to 1996–1999 survey data required several assumptions, but in most cases any violations to those assumptions would translate to fewer murrelets in the 1993 survey. In 1993, survey vessels were smaller, which may have resulted in reduced sighting distances—the reverse is unlikely. Additionally, the survey was conducted in mid-June, when murrelet numbers tend to be low compared to July and early August (Kuletz & Kendall 1998, Speckman *et al*. 2000, Arimitsu *et al*. 2011). Assessing population trends of Kittlitz's and Marbled murrelets in LCI was complicated by variable rates of species identification, especially the low proportion of birds identified in the earliest survey (Table 1). Nonetheless, in the LCI Core area, numbers of both murrelet species dropped steeply after 1993 (Fig. 6), and Kittlitz's Murrelet declined in LCI regardless of whether the 1993 survey data were included. With only five samples over 20 years, and given the high variance in murrelet counts, our power to detect change in abundance was low (Speckman *et al*. 2000, Kissling *et al*. 2007).

Kachemak Bay

Densities of Kittlitz's Murrelet in late-summer surveys tended downward but were statistically stable (Figs. 7a–c), whereas densities of Marbled Murrelets in the inner bay increased after 1988 and were stable between 1996 and 2007 (Figs. 7d–f). We likely underestimated murrelet densities in 1988, however, because murrelets were counted in a strip-transect 1000 m wide (500 m on either side of the boat; following Carter & Sealy 1990), which undoubtedly violated the assumption of perfect detection thoughout the strip. Later studies found that detectability of *Brachyramphus* murrelets from small vessels degrades markedly beyond 100 m from the boat (Becker *et al*. 1997, Mack *et al*. 2002). Although waters of the inner bay were often glassy and free of swell, allowing us to detect some percentage of birds beyond 100 m, full detection out to 500 m was unlikely. Thus, we consider Kittlitz's and Marbled murrelet densities in 1988 to be artificially low, which further limits our ability to detect trends.

Local threats to murrelet populations

One factor in the apparent decline of Kittlitz's Murrelet numbers is the alteration of glacially associated habitats resulting from climate change (US Fish and Wildlife Service 2010). Although mechanisms are poorly understood, the interaction of tidewater glaciers and marine waters potentially affects murrelet habitat use and prey availability (Day *et al*. 2000, Kuletz *et al*. 2003, Kissling *et al*. 2007). Land-locked glaciers, like those on the southern side of Kachemak Bay, also respond to climate change, altering currents and sedimentation rates (Arendt *et al*. 2002, Hall *et al*. 2005) and possibly water-column structure in foraging areas used by Kittlitz's Murrelets. Hall *et al* (2005) concluded that, since 1973 at least, the Grewingk-Yalik glacier complex that feeds into inner Kachemak Bay has been more stable than glaciers of the Harding Icefield that feed into Kenai Fjords, possibly implying better maintenance of favorable foraging conditions for Kittlitz's Murrelets in the southern inner bay.

Despite vast areas of wilderness, Cook Inlet and Kachemak Bay are not pristine environments, and the cumulative effects of climate change and human activities need to be considered in any conservation assessment for Kittlitz's Murrelets. Human activities potentially affecting Kittlitz's Murrelets may be direct (i.e. gillnet mortality and oil spills) or indirect, via changes in the ecosystem. Although murrelet densities in Kachemak Bay remained stable immediately after the *Exxon Valdez* spill in 1989 (Kuletz 1996), Kittlitz's Murrelets south of Cook Inlet were killed by the oil slick in April and May, before they occupied breeding areas (Piatt *et al*. 1990). The oil-related mortality could have affected the LCI breeding population. The Cook Inlet watershed supports ~60% of Alaska's human population, and the city of Anchorage pumps just under 106 000 000 L (28 000 000 US gallons) of primary-treated sewage into Cook Inlet daily (CH2M HILL 2006). Mining, oil and gas extraction, transport and refining have been undertaken in the region since the 1950s, and 12–15 oil platforms currently operating in Upper Cook Inlet are exempt from most restrictions on discharging hydrocarbons and heavy metals into estuarine waters (US Federal Register, v73, n238, p75104).

Within Kachemak Bay, sedimentation and pollution linked to coastal development may have led to declines in the size and distribution of *Nereocystis* kelp beds (Schoch & Chenelot 2004). Kelp forests support local food webs (Lalli & Parsons 1993) and provide habitat for juvenile Kittlitz's and Marbled murrelets (Kuletz & Piatt 1999, Kuletz *et al*. 2008). Pacific herring *Clupea pallasii* and shrimp *Pandalus* spp. were both over-exploited, leading to the closure of these fisheries (Schoch & Chenelot 2004), and murrelets feed on juveniles of both prey types (Sanger 1987, Piatt *et al*. 2007). Other changes to the bay's ecosystem in recent decades include increased sewage inputs, gill-netting for salmon, commercial aquaculture and the largest hydroelectric dam in Alaska near the head of the bay. Impacts of such changes on ecosystem and trophic dynamics, and consequent impacts on murrelets, are unknown.

Upland areas have also changed in Kachemak Bay in recent time, which may have affected nesting habitats. Nine local glaciers have retreated since the 1950s, and vegetation has covered moraines and talus slopes (S. Baird, Kachemak Bay Research Reserve, Homer, Alaska, unpublished data). Throughout the Kenai Peninsula, infestations of spruce bark beetles linked to climate change have decimated spruce forests since the 1990s (Werner *et al*. 2006), likely altering runoff into nearshore waters.

Management considerations

Post-breeding dispersal of Kittlitz's Murrelets throughout LCI and the GOA may confound at-sea population and trend estimates. Kittlitz's Murrelets breed along the shores of Kachemak Bay, judging by the presence of hatch-year birds in late summer (Kuletz *et al*. 2008), but the proportion of adults observed on the water that breed is unknown. Typically, Kittlitz's Murrelets leave their summer foraging grounds in upper fjords and bays by late summer (Day *et al*. 1999, Kissling *et al*. 2007). In Prince William Sound and Kenai Fjords, Kittlitz's Murrelets leave the fjords in early August (Stephenson 2009, Arimitsu *et al*. 2011), whereas they persist in Kachemak Bay until mid or late

August (Kuletz *et al*. 2008). Indeed, satellite telemetry indicates that some Kittlitz's Murrelets from Icy Bay (southeastern Alaska) and from Prince William Sound fly to LCI and Kachemak Bay in late July and August (J. Piatt, unpublished data). Thus, productive waters on the east side of LCI may attract nonbreeding Kittlitz's Murrelets from distant areas, and a high proportion of Kittlitz's may forego breeding in a given year (Day & Nigro 2004, M. Kissling, US Fish and Wildlife Service, Juneau, Alaska, unpublished data). The effect of a "floater" population on survey estimates in LCI could be exacerbated if GOA conditions in some years result in lower numbers of nesting birds. Monitoring efforts targeting the mid-summer (July) period would reduce variance and improve the precision of estimates, increasing power to detect trends.

The east side of LCI, and Kachemak Bay in particular, are clearly foraging hotspots for murrelets and are relatively accessible for study. Kachemak Bay is also unique in the relatively high number of Kittlitz's Murrelet juveniles observed at sea in late summer (Kuletz *et al*. 2008), suggesting a consistent "core" breeding population. We recommend continued monitoring of murrelets in inner Kachemak Bay, with an emphasis on seasonal occurrence, productivity indices and habitat and prey requirements. However, as indicated by the additional murrelets in the north outer bay in 2006 (Fig. 5), periodic influxes from the greater LCI population could confound our ability to detect trends for murrelets in Kachemak Bay alone. Therefore, recurring, comprehensive surveys of LCI, ideally incorporating some components of historical surveys, will be needed to gauge the status of the regional population.

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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.

AGLER, B.A., KENDALL, S.J., SEISER, P.E. & IRONS, D.B. 1995. Estimates of marine bird and sea otter abundance in Lower Cook Inlet, Alaska during summer 1993 and winter 1994. OCS Study MMS 94-0063. Anchorage, AK: US Fish and Wildlife Service.

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

ARENDT, A.A., ECHELMEYER, K.A., HARRISON, W.D., LINGLE, C.S. & VALENTINE, V.B. 2002. Rapid wastage of Alaska glaciers and their contribution to rising sea level. *Science* 297: 382-386.

BECKER, B.H., BEISSINGER, S.R. & CARTER, H.R. 1997. At-sea density monitoring of Marbled Murrelets in central California: methodological considerations. *Condor* 99: 743-755.

BURBANK, D.C. 1977. Circulation studies in Kachemak Bay and Lower Cook Inlet. In: Trasky, L.L., Flagg, L.B. & Burbank, D.C. (Eds). Environmental studies of Kachemak Bay and Lower Cook Inlet. Vol. 3. Anchorage, AK: Alaska Department of Fish and Game.

CARTER, H.R. & SEALY, S.G. 1990. Daily foraging behavior of Marbled Murrelets. *Studies in Avian Biology* 14: 93-102.

CH2M HILL. 2006. Performance summary of Anchorage's Asplund Water Pollution Control Facility and Cook Inlet water quality [unpublished report]. Juneau, AK: National Marine Fisheries Service.

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

DAY, R.H., KULETZ, K.J. & NIGRO, D.A. 1999. Kittlitz's Murrelet (*Brachyramphus brevirostris*). In: Poole, A. (Ed). The birds of North America, No. 435. Philadelphia, PA, & Washington, DC: Academy of Natural Sciences & American Ornithologists' Union.

DAY, R.H. & NIGRO, D.A. 2004. Is the Kittlitz's Murrelet exhibiting reproductive problems in Prince William Sound, Alaska? *Waterbirds* 27: 89–95.

DAY, R.H., NIGRO, D.A. & PRICHARD, A.K. 2000. At-sea habitat use by the Kittlitz's Murrelet *Brachyramphus brevirostris* in nearshore waters of Prince William Sound, Alaska. *Marine Ornithology* 28: 105-114.

DAY, R.H., PRICHARD, A.K. & NIGRO, D.A. 2003. Ecological specialization and overlap of Brachyramphus murrelets in Prince William Sound, Alaska. *Auk* 120: 680–699.

EVANS MACK, D., RAPHAEL, M.G. & LAAKE, J.L. 2002. Probability of detecting Marbled Murrelets at sea: effects of single versus paired observers. *Journal of Wildlife Management* 66: 865-873.

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

HALL, D., GIFFEN, B. & CHIEN, J. 2005. Change analysis of glacier ice extent and coverage for three southwest Alaska parks–Katmai National Park and Preserve, Kenai Fjords National Park, and Lake Clark National Park and Preserve: changes in the Harding Icefield and the Grewingk-Yalik Glacier complex, Kenai Fjords National Park [unpublished report]. Anchorage, AK: National Park Service.

KENDALL, S.J. & AGLER, B.A. 1998. Distribution and abundance of Kittlitz's Murrelets in southcentral and southeastern Alaska. *Waterbirds* 21: 53–60.

KISSLING, M.L., LUKACS, P.M., LEWIS, S.B., GENDE, S.M., KULETZ, K.J., HATCH, N.R., SCHOEN, S.K. & OEHLERS, S. 2011. Distribution and abundance of the Kittlitz's Murrelet in select areas of southeastern Alaska. *Marine Ornithology* 39: 3-11.

KISSLING, M.L., REID, M., LUKACS, P.M., GENDE, S.M. & LEWIS, S.B. 2007. Understanding abundance patterns of a declining seabird: implications for monitoring. *Ecological Applications* 17: 2164-2174.

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. 1996. Marbled Murrelet abundance and breeding activity at Naked Island, Prince William Sound, and Kachemak Bay, Alaska, before and after the *Exxon Valdez* oil spill. In: Rice, S.D., Spies, R.B., Wolfe, D.A. & Wright, B.A. (Eds). Proceedings of the *Exxon Valdez* oil spill symposium. Bethesda, MD: American Fisheries Society Symposium 18. pp. 770-784.

KULETZ, K.J. & KENDALL, S.J. 1998. A productivity index for Marbled Murrelets in Alaska based on surveys at sea. *Journal of Wildlife Management* 62: 446-460.

KULETZ, K.J., LABUNSKI, E.A. & SPECKMAN, S.G. 2008. Abundance, distribution, and decadal trends of Kittlitz's and Marbled murrelets and other marine species in Kachemak Bay, Alaska. Project No. 14. Anchorage, AK: US Fish and Wildlife Service.

KULETZ, K.J., NATIONS, C.S., MANLY, B.F.J., ALLYN, A., IRONS, D.B. & MCKNIGHT, A. 2011. Distribution, abundance, and population trends of the Kittlitz's Murrelet *Brachyramphus brevirostris* in Prince William Sound, Alaska. *Marine Ornithology* 39: 97–109.

KULETZ, K.J. & PIATT, J.F. 1999. Juvenile Marbled Murrelet nurseries and the productivity index. *Wilson Bulletin* 111: 257-261.

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.

LALLI, C.M. & PARSONS, T.R. 1993. Biological oceanography: an introduction. New York: Pergamon Press.

LITZOW, M.A. 2006. Climate regime shifts and community reorganization in the Gulf of Alaska: how do recent shifts compare with 1976/1977? *ICES Journal of Marine Science* 63: 1386–1396.

OKKONEN, S., PEGAU, S. & SAUPE, S. 2007. Seasonality of boundary conditions for Cook Inlet, Alaska [unpublished report]. Homer, AK: Kachemak Bay National Estuarine Research Reserve.

PIATT, J.F. (Ed). 2002. Response of seabirds to fluctuations in forage fish density. *Exxon Valdez* Oil Spill Restoration Project 00163M and Minerals Management Service OCS Study MMS 2002-068. Anchorage, AK: US Geological Survey.

PIATT, J.F. & ANDERSON, P. 1996. Response of Common Murres to the *Exxon Valdez* oil spill and long-term changes in the Gulf of Alaska marine ecosystem. *American Fisheries Society Symposium* 18: 720-737.

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

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., LENSINK, C.J., BUTLER, W., KENDZIOREK, M. & NYSEWANDER, D.R. 1990. Immediate impact of the *Exxon Valdez* oil spill on marine birds. *Auk* 107: 387-397.

PIATT, J.F., NASLUND, N.L. & VAN PELT, T.I. 1999. Discovery of a new Kittlitz's Murrelet nest: clues to habitat selection and nest-site fidelity. *Northwestern Naturalist* 80: 8–13.

SANGER, G.A. 1987. Winter diets of Common Murres and Marbled Murrelets in Kachemak Bay, Alaska. *Condor* 89: 426-430.

SCHOCH, G.C. & CHENELOT, H. 2004. The role of estuarine hydrodynamics in the distribution of kelp forests in Kachemak Bay, Alaska. *Journal of Coastal Research* SI(45): 179-194.

SPECKMAN, S.G., PIATT, J.F., MINTE-VERA, C.V. & PARRISH, J.K. 2005. Parallel structure among environmental gradients and three trophic levels in a subarctic estuary. *Progress in Oceanography* 66: 25-65.

SPECKMAN, S.G., PIATT, J. F. & SPRINGER, A. M. 2004. Small boats disturb fish-holding Marbled Murrelets. *Northwestern Naturalist* 85: 32-34.

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.

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.

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

WERNER, R.A., HOLSTEN, E.H., MATSUOKA, S.M. & BURNSIDE, R.E. 2006. Spruce beetles and forest ecosystems in south-central Alaska: a review of 30 years of research. *Forest Ecology & Management* 227: 195-206.

APPENDIX 1

Population estimates of Kittlitz's and Marbled murrelets in Lower Cook Inlet Core area (1993–1999) and in Kachemak Bay (2005–2007)[a]

Area	**Months**	**Year**	**Estimate (95% CI)**	
			Kittlitz's Murrelet	**Marbled Murrelet**
LCI Core	June	1993	5035 (7133)	30 874 (10 367)
	July	1996	2545 (3681)	10 232 (4884)
	July–August	1997	1924 (3817)	19 219 (10 110)
	July–August	1998	1043 (2475)	17 856 (7668)
	July–August	1999	857 (1383)	13 710 (7810)
Kachemak Bay	July	2005	1776 (2059)	12 244 (4931)
	July	2006	3277 (3100)	11 227 (6728)
	July	2007	1086 (1824)	9651 (8015)

[a] Population estimates include prorated unidentified murrelets.