Abundance, distribution, and decadal trends of Kittlitz's and marbled murrelets and other marine species in Kachemak Bay, Alaska

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EXECUTIVE SUMMARY

The marine avifauna of Kachemak Bay, Alaska, includes breeding populations of two unique species of seabirds, the Kittlitz's murrelet (*Brachyramphus brevirostris*) and the marbled murrelet (*B. marmoratus).* The Kittlitz's murrelet is a candidate species for listing under the Endangered Species Act, and the marbled murrelet is a species of concern in Alaska and is listed as a threatened species south of Alaska. The availability of historic data and the relative accessibility of the Kachemak Bay populations for these two species allowed us to examine decadal trends and patterns of distribution and habitat use. We used boat-based surveys and replicated historic transects where possible to determine population trends and current population size and distribution within Kachemak Bay. Based on the average of point estimates from 2005, 2006 and 2007, the July population was 10,595 (SD ± 964) for marbled murrelets and 1,937 (SD ± 1075) for Kittlitz's murrelets. These numbers were bolstered by an apparent influx of both species into Kachemak Bay in 2006, primarily in the north outer bay south of Anchor Point.

Because of low species identification rates in the 1993 June survey, we examined trends for total *Brachyramphus* murrelet numbers for our 2005 and 2006 June surveys. Between 1993 and 2005, June numbers of *Brachyramphus* murrelets indicated a declined of 32 %, for a per annum rate of – 2.7 %. However, the higher number of murrelets in 2006 resulted in no change in the June population between 1993 and 2005-2006. August surveys indicated that between 1988 – 1999 and 2004 - 2007, densities of Kittlitz's murrelets declined significantly in the inner bay and for the entire bay, the latter by 43 %, or -18 % per annum. Marbled murrelet densities, however, remained stable and even increased in the outer bay, although this difference was not significant.

During the four years of this study (2004-2007), Kittlitz's murrelets were always present in the south inner bay at the confluence of outflow from the Grewingk and Portlock glaciers, which are land locked glaciers. This area was characterized by highly stratified water, with a thin (< 3m) lens of turbid water covering clear water below. The influx of Kittlitz's murrelets to the north outer bay in 2006 coincided with a strong frontal feature that also had turbid water near the surface and clear water below and at the edge of the front, where the murrelets were located. We suggest that although Kittlitz's murrelets are found in water that

is turbid at the surface, a layer of clear water within 5 m of the surface may be an essential feature of their foraging habitat. Further study will be needed to determine the prey and physical parameters that create optimum conditions for murrelet foraging within these types of habitats.

Distribution of marbled murrelets within the bay was broader both spatially and relative to water characteristics, occurring where water was highly stratified and well mixed. Marbled murrelets were primarily found along the south shore of both inner and outer bay, but they also occurred in the north outer bay. Neither species used areas where layers of turbid water extended deeper than ~ 5 - 10 m, and most were in waters < 60 m deep.

Densities of marbled murrelet juveniles (4-year mean = 0.56 ± SD 0.22 birds · km^{-2}) were nearly five times higher than densities of Kittlitz's murrelet juveniles (mean = 0.12 ± 0.12 birds · km^{-2}). However, the ratio of juveniles:adults was comparable or higher for Kittlitz's murrelets. The higher juvenile ratios may be due to the earlier exodus of Kittlitz's murrelet adults compared to marbled murrelets. Alternatively it might reflect a larger proportion of non-breeding marbled murrelets foraging in the bay.

The seasonal patterns of juvenile abundance were different between species. The density of marbled murrelet juveniles increased throughout August, whereas Kittlitz's murrelets appeared later, peaked in mid August, and then disappeared. Marbled murrelet adults also appeared to remain in the bay longer than Kittlitz's murrelet adults, and did not consistently decline in August such as has been observed in Prince William Sound. Our 2004-2007 surveys indicate that the best time to survey for juveniles on the water is generally August 10-23 for marbled murrelets, and August 10-16 for Kittlitz's murrelets. However, because there were inter-annual differences in juvenile temporal patterns, surveys would ideally be conducted 6 – 24 August for both species.

Based on our results, we encourage continued monitoring of the south inner bay for Kittlitz's murrelets and the entire south shore for marbled murrelets. To obtain peak numbers we recommend mid to late July surveys. Although it is logistically more difficult, the north outer bay shelf edge should also be monitored periodically. The periodic influx of murrelets into north outer bay likely came from the Lower Cook Inlet population, and this could be confounding our ability to detect trends for murrelets in Kachemak Bay alone.

Therefore, an extended survey in Lower Cook Inlet, ideally to replicate the 1993 survey, will be needed to gauge the status of the regional population.

Brachyramphus murrelets comprised 15 – 22 % of the total marine birds in Kachemak Bay in July, based on point estimates from our surveys. In July we identified 31 species of marine birds, and of those the only breeding seabird with a population estimate as high or higher than marbled murrelets was the common murre (*Uria aalge*). Sooty shearwaters (*Puffinus griseus*) and smaller numbers of short-tailed shearwaters (*Puffinus tenuirostris*) also had high estimates. The shearwaters breed in the southern hemisphere and visit pelagic waters of Alaska during summer, and their estimates were based on a few sightings of large groups in the outer bay.

In general, the southern shore of Kachemak Bay had the highest densities of all birds, although some species were also abundant in the north outer bay. Other common species in the bay included black-legged kittiwakes (*Rissa tridactyla*), glaucous-winged gulls (*Larus glaucescens*), and pigeon guillemots (*Cepphus Columba*). We did not test for trends in other species, but we suggest such analyses would be useful for management and ecosystem evaluation. Several species may have declined since 1993, including murres, kittiwakes, mew gulls (*Larus canus*), and horned puffins (*Fratercula corniculata*). The most commonly encountered marine mammal was the sea otter (*Enhydra lutris*), for which the mean June estimate for 2005-2006 was 33 % lower than the 1993 point estimate. We also observed harbor seals (*Phoca vitulina*), and occasionally recorded killer whales (*Orcinus orca*), harbor porpoise (*Phocoena phocoena*), Humpback whales (*Megaptera novaeangliae*), and minke whales (*Balaenoptera acutorostrata*). Distribution and abundance of selected species are provided in figures and tables in the appendix. All survey results were submitted to the North Pacific Pelagic Seabird Database.

INTRODUCTION

The marine avifauna of Kachemak Bay, Alaska, includes breeding populations of two unique species of seabirds, the Kittlitz's murrelet (*Brachyramphus brevirostris*) and the marbled murrelet (*B. marmoratus).* Both species differ from most other seabirds in that they do not nest in colonies, rather they nest dispersed in inland areas, either on old-growth tree branches (marbled murrlelet) or on the ground in rocky, alpine areas (Kittlitz's murrelet). As a result of this nesting behavior it is difficult to monitor their populations and little is known about their reproductive behavior or success. In 2004, population declines of the Kittlitz's murrelet led the U.S. Fish and Wildlife Service to designate it as a candidate species for listing under the Endangered Species Act (69 FR 24875 24904). The marbled murrelet, which is listed as threatened from British Columbia (Burger 2002) to California (McShane et al. 2004), is a species of management concern in Alaska (USFWS 2002, Piatt et al. 2007). Both murrelet species have most of their world population centered in Alaska. The accessibility of Kachemak Bay makes it an ideal location to determine population trends and habitat needs for both species. This project examined decadal trends of these murrelets in Kachemak Bay and determined the current population size and distribution within the bay. Our results lend support to the argument for listing of Kittlitz's murrelets as a threatened species.

The Kittlitz's murrelet is one of the rarest seabirds in North America, and 85 % of the world population is estimated to breed in Alaska (Day et al. 1999, USFWS 2007). Recent surveys indicate severe population declines since the 1980-90's of 75 – 90 %, in Prince William Sound (PWS), Kenai Fjords, Malaspina Forelands, and Glacier Bay (USFWS 2007). Kittlitz's murrelets are typically associated with glaciers, and often forage in the upper portions of fjords with substantial glacial outflow, even among brash ice (Day et al. 1999, 2003). The decline of Kittlitz's in the Gulf of Alaska may be linked to recent changes in coastal glaciers (Kuletz et al. 2003a).

Similar, though less drastic declines have occurred for the marbled murrelet, which is listed as threatened south of Alaska (Piatt et al. 2007). The marbled murrelet is unique among seabirds in its use of old-growth forests for nesting. For marbled murrelets, large-scale changes in breeding habitat have occurred around Kachemak Bay since the 1970's, due to decimation of forests by spruce bark beetles. Both the rapid recession of coastal glaciers (Arendt et al. 2002), and the unprecedented spread of spruce bark beetles (Berg et al. 2004), are associated with climate change. The occurrence in Kachemak Bay of environmental changes (glacial recession and beetle infestation), coincident with breeding populations of both *Brachyramphus* murrelets, allows us to examine potential population-level effects of climate change on these two upper trophic level species.

Because they do not nest in colonies, *Brachyramphus* murrelets are most readily monitored at sea. In Kachemak Bay, selected transects, primarily along the south shore, were surveyed for marine birds in 1988-89 (Kuletz 1989, 1996), 1993 (Agler et al. 1995) and 1996-99 (Abookire et al. 2000). Most of these projects were directed at the larger scale of Cook Inlet, but they confirmed that Kittlitz's murrelets were often found in the Grewingk Glacier outflow in Kachemak Bay. However, Kittlitz's were also observed in low numbers in other parts of the bay, suggesting that the historic transects provided an incomplete indication of population size for the entire bay. Nonetheless, the historic transects provided a baseline index to examine trends in the murrelet populations over the past decade.

Counts of juveniles at sea are an index of productivity for marbled murrelets (Beissinger and Nur 1997, Kuletz and Kendall 1998, Lougheed et al. 2002), and Kuletz and Piatt (1999) identified 'nursery areas' for juvenile marbled murrelets in Kachemak Bay. The occurrence of juveniles at sea is less well documented for Kittlitz's murrelets, in part because the juvenile plumage for this species has not been well described. Day et al. (2003) found no juvenile Kittlitz's murrelets in several fjords of Prince William Sound, and suggested that the species was not reproducing, perhaps a reason for their population decline. However, juvenile Kittlitz's were reported as occurring in Kachemak Bay during historic surveys (Kuletz 1996 and unpubl. data), and one of the few nests ever located was on a mountain above the bay (Piatt et al. 1999). Thus, Kachemak Bay supports breeding populations of both species, and historic data on juvenile abundance at sea was available for comparison to new data.

The Kachemak Bay population of Kittlitz's murrelet is probably the most readily accessible in the world, yet knowledge of the abundance or trends of Kittlitz's was less known at this bay than at more remote sites. This project collected data on abundance and distribution of all marine birds and mammals encountered during the surveys, but we focused on four objectives:

Objectives:

- Obtain current population estimates for Kittlitz's murrelets and marbled murrelets in Kachemak Bay.
- Determine decadal trends of Kittlitz's and marbled murrelets in Kachemak Bay.
- Track annual and seasonal patterns of abundance of adult and juvenile Kittlitz's murrelets and marbled murrelets in Kachemak Bay.
- Describe the distribution of murrelets within Kachemak Bay, and identify marine habitats used by murrelets.

In August 2004, this project was launched with support from Ecological Services, U.S. Fish and Wildlife Service (FWS), Anchorage, Alaska. The project was supported in 2005 and 2006 by cooperative agreements with the Division of Wildlife Conservation, Alaska Department of Fish and Game; Migratory Bird Management, FWS; and non-federal match partners (see Acknowledgements). In 2007, a fourth year of July and August data was obtained with support from Migratory Bird Management, FWS.

STUDY AREA

Kachemak Bay is a large bay located northeast of the Kennedy Entrance into Cook Inlet (Fig. 1); the latter is a large tidal estuary that exchanges water with the Gulf of Alaska via the Alaska Coastal Current (ACC). Near Homer, mean tide range is approximately 6 m, with a maximum of 8 m (Schoch and Chenelot 2004). Current velocities range from 3 to 6 knots and are strongly influenced by tidal phase (Okkonen et al. 2007). Kachemak Bay is divided into two basins, referred to as the inner and outer bays, separated by the Homer Spit, which extends 6 km from the north shore. Historically, the areas east of the Homer Spit (on the north shore) and Neptune Bay and extending to Bear Island (on the south shore), were categorized as the inner bay. Areas west of these landmarks extending to Bluff Point (on the north side) and to Point Naskowhak (on the south side) were categorized as the outer bay.

Based on more extensive oceanographic analysis, Speckman et al. (2005) extended the boundary of the inner bay along the south side to Cohen Island.

The inner bay is characterized by higher surface water temperatures, lower salinity levels, and highly stratified layers with high turbidity (Abookire 2000, Schoch and Chenelot 2004, Speckman et al. 2005). These marine features are largely the result of melting snow pack and glacial runoff along the south shore, and river runoff from the Fox River delta at the bay head, which flows westward along the north shore (Fig. 2). Okkonen et al. (2007) provided the most recent, detailed description of hydrography for the study area, which we summarize here. During most months, Kachemak Bay is warmer and fresher than Cook Inlet waters and the confluence of these waters at the bay mouth results in a denser, high-salinity water mass that forms a cyclonic cell and blocks ACC waters from entering the bay. However, cold saline water from the ACC periodically enters the inner basin at depth along the south shore when the differences between water masses is reduced, primarily during late summer and fall months. The outer bay is more directly influenced by the mixing of cold saline waters from the Gulf of Alaska, with periodic pulses of ACC water entering from the south. The predominate currents of the outer bay circle from south to north and do not enter the inner basin (Schoch and Chenelot 2004). As a result, the outer bay is characterized by cold, well-mixed, saline and clear waters. Turnover for water circulation in the bay is approximately one month, with prevailing currents leaving the bay along the north shore, although turbid, fresher water can also enter the northwest region of Kachemak Bay from upper Cook Inlet (Trasky et al. 1977). Ten-year averaged monthly water temperatures at Seldovia, on the outer south shore of the bay, ranged from winter lows of 1.1 to 4.7 ^{0}C, and summer highs of 9.9 to 12.1 ^{0}C (Okkonen et al. 2007). During the four years of our study, surface water temperatures ranged from a low of 4.7^{0}C in April 2005 to a maximum of 16.4^{0}C in August 2007.

Several species of colonially nesting seabirds nest on several islands in Kachemak Bay, with Gull Island having the largest number of nesting birds (Fig. 1). The most abundant colonial birds are black-legged kittiwakes (*Rissa tridactyla*) and common murres (*Uria aalge*). Other common species at the colonies include tufted puffin (*Fratercula arctica*) , pelagic cormorant (*Phalacrocorax pelagicus*), glaucous-winged gull (*Larus glaucescens*), and pigeon guillemots (*Cepphus columba*), and a variety of species in smaller numbers.

METHODS

To meet our objectives, our four main approaches were: 1) To obtain current population estimates, we designed a systematic survey of the entire bay during peak murrelet abundance in mid-July. 2) We examined population trends by replicating historic surveys, which occurred June through August. 3) From a compilation of all surveys we outlined seasonal patterns of abundance for both murrelet species, in particular the occurrence of juveniles on the water. 4) We mapped current distribution of murrelets within the bay, and used associated habitat characteristics to describe marine habitat use by murrelets.

Sampling Design

Historical data from Kachemak Bay were provided by the U.S. Fish and Wildlife Service (K. Kuletz), or the U.S. Geological Survey, Alaska Science Center (J. Piatt and S. Speckman). Data collected from 1988 to 1993 consisted of total numbers of birds counted along each transect. Transect end points for historic surveys were generally defined by major landmarks. Data collected since 1995 were GIS-based, so that each sighting is associated with a latitude and longitude. The majority of surveys in Kachemak Bay were conducted from 8-m Boston whalers, using two observers and a driver. All available data resulted from strip transect surveys, but transect widths ranged from 200m to 1000m (the latter in 1988 only). The 2004-2007 surveys were consistent in platform, protocol, and primary observers. The June set of transects were randomly selected (Agler et al. 1995), but selection was from a grid for a larger Lower Cook Inlet survey. Except for the July comprehensive surveys, the 2004-2007 surveys were designed to replicate transects and survey dates from the most complete historic surveys.

Population Estimates

Brachyramphus murrelet abundance shows strong seasonal patterns, making it imperative to compare data collected during similar time periods (Kuletz and Kendall 1998, Kuletz et al. 2003b). There were no historic surveys that covered all portions of the bay during mid July, which is typically a period of peak murrelet abundance in Alaska’s nearshore waters (Kuletz and Kendall 1998, Speckman et al. 2004). Furthermore, the 1993 June set of transects did not adequately cover the inner bay. In particular, few transects fell in the south inner bay. Therefore, to obtain a current population estimate and establish a baseline for future comparisons, we designed a July survey consisting of systematic transect lines throughout the bay at 4 km intervals (Fig. 3). These lines were selected by extending the same north-south longitude lines from a grid used to randomly select the 1993 FWS transects. To avoid over-sampling shoreline habitat in a bay with highly convoluted shoreline (G. Drew, unpublished data, USGS, Anchorage, Alaska), we did not include a shoreline strata, but did record birds in the zone from 0 - 200 m off shore separately, to accommodate future stratification. The July survey was comprised of twelve transects, which as measured from the GPS-derived track lines varied slightly among years (due to tide or weather effects on the boat's movements), and totaled approximately 188 km (38 km^2) each year.

Population Trends

For analysis of decadal population trends, we used two time periods – mid June (incubation period), and 25 July to 18 August (late chick-rearing and fledging period). The June surveys included one historic survey from 1993 and our recent surveys in 2005 and 2006. June surveys were comprised of transects within Kachemak Bay that were part of a 1993 FWS survey of Lower Cook Inlet (Agler et al. 1994), and included randomly selected transects from two strata: shoreline and pelagic. Because these were randomly selected transects we were able to estimate population size in addition to calculating densities. The June survey was comprised of 46 transects (Fig. 4) for a total of 166 km (33.3 km^2). Individual transect identification numbers are available in Appendix A-1.

We defined the late summer time period (25 July – 18 August) by making a preliminary examination of the seasonal changes in murrelet abundance from all available surveys. Surveys earlier than 25 July had variable and high numbers of murrelets, and after 18 August numbers declined quickly. The late summer surveys were divided into three regional strata, the inner bay, south outer bay, and north outer bay. These transects had been designed in the past to monitor abundance patterns and juvenile murrelet occurrence, and thus were established to optimize murrelet encounters (Kuletz 1989, Kuletz and Piatt 1999). The historic transects roughly paralleled the shoreline or zigzagged between shore and mid-bay, and used topographic features to delineate transect end points (Fig. 5A). Because these transects were not randomly or systematically selected they could not be used to derive population estimates, but could be used to compare murrelet densities (birds • km^{-2}). To analyze population trends during the murrelet fledging period, we considered a sample to be a set of transects in the same strata that could be surveyed in one day (hereafter, Transect Set). There were six late summer Transect Sets (Fig. 5B), with two in the inner bay – Inner South Shore and the Inner Zigzag, three in the south outer bay – Outer Zigzag, Outer South Shore, and Eldredge Passage, and one in the outer north bay – Outer North Shore. Individual transect identification numbers are shown in Appendix A-2.

Seasonal Patterns, Chronology, Productivity

We conducted surveys during April, June, July, August, and September for a total of 86 survey days over four years (Table 1). We used all surveys conducted from 2004 through 2007 to describe the seasonal patterns and chronology of both murrelet species. The most complete seasonal data within a given year was obtained in 2005. Data from that year describes seasonal patterns from April to September. In addition, murrelet occurrence in lower Cook Inlet was documented in September and October of 2005, in collaboration with oceanographic surveys by Dr. S. Pegau (Kachemak Bay National Estuarine Research Reserve). The Cook Inlet survey track lines were run opportunistically as the vessel transited among Homer harbor, the Barren Islands, Shuyak Island, Cape Douglas, Chinitna Bay, and Anchor Point.

Marine Habitat Use

We identified critical habitats for Kittlitz's and marbled murrelets in Kachemak Bay by combining at sea surveys with GIS bathymetric coverages and concurrent CTD sampling of the water column. Water column profiles and bathymetric data were used to describe marine features associated with areas of high murrelet density. Murrelet observations were mapped using ArcView GIS (ESRI, Redlands, CA). Habitat maps and satellite imagery were provided by the Kachemak Bay Research Reserve (primarily marine) and the Kenai Peninsula Borough Spruce Bark Beetle Mitigation Program.

At-sea Survey Protocol

The June survey took 4 - 5 days (depending on weather) and was done once each year (1993, 2005, 2006) between 16 - 20 June. The July survey took 4 - 6 days and also occurred once each year (2005-2007), between 18 - 25 July (Table 1). The late summer surveys of the six Transect Sets were conducted in 2004-2007 between 1 - 23 August. The number of survey days varied among years, with 2007 having the fewest survey days (Table 1). We used historic late summer surveys that were conducted between 25 July and 18 August. Each late summer Transect Set was surveyed 1 - 5 times each year (1988, 1990, 1995 – 1999, 2004-2007). We alternated survey days between inner and outer bays to reduce autocorrelation and bias from seasonal changes in murrelet abundance. Transect Sets with multiple surveys in a given year were typically spaced at 3 - 8 day intervals. To obtain information on seasonal patterns of murrelet abundance, in 2005 we conducted several surveys ancillary to the ones used for population estimates and trends. We surveyed a subset of the Inner South Shore transects (no. 8801 - 8804) on 24 April, 20 June, 24 July, and 2 September. We also surveyed the Eldredge Passage Transects Sets on those dates, with the exception of 20 June.

Surveys were conducted from an 8-m fiberglass boat traveling approximately 10-20 km • hour^{-1}, with observers using standard USFWS strip transect protocol (Kendall and Agler 1998) with some modifications to accommodate murrelet surveys (Appendix B-1). Surveys were conducted between 0700 and 1700 hours, by crews consisting of two observers and one boat driver. Two observers stood on opposite sides of the boat and used 10x42 binoculars to record all birds and mammals observed within 100 m of the boat. Species' behavior at the time of the observation was recorded as on water, in air, on land, foraging, or in a forage flock. We considered murrelets to be actively foraging if they were observed forage diving (crouched in a deep-dive position and subsequently diving, with a different behavior from avoidance diving), associated with a feeding flock, chasing fish to the surface, or bringing fish to the surface. Observations of birds holding fish were used to determine diet when possible and as an indication of chick-feeding activity. All vessels (boats and kayaks) present on transect were recorded, and vessels within 100 - 500 m of the transect line were recorded as present but off transect.

We used GIS to incorporate the historic and the new July track lines into the DLOG program (R.G. Ford, Inc., Portland, OR), and then used the vessel's navigation system to follow those lines during surveys. The observers entered sightings directly into a laptop computer using DLOG survey software and integrated with a Global Positioning System (GPS). The system logged an associated latitude and longitude for each recorded observation, and automatically wrote to record location data at 20 second intervals to track our effort. DLOG allowed us to map precise locations of observed birds for *post hoc* analysis of habitat use, but we continued to record historic transect reference numbers to allow comparisons for the decadal trends component. Occasional deviation from the transect route was necessary for murrelet identification, or more commonly during late summer surveys, for age-class confirmation. When this occurred we ceased survey effort, entered a waypoint into the navigation system, and went off transect to get a better look at the bird. The distance traveled during this time was not included in the transect route used later to calculate birds • km^{-2}. After age class or identification was confirmed, the vessel would return to the waypoint and we resumed surveying "on transect" (see Appendix B-1).

We recorded all birds and mammals encountered on the transect, and recorded as off transect any unusual sightings (i.e., rare species of birds or mammals, or large groups). Off-transect sightings were not included in density calculations but were used for mapping distribution of rare species. For each murrelet or murrelet group we also recorded the bird's estimated distance from the boat in 25 m incremental bins, plumage class, age category, and group size.

Juvenile identification – Observers were trained to distinguish after-hatch-year birds, heareafter referred to as 'adults', and hatch-year birds, hereafter referred to as 'juveniles'. Thus, for this report adults include an unknown proportion of immature birds (approximately 1-3 years old; Day et al. 1999), which can not be distinguished in the field from mature, breeding age birds. We used established identification criteria for marbled murrelet juveniles (Carter and Stein 1995, Kuletz and Kendall 1998), and also developed photographic field guides to assist observers (Appendix B-2). There was little information available on identification of Kittlitz's murrelet juveniles. To enable this and future surveys to identify juvenile Kittlitz's murrelets we made extensive visual observations of suspected juveniles.

We also examined study skins and photographs taken of known Kittlitz's murrelet chicks and fledglings, and developed photographic field guides for this species (Appendix B-2).

Ancillary Surveys

Lower Cook Inlet Surveys. -- One observer stationed on the bridge of the *F/V Columbia* surveyed for marine birds and mammals using standard FWS protocol and entered observations into a laptop equipped with DLOG and GPS. This vessel was larger than our standard platform (approximately 14 m in length and 4 m above the water), so the observer counted all birds and mammals within 150 m of one side (port) of the vessel. We used ArcGIS to plot observations (Appendix D).

Nighttime activity. -- On August 23, 2004 between 2230 and 0500 hours we used a spotlight to search for murrelets at night. We covered an area where we had observed high densities of adult and juvenile Kittlitz's during our daily surveys. From Glacier Spit to Aurora Lagoon we traveled parallel to the shoreline at 100 m and 200 m off shore in a zigzag pattern.

*Inland juvenile search***. --** Russian scientists have suggested that newly fledged Kittlitz's murrelets fledge to upland glacial lakes, which may explain low encounter rates of juvenile birds at sea early in the fledging period (T. Van Pelt, pers. comm.). To explore this possibility we hiked to the most likely and accessible lake in Kachemak Bay during a time when fledging should have begun. We were ferried between the Homer boat harbor and Glacier Spit on the south side by one of our project partners, Cook Inlet Keeper. During 25 – 26 July 2005, we conducted a land-based recognizance survey of Grewingk Glacier Lake, 4 km inland of the Grewingk Glacier outflow into Kachemak Bay. Four observers spent two days canvassing the area with spotting scopes and binoculars.

Marine Habitat Use

Survey Conditions and Environmental Data -- Environmental variables were recorded at the start of each transect, and at pre-selected intervals during long transects. We recorded start time, weather and sea conditions, water clarity (Secchi disk), surface salinity, sea surface temperature (Salinity meter), wind speed (Kestrel wind gauge) and air temperature, and overall observation conditions.

Hydrographic surveys.- During the June and July surveys we conducted hydrographic surveys using a CTD (Conductivity-Temperature-Depth) probe (Seabird Electronics Inc., SBE 19 SEACAT), fitted with an additional sensor to measure turbidity. Sampling effort for the CTD varied among years and months. Immediately following the June surveys of 2005 and 2006 we sampled a line of 11 CTD stations, at 4 km intervals, running east-west down the middle of the bay (Fig. 6). Following the July surveys in 2005 and 2006 we sampled 9 lines running north-south, at roughly 4 km intervals, for a total of 32 stations. In 2007 we sampled 3 north-south lines, two in the inner bay and one in the outer bay (Fig. 6). Dr. Scott Pegau of the Kachemak Bay National Estuarine Research Reserve also provided us with his CTD data. He sampled a line, referred to as the Barabara line, which ran across the outer bay from Bluff Point on the north to Barabara Point on the south (Fig. 6). The Barabara line was sampled in June and July of 2005 and July and August of 2006. Stations were spaced 1 nautical mile (nm) apart; the closer spacing of sample stations provided a more detailed water profile. The CTD used for the Barabara line included an ancillary flourometer sensor, which provided an indication of chlorophyll *a*, and thus of primary productivity. We also sampled the Barabara line using Dr. Pegau's stations in July 2007, but did not have access to a flourometer.

We used the vessel's navigation system to locate each station and record a depth reading. The CTD was flushed with distilled water and a 10 km weight tied to a 1 m line at the end to reduce flagging of the CTD in the currents. Before lowering the CTD it soaked for 1 min at 1 m below surface. We then lowered the CTD at approximately half meter a second until it reached a depth 5 – 10 m from bottom, or it reached 200 m. A mechanical winch was used to maintain a steady lowering and raising speed. Data from the CTD was downloaded onsite and processed later by Dr. Scott Pegau and E. Labunski.

Data analysis

Population Estimates

We used ArcGIS software to analyze daily track lines to calculate the kilometers traveled, which resulted in slight variations in transect lengths among surveys of the same lines. Daily transect lengths were multiplied by transect width (0.2 km) and converted to km^2, and these area values were used to calculate bird densities (birds • km^{-2}). We present densities and numbers of birds for marbled murrelets, Kittlitz's murrelets, unidentified *Brachyramphus* murrelets and total *Brachyramphus* murrelets. The July transects bisected several seabird colony islands, and we did not have time to do a complete census of colonially nesting birds. The seabirds rafting and flying near the colonies skewed the at-sea counts. For the July survey only, we therefore used GIS to create a 400 m radius buffer around the colonies in the Gull Island complex and Sixty Foot Rock, and did not include birds within that buffer in our transect density calculations.

The study areas used to extrapolate densities to population estimates were separated using ArcGIS between inner and outer bay areas (Fig 4). Because the June surveys replicated the two strata used for the 1993 surveys, for the June surveys we also used ArcGIS to separate areas into a 200 m buffered shoreline strata and a pelagic strata. The shoreline strata included waters 0-200 m from shore (total of 57.84 km^2) and pelagic strata were waters >200 m from shore (total of 742.79 km^2).

The areas used to extrapolate bird densities to population estimates totaled 815.64 km^2 for all of Kachemak Bay, with 315.9 km^2 in the inner bay and 499.74 km^2 in the outer bay. For the June data we used a ratio estimator to estimate population sizes and variances for each stratum (shoreline and offshore) and for inner, outer, and entire bay. For each region, we summed the estimates of the strata, and added the variances of the estimates to obtain 95% confidence intervals (Cochran 1977). For July surveys we did not stratify habitats, and included all waters to shoreline. We again used a ratio estimator to estimate population sizes, and variances reflect spatial variation in bird densities among 12 transects. We estimated both June and July population sizes with and without flying birds. For June we present estimates using all birds, to insure the best comparison with 1993 data. For July we present estimates for murrelets both with and without flying birds.

Population Trends

We minimized seasonal variability in counts by limiting data analysis to the same time window for any given set of transects. Analysis of these congeneric murrelets is complicated by the fact that they are difficult to separate in the field. The proportion of birds that fell into the unidentified category tended to decline in later years. This trend in species identification can confound detection of species-specific population trends. We therefore analyzed trends for four species groups: Kittlitz's murrelets, marbled murrelets, unidentified *Brachyramphus* (birds identified only to genus), and total *Brachyramphus* murrelets (identified and unidentified combined).

For the late summer changes in population trends we could only examine murrelet densities. Changes in murrelet density over time were modeled with least-squares linear regression. The slope of the regression was tested for a significant deviation from zero at the alpha 0.05 significance level, indicating either a positive or negative significant change. Changes in density over time were modeled as the natural logarithm of that year's count converted to a percentage of the initial or first year's count (R. Stehn, USFWS, pers. comm.). The slope of a least-squares linear regression through the transformed counts is the growth constant (positive slopes) or the decay constant (negative slopes). The slopes of these regressions were also tested for significant deviations from zero at the alpha 0.05 significance level. The per-annum percent change in the population (indexed by the density) was derived from the back-transformed best-fit slope of the regression (R. Stehn, pers. comm.).

Trends analyses were performed for each Transect Set in Kachemak Bay, 1988 - 2007 for surveys conducted between 25 July and 18 August. The analyses were done for all murrelet categories except Kittlitz's murrelets in the outer bay; only a few Kittlitz's (0 - 2 % of total Kittlitz's) occurred in the outer bay and a single sighting in a given year skewed analyses, thus a test of Kittlitz's murrelet trends in the outer bay would not be statistically valid or biologically meaningful. We also compared murrelet densities between two decadal time periods, 1988-1999 (historic) and 2004-2007 (recent). We tested for differences in murrelet densities between time periods with a Wilcoxon Rank Sum test, and we did this for the entire bay and for the inner and outer bay regions separately.

Archiving of survey data. -- All survey data were prepared and formatted for entry into the North Pacific Pelagic Seabird Database (NPPSD; USFWS, Anchorage). To complete this task, we contracted with Dr. M. Renner (University of Washington, Seattle) who developed a conversion program in 'R'. For preparation for the NPPSD, our survey lines and observations were binned into transect lengths of 3 km. We also ran the program to bin observations into 1 km lengths for future fine-scale analyses.

Seasonal Patterns, Chronology, and Productivity

Seasonal changes in murrelet density or population estimates were graphed to examine temporal patterns of murrelets in Kachemak Bay. For both adult and juvenile murrelets, we standardized daily densities during late summer as a proportion of the year's maximum density, graphed over time, and separated into inner and outer bay regions. The numbers of birds holding fish, indicative of chick-rearing, were graphed by weekly time periods, using the combined observations from 2004-2007.

Productivity indices were obtained from the densities of juveniles observed on late summer transects, and the ratios of juvenile:adult murrelets (hereafter, juvenile ratios) during a day's survey. We used the juvenile murrelet density from each survey day to test for differences among years and regions. We tested for differences in juvenile densities and juvenile ratios among years and regions (inner vs outer bay) with ANOVA, with alpha = 0.05 as significant.

Marine Habitat Use

Data from the CTD was processed using standard SeaBird processing alogorithms by Dr. Pegau (details in Okkonen et al. 2007). The station location, date, time, water depth, and associated data were used to plot the data on conductivity, temperature, and density throughout the water column. The final analysis provided water profiles for temperature (^{0}C), salinity (psu), and an index of turbidity. Turbidity is shown as Obs[V], based on transmissometer voltage (tran[v]), or as c650[/*m*], which is calculated from the tran[v] to calibrate between different instruments; the two values use different scales, so the magnitudes can not be compared, however the patterns of turbidity that they depict are comparable. The Barabara line also included productivity as indexed by fluorescence (fluor[V]). To describe the hydrography of our study areas for this report, we used the lines with the best resolution, multiple sampling periods or years, and lines that ran across areas with both high and low murrelet densities. The selected lines included July sampling of lines 2 and 3 in the inner bay, and in the outer bay, line 12 and the Barabara line (Fig. 6). Data from the remaining stations was archived for future fine-scale analyses.

RESULTS

Results for Other Species

June and July population estimates for all species encountered are presented in Appendix E-1 and E-2, respectively. Distribution maps for selected species or species groups in July are presented in Appendix F. For the more abundant species, we mapped the results of the July 2006 survey as representative of species distribution. For less abundant species we present all three years of July surveys, or include multiple species for 2006 only. The complete data set will be archived in the NPPSD.

In June we recorded 34 identified species of birds and 3 species of marine mammals (Appendix E-1). Common murres (*Uria aalge*), marbled murrelets, black-legged kittiwakes (*Rissa tridactyla*), and glaucous-winged gulls (*Larus glaucescens*) were the most abundant species in June, although there were a few groups of sooty shearwaters (*Puffinus griseus*) in the outer bay that resulted in high population estimates for this visitor from the southern hemisphere.

Brachyramphus murrelets comprised 15 – 22 % of the total marine birds in Kachemak Bay in July, based on point estimates from our surveys. In July we identified 31 species of marine birds and 4 species of marine mammals (Appendix E-2). Of identified birds, the only breeding seabird with a population estimate as high or higher than marbled murrelets was the common murre. Sooty shearwaters and smaller numbers of short-tailed shearwaters (*P. tenuirostris*) also had high estimates, but these were based on a few large groups. In general, the southern shore of Kachemak Bay had the highest densities of all birds, although some species were also abundant in the north outer bay. The north side of the inner bay was mostly devoid of birds except near the Homer Spit. Other common species in July included black-legged kittiwakes, glaucous-winged gulls, and pigeon guillemots (*Cepphus columba*).

We did not test for trends in June populations for species other than murrelets, but the population estimates suggested that several species may have declined since 1993, including murres, kittiwakes, mew gulls (*Larus canus*), and horned puffins (*Fratercula corniculata*). The most commonly encountered marine mammal was the sea otter (*Enhydra lutris*), for which the mean June estimate for 2005-2006 was 33 % lower than the 1993 point estimate. We also observed harbor seals (*Phoca vitulina*), and occasionally recorded killer whales

(*Orcinus orca*), harbor porpoise (*Phocoena phocoena*), Humpback whales (*Megaptera novaeangliae*), and minke whales (*Balaenoptera acutorostrata*).

Results for *Brachyramphus* murrelets

During our 2005-2006 June surveys we counted 237 murrelets ‘on transect’, of which Kittlitz’s were 0 – 4 %, marbled murrelets were 100 - 92 %, and unidentified *Brachyramphus* were 0 – 4 % (2005 and 2006, respectively). During the 2005-2007 July surveys we counted 2,057 murrelets, with Kittlitz’s ranging 9 – 21 % of the total, marbled murrelets ranging 74 – 82 %, and unidentified *Brachyramphus* ranging 5 – 11 % (mean = 6.3 %). During the 2004 - 2007August surveys we counted 12,676 murrelets on transect, with unidentified *Brachyramphus* comprising between 3 % (2006) and 10 % (2004) of total murrelets. In August, Kittlitz’s murrelets ranged from 4 to 24 % of total murrelets and marbled murrelets ranged from 73 to 85 % of total murrelets. See Appendix C for murrelet densities on individual transects.

Current Population Estimates

June. -- Population estimates were higher for both murrelet species in June of 2006 than in June 2005 (Table 2). No Kittlitz’s murrelets were observed during the June 2005 survey, but 8 were observed during the June 2006 survey, which resulted in a population estimate in 2006 of 319 ± 435 95% CI. The marbled murrelet population in June was estimated at 3,651 ± 1823 in 2005 and 7,312 ± 4376 in 2006. For both species, over 96 % of the estimated population occurred in waters > 200 m from shore; only 1 % of marbled murrelets and 2 – 4 % of Kittlitz’s murrelets were in the ‘shoreline’ strata. In 2005 and 2006 the estimated population of marbled murrelets was greater in the outer bay than in the inner bay, whereas Kittlitz’s murrelets were entirely in the inner bay in June (Table 2). Note that the inner and outer bay population estimates were not exactly the same as the estimates derived from applying densities of all transects to the area of the entire bay.

July. -- For both murrelet species, the highest population estimate was obtained in July (Table 3). The marbled murrelet population in July declined each year between 2005 and 2007, although the decline was not statistically significant. The July population of Kittlitz’s murrelets was highest in 2006 and lowest in 2007 (Table 3). The maximum population size (without flying birds) was estimated at 11,355 ± 4546 95% CI for marbled murrelets in 2005 and 3,108 ± 2932 for Kittlitz's murrelets in 2006. Based on the annual point estimates, the average July population estimate over three years (2005-2007) was 10,595 (SD ± 964) for marbled murrelets and 1,937 (SD ± 1075) for Kittlitz's murrelets.

Population Trends

Trends in Murrelet Population Estimates

June surveys indicated a decline in total *Brachyramphus* murrelets of 32 % between 1993 and 2005, a per annum decrease of -2.7 %. However, the 2006 population estimate was higher than in 1993 (Table 2), and there was no change in trend for total *Brachyramphus* murrelets from 1993 to the 2005-2006 estimates.

For July population estimates we found no significant trends between 2005 and 2007, although the 2007 estimate was the lowest among these three years for both murrelet species (Table 3). The 2007 estimate for marbled murrelets was 84 % of the highest estimate in 2005, and the Kittlitz's murrelet estimate was only 32 % of the 2006 estimate.

Trends in Murrelet Densities

Compared to historic late-summer murrelet densities, the August 2004-2007 densities declined for Kittlitz's murrelets in the inner bay (Inner South Shore and Inner Zigzag Transect Sets), but increased or remained stable for marbled murrelets (Fig. 7A&B). The increase in marbled murrelets is significant in the Inner South Shore Transect Set, but this is concurrent with a significant decrease in unidentified murrelets (Fig. 7A). Because marbled murrelets were always numerically dominant, most unidentified murrelets were likely marbled murrelets, and because identification of species improved over time, results must be examined in conjunction with results for unidentified murrelets and total *Brachyramphus* murrelets. The apparent increase in marbled murrelets is likely an artifact of the much higher percentage of unidentified *Brachyramphus* murrelets in historic surveys. Total *Brachyramphus* densities in August showed no trend in the Inner South Shore (Fig 7A). In the outer bay, marbled murrelets and total murrelets increased, but not significantly (Fig. 7C&D). For identified murrelets, the highest per annum change was -18 % for Kittlitz's murrelets in the inner bay (Fig. 7B, Inner Zigzag). The highest per annum changes for total

Brachyramphus murrelets were a -6 % decline per year in Eldredge Passage (7E), and a 6 to 8 % increase per annum in the north and south outer bay (Fig. 7C,D,F).

In summary, for identified murrelets during August surveys, in the inner bay Kittlitz's murrelets declined and marbled murrelets increased or remained stable (Table 4). Total *Brachyramphus* remained stable or declined in the inner bay and in Eldredge Passage area, but increased in the outer bay (Table 4). The only statistically significant trend was the increase in marbled murrelets in the Inner South Shore, but this was confounded by the significant decrease in unidentified murrelets.

Between the two decadal periods (1988-1999 and 2004-2007), Kittlitz's murrelet densities declined significantly in the inner bay and in the entire bay (Table 5). For the entire bay, Kittlitz's densities declined by 43 % and in the inner bay 20 % between decadal periods. Total *Brachyramphus* densities increased significantly in the outer bay, however, murrelet densities in the outer bay were never > 20 % of densities in the inner bay (Table 5), and the change in densities for the entire bay was not statistically significant. The apparent increase in marbled murrelet densities is, again, likely due to the concurrent decline in unidentified *Brachyramphus* as identification rates improved over time.

Seasonal Patterns, Chronology, and Productivity

Seasonal Patterns of Abundance

Based on the 2005 surveys of selected south shore transects, both murrelet species were present but in very low numbers in April (Fig. 8). During the April survey we recorded only two Kittlitz's murrelets in basic (winter) plumage, and six marbled murrelets in basic or transitional plumage. Murrelet densities increased in June (except for Kittlitz's murrelet in 2005), peaked in late July, and declined by mid August (Fig. 9). By mid-June, there was little change in abundance of Kittlitz's murrelets, but marbled murrelets had increased to roughly half of their peak July numbers. In July marbled murrelets reached a density of 32.14 birds • km^{-2} in the inner bay and 44.80 birds • km^{-2} in the outer bay. Peak Kittlitz's murrelet densities also occurred in late July, at 10.71 birds • km^{-2} in the inner bay. Kittlitz's were not recorded in the outer bay during the 2005 surveys. Both species declined by nearly half by mid August. By early September, only a few Kittlitz's murrelets were recorded (0.24

birds • km^{-2} in the inner bay) and densities of marbled murrelets were lower than in June, with 8.63 and 2.73 birds • km^{-2} in the inner and outer bay, respectively.

We found a similar seasonal pattern in the densities recorded during the more comprehensive population surveys in June and July, and the August surveys of 2004-2007. Densities of both murrelet species increased between mid June (Table 2) and late July (Table 3), and then decreased in August (Table 4 and Appendix C). Kittlitz's murrelets were either not present or occurred in low numbers in June, whereas marbled murrelet densities were comparatively high by June.

Adult patterns of abundance in August. -- We were able to examine changes in murrelet densities throughout August in more detail because of the more intensive survey effort during the murrelet fledging period. In August, adult Kittlitz's murrelets (Fig. 10), were almost exclusively in the south inner bay, and they peaked around 10 August and declined abruptly after 16 August (with a less abrupt decline in 2005). In contrast, changes in marbled murrelet numbers during August varied among years, with peak numbers ranging from early August (in 2005) to mid August (in 2004). In general, marbled murrelets also had less drastic declines in late August (Fig. 10). Marbled murrelet densities were always greater in the inner bay, and their presence in the outer bay during August was highly variable, ranging from 66.69 birds • km^{-2} (4 August 2004) to 1.64 birds • km^{-2} (22 August 2005). Marbled murrelets showed no clear pattern of increasing or decreasing in the outer bay during August; in 2005 and 2007, numbers generally increased with date, whereas in 2004 and 2006, their numbers generally decreased with date (Fig. 10).

Murrelet Chronology

Between 2004 and 2007, observations of birds holding fish, indicative of chick rearing, were recorded during surveys on 28 and 56 occasions for Kittlitz's and marbled murrelets, respectively. Of these, two of the Kittlitz's and three of the marbled murrelets were juveniles feeding themselves. Omitting the juvenile birds, the number of birds holding fish was high throughout the first half of August, after which only 7 marbled murrelets and no Kittlitz's murrelets were observed holding fish (Fig. 11). The first observation of fish-holding was 19 and 20 July for marbled and Kittlitz's murrelets, respectively. The last observation of fish-holding was 16 and 23 August for Kittlitz's and marbled murrelets, respectively, but August 23 was our latest survey date.

Our earliest observations of newly fledged marbled murrelets were between 2 and 8 of August, but the late sighting was also our first late summer survey in 2007. The density of marbled murrelet juveniles in August ranged from a high mean of 0.79 (SE ± 0.21) birds • km^{-2} in 2004 to a low mean of 0.27 (SE ± 0.06) in 2007. Among years there was no clear pattern in the occurrence of juvenile marbled murrelet densities, with peak densities recorded as early as 7 August and as late as 23 August (Fig. 12). The earliest observation of juvenile Kittlitz's murrelets was 5 August and peak juvenile densities occurred between 8 and 16 August (Fig. 12).

Because of the low numbers of juveniles and the lack of a strong pattern within years for both species, we combined observations for all four years (August surveys of 2004-2007) and examined seasonal patterns of juvenile abundance in 5-day periods (except for the last period, which included only 3 days; Fig. 13). At this coarser temporal scale, marbled murrelet juveniles show increasing densities throughout August, with the highest densities occurring August 21-23. Kittlitz's murrelet juveniles show a very different pattern, with very low densities before 10 August, a pronounced peak in 11-15 August, and a rapid drop off of juveniles afterwards (Fig. 13).

Murrelet Productivity Indices

Mean annual marbled murrelet juvenile densities were nearly five times, and significantly higher, than those of Kittlitz's murrelets (Wilcoxon Rank Sum test; $Z = -6.9254$, $P = 0.001$). However, juvenile:adult ratios were comparable or even higher for Kittlitz's murrelets (Table 6). When juvenile densities were tested as a function of year and region (inner vs. outer bay), only region showed significant differences. Marbled murrelet juvenile density was significantly higher in the outer bay (ANOVA; $F_{1,63} = 11.86$, $P = 0.0010$). Kittlitz's murrelet juvenile density approached significance, with higher densities in the inner bay, but more variance (ANOVA; $F_{1,63} = 3.36$, $P = 0.071$).

For marbled murrelets, annual mean juvenile density was highest in 2004 and lowest in 2007 (Fig. 14). For Kittlitz's murrelets, juvenile density was highest in 2006 and lowest in 2005, with a pattern of alternating years (Fig. 14). For Kittlitz's murrelets, juvenile:adult ratios were extremely low in 2006 and relatively high in 2007 (Fig. 14). Marbled murrelet juvenile:adult ratios did not vary as drastically among years, and were highest in 2006 and lowest in 2007 (Fig. 14).

Distribution and Marine Habitat Use

Adult Distribution

In April, the few murrelets observed during surveys along the south shore occurred primarily in the inner bay, although one marbled murrelet was recorded near Hesketh Island (Fig. 8). In June, marbled murrelets were distributed throughout the bay, but were absent from most of the shoreline and mid-bay transects in both years (Fig. 15A,B). No Kittlitz's murrelets were recorded in June 2005, and the few Kittlitz's observed in June 2006 were offshore in the inner bay and in Halibut Cove Lagoon (Fig. 15C).

During the more comprehensive July surveys, marbled murrelets were generally found throughout the inner bay east of Halibut Cove, and in the outer bay in the Eldredge Passage area (especially in 2007) as well as across the bay mouth (Fig. 16). In all years, particularly in 2007, few marbled murrelets were observed in the center and deepest part of the bay, an area roughly 4 km east of and 12 km west of the Homer Spit. Kittlitz's murrelets were more restricted in distribution (Fig. 17), and in July of 2005 and 2007, nearly all Kittlitz's were observed on just three transects in the inner bay between Glacier Spit and Bear Cove. In contrast, in 2006 Kittlitz's murrelets were observed on these same transects, but also in the north outer bay. For all three July surveys combined, approximately 98 % of all Kittlitz's murrelets were found within these two 'hot spots'. The hot spot in the south inner bay was approximately 75 km^2, and included the deeper waters of the inner bay, which were < 20-60 m deep (Fig. 18). The outer bay hot spot (at least in 2006), was approximately 128 km^2 and included the more shallow waters of the outer bay, approximately 20-40 m deep (Fig. 18). In 2007, Kittlitz's murrelets were highly aggregated from shore to < 2 km off of Aurora Lagoon, in water 20-60 m deep (Fig. 17, 18).

Between 2005 and 2007, the (non-significant) decline in marbled murrelets was primarily evident in the much lower numbers in the inner bay in 2006 and 2007, concurrent with slight increases in the outer bay (Fig. 19). The Kittlitz's murrelet population was highest in 2006, due almost entirely to an increase in the outer bay (Fig. 19).

During August, surveys were primarily conducted in the southern half of the bay, with the exception of two transects along the north outer shore. August patterns of distribution were consistent among years. As an example, in August, 2005, marbled murrelets were found throughout the inner and outer bay, including the north outer transects (Fig. 20). During the same surveys, Kittlitz's murrelets were almost exclusively in the south inner bay (Fig. 20), showing a distribution similar to what we observed in June of that year.

During the ancillary surveys conducted in Lower Cook Inlet, we found low murrelet abundance in September and October of 2005. In September, marbled murrelets were observed in the north outer bay and to a lesser extent off of Anchor Point (Appendix D), with densities of up to 3.59 birds $\cdot$ km^{-2} (Appendix E-3). Murrelets were also observed on the south side of the bay mouth near Port Graham, with densities of up to 1.40 birds $\cdot$ km^{-2}. In October, fewer murrelets were recorded off of Anchor Point (Appendix D), with a total *Brachyramphus* density of 0.89 birds $\cdot$ km^{-2} for that area (Appendix E-3). We did not observe *Brachyramphus* murrelets elsewhere in outer Kachemak Bay during these fall surveys.

Juvenile Distribution

Marble murrelet juveniles were found along the south outer bay and the south inner bay in roughly equal proportions, with few juveniles in the central region of the south shore or in the north outer shore (Fig. 21). Kittlitz's murrelet juveniles were found primarily in the same area as Kittlitz's adults, between Glacier Spit and Aurora Lagoon, and generally < 1.5 km from shore (Fig. 22). However, for 2004-2007 combined, 25 % of observed Kittlitz's juveniles were recorded farther west along the south side, from the Eldredge Passage area to the mouth of Seldovia Bay, and one near the outer north shore.

During our inland search of Grewingk Glacier Lake, we did not observe any Kittlitz's murrelets. We did however observe approximately 2,000 – 3,000 glaucous-winged gulls on rocky islands in the lake. There were also a few dispersed breeding pairs of arctic terns (*Sterna paradisaea*) nesting along the lake edges.

Foraging Observations

Murrelets that were recorded as actively foraging during our surveys were concentrated in the south inner bay within ~ 2 km from shore (Fig 24). Marbled murrelets were also foraging near shore along the south outer shoreline and islands of Eldredge Passage, and in scattered locations in the north outer bay and bay mouth (Fig. 23). Actively foraging Kittlitz's murrelets were almost entirely in the south inner bay, again within ~2 km of shore (Fig. 24). Marbled murrelets sitting on the water's surface holding fish (indicative of chick-feeding) were observed in the south inner bay between Glacier Spit and Bear Cove, in Halibut Cove, and the Eldredge Passage area, with roughly equal numbers of birds in the inner and outer bay (Fig. 25). All but two Kittlitz's murrelets that were observed holding fish were in the south inner bay, between Glacier Spit and Aurora Lagoon (Fig. 25).

Of the 56 fish held by marbled murrelets, 9 fish were identified, including 8 sand lance (*Ammodytes hexapterous*) and 1 juvenile Pacific herring (*Clupea pallasii*). The fish ranged from 2 to 7 eye-to-bill tip length (mean = 23 mm; Kuletz 2005), indicating that fish were 46 – 161 mm in length. Of the 28 fish held by Kittlitz's murrelets, 6 were identified and all were sand lance, ranging in size from 4 to 7 eye-to-bill tip length (27 mm; Kuletz unpublished data), indicating fish lengths of roughly 108 – 189 mm.

Murrelet Distribution and Bathymetry

The water depths within our July transect (using a 200 m^2 buffer for the transect) were similar to water depths for the entire bay, based on GIS summaries of depth classes (Fig. 26), indicating that the transects were representative of available water depth classes within the bay. During July surveys, both murrelet species showed differences among years in their distribution relative to water depths, although these were not statistically different from expected use. Marbled murrelets were primarily in water < 40 m deep in 2005 and 2006, but were equally distributed in 41-80 m depths in 2007, and showed some use of waters 81-120 m deep in 2007 (Fig. 27). Kittlitz's murrelets were in water 0 – 80 m deep, although in 2006 the majority (78%) were in waters < 40 m (Fig. 26). For the three years combined, marbled murrelets were found primarily in water depths of < 40 m (59%), followed by 41-80 m (33 %), and the remaining birds in waters > 80 m deep (mainly in 2007). Kittlitz's murrelets were found in roughly equal proportions in water depths of < 40 m (49 %), 41-80 m (51 %), and < 1 % in deeper water.

Water column characteristics

Inner vs. outer bay in July 2006. -- In 2006 the water column in the outer bay (line 12; Fig. 6), was well mixed whereas the inner bay (lines 3 and 2; Fig. 6) was highly stratified (Fig. 27). Line 12 had a weak frontal signal in the upper portion of the water column along the north shore (Fig. 27, top row), with slightly warmer, fresher water on the north side and warmer temperatures to depths of about 25 m, over the shelf. In the inner bay off of Glacier Spit (line 3), a warm, fresh surface layer of 5-10 m depth was evident throughout, and water < 8^0C was 25 – 50 m deep (Fig. 28, middle row). Turbidity, however, was very different along the north-south gradient in the inner bay. On the north side, water was turbid to the bottom (20 m) near shore, and to a depth of at least 10 m towards mid-bay. On the south shore, the surface layer of turbid water was < 2 m deep, with very clear water below 5 m. This clear water extended to the bottom near the south shore and to mid-bay before meeting the tongue of turbid water from the north. Off of Aurora Lagoon (line 2), the pattern was similar to line 3, except that colder water < 8^0C was higher in the water column, at 10 – 20 m depth. In addition, the turbidity along the north shore was more complicated, with thin, multiple layers of turbid and clear water (Fig. 27, bottom row).

Inner bay in July 2007. -- In July 2007 we increased the number of CTD stations along lines 3 and 2 in the inner bay to improve resolution. Although there were minor differences from 2006, the basic patterns were the same, with highly stratified waters and a shallow (< 5 m depth) thermocline (Fig. 28). In 2007, however, the cold water extended from the bottom to higher in the water column along both lines, and water < 7^0C extended up to 20 m from the surface along the south side (Fig. 28, left column). Off of Glacier Spit (line 3), a thin turbid layer went to 5 m, with clearer water below extending to the sea floor. On the north side of line 3, in addition to surface turbidity, there were at least two layers of turbid water extending to mid-bay. Off of Aurora Lagoon (line 2), the south shore had moderately clear water to about 15 m depth, and at least three discreet layers of turbid water, with the bottom layer of turbid water starting at about 35 m on the south side and 25 m on the north side (Fig. 28, right column).

Inter-annual comparison in the outer bay. -- The Barabara line is 4 km east of line 12 in the outer bay, and crosses the north outer bay ‘hot spot’ where murrelets were occasionally abundant. This area had well defined fronts in July of 2005, 2006, and 2007, particularly on the north side. The north side front of turbid, fresh, warm water flows over a relatively shallow underwater shelf that is approximately 30-40 m deep (evident as dark gray bottom topography in the water profile). The front extended from the surface to approximately 15 m depth, but it varied among years and was typically < 10 m at its deepest (Fig. 29). Water temperature along the Barabara line shows weak stratification, with warmer water in the upper 10 - 20 m in 2005 and 2006, but only on the north side in 2007. In 2005 and 2006, waters < 8^0C were generally > 60 m deep, but in 2007 a band of cold water extended to the shelf edge on the north side (Fig. 29, left column). Also in 2007 a large pool of water < 7^0C was evident in the deepest trough. Salinity was generally well mixed, but fresh water signals were evident over the north side shelf in 2005 and 2006, and less so in 2007 (Fig. 29, center column). A much smaller front is evident in the fresh water signal near the south shore in 2005 and 2006. Turbidity was only high along the north shore front extending over the shelf, with clear water starting at approximately 5 - 10 m depth (Fig. 29, right column).

The 2005 and 2006 sampling of the Barabara line completed by S. Pegau included a measurement of fluorescence as an indicator of primary productivity. His results show how the strong frontal signals along the north shore, evident from temperature, salinity and turbidity, were associated with high fluorescence (Fig. 30). In 2005 the zone of higher productivity extended from the north shore to mid-bay and to a depth of 10 m, and there was a weaker signal of productivity next to the south shore at 10 – 20 m depth (Fig. 30A). In 2006, the zone of high productivity was concentrated over the shelf and slope break (roughly between latitude 59.61 N to 59.56 N), at a depth of 5 – 20 m (Fig. 30B).

Sea surface measurements. -- The measurements that we took at the water surface prior to each transect show the general increase in sea surface temperatures (SST) from April to August (Table x). In August (when all years were surveyed), average SST varied significantly among years (Kruskal-Wallis chi-square = 83.10, df = 3, $P < 0.005$), with 2004 and 2006 having lower SST than 2005 and 2007 (Table 8). Sechi disk measurements, a visual index of turbidity, suggested that surface waters were more turbid in 2007 than previous years, but the difference wasn’t significant (Kruskal-Wallis chi-square = 6.59, df =

3, *P* = 0.086). There was no difference in sea surface salinity (SSS) among years (Kruskal-Wallis chi-square = 1.98, df = 3, *P* = 0.58).

DISCUSSION

Murrelet Abundance

We provide population estimates of Kittlitz's and marbled murrelets (Appendix C), as well as other seabirds (Appendix E), for all of Kachemak Bay in June and July. Based on the three-year average of the July point estimates, Kachemak Bay currently supports approximately 10,600 marbled murrelets and 1,900 Kittlitz's murrelets. The most recent summary of the total estimated Kittlitz's population in Alaska (USFWS 2007) is 15,983 (range 7,760 – 26,962). Our results therefore indicate that the Kachemak population represents approximately 12 % of the known Kittlitz's population. The much larger population of marbled murrelets in Kachemak Bay may represent only 1 % of the estimated Alaska population, if estimates from the early 1990s are considered stable (Piatt et al. 2007). However, if typical rates of decline are applied to large areas that lack current estimates, such as Lower Cook Inlet and Southeast Alaska, the Alaska population may only be ~ 272,000 birds (Piatt et al. 2007), and the Kachemak Bay population would then represent 4 % of that total. Thus, although marbled murrelets are the numerically dominate species in Kachemak Bay, the population of Kittlitz's murrelets contributes more to the species' metapopulation. Based on our results for other species in Kachemak Bay (Appendix C-2), *Brachyramphus* murrelets comprised 15 – 22 % of all birds during July, and thus they are an important component of the local avifauna as well.

Interannual variability was high, and a confounding factor was the apparent influx of murrelets in 2006, especially Kittlitz's murrelets, into the north outer bay. It was beyond the scope of this study to determine the frequency of this occurrence on an intra- or inter-annual scale, but the region warrants further study to determine its importance to the Kittlitz's murrelet population. Because numbers of Kittlitz's murrelets remained roughly the same in the inner bay, it is likely that the high numbers of Kittlitz's murrelets in the north outer bay in 2006 were part of a fluid Lower Cook Inlet population. In 1993, the FWS survey of Lower

Cook Inlet resulted in an estimate of > 58,000 *Brachyramphus* murrelets (Agler et al. 1998), and found large numbers, including Kittlitz's murrelets, occupying waters just outside of north Kachemak Bay and south of Anchor Point (Fig. 31; modified from data used in Agler et al. 1998). More recently, while conducting hydrographic surveys, S. Pegau (pers. comm.) reported frequent observations of murrelets during multiple crossings of this area over several years. If this larger area has generally high foraging activity, birds could be moving into and out this region of Kachemak Bay depending on tidal and seasonal influences on prey. It is apparent that a true measure of this region's trends in *Brachyramphus* murrelet population will require a resurvey of the larger Lower Cook Inlet.

The population size of Kittlitz's murrelets occupying the inner bay is not large, but the density of birds in that hot spot is high compared to areas such as Kenai Fjords, Lower Cook Inlet, and Prince William Sound. Between 2005 and 2007, average Kittlitz's murrelet density for the entire bay was 2.38 ± SD 1.32 birds • km^{-2}, and for the inner bay specifically, density was 5.38 ± SD 1.75 birds • km^{-2} (Table 3). The inner bay would thus be second only to Icy Bay, based on results from surveys in Southeast Alaska in 2002 – 2004 (Kissling et al. 2007b).

Murrelet Population Trends

Monitoring population trends of marbled and Kittlitz's murrelets is complicated by variable rates of species identification, in particular the low proportion of birds identified in historic surveys (Kuletz et al. 2005). At least since the 1970s, marbled murrelets have always been more abundant than Kittlitz's murrelets in Kachemak Bay. The apparent increase in marbled murrelets is usually concurrent with declines in unidentified murrelets, and simply reflect improved identification in recent years. For this reason, the most meaningful data sets to examine are the trends in Kittlitz's murrelets and trends in total *Brachyramphus* murrelets.

The June surveys did not reveal a decline in Kittlitz's murrelets since 1993, despite the absence of Kittlitz's in 2005. Marbled murrelets appeared to increase since 1993, but when examined with the trend for total murrelets, there was no change between 1993 and the 2005 - 2006 surveys. The 2006 spike in murrelet numbers for both species makes it difficult to analyze trends with just three years of data for June.

The trends in murrelet densities during August surveys showed significant differences from some historic transect sets. Between decades, Kittlitz's murrelets declined significantly in the inner bay and in the entire bay, and individual Transect Sets (Table 4) indicated a decline in the inner bay for Kittlitz's murrelets of between - 4 to -18 % per annum. This is consistent with declines noted in other populations in the Gulf of Alaska (USFWS 2007).

Compared to historic surveys, densities for total murrelets in recent surveys were slightly lower for the entire bay, and identical in the inner bay. Densities for total murrelets increased in the outer bay, and this appears to be due to an increase in marbled murrelets, since Kittlitz's densities declined between decades (Table 5). At a finer scale, the transect sets indicated that the increase in marbled murrelets in the outer bay was primarily along the south outer shore, since that area also showed a concurrent increase in unidentified murrelets. The results suggest a 9 % per annum increase in marbled murrelets along this stretch of shoreline (Table 5). While this is a relatively small area, it is one of only two data sets that show an increase in marbled murrelets, the other being a temporary increase in the Kenai Fjords between the 1980s and 2002 (Piatt et al. 2007). Because of a possible shift in distribution within the bay and likely movement of birds near the bay's confluence with Lower Cook Inlet, a resurvey of the Lower Cook Inlet region would be required to determine if there has been a positive population trend.

We conclude that the decline in Kittlitz's murrelets is real, and in fact is likely conservative, because low species identification rates in historic surveys would have reduced density estimates for identified Kittlitz's in early years. The rate of decline in the inner bay, where Kittlitz's murrelets were always present and aggregated, is an indication of a compromised population, and is comparable to declines in other summer breeding areas within its range. Since the 1980s or early 1990s Kittlitz's have declined dramatically in Prince William Sound at -18% per annum (Kuletz et al. 2005), in Kenai Fjords at – 8.7 % per annum (Van Pelt and Piatt 2003), and Glacier Bay at – 8.9 % per annum (Robards et al. 2003). Our results lend support to the argument for listing of Kittlitz's murrelets as a threatened species.

The trends in marbled murrelets are more problematic, but suggest that the overall population may be stable, with a possible shift in distribution to the outer bay. Murrelets did, however, decline in Eldredge Passage, which is in the central part of the south shore and in terms of oceanographic characteristics, borders the inner bay (Speckman 2004). Despite apparent increases in the outer bay since the 1988 – 1999 period, the annual declines in July population estimates for marbled murrelets between 2005 and 2007 suggest that caution is warranted before concluding that the population is stable.

Potential Influences on Murrelet Populations

One of the primary factors considered to be a potential cause for the range-wide decline in Kittlitz's murrelets is the alteration of glacial-associated habitats due to climate change (USFWS 2007). The stability or recession of tidewater glaciers has been linked to murrelet habitat use (Day et al. 2000, Kissling et al. 2007a) and to population declines (Kuletz et al. 2003a). Land-based glaciers such as occur on the south side of Kachemak Bay can also respond to short-term climate change (Hall et al. 2005). The water column structure in the Kittlitz's murrelet hot spot was relatively restricted spatially, and could be subject to changes in flow and sedimentation caused by further retreat of the associated land-based glaciers. Hall et al (2005) concluded that since at least 1973, the Grewingk-Yalik glacier complex that feeds into inner Kachemak Bay has been more stable than the glaciers from the Harding Icefield that feed into Kenai Fjords. This local stability may have resulted in a refugium for Kittlitz's murrelets. The importance of the glacial outflow near Glacier Spit and Aurora Lagoon is apparent when our survey results are overlaid with satellite imagery of the bay (Fig. 32). Kittlitz's murrelets are clearly associated with the plume of glacial silt, and densities are particularly high on the western edge of the plume near Glacier Spit.

Marbled murrelets also foraged extensively in the glacial outflow of the south inner bay, and thus would also be affected by changes to this habitat. Sand lance was a primary prey in this area of the bay, and this important forage fish depends on fine gravel and sandy substrates (Robards et al. 1999), which could be altered with changes in sedimentation and sill formation. Additionally, marbled murrelets have likely been affected by drastic alteration of the upland habitat that has resulted in loss of nesting habitat. Increasingly warmer springs have led to outbreaks of spruce bark beetles in southcentral Alaska (Berg et al. 2004). Spruce bark beetles have removed forests from much of the Kenai Peninsula (Fig. 33), and aerial surveys show that deforestation became evident in inner Kachemak Bay in 1992, with peak infestation rates in the mid 1990s (Fig. 34). Outer Kachemak Bay has been less affected and this may be one reason for the apparent shift by marbled murrelets into the outer bay. There has not been a comprehensive study of upland nesting habitat using dawn surveys to gauge this potential impact. It may be possible to conduct a comparative study between outer and inner uplands using radar to detect inland flights.

Other potential factors affecting murrelets include gillnet mortality, increased boat traffic, and changes in prey (Day et al. 1999, Nelson 1997, Piatt and Anderson 1996). Oil spills are also a risk (King and Sanger 1979, Van Vliet and McAllister 1994), although the murrelet populations in Kachemak did not show evidence of direct impact from the 1989 *Exxon Valdez* spill (Kuletz 1996). There are salmon gillnet set net sites in Kachemak Bay, primarily along the outer south side. A two-year study of gillnet mortality in the set net and drift gillnet commercial salmon fishery of Cook Inlet estimated about 37 murrelets were taken annually. However, sampling effort was too low to accurately gauge seabird bycatch for this fishery (Manly 2006). In the Kodiak Island set gillnet salmon fishery, Manly et al. (2007) estimated that between 56 (2002) and 143 (2005) murrelets per annum were taken incidentally, and this included 17 Kittlitz's' murrelets. Wherever gillnets and murrelets overlap, gillnet mortality is known to occur (Piatt et al. 2007). However, even if these numbers are representative of potential bycatch of murrelets in Kachemak Bay, they are small relative to the population, and at least currently, few murrelets occupy the nearshore areas where set gillnets were deployed during our surveys.

Compared to the locations of other populations of Kittlitz's, Kachemak Bay has relatively high boat activity, although most of the traffic during our surveys was from recreational or fishing vessels < 45 ft. However, even small boats can disturb murrelets (Speckman et al. 2004), and boat traffic was high throughout nearshore areas, particularly along the southern shore and including the inner bay area < 2 km from the southern shore, and throughout the Eldredge Passage area (Appendix F). Disturbance in forage areas by large vessels can be energetically expensive for murrelets during the breeding season (Agness 2006). We did not analyze the relationship between boat traffic and murrelet density, but this dataset would be one way to examine potential impacts from boat traffic.

Seasonal Patterns of Abundance and Chronology

We observed newly fledged marbled murrelets at sea on the first August surveys of 2005 and 2007, indicating that we did not capture the initiation of fledging for marbled murrelets those years. The patterns of juvenile abundance suggest that marbled murrelet chronology in Kachemak begins earlier and extends over a longer period than does Kittlitz's murrelet chronology. The increase in marbled murrelet juveniles late in August may also indicate a longer residency in the bay, whereas Kittlitz's murrelet juveniles appear to leave the area by late August. This remains speculative, however, due to the low frequency of encounters for Kittlitz's juveniles. We also found it harder to distinguish juvenile from adult Kittlitz's, especially after mid-August, when many of the adults appeared to be molting. Furthermore, the plumage sequence between newly fledged juveniles and older juveniles has not been described, and we observed birds that appeared to be juveniles that were in basic black-and-white plumage as opposed to the dark grey and speckled plumage of newly fledged juveniles (based on videos at nest sites [Van Pelt, unpubl. data] and photo documentation from a variety of contributors).

One of the goals of this project was to determine if Kittlitz's were reproducing, because Day and Nigro (2004) suggested that Kittlitz's murrelets in Prince William Sound (PWS) were not successfully raising chicks. It is apparent that a closer examination of plumage characteristics of juvenile Kittlitz's murrelets is needed so that accurate age class determination can be made. Our experiences in Kachemak Bay and in PWS suggest that juvenile Kittlitz's murrelets could easily be overlooked if they are among adults. Because we had a core crew of people experienced in murrelet identification during the four years of this study, we are confident in the identifications that we made. The information obtained in Kachemak Bay in 2004-2007 constitutes the most complete record available of juvenile Kittlitz's murrelet distribution and density.

Productivity

The low encounter rate with juveniles of both murrelet species makes it difficult to obtain statistical power in detecting changes in murrelet productivity with at-sea surveys, although power can be moderately high in areas with high murrelet densities (Kuletz 2005). At-sea surveys can, however, quickly indicate areas that are important to juvenile murrelets and they provide a relative index of local productivity (Kuletz 2005). Our data suggest that both murrelets did poorly in 2007, a year that also had the lowest densities of adult murrelets. For Kittlitz's murrelets, there was some evidence of alternating years of good (2004, 2006) and poor (2005, 2007) productivity. Marbled murrelet productivity showed a similar, but less dramatic pattern. For marbled murrelets in particular, however, the 2007 August surveys may have missed the peak juvenile densities, since we could not survey past mid August that year. For Kittlitz's murrelets, juvenile:adult ratios were extremely low in 2006 and relatively high in 2007 (Fig. 14), reflecting high numbers of adult birds present in 2006 and low numbers of adults in 2007. Juvenile densities of both species showed a negative relationship with SST between 2004 and 2007 (Fig. 35), but more years will be needed to determine if SST is a good predictor of murrelet productivity, and to explore the mechanisms involved.

Compared to intensive surveys for juveniles in Kachemak Bay in 1996 (Kuletz and Piatt 1999), marbled murrelet juvenile densities were lower overall in 2004-2007. The mean marbled murrelet juvenile density for 10 survey days between 7 – 24 August 1996 was 1.12 ± 1.64 birds · km^{-2}, whereas the mean for 2004-2007 was 0.56 ± 0.22 birds · km^{-2}. However, in 1996 there were two very high juvenile counts in mid and late August which accounted for most of the juvenile observations (Kuletz and Piatt 1999). There also appears to have been a shift in distribution of juveniles. In 1996, 96 % of marbled murrelet juveniles were observed along the south outer shore, primarily between Barabara Point and Seldovia Bay, and Kuletz and Piatt (1999) suggested this was a murrelet 'nursery' area. In contrast, only about half of the juveniles we recorded in 2004 – 2007 were in the nursery area. Although we found juvenile marbled murrelets in the outer bay more than in the inner bay (Table 6), they were dispersed throughout the southern side of the bay (Fig. 21).

In 1996, Kuletz and Piatt (1999) noted that the murrelet nursery area had the only large *Nereocyctis leutkeana* kelp beds, and this appeared to be a defining characteristic. Indeed, Schoch and Chenelot (2004) documented that in Kachemak Bay, *Nereocystis* beds are found only in the outer basin, and they concluded they were not in the inner bay because of the low salinity, high turbidity, and low nutrient levels in the water column of the inner basin.

Aerial surveys documented significant declines in the size and distribution of *Nereocystis* beds in Kachemak Bay (Schoch 2001). The kelp beds were found in the same locations over three years of their study (2000 – 2002), but decreased in size significantly

(Schoch and Chenelot 2004). Kelp forests support local marine food webs (Lalli and Parsons 1993), and have been recognized as habitats preferred by juvenile murrelets throughout their range (Piatt et al. 2007). Anecdotally, Schoch and Chenelot (2004) report local knowledge of historically more extensive kelp beds along the south outer shore. If the *Nereocystis* beds have been declining over the last two decades and are continuing to decline, it could potentially affect the survival of juvenile murrelets in the bay. Adult foraging could also be affected, since Schoch and Chenelot (2004) also found declines in the size of kelp beds along the north outer shore, in the shallow shelf south of Anchor Point to Bluff Point where murrelets occasionally aggregated.

Concurrent with evidence for changes in the marine habitat, there is circumstantial evidence that the food web of Kachemak Bay in general has experienced perturbations, including human-induced changes from fishing and alteration of nearshore habitats that result in sedimentation and pollution (Schoch and Chenelot 2004). Fisheries that have been closed due to population crashes in the past decades include Pacific herring (*Clupea pallasii*) and shrimp (*Pandalus* spp.), and murrelets feed on juveniles of these species (Sanger 1987, Piatt et al. 2007). Sand lance are also an important forage fish for seabirds in Kachemak Bay (Abookire et al. 2000, Litzow et al. 2004, Speckman et al. 2005), and we found both murrelet species feeding on adult sand lance. In July 2006, we noticed continuous feeding activity by a variety of seabirds along the north outer shoreline, and from the beach it was possible to pick up large adult sand lance that were swarming in the shallows. Off shore of this area is where the influx of murrelets occurred that year. The historic abundance of sand lance in Kachemak Bay is unknown, but it was critical to some breeding seabirds in the 1990s (Litzow et al. 2000, 2004). It was evident that sand lance were consistently available to seabirds in the area from Glacier Spit and Aurora Lagoon, suggesting this is an important area to monitor for changes in the food web.

Other forage species for murrelets in Kachemak Bay include capelin (*Mallotus villosus*), mysids and euphausiids (Sanger 1987). Euphausiids are an important prey for Kittlitz's murrelets (Day et al. 1999), but we could not determine where or how frequently they were used by Kittlitz's murrelets by making visual observations. To understand the biology of Kittlitz's murrelets in Kachemak Bay it will be necessary to know more about the abundance and distribution of euphausiids in the bay.

Although we did not find evidence of Kittlitz's juveniles using the glacial lake, a more intensive effort, or radio tagging of a juvenile prior to fledging, is recommended to determine if this is a post-fledging habitat. Of note were the high numbers of glaucous-winged gulls at the lake, which are believed to be the main predators of Kittlitz's murrelet chicks on Attu Island (Kaler et al. *in press*). In addition to high numbers of gulls, the bald eagle population of Kachemak Bay may have increased since 1993 (Appendix E-1), and eagles take both murrelet species on the water (Piatt et al. 2007). Human activity that enhances the populations of these avian predators could have adverse affects on both marbled and Kittlitz's murrelets via predation on eggs, chicks, and adults.

Distribution and habitat use

The abundance of sand lance and other forage fish in Cook Inlet and Kachemak Bay vary considerably with tidal phase, water column structure, and season (Robards et al. 1999, Abookire et al. 2000, Speckman et al. 2005). The CTD casts found temporal differences in depth and magnitude of the halocline and thermocline and associated fronts, but these also depend on tidal phase (Okkonen et al. 2007). The general pattern of water characteristics, however, remained consistent. The distribution of marbled murrelets indicates that they use a variety of marine habitats within the bay, from the highly mixed waters of the outer bay to the highly stratified layers of the inner bay. In contrast, Kittlitz's murrelets were primarily found in the highly stratified waters of the inner bay, where glacial outflow was most intense (Fig. 32). A particular feature of these areas was a layer of clear water typically < 5 m below the surface layer of turbid water. Water depth appears to be a primary limiting factor, as most murrelets occurred in water < 60 m deep (Fig. 26).

The exceptionally high densities of both murrelet species in the north outer bay in July 2006 occurred in an area with strong frontal properties, particularly at a zone of convergence 4 – 5 km offshore, with a strong turbidity front. Within this frontal zone, murrelet densities were highest where the bottom topography forms a relatively shallow shelf, and the deep trench to the south of this shelf is a feature that can focus the general outflow of water from the bay, and thus maintain the frontal zone (S. Pegau, pers. comm.). Additionally, approximately 5 - 10 km from the north shore is the edge of a cyclonic eddy that varies in size with tidal phase (Okkonen et al. 2007, Pegau, unpubl. data), and this area also attracted high densities of marbled murrelets. Another area of intensified water exchange is Eldredge Passage, which was a marbled murrelet hot spot. The Eldredge Passage area was identified as a marbled murrelet hot spot in the 1970s (Erickson 1977) and in 1993 (Kendall and Agler 1998). Areas of upwelling, tidally induced mixing, and fronts act to concentrate prey species in the upper water column, and are known to attract seabirds, and murrelets in particular (Coyle et al. 1992, Hunt 1995, Hunt et. al. 1999). The decline of murrelets in the Eldredge Passage area may be indicative of changes in the marine habitat that affect prey, but could also be associated with high boat traffic through the passage (see Appendix F).

The location of marine foraging areas relative to nesting habitat may be a limiting factor for both murrelet species. Kachemak Bay offers a variety of both marine and upland habitats within ~ 60 km of each other, which is below the known maximum foraging range of marbled murrelets (Piatt et al. 2007), and possibly for Kittlitz's murrelets as well (M. Kissling, unpubl. data). Nonetheless, a rough GIS measure of the Kachemak Bay foraging spots relative to potential nesting habitats (Table 8) suggested that the south inner bay and Eldredge Passage are the most readily accessible for birds nesting along the south shore. In contrast, the north outer bay (which does not have nesting habitat for either murrelet species) had the greatest distances from most south side watersheds (range 35 – 56 km). Notably, however, the one discovered nest of a Kittlitz's murrelet on Red Mountain (Piatt et al. 1999) was one of the farthest potential nest sites from the inner bay, at 42 km one-way. Indeed, a bird could fly through the mountain passes between the inner bay and the Kenai Fjords with one-way trips of only 10 - 40 km (Table 8), depending on the route. Because people have provided anecdotal reports (to KJK) of murrelets flying through the passes at dawn, it is possible that some of the birds in Kachemak Bay are nesting on the south side of the Kenai Peninsula.

Both murrelet species appear to leave the bay during the night, at least the inner bay and nearshore areas. We were unsuccessful at finding murrelets at night in areas that had high densities during the day. This diel pattern was also observed by KJK during 24 hour land-based watches conducted in 1988. Whether the murrelets move offshore into the outer bay, or farther into Lower Cook Inlet, or even the Kenai Fjords, remains unknown.

Distribution of Other Species

The mapped distributions of marine birds and mammals show that some species or species groups frequent certain areas of the bay, indicative of habitat preferences. For example, pigeon guillemots were most abundant along the south shore (where they have numerous colonies), but were also observed diving over the shallow shelf of the north outer bay (Appendix F). Sea ducks were found primarily along the south shore and near MacDonald Spit in the outer bay, whereas common murres occupied the middle, deepwater portions of the bay. Black-legged kittiwakes were ubiquitous, but showed less use of the turbid north inner bay and of the deep waters of the central outer bay. Harbor seals were most abundant in the inner bay, while the largest groups of sea otters were in the outer bay. A full description of the distributions of other species is beyond the scope of this report, but will be available through the NPPSD and from the authors on request.

Recommendations

Both murrelet species increased in number between June and July surveys, particularly for Kittlitz's murrelets, which were rarely observed during mid-June surveys. The peak in mid-July numbers corresponds to the chick rearing period, when both members of a nesting pair are at sea, and thus would be the best time to obtain maximum population counts. High variance due to clumped distribution was particularly evident for Kittlitz's murrelet, and this problem has been noted in Prince William Sound (Kendall and Agler 1998) and Icy Bay in Southeast Alaska (Kissling et al. 2007b). The annual and seasonal patterns of distribution and abundance of murrelets will assist in development of appropriate protocol for long-term monitoring, as well as identify sensitive marine habitats.

In the Gulf of Alaska, many large populations of Kittlitz's murrelets are associated with tidewater glaciers (Day et al. 1999, Kuletz et al. 2003a, Kissling et al. 2007a,b). The floating brash ice and icebergs make surveying for Kittlitz's difficult. In addition to the logistical constraints and safety issues, the ice can affect detectability of murrelets, prohibit surveys of the same areas among days (due to movement of ice with winds and tides), and alter the surface area to which counts are extrapolated for population estimates (Kissling et al. 2007a). Kachemak Bay, with no floating ice, does not have these disadvantages, and thus population estimates should be more reliable, at least in the inner bay where the population is highly concentrated and always present from late June to early August. The easternmost area of the inner bay is less than an hour boat ride from the Homer harbor, which makes the area readily accessible in most days of the year. We conducted most of our surveys in the morning hours to avoid the afternoon winds that are typical in Kachemak Bay and can produce seas that reduce murrelet detectability.

Confidence intervals were proportionally higher for Kittlitz's murrelets than for marbled murrelets, due to the former's clumped and limited distribution. The high variance could probably be reduced for Kittlitz's murrelets by increasing survey intensity (number of transects or replicates) within the two 'hot spots'. In particular, monitoring of the south inner bay, within a 4 km band off of Glacier Spit to Bear Cove, would be essential to obtain trends and productivity data on Kittlitz's murrelets. Still, because of the movement of birds in the outer bay, a true measure of this region's trends in *Brachyramphus* murrelet population will require a resurvey of the larger Lower Cook Inlet.

To enable long-term monitoring of murrelets in Kachemak Bay, it will be necessary to maintain trained personnel, since species identification is critical to detecting population changes of a rare species that co-exists with a more abundant species (Kuletz et al. 2005). An examination of plumage characteristics of juvenile Kittlitz's murrelets is also needed so that accurate age class determination can be made.

Because Kittlitz's murrelets have declined in Kachemak, as they have in other areas, the bay's location would be the most convenient for future research into causal factors, or to refine monitoring methods. For marbled murrelets, there is the unique opportunity to track population size and indices of productivity following large-scale loss of breeding habitat due to 'natural' insect infestation. We recommend a comparative study between outer and inner uplands using radar to detect inland flights into infected and uninfected watersheds.

The Kittlitz's murrelet population in particular is a unique aspect of the Kachemak Bay ecosystem, and additionally, they are important to the world population of the species. We recommend a public outreach effort to educate Alaskans and tourists about the ecology of Kittlitz's murrelets and their status relative to human activities and climate change. Conservation efforts could stress the importance of minimizing disturbance on the water and preventing human activities that attract avian predators such as gulls and bald eagles.

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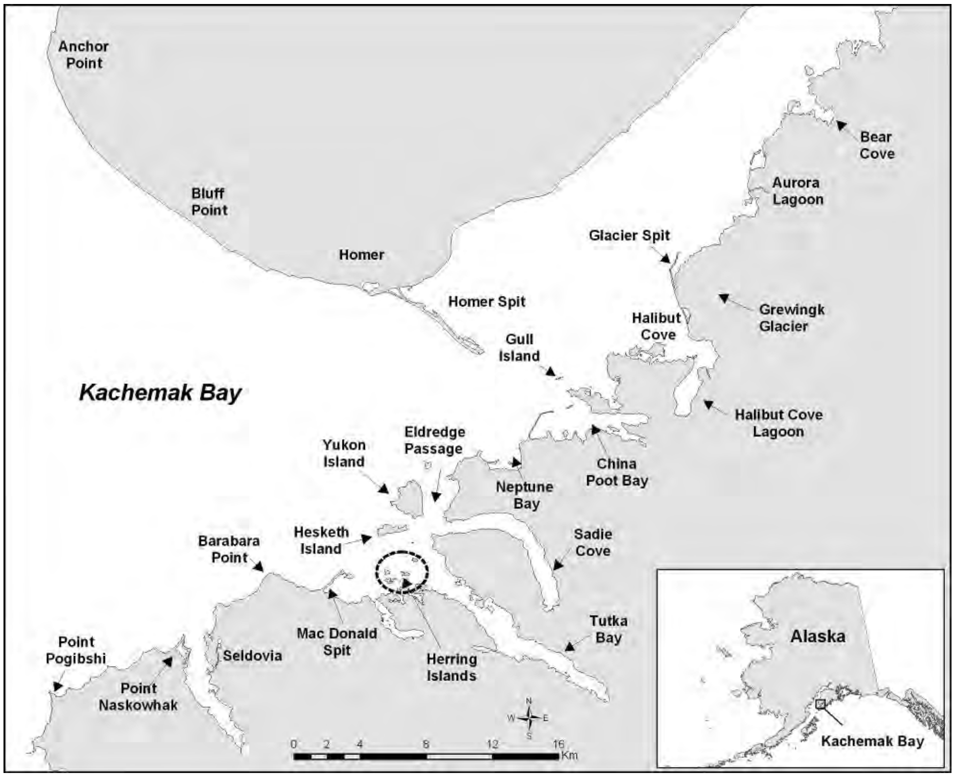


Figure 1. The Kachemak Bay study area.

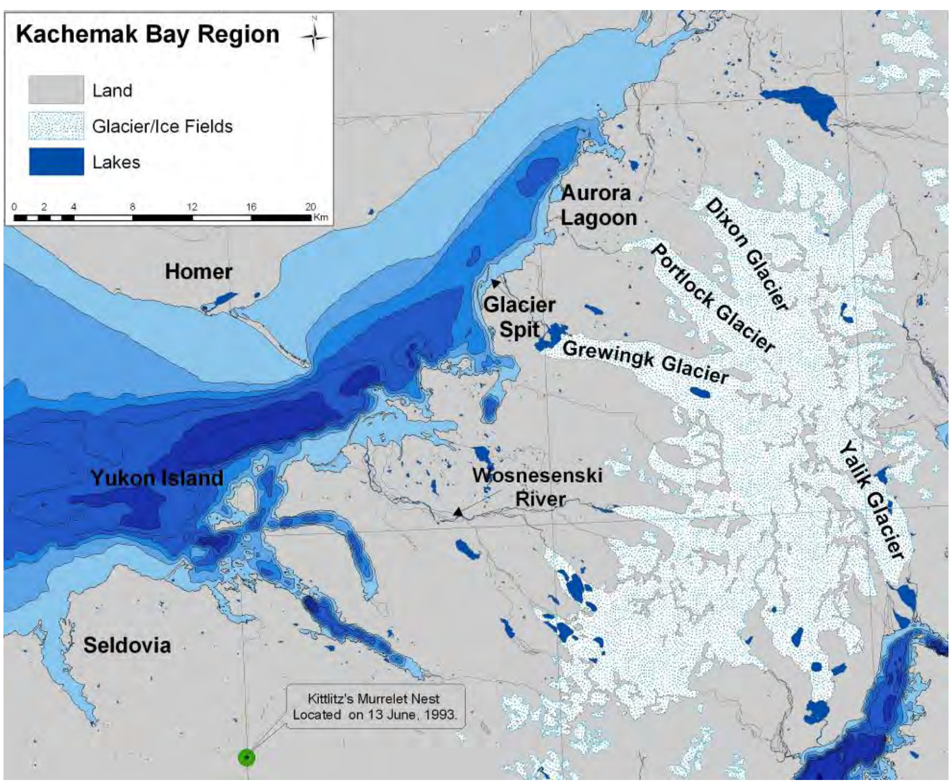


Figure 2. Kachemak bathymetry, glaciers, and location of Kittlitz's murrelet nest discovered in 1993 (green dot).

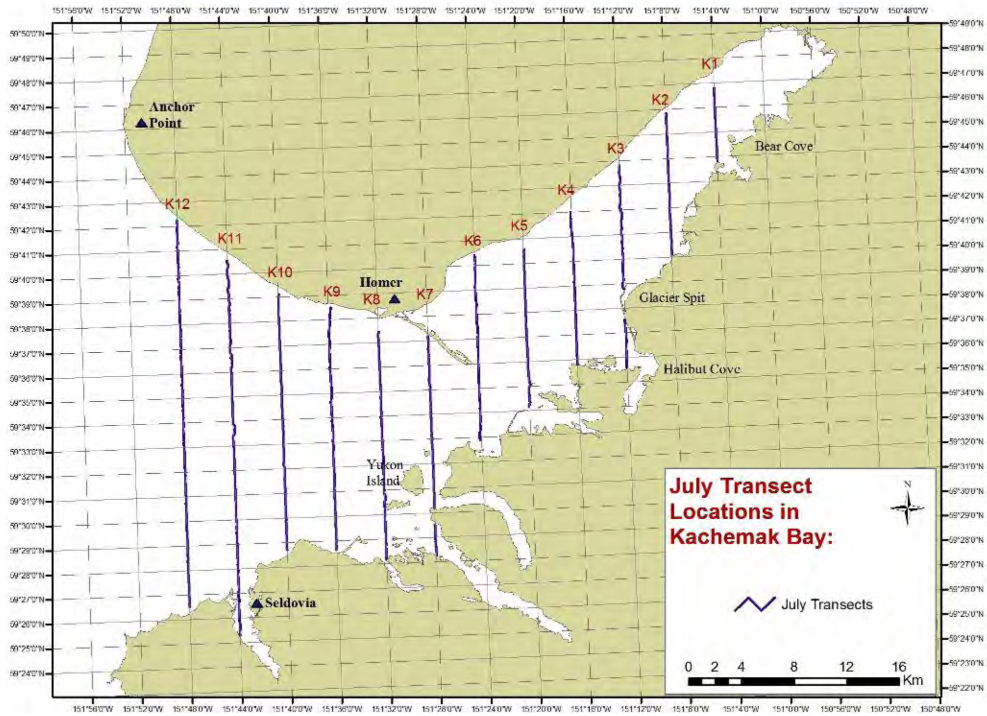


Figure 3. Transects surveyed between 18-25 July of 2005, 2006, and 2007.

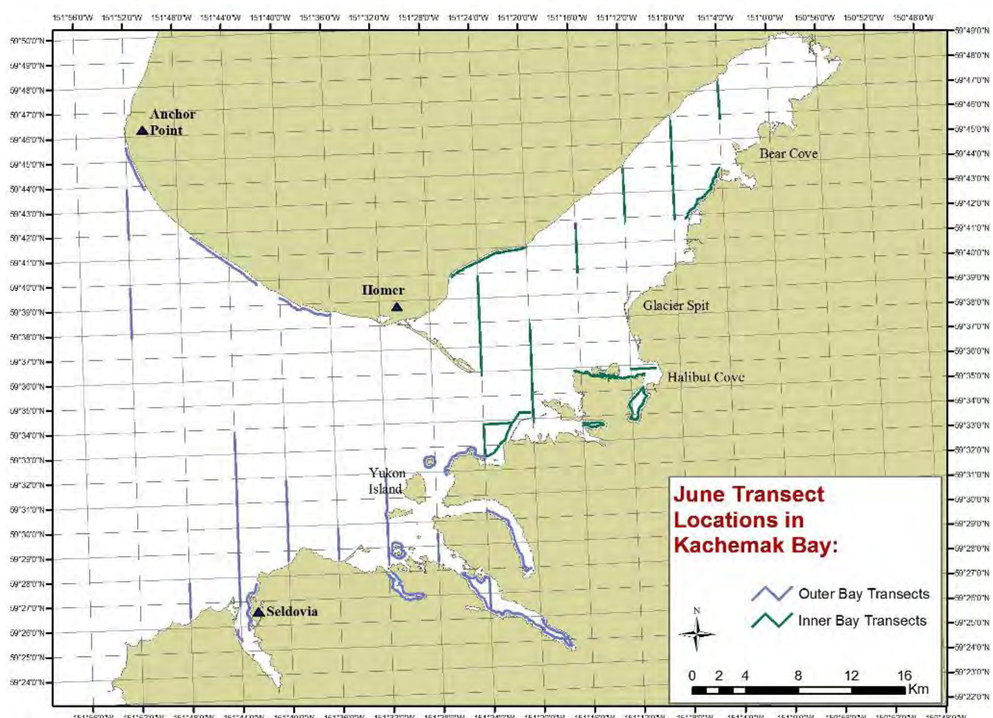


Figure 4. Location of transects surveyed between 16 – 20 June in 2005 and 2006. These transects were originally surveyed in 1993 as part of a USFWS survey of Lower Cook Inlet, and were randomly selected from shoreline and pelagic strata

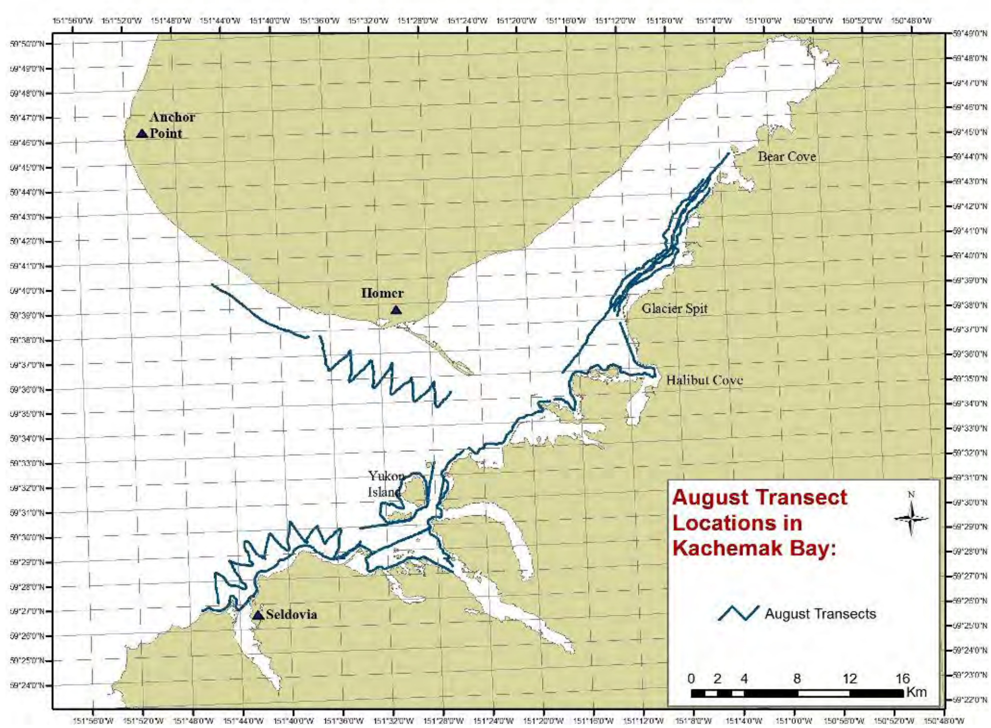


Figure 5A. Historic transects that were surveyed in August of 2004 – 2007. See Appendix A-3 for individual transect reference numbers.

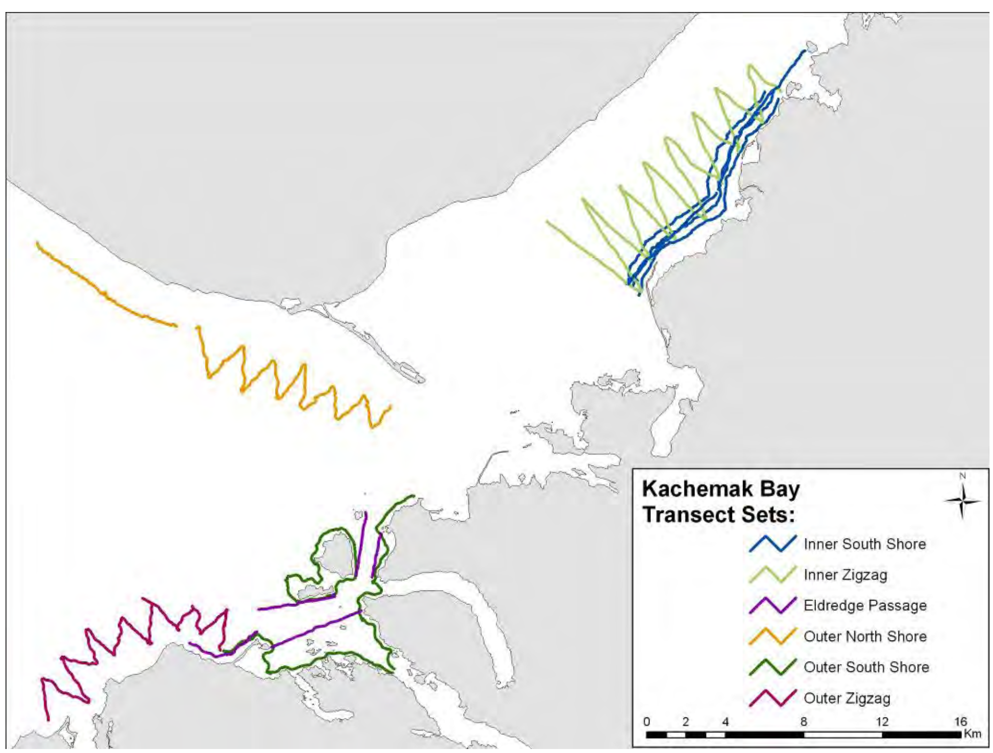


Figure 5B. Six Transect Sets used for late summer analysis of trends in murrelet density. Each set of transects could be surveyed in one day and had historic and recent survey coverage.

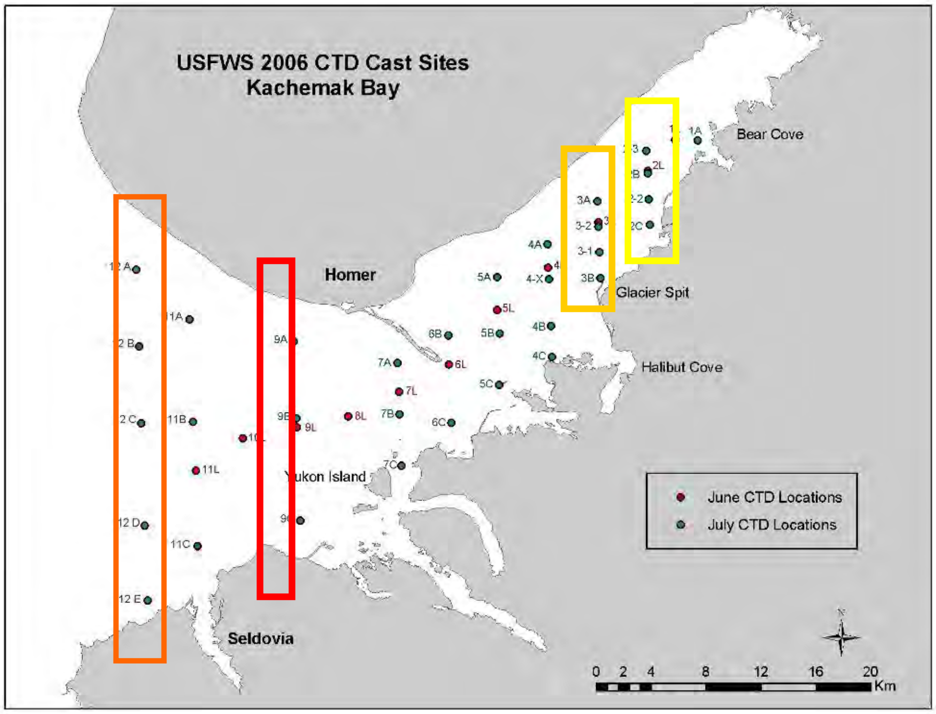


Figure 6. Location of CTD sampling lines used to derive water column profiles. Line 12 (orange box), line 3 (gold box), and line 2 (yellow box) were sampled by the FWS. The Barabara line (red box; 10 stations not shown) was sampled by Dr. Scott Pegau in 2005 and 2006, and by FWS in 2007

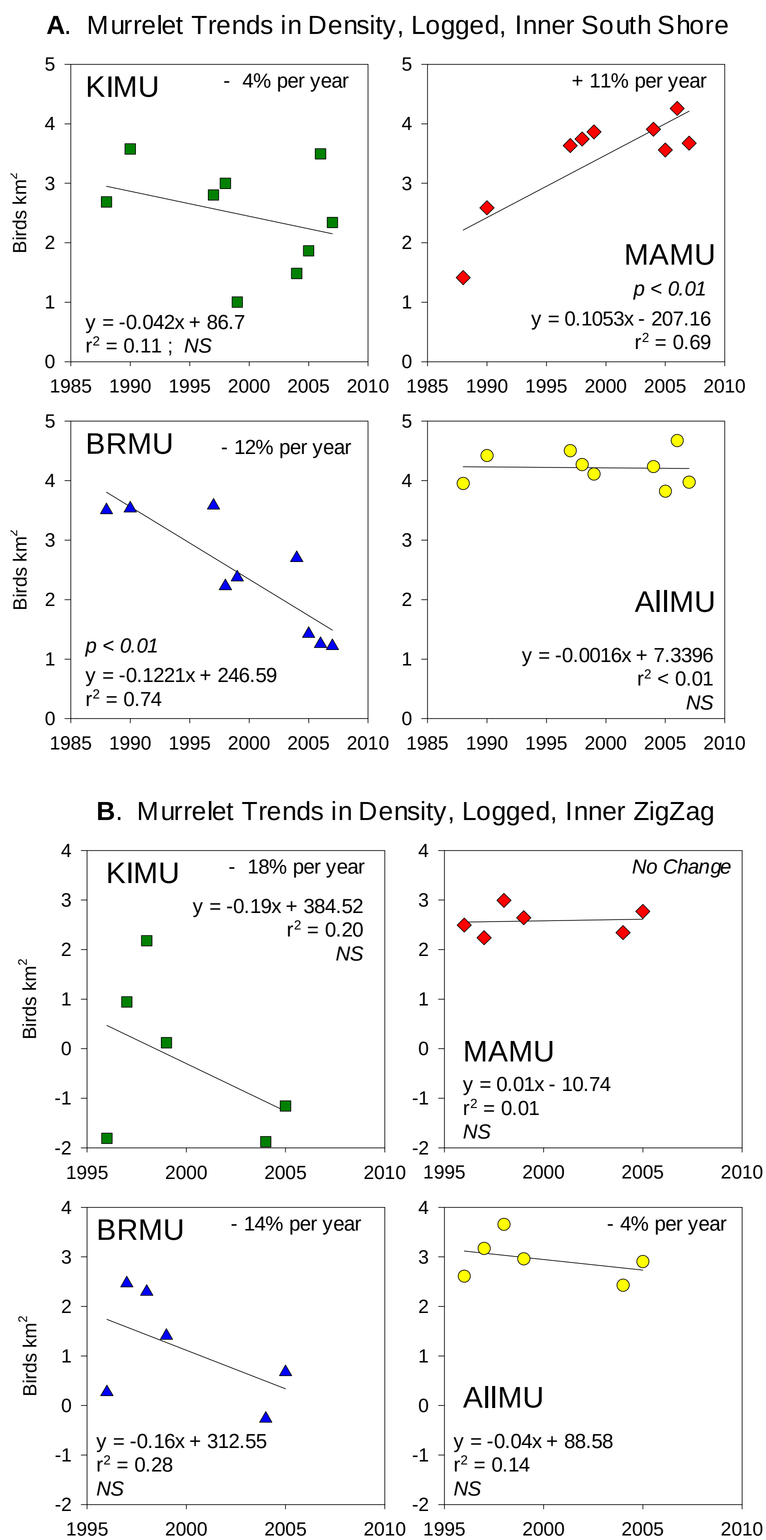
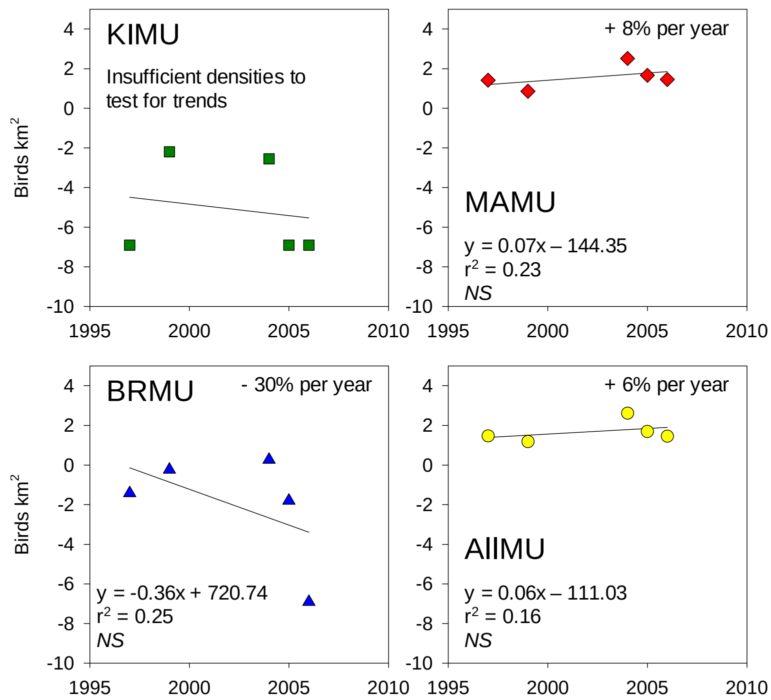
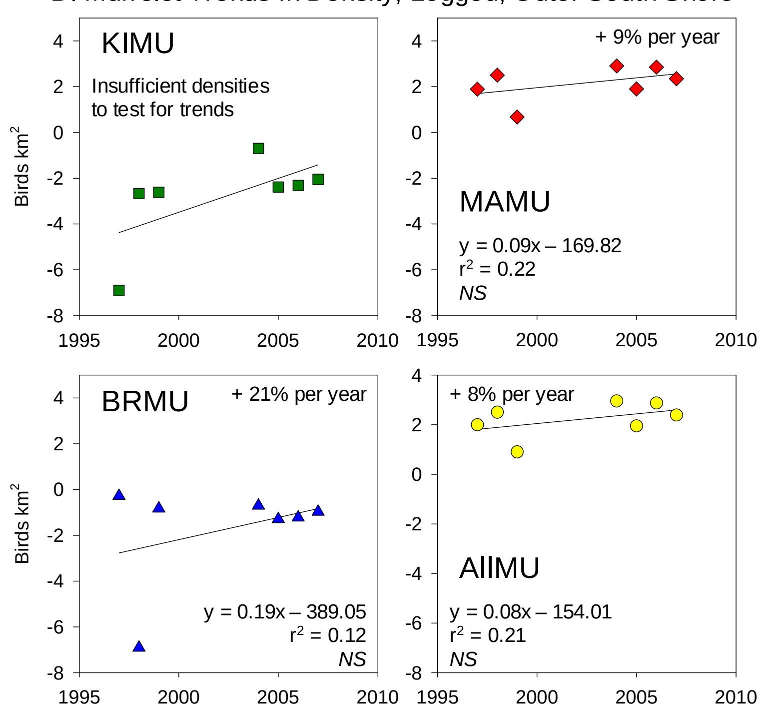


Figure 7 A-F. Trends in murrelet densities (logged), based on late summer surveys in Kachemak Bay, Alaska.

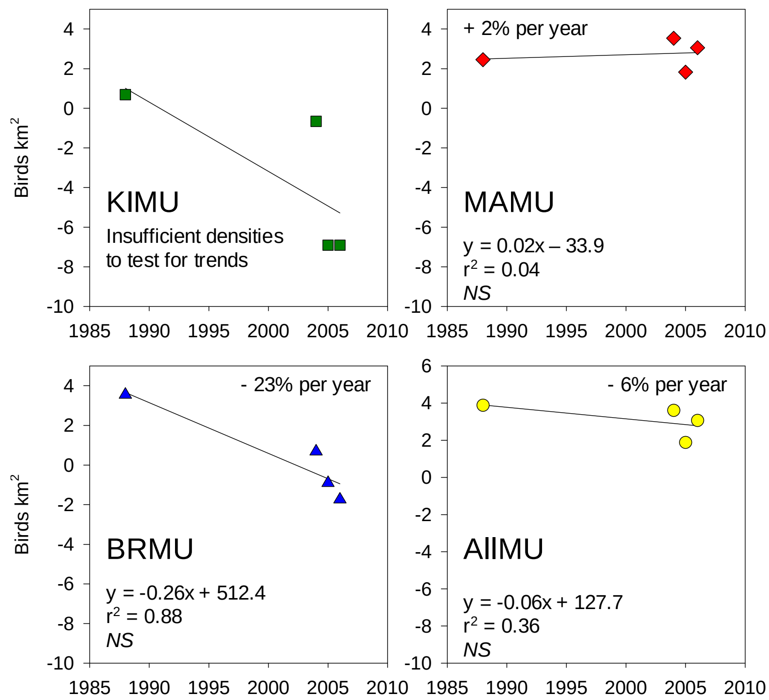
C. Murrelet Trends in Density, Logged, Outer Zigzag



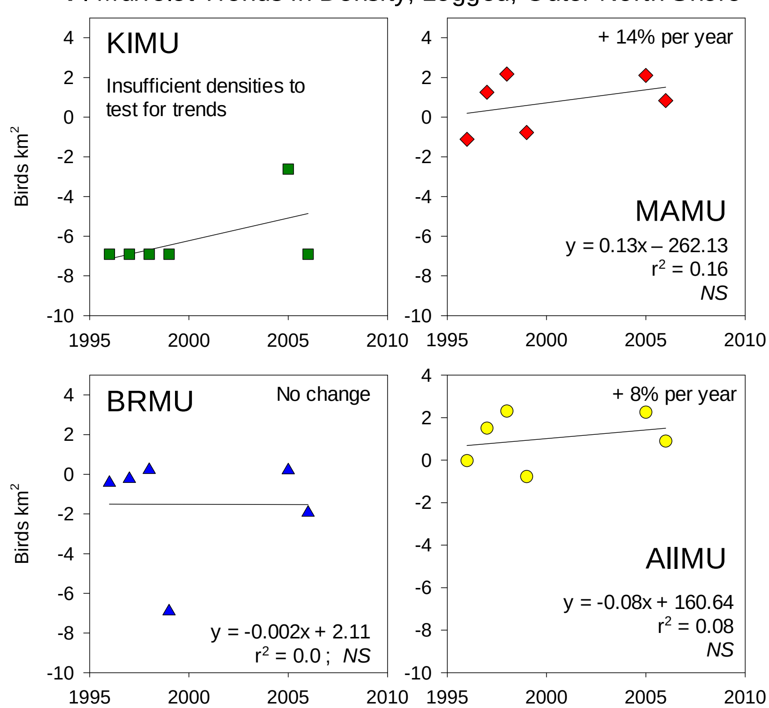
D. Murrelet Trends in Density, Logged, Outer South Shore



E. Murrelet Trends in Density, Logged, Eldredge Passage



F. Murrelet Trends in Density, Logged, Outer North Shore



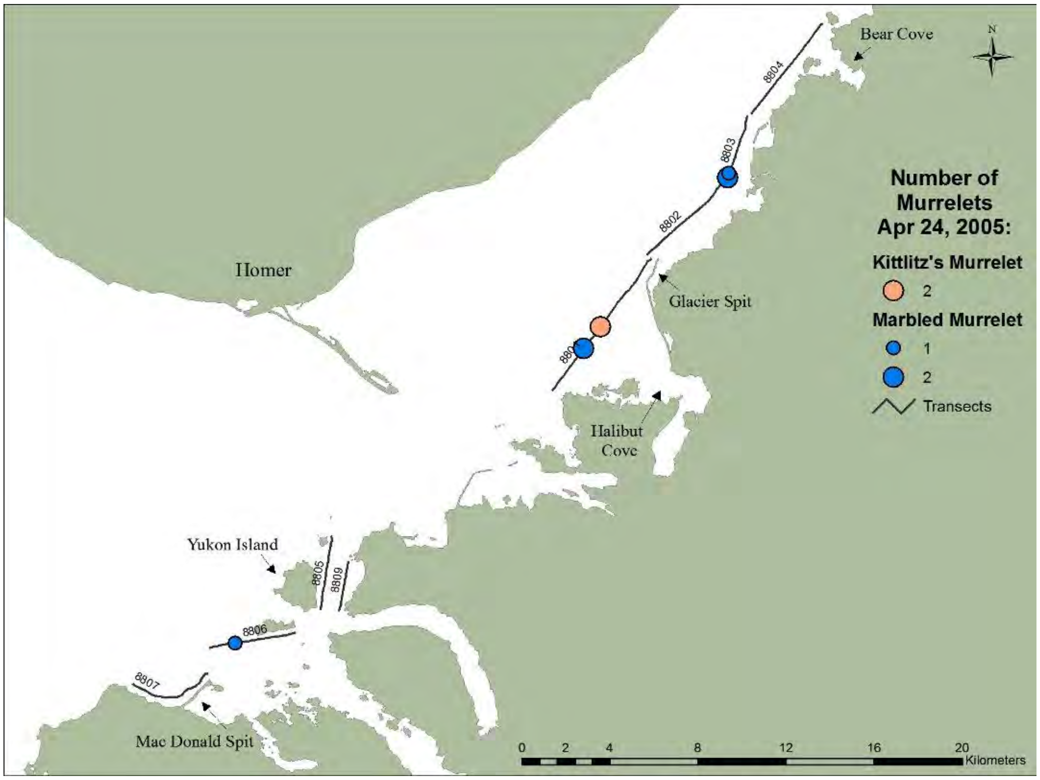


Figure 8. Location of marbled and Kittlitz's observed during a survey of south shore transects on 24 April, 2005 in Kachemak Bay.

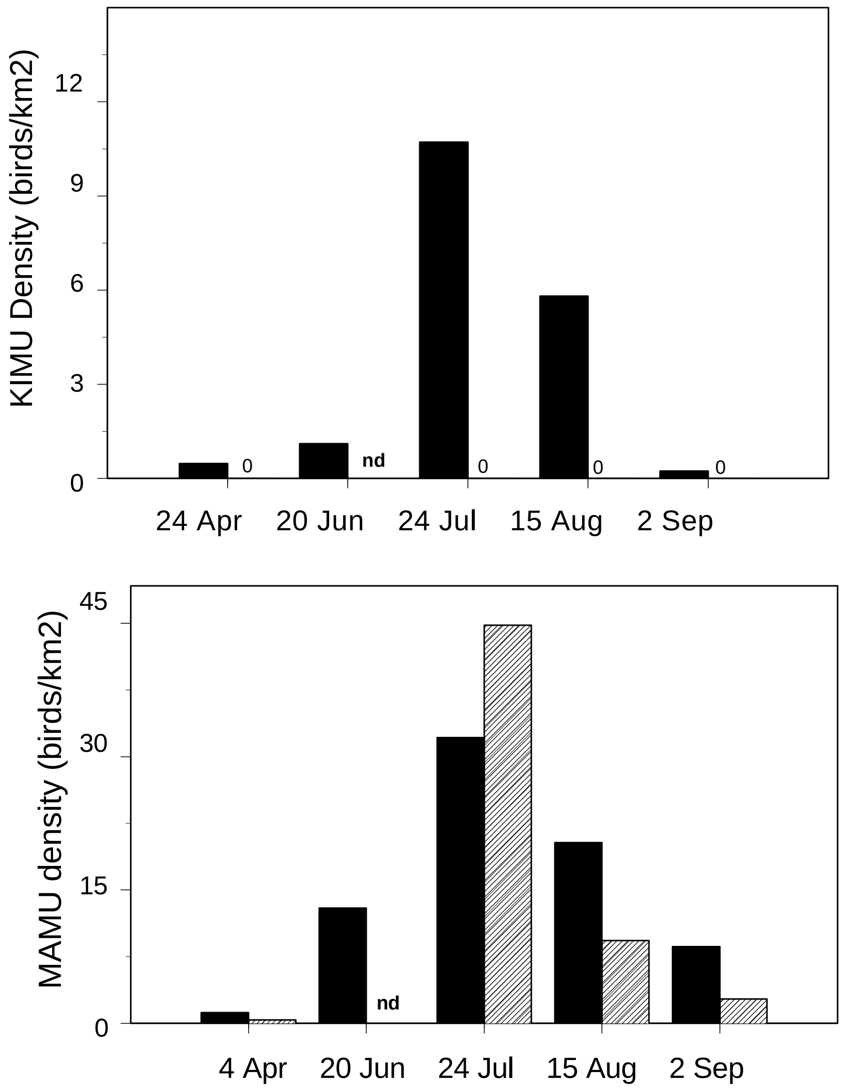


Figure 9. Seasonal patterns of abundance for Kittlitz's murrelets (top) and marble murrelets (bottom) based on at-sea surveys of the same Transect Sets in the inner bay (black bar) and outer bay (striped bar) regions of Kachemak Bay in 2005. No Kittlitz's murrelets were observed during these surveys in the outer bay. The outer bay transects were not surveyed in June. Nd = no data.

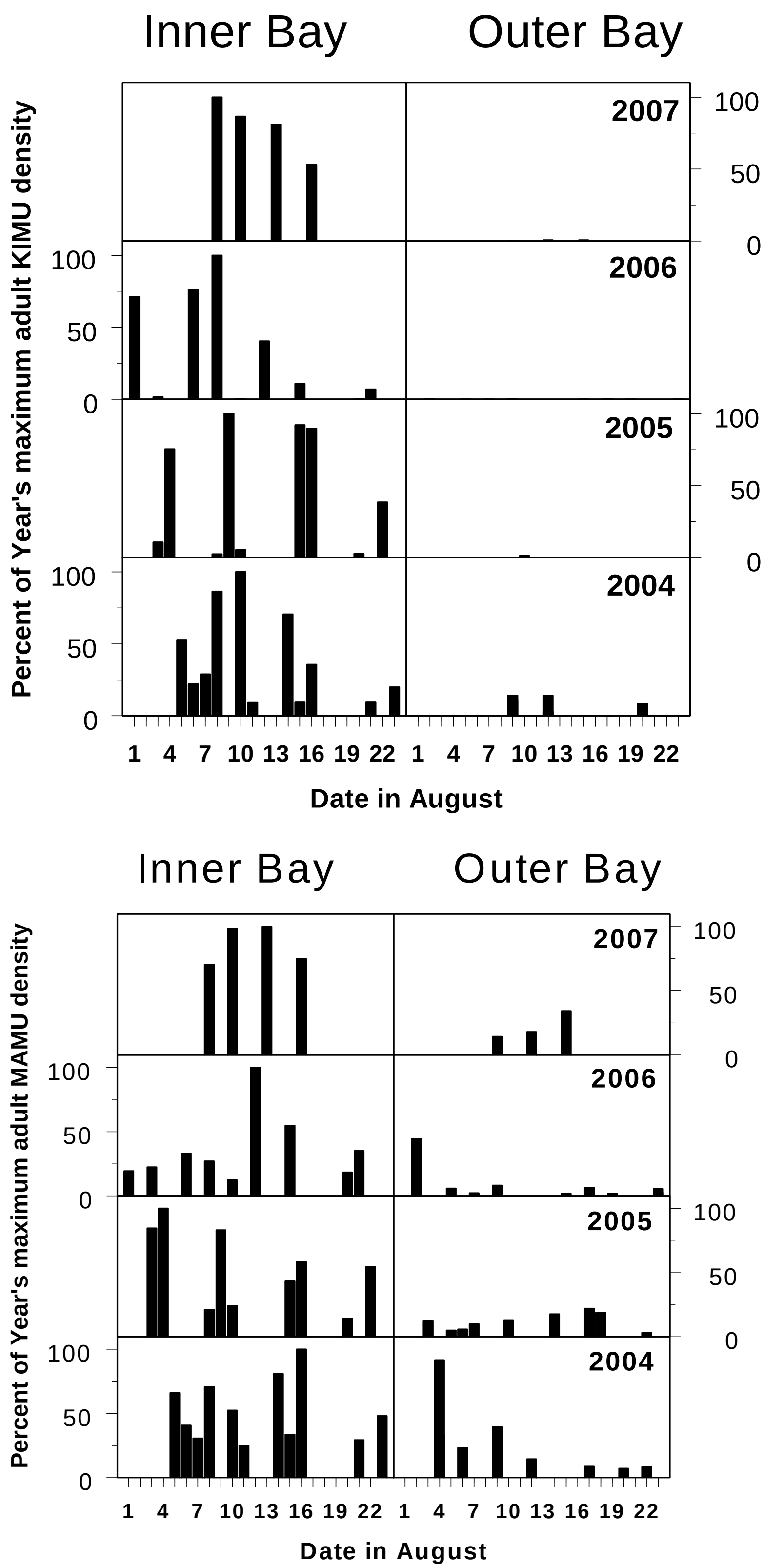


Figure 10. Relative abundance of adult Kittlitz's murrelets (top) and marbled murrelets (bottom) throughout August, 2004-2007

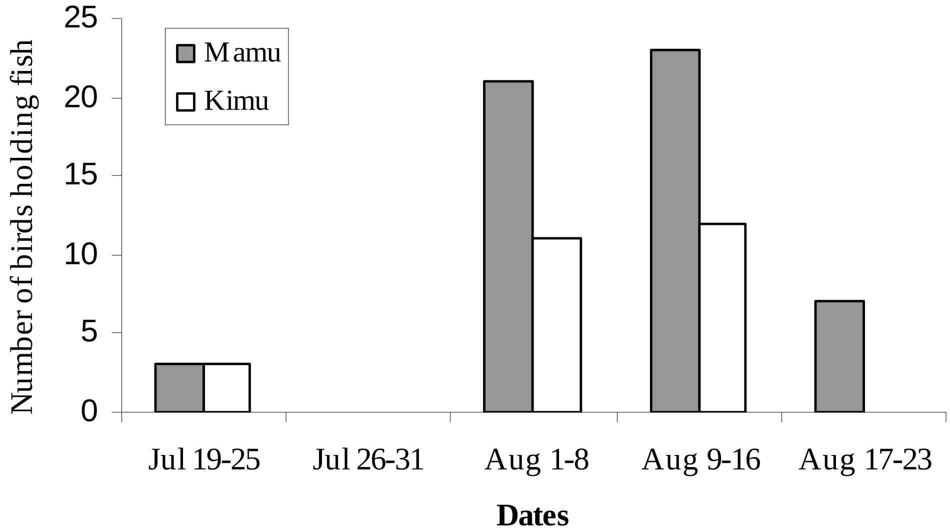


Figure 11. Number of adult murrelets observed holding fish (indicative of chick rearing), by weekly periods, in Kachemak Bay during boat-based surveys in late July through August of 2004 – 2007.

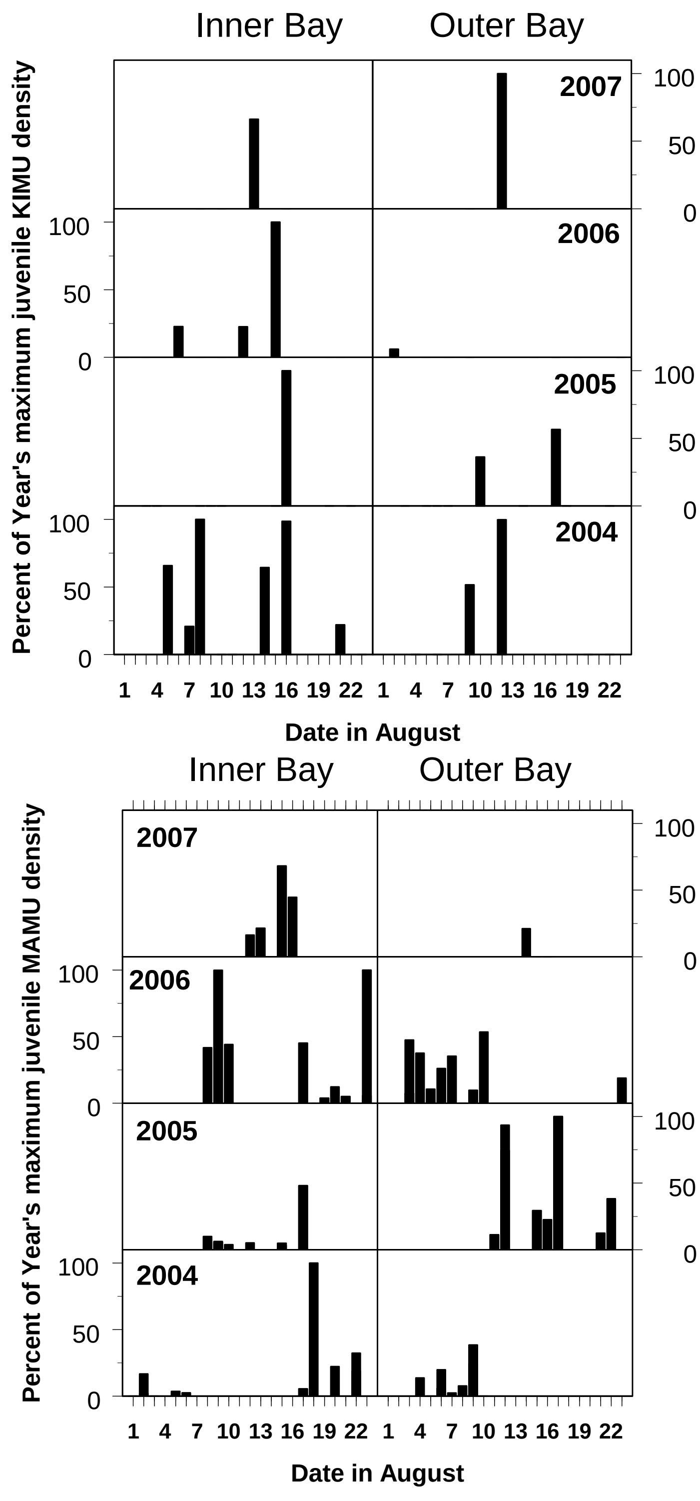


Figure 12. Relative abundance of juvenile Kittlitz's murrelets (top) and juvenile marbled murrelets (bottom) throughout August, 2004-2007.

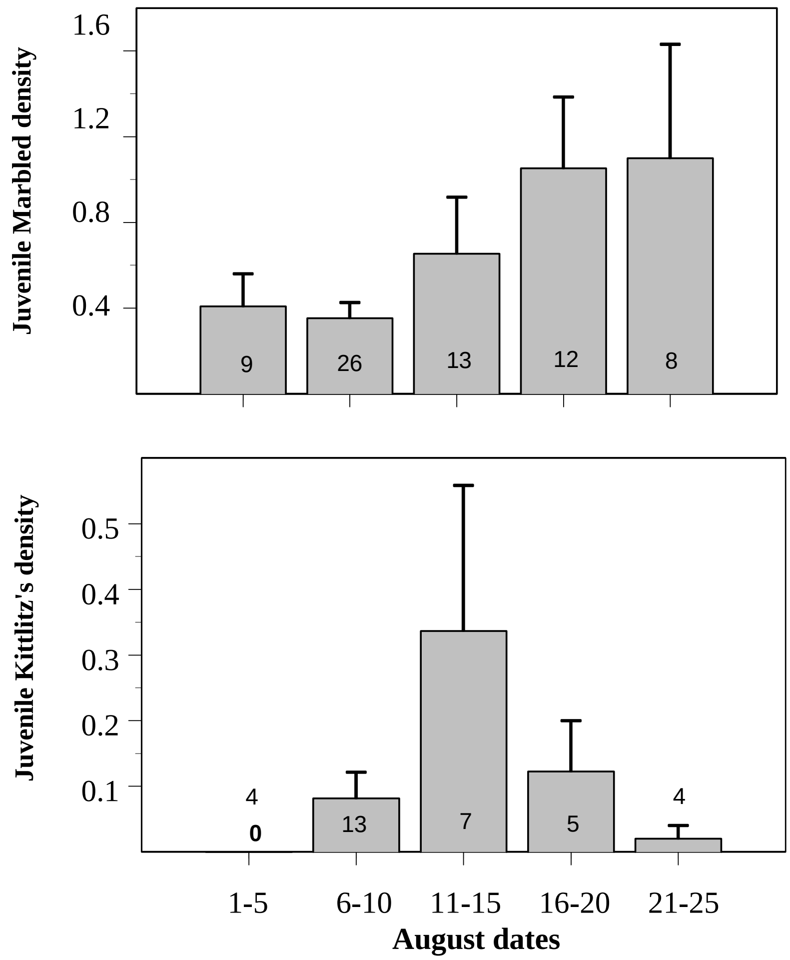


Figure 13. Mean (± SE) density (birds• km^{-2}) of juvenile marbled murrelets (top) and Kittlitz's murrelets (bottom), summarized in 5-day periods in August (except for 21-23), 2004-2007. Juvenile marbled murrelet densities include surveys conducted throughout Kachemak Bay because juveniles were widely distributed. Juvenile Kittlitz's murrelets include only surveys in the inner bay region, because few juveniles were observed in the outer bay. Numbers in (or above) the bars are the number of survey days. Note different scales on the Y-axis between plots.

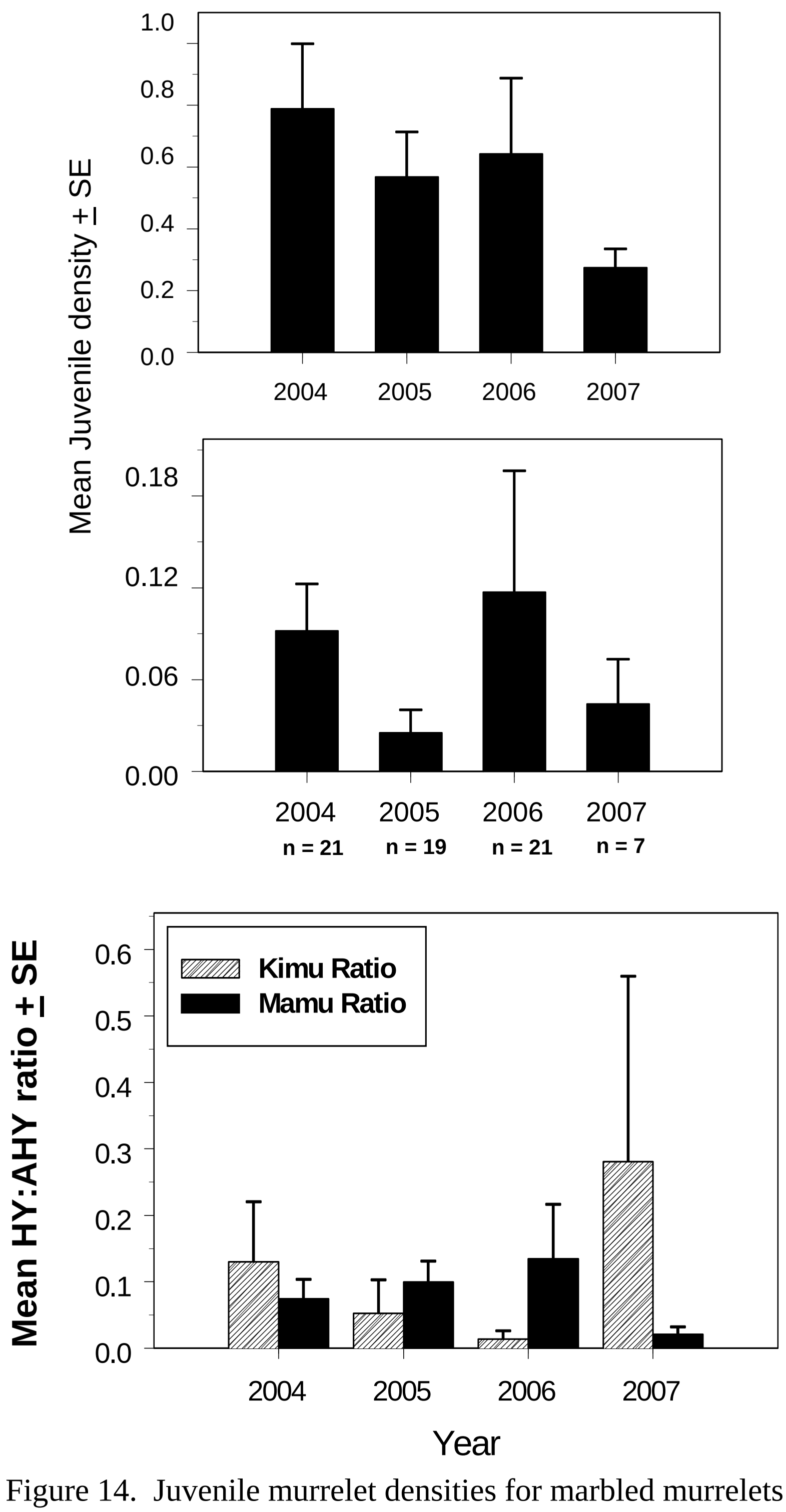
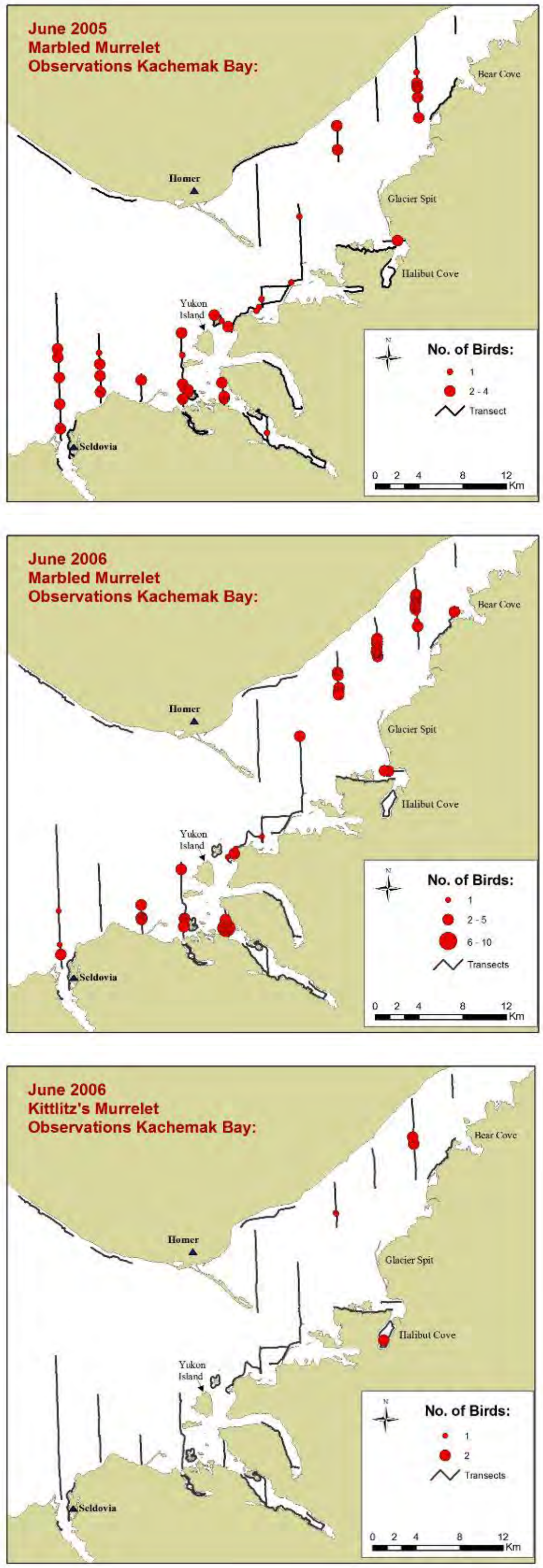


Figure 14. Juvenile murrelet densities for marbled murrelets (top), Kittlitz's murrelet (center), and juvenile (HY): adult (AHY) ratios for both species (bottom) based on at-sea surveys in Kachemak Bay during August of years 2004 – 2007. Note different scales on Y axis for juvenile densities of marbled and Kittlitz's murrelets



A

B

C

Figure 15. Distribution of marbled murrelets during Kachemak Bay surveys in June of 2005 (A) and 2006 (B), and Kittlitz's murrelets in June 2006 (C) (there were none in June 2005).

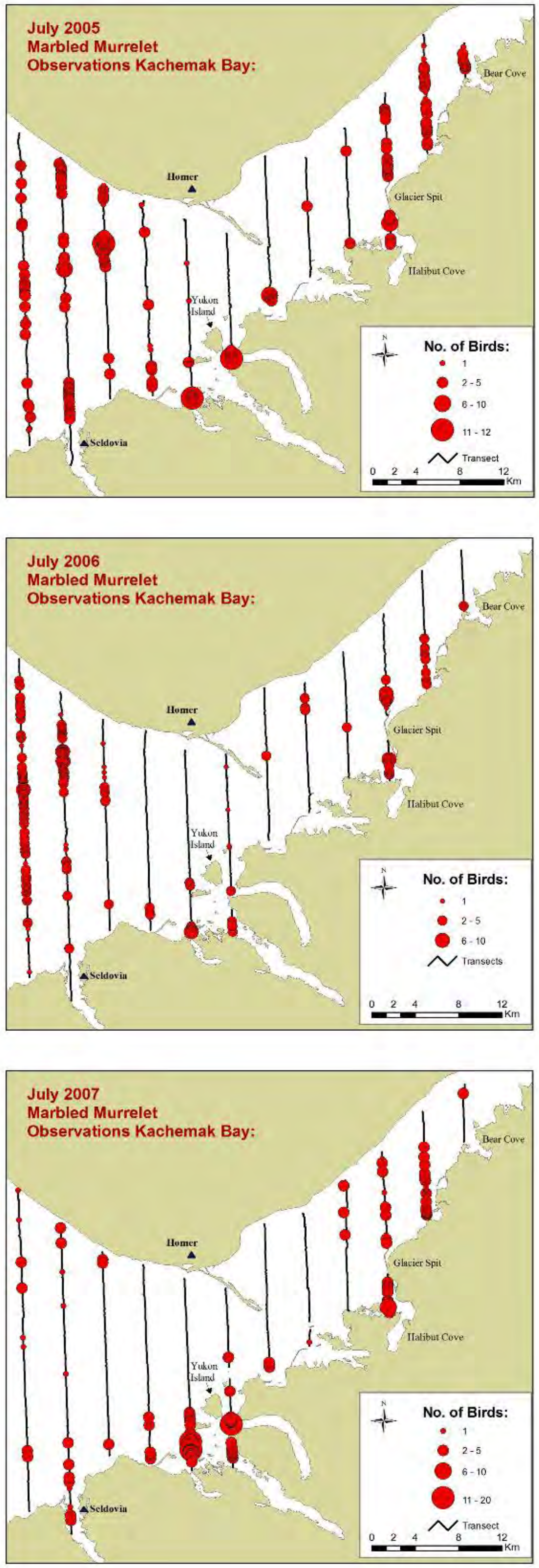


Figure 16. Distribution of marbled murrelets during surveys of Kachemak Bay between 18 – 25 July of 2005, 2006, and 2007.

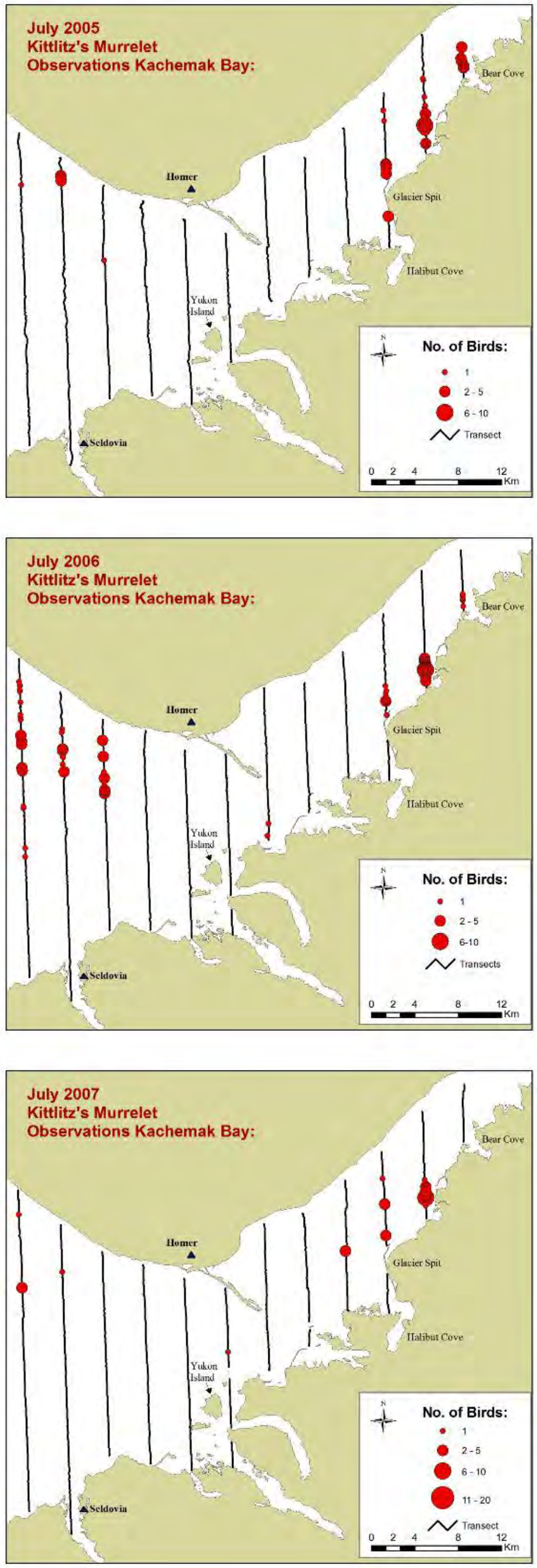


Figure 17. Distribution of Kittlitz's murrelets during surveys of Kachemak Bay between 18 – 25 July of 2005, 2006, and 2007.

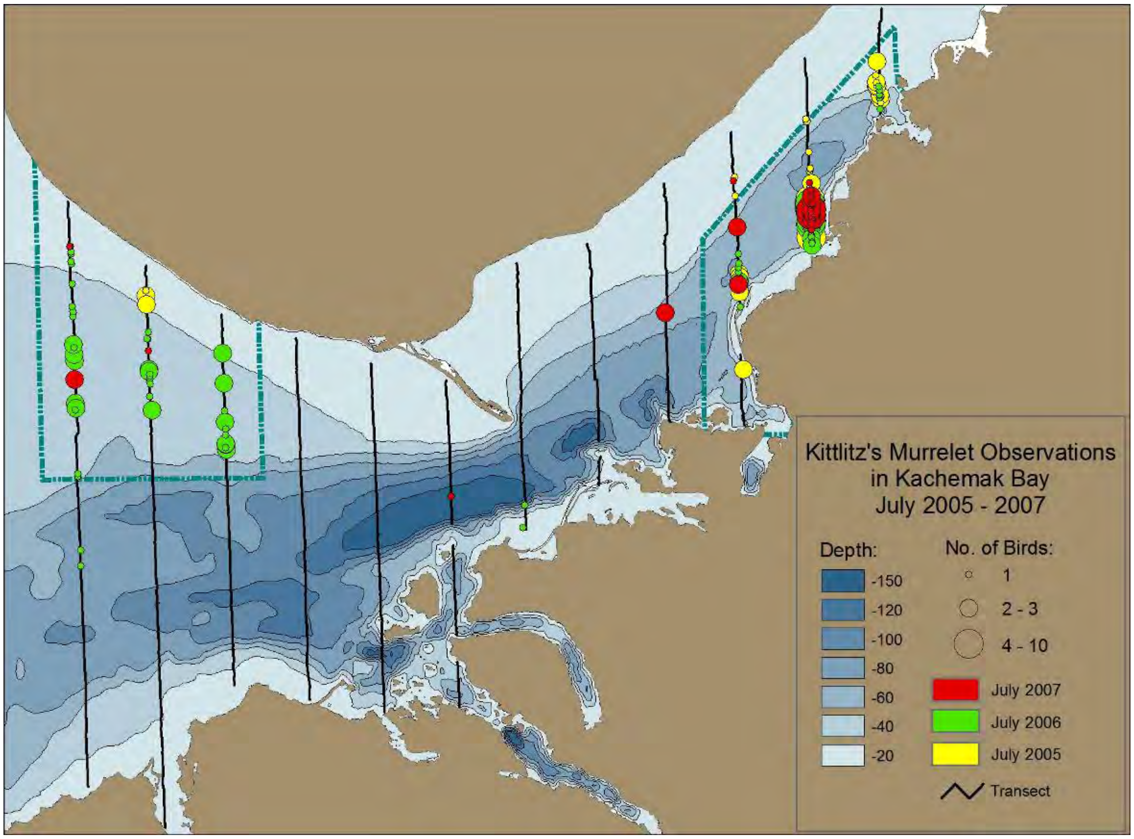


Figure 18. Combined distribution of Kittlitz's murrelets during July surveys for 2005 – 2007, with bathymetric coverage for Kachemak Bay. The two Kittlitz's murrelet hot spots are outlined in a blue dashed line. They include 128 km^2 area in the north outer bay, which was used by Kittlitz's murrelets primarily in July 2006, and a 75 km^2 area in the south inner bay, which was used all three years.

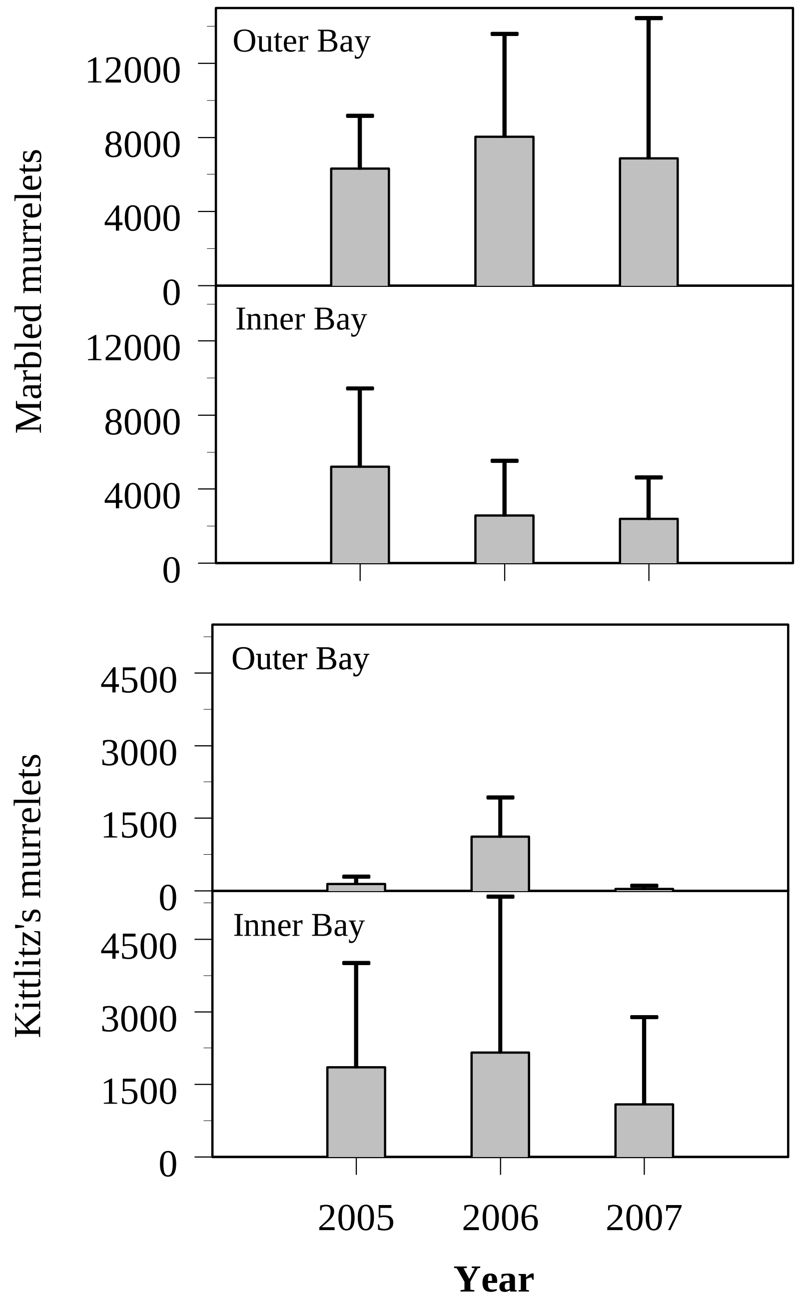


Figure 19. July population estimates (± 95% CI) for marbled murrelets (top) and Kittlitz's murrelets (bottom) by year and by regions (outer bay and inner bay). Estimates were derived from surveys conducted in Kachemak Bay, 16-26 July, 2005 – 2007.

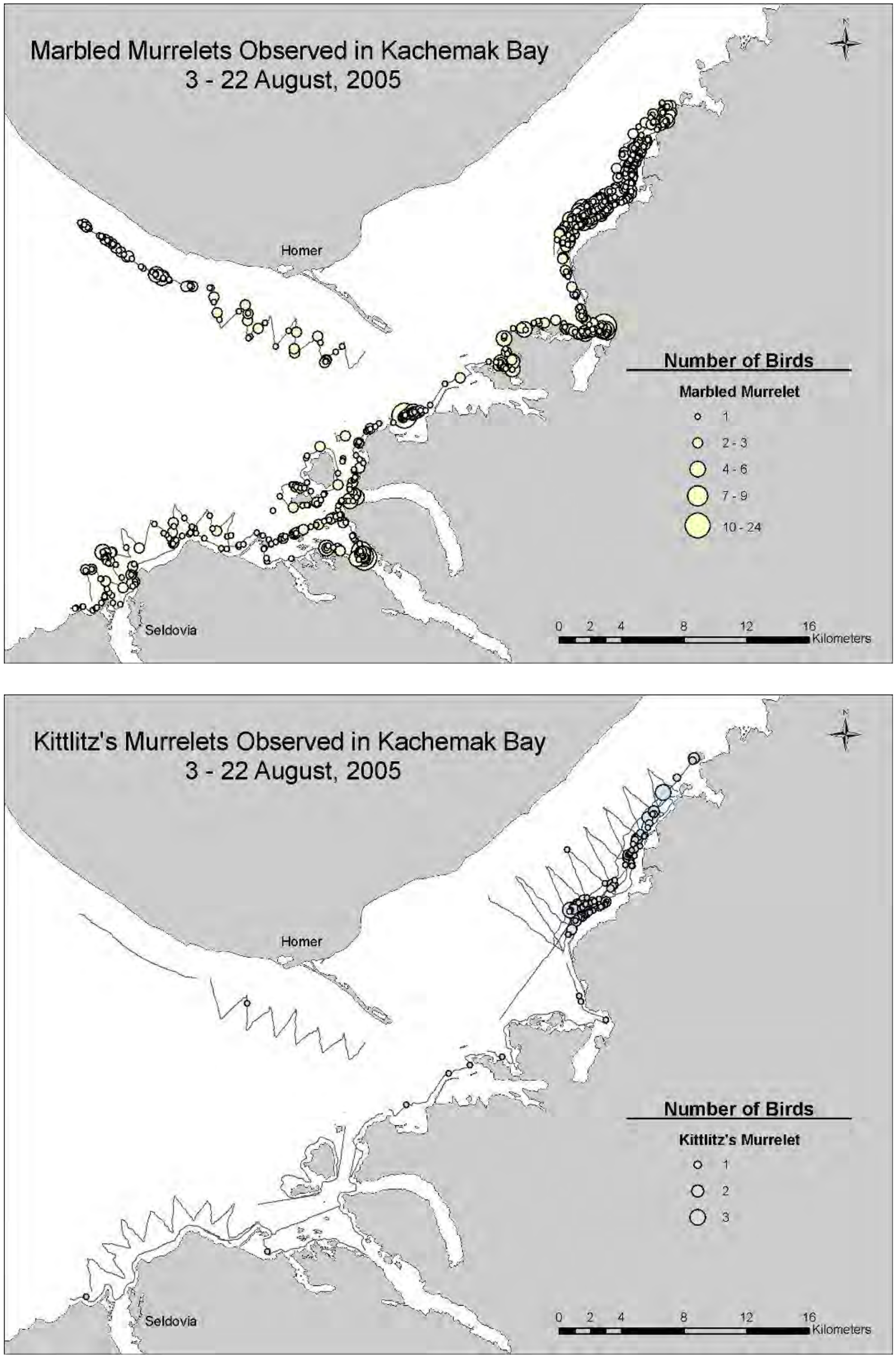


Figure 20. Distribution of marbled murrelets (top) and Kittlitz's murrelets (bottom) observed during all August surveys in 2005. Transect lines are shown in grey.

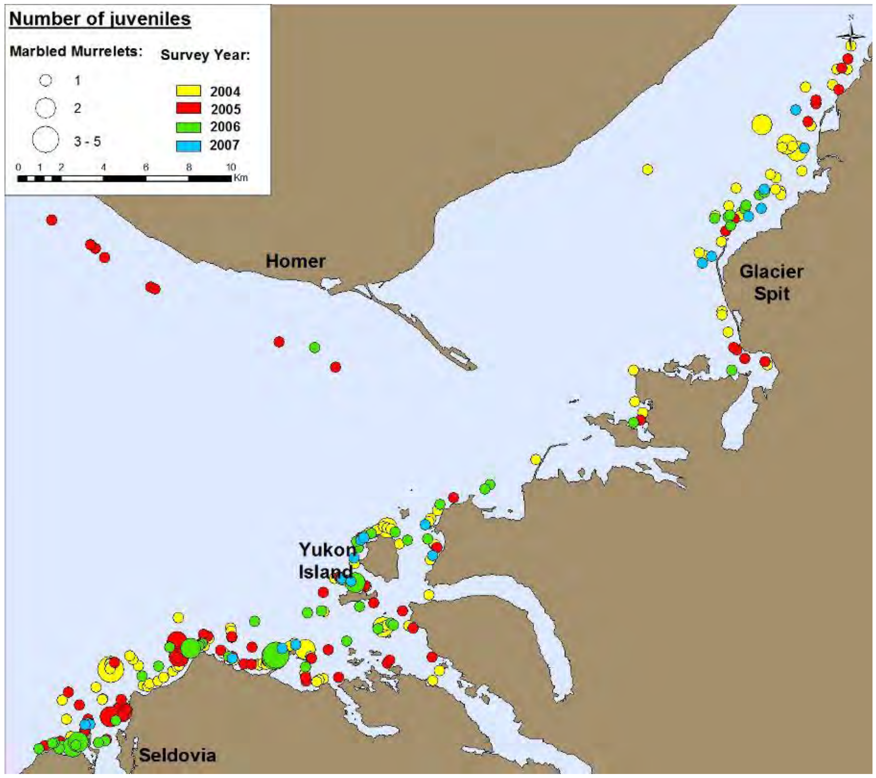


Figure 21. Distribution of juvenile marbled murrelets in Kachemak Bay, August 2004-2007.

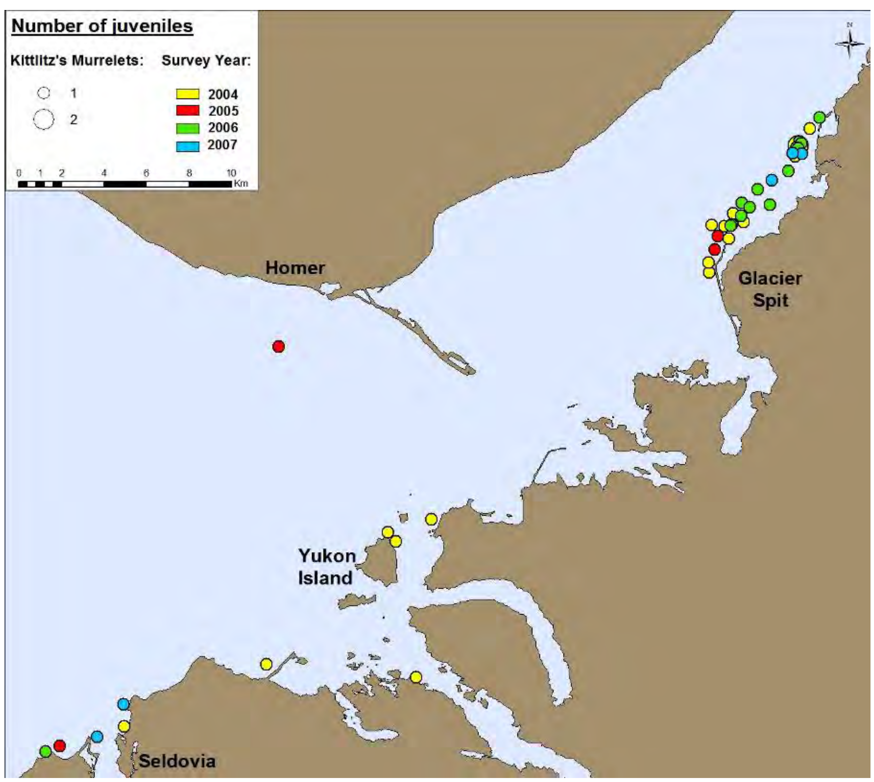


Figure 22. Distribution of juvenile Kittlitz's murrelets in Kachemak Bay, August 2004-2007.

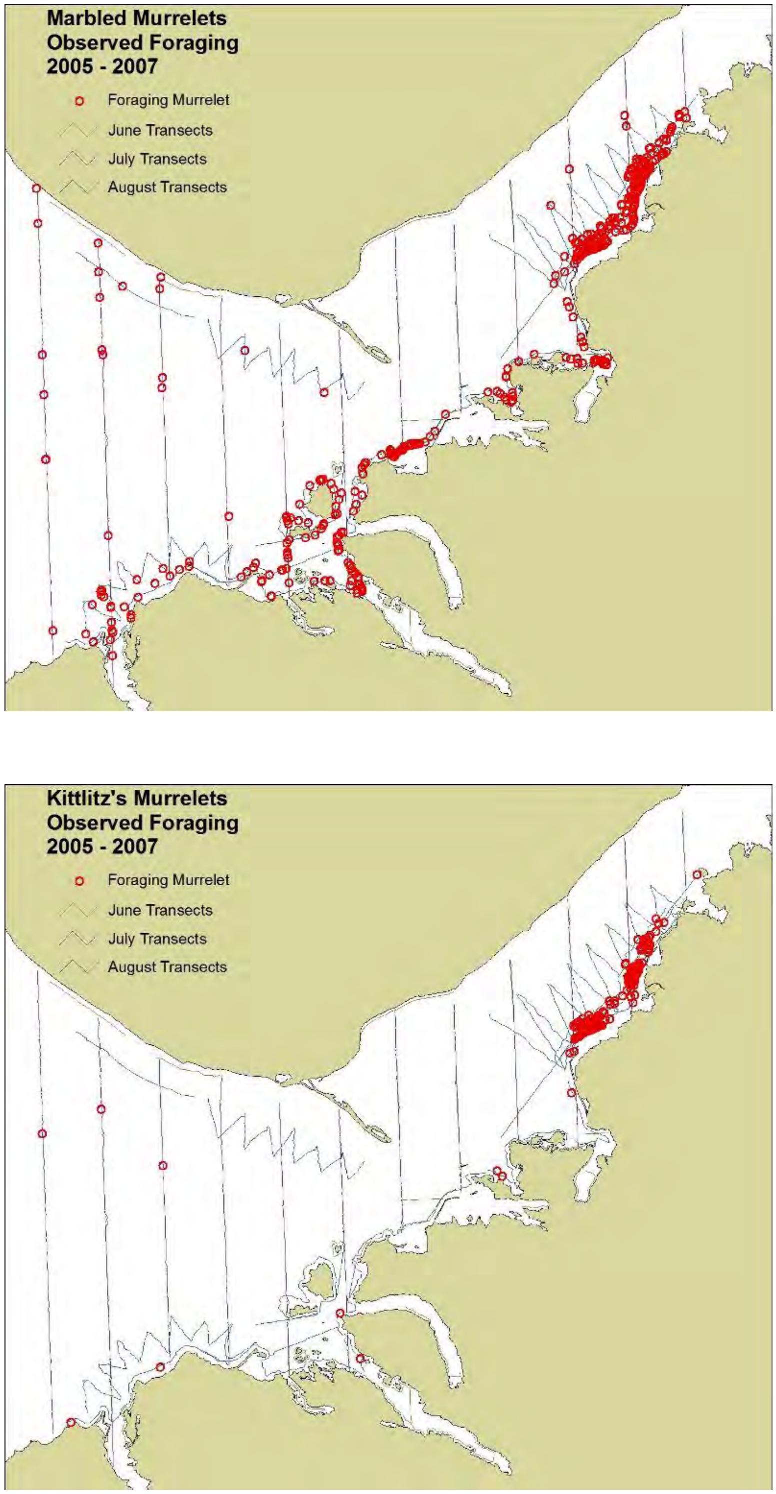
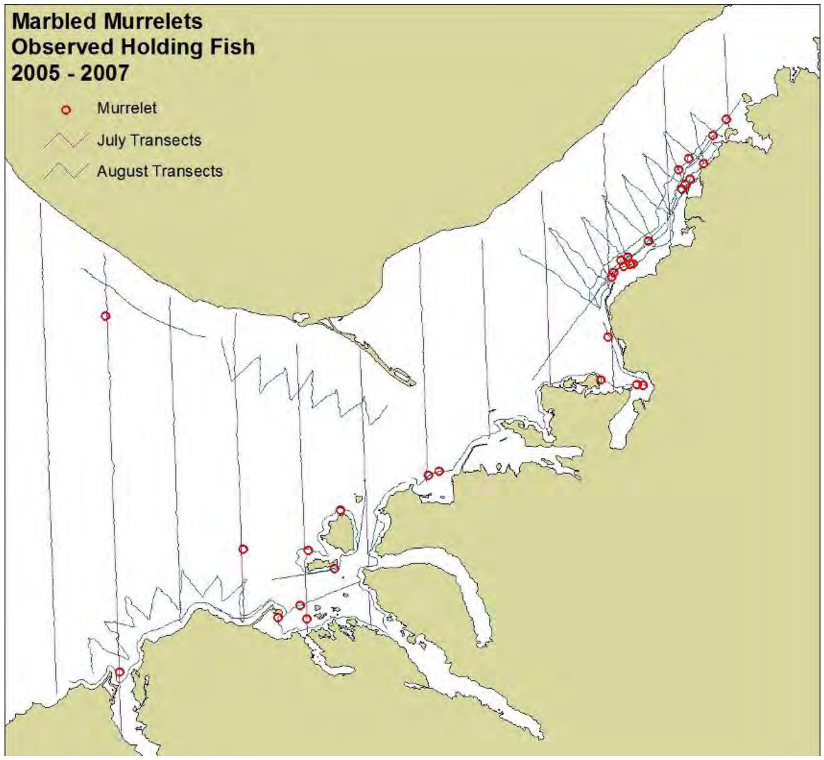


Figure 23. Location of marbled murrelets (top) and Kittlitz's murrelets (bottom) recorded as actively foraging during surveys in Kachemak Bay, June, July, and August of 2005 – 2007.



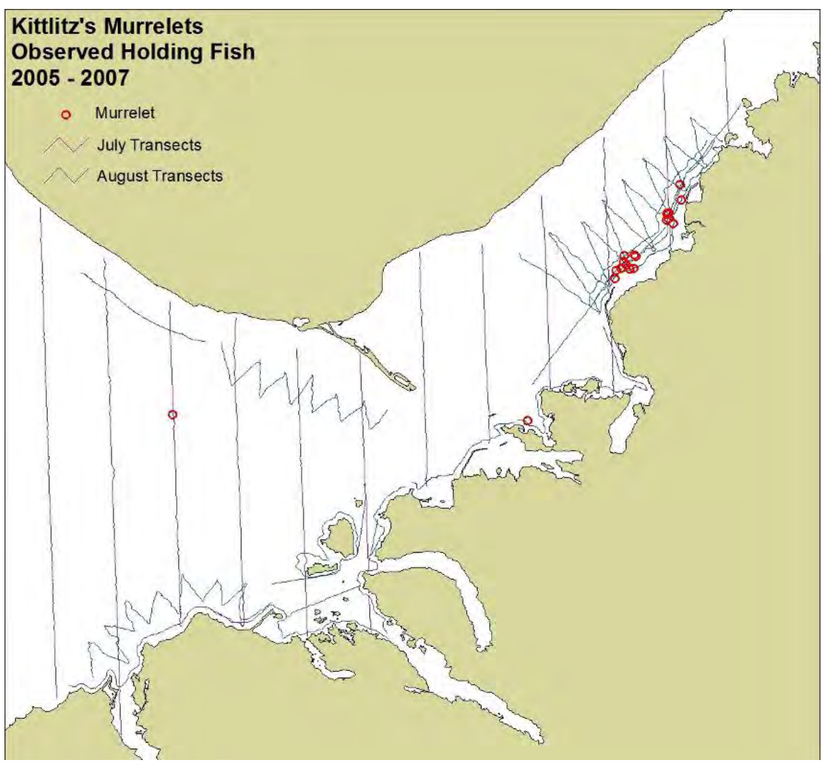


Figure 24. Observations of marbled murrelets (top) and Kittlitz's murrelets (bottom) holding fish at the surface during surveys of Kachemak Bay in July and August, 2005 – 2007.

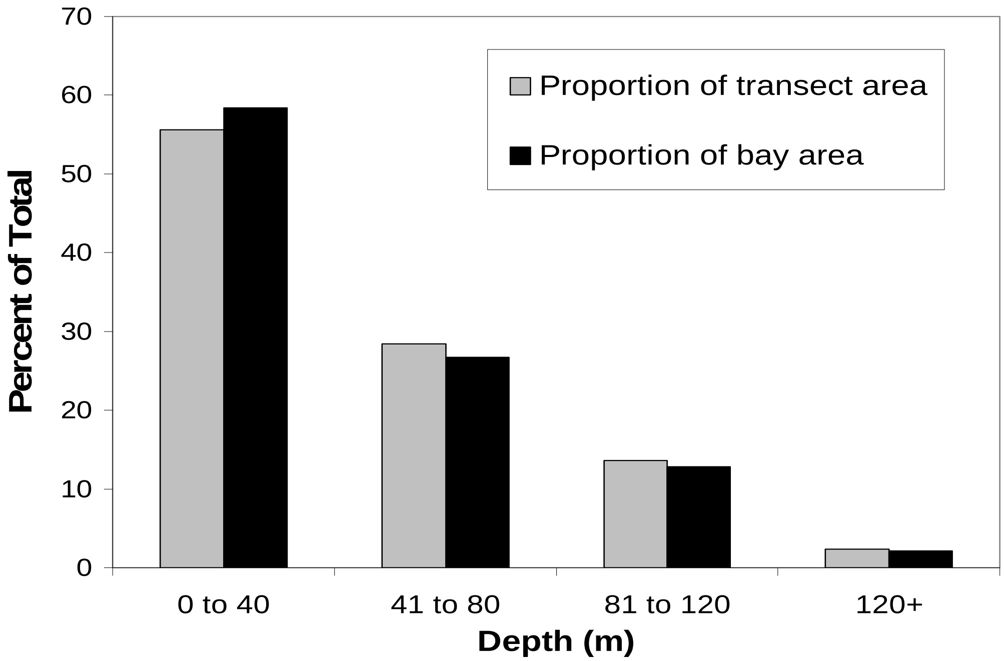


Figure 25. Proportions of water depth categories for all of Kachemak Bay (black bars) and for the area covered by survey tracks of this study in July of 2005 – 2007 (grey bars).

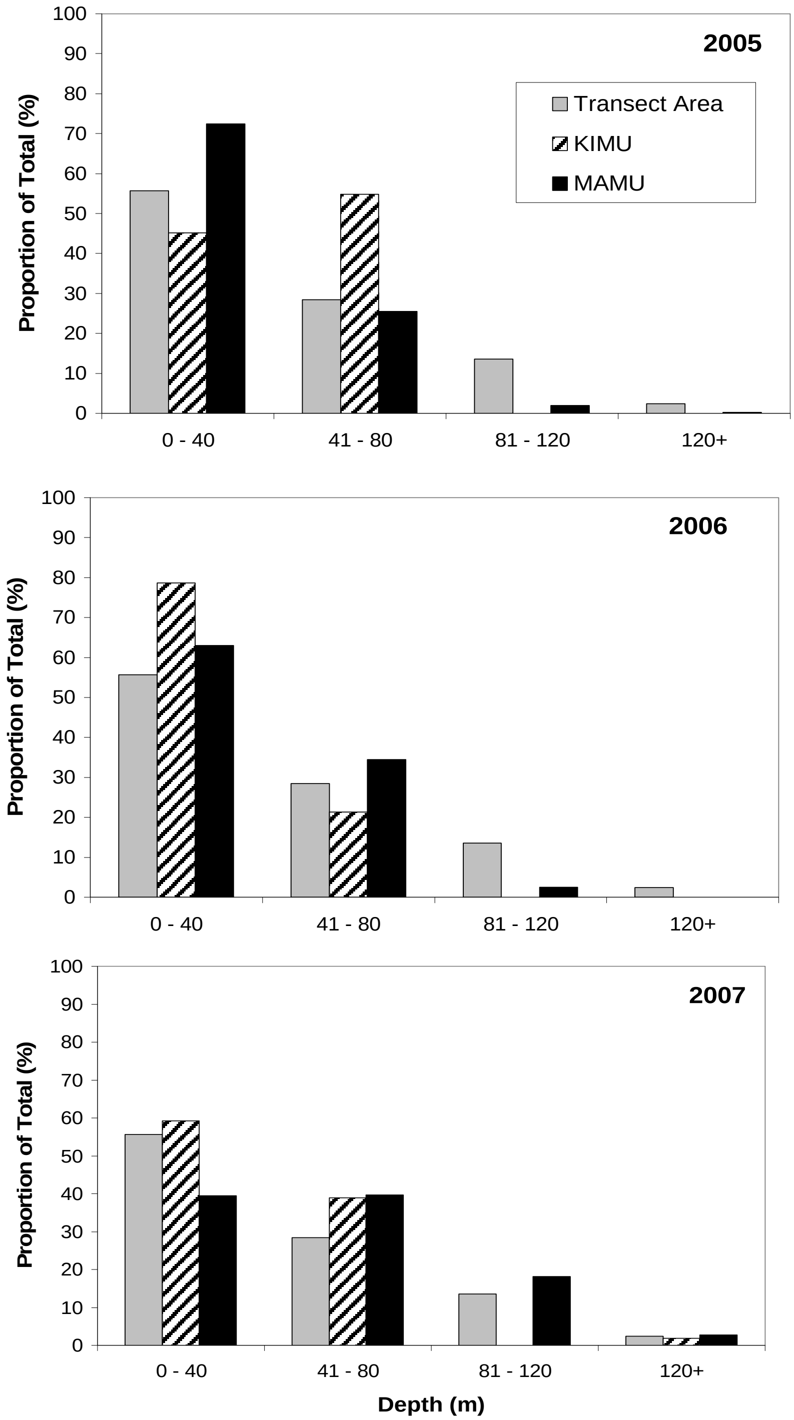


Figure 26. Proportions of water depth categories for survey transects (grey bars), Kittlitz's murrelet numbers (striped bars), and marbled murrelet numbers (black bars).

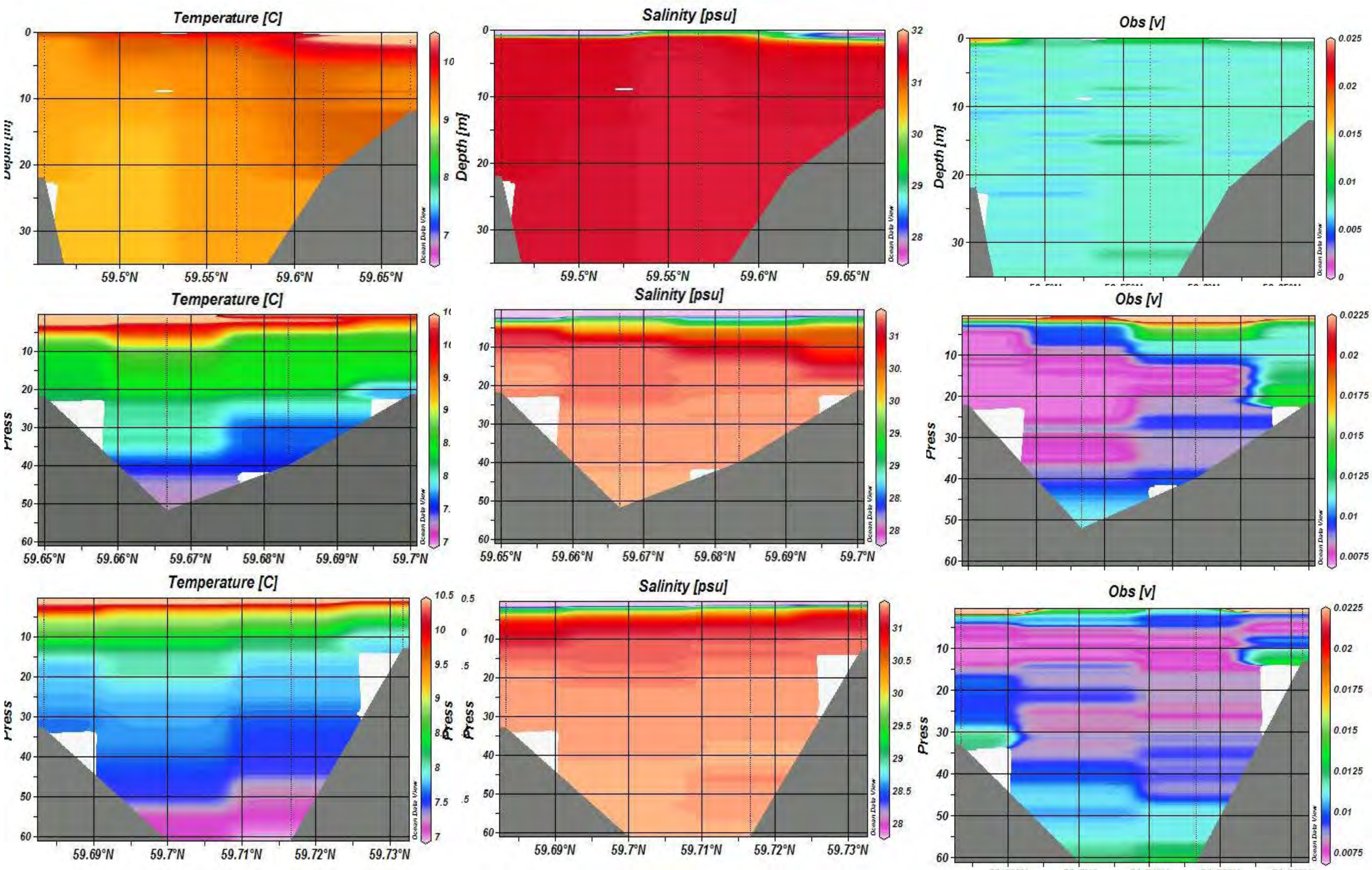


Figure 27. Water profiles for July 2006 along line 12 in the outer bay (top row), line 3 in the inner bay near Glacier Spit (middle row), and line 2 in the inner bay near Aurora Lagoon (bottom row). The north shore is on the right. Note that turbidity scale is different for line 12; it is moderately clear water.

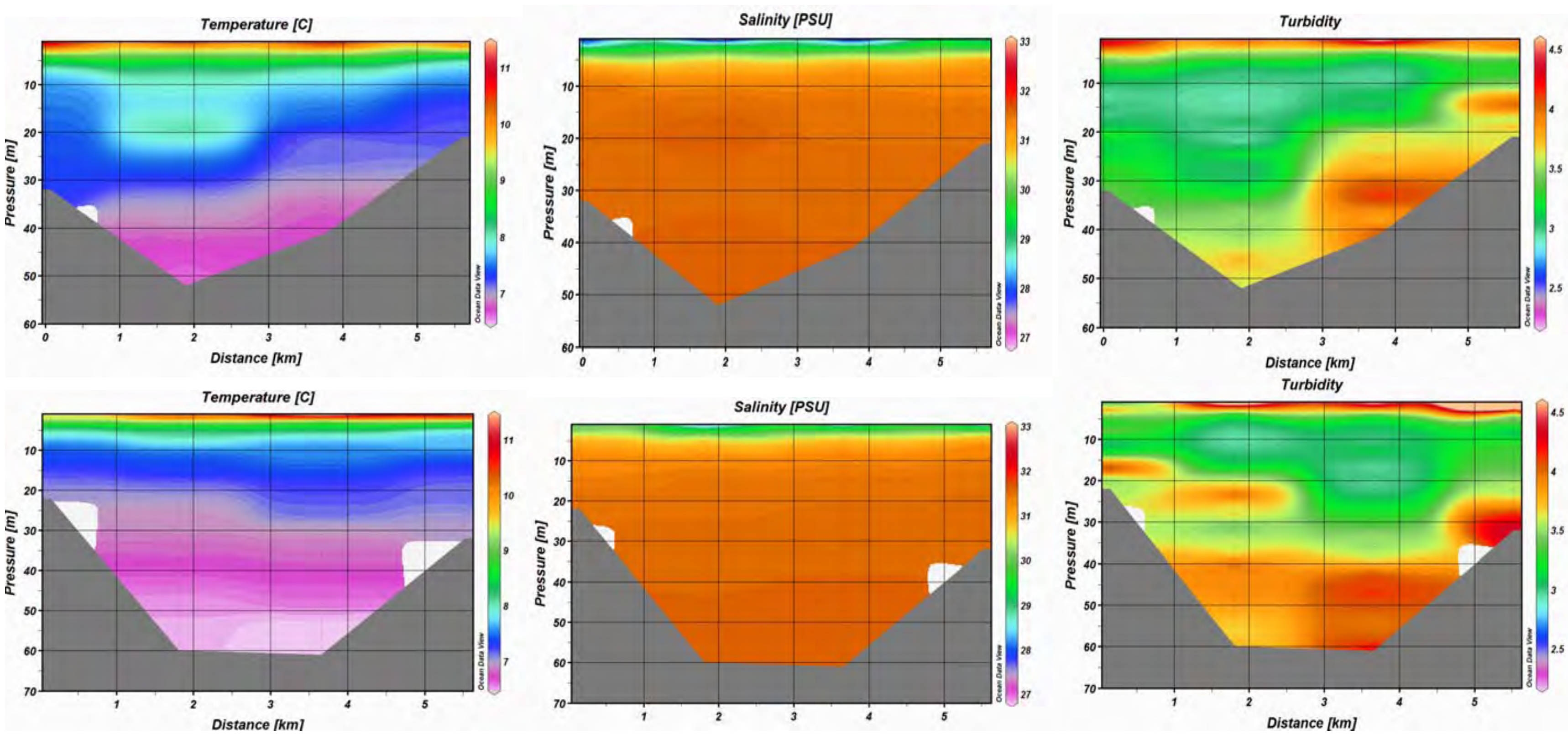


Figure 28. Water profiles for July 2007 along line 3 in the inner bay near Glacier Spit (top row), and line 2 in the inner bay near Aurora Lagoon (bottom row). The north shore is on the right.

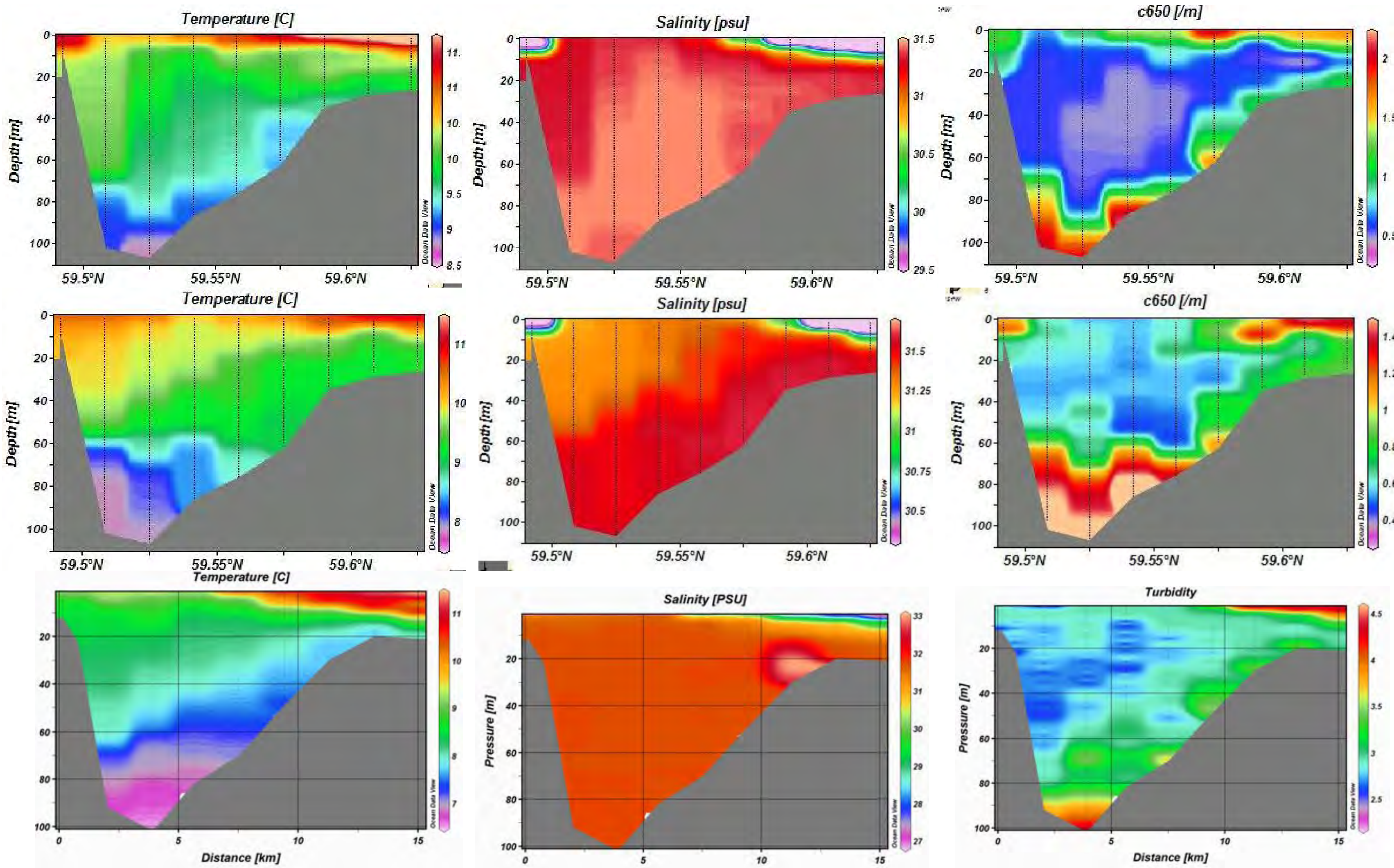
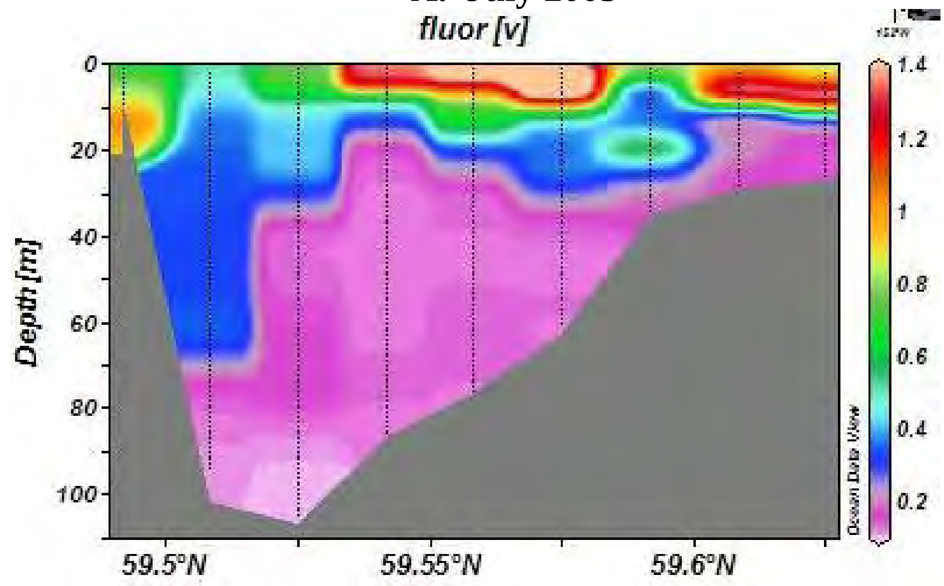


Figure 29. Water profiles along the Barabara Line, based on CTD sampling in July of 2005 (top row), 2006 (middle row), and 2007 (bottom row). Note that scales along the Y axis are different among years for turbidity (c650[/*m*]). The north shore is on the right.

A. July 2005



B. July 2006

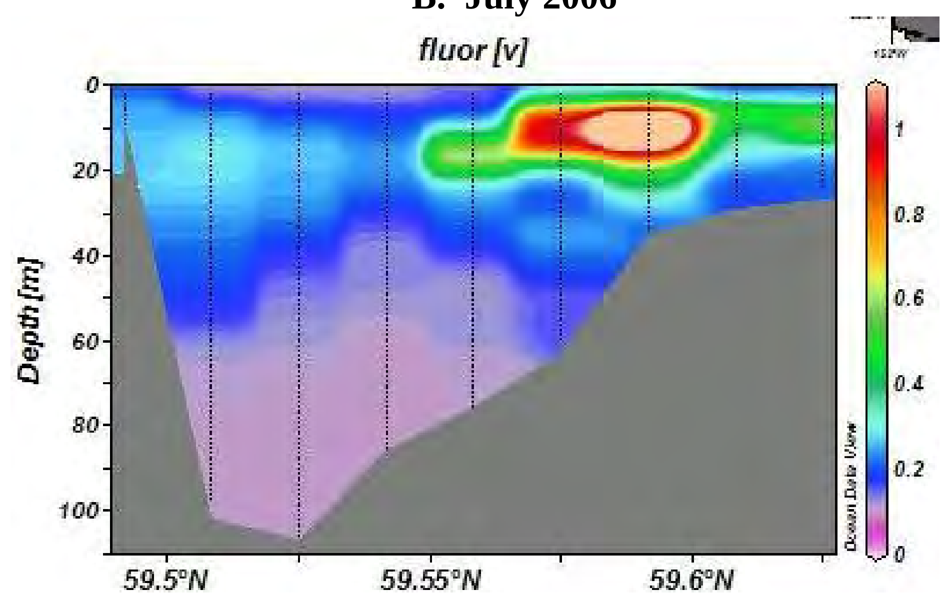


Figure 30. Fluorescence (an indicator of primary productivity) as measured by CTD casts along the Barabara Line across the mouth of Kachemak Bay in July of 2005 (A) and 2006 (B). The North Shore is on the right side of the graph. Data are from Dr. S. Pegau (formerly with Kachemak Bay National Estuarine Research Reserve). Fluorescence was not measured in 2007.

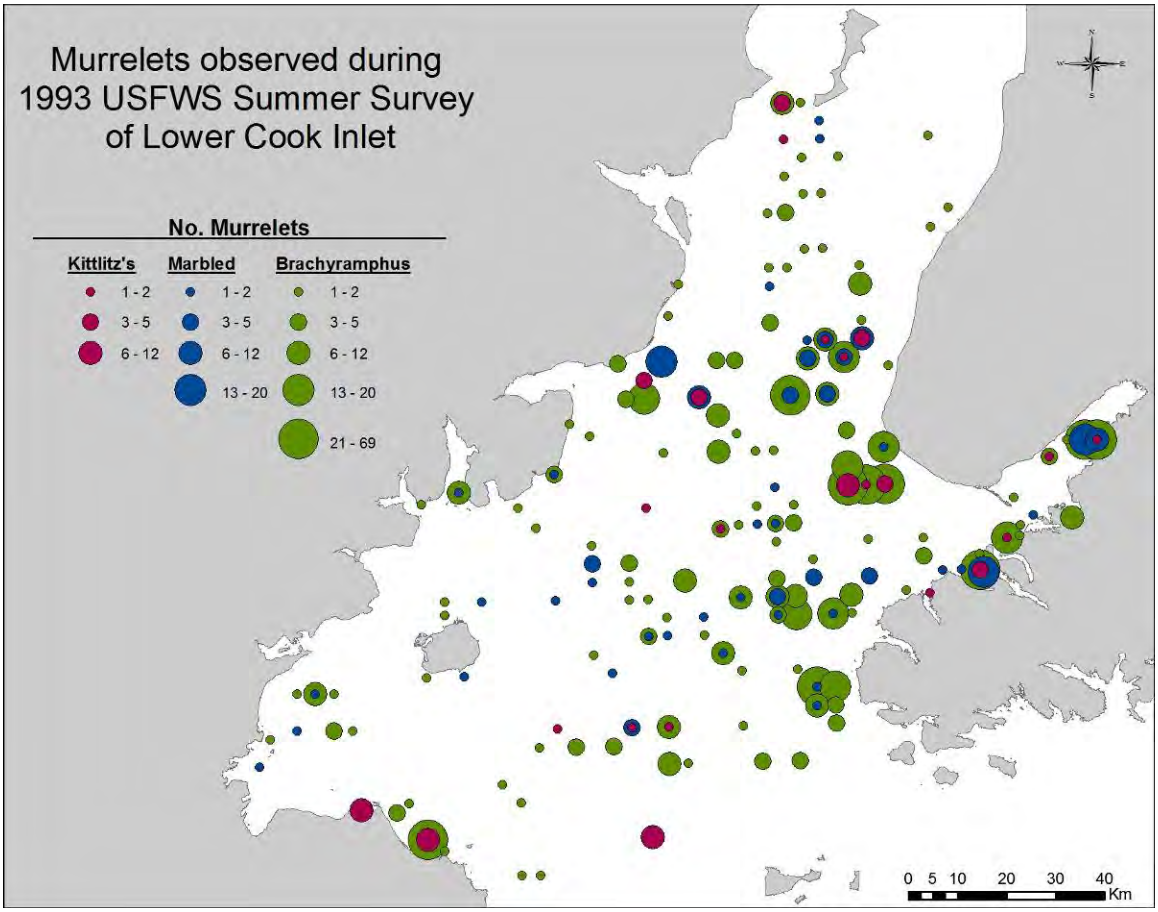


Figure 31. Distribution of marbled murrelets, Kittlitz's murrelets, and unidentified *Brachyramphus* murrelets in Lower Cook Inlet during the June 1993 survey conducted by U.S. Fish and Wildlife Service. Note the large numbers of murrelets in Kachemak Bay's inner bay, Eldredge passage, and the outer north shore at the mouth of the bay.

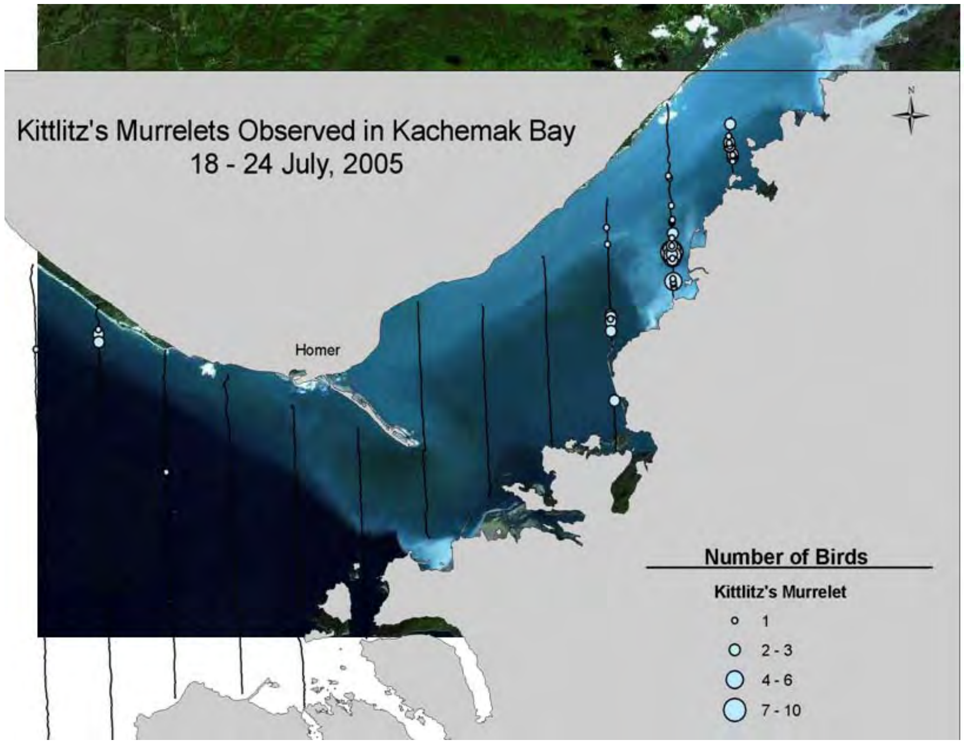


Figure 32. A satellite image of Kachemak Bay overlaid with maps of Kittlitz's murrelet observations in July (top) and August (bottom).

Figure 33. Cumulative Spruce Bark Beetle infestation in the Cook Inlet Region, 1989-2002. Figure provided by U.S. Forest Service, Soldotna, Alaska.

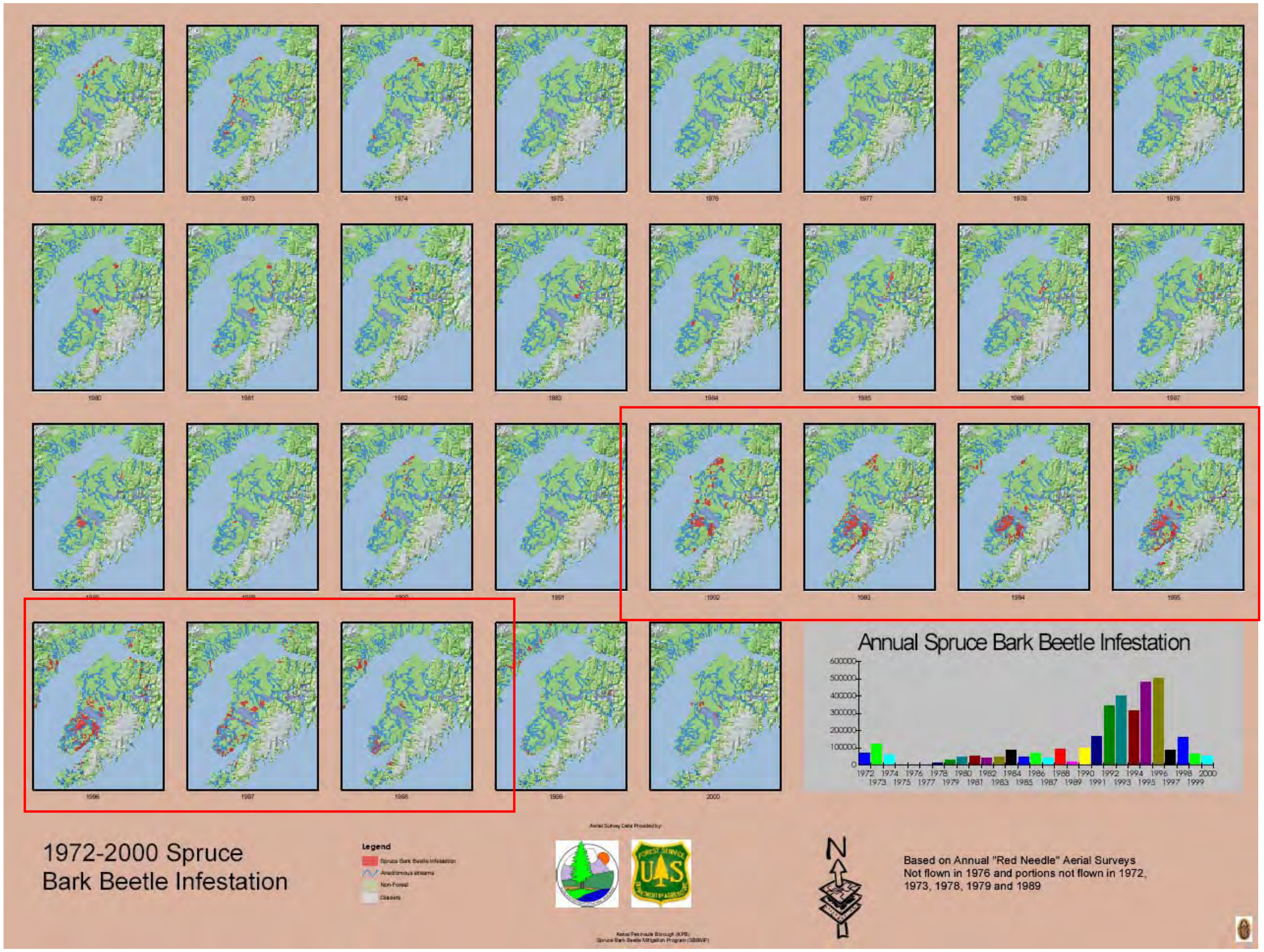


Figure 34. Progression of Spruce Bark Beetle Infestation on the Kenai Peninsula, 1972-2000, based on aerial surveys by the U.S. Forest Service. Red polygons indicate areas with new outbreak in a given year, and do not show cumulative infestation impacts. Note that the greatest ‘new’ infestations in the Kachemak Bay area occurred between 1992- 1998 (maps outlined in red).

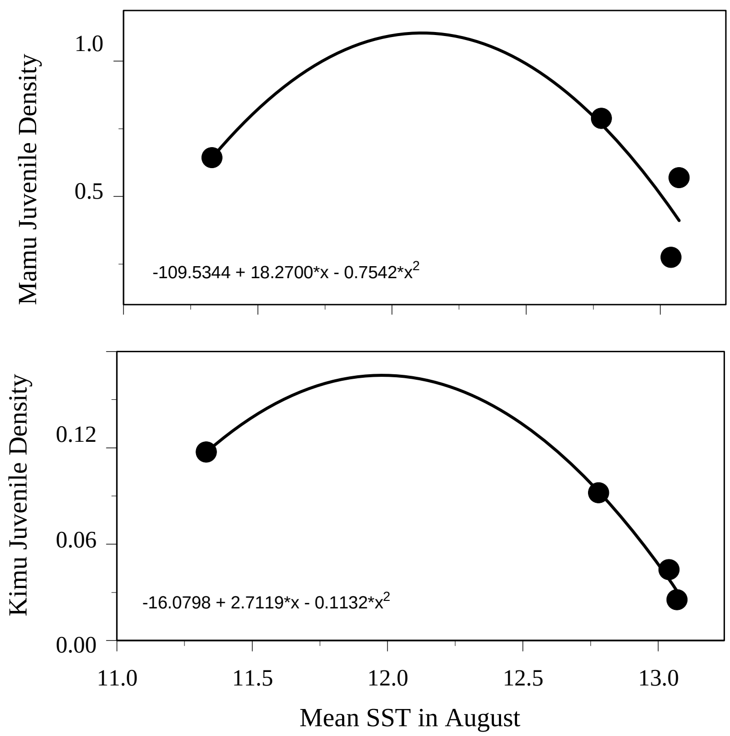


Figure 35. Mean juvenile density for marbled murrelets (top) and Kittlitz's murrelet (bottom) as a function of mean Sea Surface Temperature (SST) in August, based on surveys in Kachemak Bay, 2004 – 2007. SST values were obtained during the surveys. A polynomial curve was the best fit to the data.

Table 1. Survey effort for Kachemak Bay murrelet surveys, 2004 – 2007.

Year	Month	Survey Dates	No. Survey Days	No. Transects	Transect type	Total Area Surveyed (km^2)	Historic Source
2004	August	Aug 3-23	18	68	shoreline & zigzag	150.28	USFWS (Kuletz) & USGS (Piatt/Speckman)
2005	April	Apr 24	1	9	parallel shoreline	6.92	USFWS (Kuletz 1989, 1996)
	June	June 16-30*	5	46	shoreline & pelagic	32.56	USFWS (Agler et. al. 1995)
	June	June 20	1	4	parallel shoreline	2.7	USFWS (Kuletz 1989, 1996)
	July	July 18-23	5	12	pelagic, shore-to-shore	37.64	none
	July	24-Jul	1	9	parallel shoreline	7.95	USFWS (Kuletz 1989, 1996)
	August	Aug 3-22	17	54	shoreline & pelagic	125.86	USFWS (Kuletz) & USGS (Piatt/Speckman)
	September	Sept 2	1	5	parallel shoreline	7.11	USFWS (Kuletz 1989, 1996)
2006	June	June 17-20	4	45	shoreline & pelagic	32.55	USFWS (Agler et. al. 1995)
	July	July 18-21	4	12	pelagic, shore-to-shore	39.37	none
	August	Aug 2-23	18	66	shoreline & zigzag	128.8	USFWS (Kuletz) & USGS (Piatt/Speckman)
2007	July	July 22-25	4	12	pelagic, shore-to-shore	38.59	none
	August	Aug 8-16	7	25	shoreline & zigzag	59.64	USFWS (Kuletz) & USGS (Piatt/Speckman)
Total			86	367		669.97	

* Two inner lagoon transects that we could not access were completed by Cook Inlet Keeper on June 30.

Table 2. Densities (birds • km^{-2}) and population estimates (*N*) with 95% confidence intervals for *Brachyramphus* murrelets in Kachemak Bay during June for 1993, 2005, and 2006. The estimates shown include flying birds.

			Kittlitz's Murrelet			Marbled Murrelet			Unidentified *Brachyramphus*			Total *Brachyramphus*		
Survey	Stratum	Region	*density*	*N*	*95% CI*	*density*	*N*	*95% CI*	*density*	*N*	*95% CI*	*density*	*N*	*95% CI*
June 1993	Pelagic	Combined	0.42	317	447	1.18	897	1332	5.50	4170	4615	7.10	5384	5780
		Inner Bay	0.28	81	156	1.97	569	1012	5.48	1586	2377	7.73	2237	3376
		Outer Bay	0.59	279	537	0.45	209	302	5.95	2785	4625	6.99	3273	5127
	Shoreline	Combined	0.20	12	11	1.49	86	99	3.19	184	141	4.88	282	225
		Inner Bay	0.23	6	6	1.24	33	53	5.53	146	127	7.00	185	172
		Outer Bay	0.18	6	9	1.69	53	85	1.34	42	67	3.21	101	151
	All Bay			**328**	**447**		**984**	**1336**		**4354**	**4617**		**5666**	**5784**
June 2005	Pelagic	Combined	0.00	0	0	4.77	3613	1822	0.00	0	0	4.77	3613	1822
		Inner Bay	0.00	0	0	3.37	976	1089	0.00	0	0	3.37	976	1089
		Outer Bay	0.00	0	0	6.24	2924	1361	0.00	0	0	6.24	2924	1361
	Shoreline	Combined	0.00	0	0	0.66	38	32	0.00	0	0	0.66	38	32
		Inner Bay	0.00	0	0	0.65	17	23	0.00	0	0	0.65	17	23
		Outer Bay	0.00	0	0	0.67	21	23	0.00	0	0	0.67	21	23
	All Bay			**0**	**0**		**3651**	**1823**		**0**	**0**		**3651**	**1823**
June 2006	Pelagic	Combined	0.41	313	435	9.62	7292	4375	0.48	365	351	10.52	7969	4703
		Inner Bay	0.78	225	300	11.01	3187	2421	0.52	150	199	12.31	3562	2586
		Outer Bay	0.00	0	0	8.05	3772	3758	0.44	206	300	8.49	3978	4032
	Shoreline	Combined	0.11	6	10	0.33	19	22	0.00	0	0	0.33	19	22
		Inner Bay	0.30	8	13	0.90	24	27	0.00	0	0	0.90	24	27
		Outer Bay	0.00	0	0	0.00	0	0	0.00	0	0	0.00	0	0
	All Bay			**319**	**435**		**7312**	**4376**		**365**	**351**		**7989**	**4703**

Table 3. Densities and population estimates for *Brachyramphus* murrelets during July surveys in Kachemak Bay, 2005-2007. Calculations were done excluding flying birds, and with flying birds included, for Inner and Outer Bay regions, and combined.

		Entire Bay - Combined			**Inner Bay**			**Outer Bay**		
	July 2005	*density*	*N*	*95% CI*	*density*	*N*	*95% CI*	*density*	*N*	*95% CI*
no flyers	Unidentified *Brachyramphus*	1.17	953	587	1.22	386	494	1.14	571	414
	Kittlitz's Murrelet	2.10	1712	2025	5.87	1854	2160	0.28	138	156
	Marbled Murrelet	13.92	11355	4546	16.54	5226	4230	12.65	6323	2856
	Total *Brachyramphus*	17.19	14020	6369	23.63	7466	6386	14.07	7032	3329
with flyers	Unidentified *Brachyramphus*	2.26	1842	856	2.36	747	726	2.21	1103	603
	Kittlitz's Murrelet	2.47	2015	2474	7.01	2214	2664	0.28	138	156
	Marbled Murrelet	14.82	12092	4506	17.28	5458	4399	13.64	6816	2682
	Total *Brachyramphus*	19.55	15949	6811	26.65	8419	7332	16.12	8057	3011
	July 2006	*density*	*N*	*95% CI*	*density*	*N*	*95% CI*	*density*	*N*	*95% CI*
no flyers	Unidentified *Brachyramphus*	0.56	456	241	0.67	211	221	0.50	251	146
	Kittlitz's Murrelet	3.81	3108	2932	6.83	2159	3224	2.24	1119	811
	Marbled Murrelet	13.39	10919	6691	8.17	2582	2960	16.10	8045	5558
	Total *Brachyramphus*	17.76	14483	7627	15.68	4952	4995	18.84	9414	6055
with flyers	Unidentified *Brachyramphus*	1.02	829	468	1.63	516	486	0.69	347	150
	Kittlitz's Murrelet	4.04	3294	3171	7.43	2347	3486	2.28	1138	832
	Marbled Murrelet	14.02	11437	6895	9.21	2910	3506	16.52	8257	5643
	Total *Brachyramphus*	19.08	15561	8112	18.28	5773	5829	19.49	9742	6256
	July 2007	*density*	*N*	*95% CI*	*density*	*N*	*95% CI*	*density*	*N*	*95% CI*
no flyers	Unidentified *Brachyramphus*	0.29	232	376	0.69	218	427	0.08	39	46
	Kittlitz's Murrelet	1.22	993	1640	3.44	1088	1804	0.08	39	69
	Marbled Murrelet	11.66	9511	8002	7.58	2393	2245	13.75	6872	7593
	Total *Brachyramphus*	13.16	10737	8472	11.71	3699	4111	13.91	6950	7556
with flyers	Unidentified *Brachyramphus*	1.22	993	757	2.07	653	811	0.78	392	245
	Kittlitz's Murrelet	1.40	1141	1759	3.75	1185	1941	0.20	98	93
	Marbled Murrelet	12.15	9912	8201	8.11	2563	2366	14.22	7107	7768
	Total *Brachyramphus*	14.77	12047	8840	13.93	4400	4810	15.20	7597	7670

Table 4. Summary of trends in murrelet densities, as determined by linear regressions on logged annual mean densities. Trends analysis were performed for each Transect Set in Kachemak Bay, 1988 - 2007 (see Figure 7 for graphs and Appendix C for individual transect results). For this test, only surveys conducted between 25 July and 18 August were included. Because few Kittlitz's murrelets occurred in the outer bay, we did not include analyses on Kittlitz's for that region. Because marbled murrelets were numerically dominate and species identification improved over time, the regression results for these two categories should be examined in conjunction with results for Total *Brachyramphus* murrelets.

					Percent change per year			
Region	Transect Set	Years	N years surveyed	N replicates	Kittlitz's	Marbled	Unidentified Brachyramphus	Total Brachyramphus
Inner	Inner South Shore	1988 - 2007	9	14	- 4	+ 11	- 12	0
Inner	Inner Zigzag	1996 - 2005	6	6	- 18	0	- 14	- 4
Outer	Eldredge Passage	1988 - 2006	4	10	na	+ 2	- 23	- 6
Outer	Outer North Shore	1996 - 2006	6	7	na	+ 14	0	+ 8
Outer	Outer South Shore	1996 - 2007	7	13	na	+ 9	+ 21	+ 8
Outer	Outer Zigzag	1996-2006	5	8	na	+8	- 30	+ 6

na = not applicable

Table 5. Mean densities (birds • km^{-2}) for murrelets in Kachemak Bay during late summer surveys (25 July - 18 August) for two decadal periods, 1988 - 1999 and 2004 - 2007. Daily surveys were combined by period and region. KIMU = Kittlitz's murrelets, MAMU = marbled murrelets, Unid BRMU = *Brachyramphus* murrelets not identified to species, All BRMU = identified and unidentified murrelets combined. Significant results are in bold. Between decadal periods there were significant declines in Kittlitz's murrelets for the Inner bay and the entire bay, and a significant increase in total murrelets for the Outer bay.

Survey effort				Mean (± SE)			
Period	Region	N years	replicates	KIMU	MAMU	Unid BRMU	All BRMU
1988-1999	all bay	6	19	**5.50 (2.22)**[a]	13.29 (3.24)	10.00 (3.2)	28.80 (6.87)
2004-2007	all bay	4	18	**3.11 (1.87)**	20.44 (4.36)	1.97 (0.82)	25.51 (6.49)
1988-1999	Inner	6	9	**11.37 (3.90)**[b]	22.28 (5.31)	16.71 (4.57)	50.36 (9.43)
2004-2007	Inner	4	6	**9.09 (5.01)**	36.86 (9.04)	4.77 (2.08)	50.73 (14.30)
1988-1999	Outer	5	10	0.22 (0.20)	5.19 (1.39)	3.95 (3.41)	**9.39 (4.48)**[c]
2004-2007	Outer	4	12	0.12 (0.05)	12.22 (2.65)	0.57 (0.17)	**12.91 (2.80)**

[a] Wilcoxon Rank Sum test between periods; Z = -2.63, $P = 0.009$

[b] Wilcoxon Rank Sum test between periods; Z = -2.57, $P = 0.01$

[c] Wilcoxon Rank Sum test between periods; $Z = 4.71$, $P < 0.01$

Table 6. Kittlitz's murrelet and marbled murrelet juvenile density (mean ± SE) and juvenile:adult ratios (mean ± SE) in Kachemak Bay, derived from August surveys, 2004 - 2007.

Year	N survey days		Juvenile Densities (Mean ± SE)					
			Kittlitz's murrelets			Marbled murrelets		
	Inner	Outer	Inner	Outer	All bay	Inner	Outer	All bay
2004	11	10	0.12 (0.05)	0.06 (0.04)	0.09 (0.03)	0.32 (0.10)	1.30 (0.38)	0.79 (0.21)
2005	9	10	0.03 (0.03)	0.02 (0.02)	0.03 (0.02)	0.27 (0.11)	0.84 (0.23)	0.57 (0.15)
2006	9	12	0.26 (0.18)	0.01 (0.01)	0.12 (0.08)	0.23 (0.06)	0.95 (0.41)	0.64 (0.25)
2007	4	3	0.03 (0.03)	0.06 (0.06)	0.04 (0.03)	0.22 (0.03)	0.35 (0.14)	0.27 (0.06)

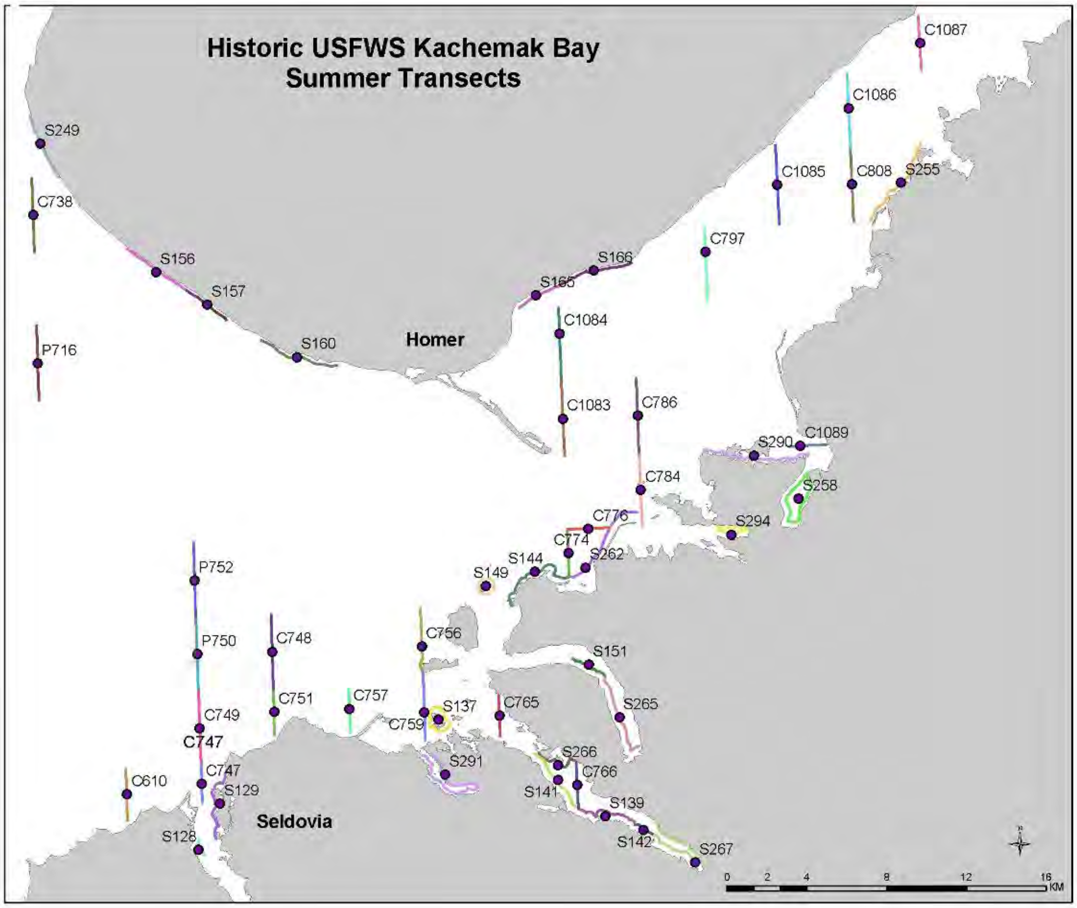
	N survey days		Juvenile:Adult ratios (Mean ± SE)					
	Inner	Outer	Kittlitz's murrelets			Marbled murrelets		
			Inner	Outer	All bay	Inner	Outer	All bay
2004	11	10	0.049 (0.02)	0.219 (0.19)	0.13 (0.09)	0.011 (0.00)	0.145 (0.06)	0.07 (0.03)
2005	9	10	0.004 (0.00)	0.096 (0.10)	0.05 (0.05)	0.013 (0.01)	0.178 (0.05)	0.10 (0.03)
2006	9	12	0.032 (0.03)	0	0.01 (0.01)	0.008 (0.00)	0.230 (0.14)	0.13 (0.08)
2007	4	3	0.003 (0.00)	0.652 (0.65)	0.28 (0.28)	0.006 (0.00)	0.041 (0.02)	0.02 (0.01)

Table 7. Mean (± SE) water surface variables measured on site prior to each transect surveyed in Kachemak Bay, 2004 – 2007. SST = sea surface temperature.

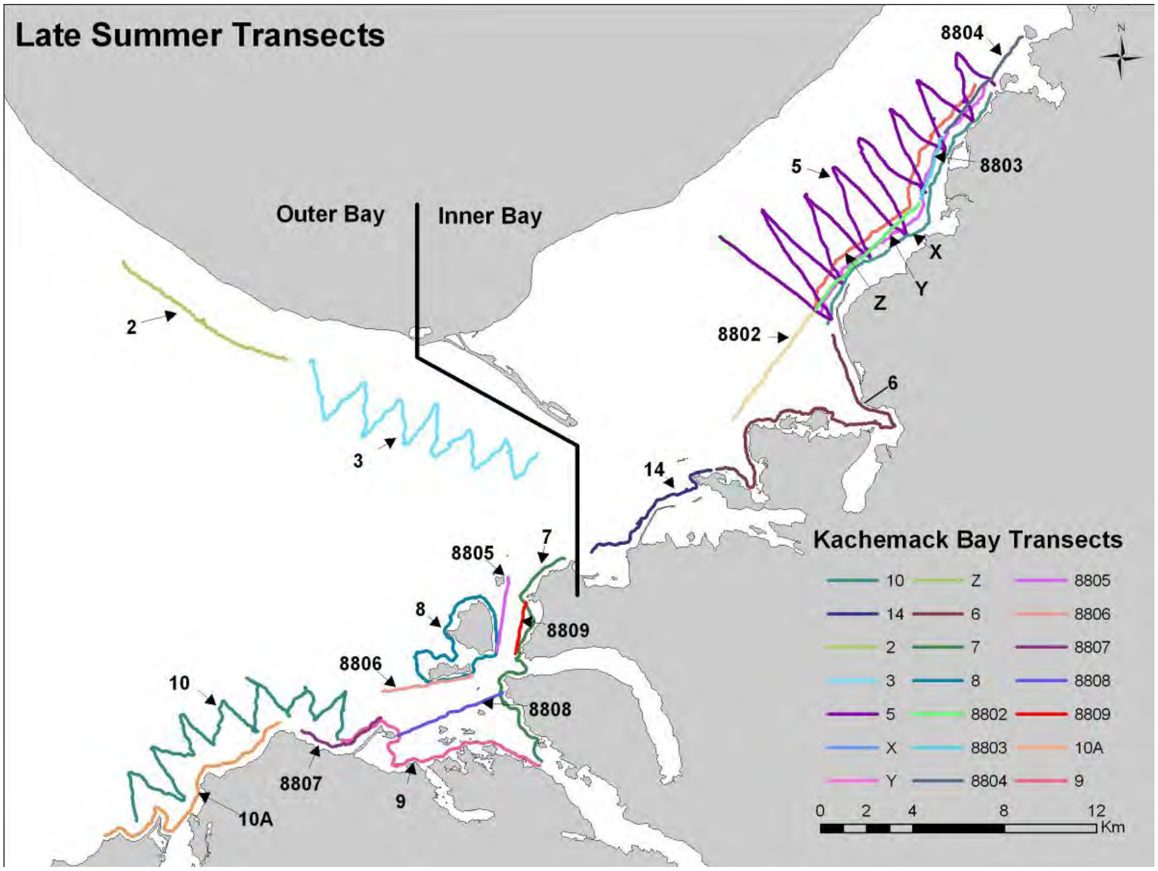
Month	Year	N	SST (°C)		Salinity (ppu)		Secchi depth (m)	
			x	*SE*	*x*	*SE*	*x*	*SE*
April	2005	8	5.2	0.1	30.4	0.3	3.8	0.6
June	2005	49	11.0	0.2	26.9	0.7	2.9	0.3
	2006	43	8.9	0.2	26.9	0.6	3.8	0.4
July	2005	54	12.8	0.2	25.7	0.7	4.2	0.4
	2006	49	10.7	0.2	27.9	0.4	3.9	0.4
	2007	36	11.0	0.2	27.6	0.5	3.1	0.2
August	2004	83	12.8	0.1	26.4	0.4	4.1	0.3
	2005	67	13.1	0.2	26.8	0.4	4.5	0.3
	2006	72	11.3	0.1	26.1	0.6	4.1	0.3
	2007	25	13.0	0.3	26.0	0.7	3.5	0.4
September	2005	5	12.9	0.2	25.4	0.8	4.0	0.7

Table 8. Approximate distances (kilometers) in Kachemak Bay between marine areas used by *Brachyramphus* murrelets and upland watersheds with potential murrelet nesting habitat. Sites include the Red Mountain nest site discovered for a Kittlitz's murrelet in 1993 (Piatt et al. 1999), and one of the river valleys linking Kachemak Bay to a fjord on the south side of the Kenai Peninsula.

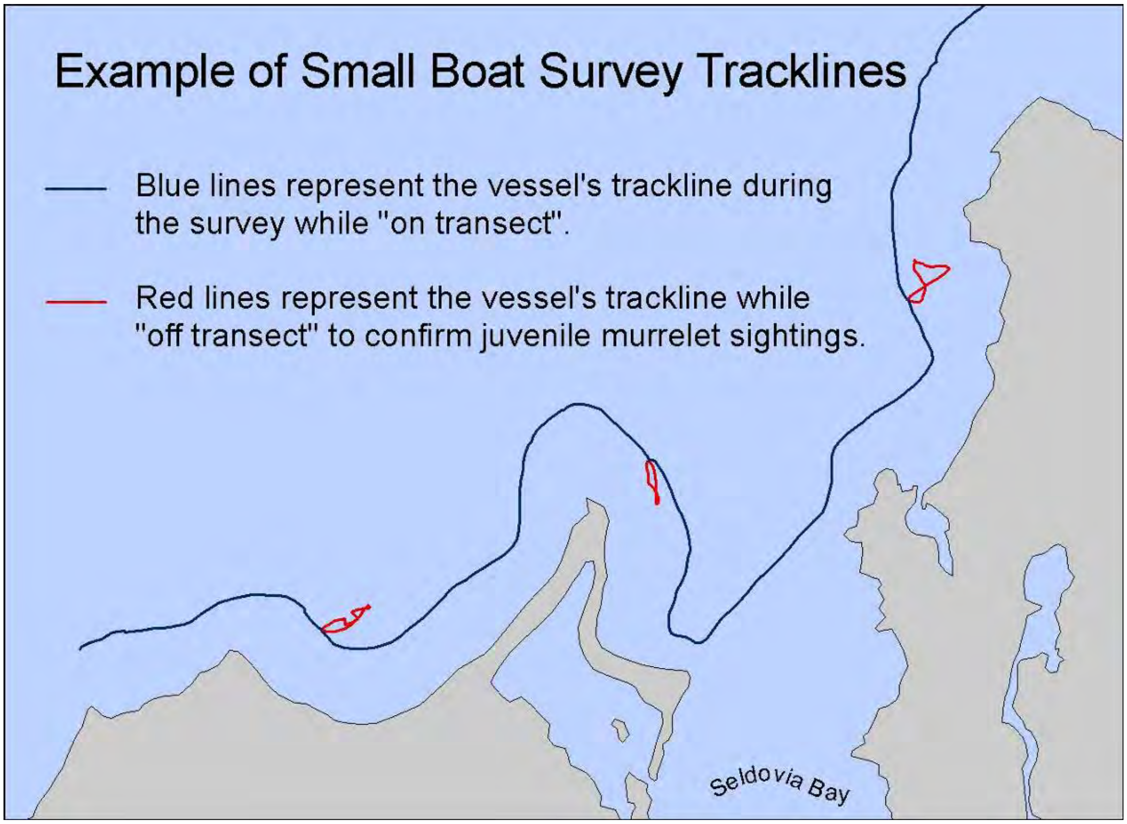
Potential Nesting Areas	Known foraging areas for murrelets				
	Inner Bay (Aurora Lagoon)	Eldredge Passage	Barabara Point	North shore shelf	North outer bay (off Anchor Point)
Red Mountain nest	42	17	16	33	42
Seldovia watershed	44	19	10	24	36
Tutka Bay watershed	30	4	10	17	35
Halibut Cove watershed	12	19	30	31	48
Grewingk watershed	6	24	35	34	52
Bear Cove watershed	8	33	44	41	56
Rocky Bay, Kenai fjords	26	10	10	23	35



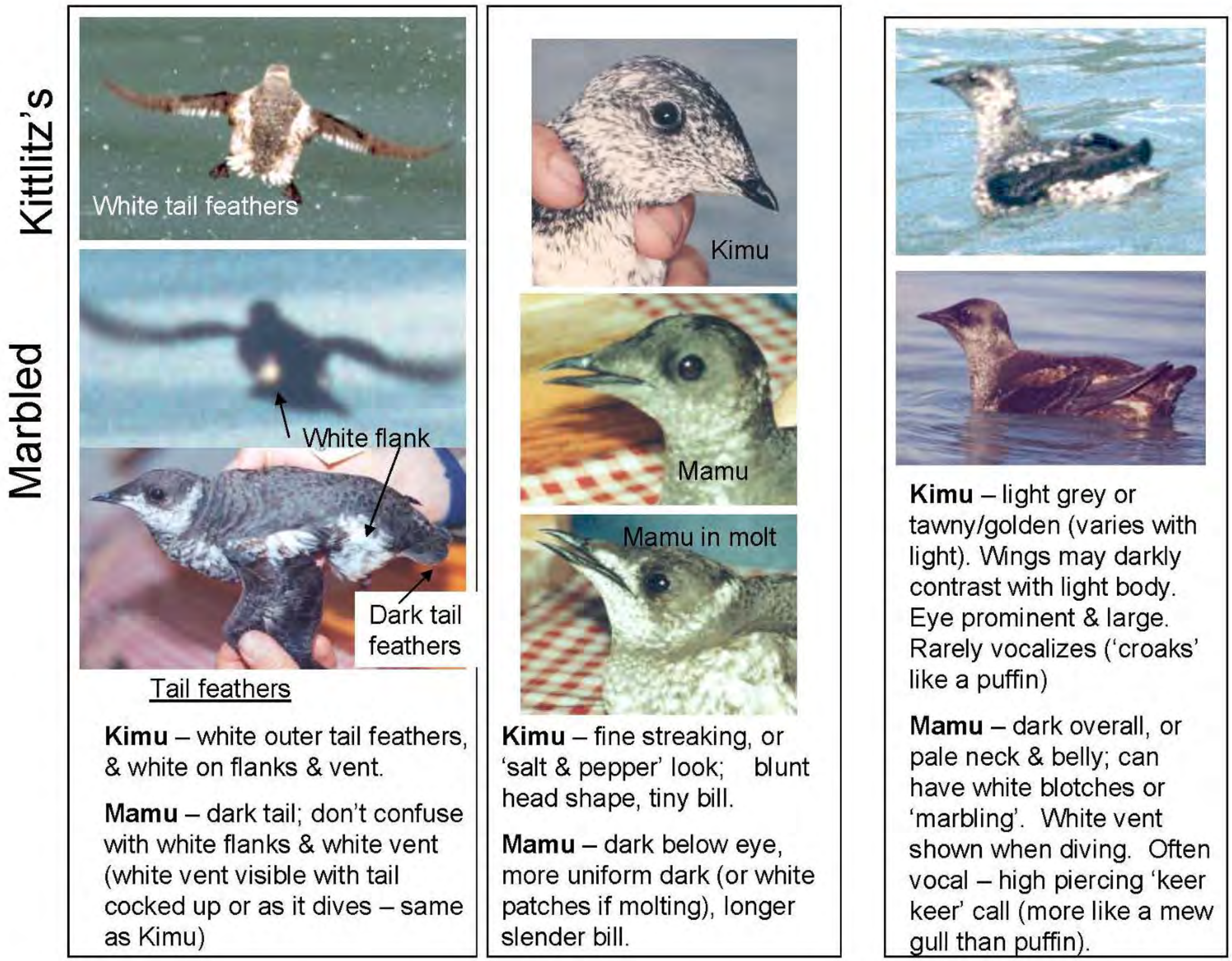
Appendix A-1. Randomly selected transects from the 1993 FWS survey of Lower Cook Inlet that fell within Kachemak Bay. Transects are labeled with the original transect numbers used in FWS database. The first letter denotes the strata of the transect: P = pelagic, C = coastal pelagic, S = shoreline.



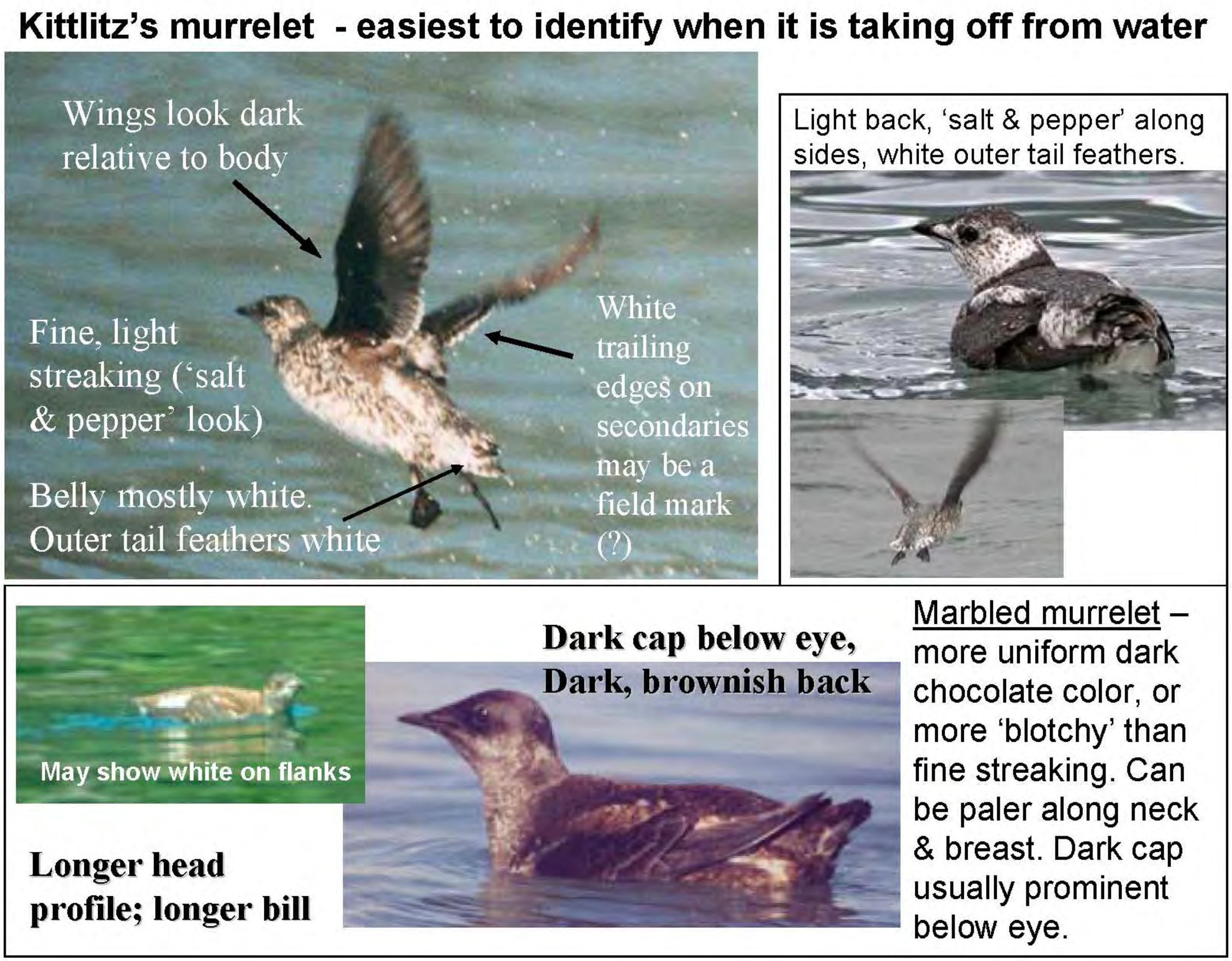
Appendix A-2. Location and reference numbers for late summer transects. These transects had both historic (see Appendix x) and recent (2004-2007) surveys. Murrelet densities for individual transects during the 2004-2007 surveys are in Appendix C.



Appendix B-1. Example of survey trackline during August juvenile surveys, showing 'off transect' portion in red.



Appendix B-2. Field guide for distinguishing Kittlitz's and marbled murrelets, page 1.



Appendix B-2. Field guide for distinguishing Kittlitz's and marbled murrelets, page 2.

AHY ?

Kittlitz's Juveniles: Limited documentation suggested juveniles might range from black & white (similar to winter) plumage (top left), to dark grey with white contrasts (middle left). But, we observed that newly fledged juveniles have a 'smudgy' grey appearance & no clean white on face. Bird on right (PWS, July 2004) is a confirmed juvenile. Note dark 'smudged' appearance, perhaps newly fledged.

Bird at left acted like a juvenile, but has white in front of eye, and brown on wings. Possibly a transitional AHY. But, transitional phases of older juveniles are not well described.

The black/white barring on outer tail feathers may be diagnostic. This bird still had an egg tooth, was very small, was a weak diver, and did not fly.

The Kittlitz's juvenile (below & upper right) was caught in PWS July 28, 2004. Although it had a contrasting dark/white plumage that caught your eye from a distance, up close it's plumage was dark grey and smudgy around head and breast. It had a distinct neck ring (also seen in black-&-white Mamu juveniles)

This barring can be seen as the bird takes off, or as it tries to fly. Older fledglings may be more likely to fly.

Appendix B-2. Field guide for distinguishing juvenile and adult Kittlitz's murrelets, page 1.

Bird above likely NOT a juv. Note distinct mandible/supraloral patch, and brown/tawny color in wings & back. No dark below or in front of eye.

Kimu juv in Icy Bay, SEAK, 2005 (by M. Reid)

Note that some non-juveniles (in transition) may also refuse to fly, and their behavior can be similar to juveniles

Note heavy speckling on chin, breast, belly, wing patches. Also, dark necklace when hunched.

Of all definite juveniles (in hand), none had white on upper mandible or brown on wings/back.

Appendix B-2. Field guide for distinguishing juvenile and adult Kittlitz's murrelets, page 2.

MARBLED MURRELETS

ID GUIDE for JUVENILES

No strong white above mandible. Dusky speckling on neck or breast, with evident 'necklace' (formed when they scrunch up neck).

Small size, especially beak. This is relative, but noticeable when seen with adults, or up close.

Note also small white 'eyebrow' (or eyelid?), which is often visible on juveniles.

Juvenile Mamu found in forest in Kodiak.

Photo by Denny Zwiefelhofer

Usually poor divers & flyers; attempt to fly, but can't, or make shallow, brief dives (but may manage to disappear from view anyway).

Adult Mamu caught in June.

Both birds had brood patches.

Top: in transition, but not uncommon in breeding birds in Alaska.

Bottom: bird in basic. Note large blotches on white breast – common in basic adults, as opposed to fine speckling on neck / breast of juveniles.

Both: note large white patch on upper mandible area (feathered area between eye and mandible).

Mamu Juveniles:

Left (same bird), from nest in PWS. Below, from different nest. **Note**:

•fine speckling on neck / breast

•dusky patch between eye & upper mandible

• small beak (remnants of egg tooth visible).

Juvenile marbled murrelet

Mamu at Kodiak on 14 Feb, 2004. (But still looks like a hatch-year bird).

Photo by Rich MacIntosh

Note:

• Faint patch on upper mandible area (no large white patch).

• Fine speckling on neck and breast (no blotches).

• Relatively small beak (egg tooth gone).

• If wings or tail spread out, would be no gaps & feather tips would be clean, pointed.

Mamu – AHY (after-hatch-year bird), late May, Auk Bay

Photo by Gus van Vliet.

Note:

•Large white patch on upper mandible area.

• Large dark blotches on neck / breast (not fine speckling).

• Could be a 1-yr old ? (prominent neck band & late molt).

• If wings or tail spread out, likely would notice gaps (from missing feathers) or ragged, 'weathered' feather tips.

Appendix B-2. Field guide for distinguishing juvenile and adult marbled murrelets.

Appendix C-1. Murrelet numbers and densities during Kachemak Bay surveys in June of 2005.

June 2005				**No. of observed murrelets**				**Murrelet Density (birds/km^2)**			
Region	Transect	Date	Area (km^2)	Unid.	Kittliz's	Marbled	Total Murrelets	Unid	Kittliz's	Marbled	Total Murrelets
Inner Bay	C1083	17-Jun-05	0.72	0	0	0	0	0.00	0.00	0.00	0.00
	C1084	17-Jun-05	0.77	0	0	0	0	0.00	0.00	0.00	0.00
	C1085	17-Jun-05	0.78	0	0	0	0	0.00	0.00	0.00	0.00
	C1086	17-Jun-05	0.75	0	0	1	1	0.00	0.00	1.33	1.33
	C1087	20-Jun-05	0.32	0	0	0	0	0.00	0.00	0.00	0.00
	C1089	20-Jun-05	0.39	0	0	2	2	0.00	0.00	5.11	5.11
	C774	20-Jun-05	0.33	0	0	1	1	0.00	0.00	2.99	2.99
	C776	20-Jun-05	0.53	0	0	0	0	0.00	0.00	0.00	0.00
	C784	20-Jun-05	0.64	0	0	0	0	0.00	0.00	0.00	0.00
	C786	20-Jun-05	0.75	0	0	1	1	0.00	0.00	1.34	1.34
	C797	17-Jun-05	0.75	0	0	5	5	0.00	0.00	6.64	6.64
	C808	17-Jun-05	0.75	0	0	14	14	0.00	0.00	18.59	18.59
	S165	17-Jun-05	0.54	0	0	0	0	0.00	0.00	0.00	0.00
	S166	17-Jun-05	0.79	0	0	0	0	0.00	0.00	0.00	0.00
	S255	17-Jun-05	1.01	0	0	0	0	0.00	0.00	0.00	0.00
	S258	17-Jun-05	1.17	0	0	0	0	0.00	0.00	0.00	0.00
	S262	20-Jun-05	0.96	0	0	1	1	0.00	0.00	1.04	1.04
	S290	20-Jun-05	1.48	0	0	0	0	0.00	0.00	0.00	0.00
	S294	30-Jun-05	0.70	0	0	0	0	0.00	0.00	0.00	0.00
Outer Bay	C747	16-Jun-05	0.43	0	0	2	2	0.00	0.00	4.62	4.62
	C748	16-Jun-05	0.76	0	0	3	3	0.00	0.00	3.96	3.96
	C749	16-Jun-05	0.75	0	0	4	4	0.00	0.00	5.32	5.32
	C751	16-Jun-05	0.52	0	0	5	5	0.00	0.00	9.59	9.59
	C756	18-Jun-05	0.67	0	0	4	4	0.00	0.00	5.96	5.96
	C757	18-Jun-05	0.51	0	0	2	2	0.00	0.00	3.93	3.93
	C759	18-Jun-05	0.72	0	0	7	7	0.00	0.00	9.78	9.78
	C765	18-Jun-05	0.46	0	0	10	10	0.00	0.00	21.56	21.56
	C766	19-Jun-05	0.46	0	0	1	1	0.00	0.00	2.19	2.19
	P750	16-Jun-05	0.76	0	0	4	4	0.00	0.00	5.25	5.25
	P752	16-Jun-05	0.75	0	0	0	0	0.00	0.00	0.00	0.00
	S128	16-Jun-05	0.23	0	0	0	0	0.00	0.00	0.00	0.00
	S129	16-Jun-05	0.98	0	0	0	0	0.00	0.00	0.00	0.00
	S137	18-Jun-05	0.82	0	0	4	4	0.00	0.00	4.87	4.87
	S139	19-Jun-05	0.63	0	0	0	0	0.00	0.00	0.00	0.00
	S141	19-Jun-05	0.71	0	0	0	0	0.00	0.00	0.00	0.00
	S142	19-Jun-05	0.34	0	0	0	0	0.00	0.00	0.00	0.00
	S144	18-Jun-05	1.06	0	0	4	4	0.00	0.00	3.79	3.79
	S149	18-Jun-05	0.66	0	0	3	3	0.00	0.00	4.55	4.55
	S151	18-Jun-05	0.17	0	0	0	0	0.00	0.00	0.00	0.00
	S156	17-Jun-05	0.71	0	0	0	0	0.00	0.00	0.00	0.00
	S157	17-Jun-05	0.46	0	0	0	0	0.00	0.00	0.00	0.00
	S160	17-Jun-05	0.78	0	0	0	0	0.00	0.00	0.00	0.00
	S265	18-Jun-05	1.12	0	0	0	0	0.00	0.00	0.00	0.00
	S266	19-Jun-05	0.70	0	0	0	0	0.00	0.00	0.00	0.00
	S267	19-Jun-05	0.92	0	0	0	0	0.00	0.00	0.00	0.00
	S291	18-Jun-05	1.34	0	0	0	0	0.00	0.00	0.00	0.00

Appendix C-1. Murrelet numbers and densities during Kachemak Bay surveys in June of 2006.

June 2006				**No. of observed murrelets**				**Murrelet Density (birds/km²)**			
Transect Location	Transect	Date	Area (km^2)	Unid.	Kittliz's	Marbled	Total Murrelets	Unid	Kittliz's	Marbled	Total Murrelets
Inner Bay	C1083	19-Jun-06	0.83	0	0	0	0	0.00	0.00	0.00	0.00
	C1084	19-Jun-06	0.66	0	0	0	0	0.00	0.00	0.00	0.00
	C1085	19-Jun-06	0.72	2	0	31	33	2.78	0.00	43.06	45.83
	C1086	20-Jun-06	0.65	0	0	19	19	0.00	0.00	29.23	29.23
	C1087	20-Jun-06	0.42	0	0	0	0	0.00	0.00	0.00	0.00
	C1089	20-Jun-06	0.37	0	0	5	5	0.00	0.00	13.51	13.51
	C774	19-Jun-06	0.48	2	0	1	3	4.17	0.00	2.08	6.25
	C776	17-Jun-06	0.50	0	0	0	0	0.00	0.00	0.00	0.00
	C784	17-Jun-06	0.65	0	0	0	0	0.00	0.00	0.00	0.00
	C786	17-Jun-06	0.81	0	0	2	2	0.00	0.00	2.47	2.47
	C797	19-Jun-06	0.82	0	2	13	15	0.00	2.44	15.85	18.29
	C808	20-Jun-06	0.8	0	4	14	18	0.00	5.00	17.50	22.50
	S165	20-Jun-06	0.28	0	0	0	0	0.00	0.00	0.00	0.00
	S166	20-Jun-06	0.82	0	0	0	0	0.00	0.00	0.00	0.00
	S255	20-Jun-06	1.02	0	0	2	2	0.00	0.00	1.96	1.96
	S258	29-Jun-06	1.17	0	0	0	0	0.00	0.00	0.00	0.00
	S262	17-Jun-06	0.79	0	0	0	0	0.00	0.00	0.00	0.00
	S290	29-Jun-06	1.45	0	0	0	0	0.00	0.00	0.00	0.00
	S294	not surveyed									
Outer Bay	C747	18-Jun-06	0.39	0	0	3	3	0.00	0.00	7.69	7.69
	C748	19-Jun-06	0.76	0	0	0	0	0.00	0.00	0.00	0.00
	C749	18-Jun-06	0.75	0	0	2	2	0.00	0.00	2.67	2.67
	C751	18-Jun-06	0.48	0	0	0	0	0.00	0.00	0.00	0.00
	C756	17-Jun-06	0.77	0	0	2	2	0.00	0.00	2.60	2.60
	C757	19-Jun-06	0.52	1	0	11	12	1.92	0.00	21.15	23.08
	C759	17-Jun-06	0.66	0	0	12	12	0.00	0.00	18.18	18.18
	C765	17-Jun-06	0.47	2	0	25	27	4.26	0.00	53.19	57.45
	C766	20-Jun-06	0.51	0	0	0	0	0.00	0.00	0.00	0.00
	P750	18-Jun-06	0.76	0	0	0	0	0.00	0.00	0.00	0.00
	P752	18-Jun-06	0.76	0	0	0	0	0.00	0.00	0.00	0.00
	S128	18-Jun-06	0.21	0	0	0	0	0.00	0.00	0.00	0.00
	S129	18-Jun-06	1.13	0	0	0	0	0.00	0.00	0.00	0.00
	S137	17-Jun-06	0.91	0	0	0	0	0.00	0.00	0.00	0.00
	S139	20-Jun-06	0.72	0	0	0	0	0.00	0.00	0.00	0.00
	S141	20-Jun-06	0.76	0	0	0	0	0.00	0.00	0.00	0.00
	S142	20-Jun-06	0.31	0	0	0	0	0.00	0.00	0.00	0.00
	S144	19-Jun-06	1.17	0	0	4	4	0.00	0.00	3.42	3.42
	S149	17-Jun-06	0.73	0	0	0	0	0.00	0.00	0.00	0.00
	S151	18-Jun-06	0.42	0	0	0	0	0.00	0.00	0.00	0.00
	S156	18-Jun-06	0.82	0	0	0	0	0.00	0.00	0.00	0.00
	S157	18-Jun-06	0.54	0	0	0	0	0.00	0.00	0.00	0.00
	S160	18-Jun-06	0.84	0	0	0	0	0.00	0.00	0.00	0.00
	S265	18-Jun-06	0.84	0	0	0	0	0.00	0.00	0.00	0.00
	S266	20-Jun-06	0.85	0	0	0	0	0.00	0.00	0.00	0.00
	S267	20-Jun-06	0.90	0	0	0	0	0.00	0.00	0.00	0.00
	S291	19-Jun-06	1.32	0	0	0	0	0.00	0.00	0.00	0.00

July 2005				**No. of observed murrelets**				**Murrelet Density (birds/km²)**			
Region	Transect	Date	Area (km²)	Unid.	Kittliz's	Marbled	Total Murrelets	Unid	Kittliz's	Marbled	Total Murrelets
Inner Bay	K1	23-Jul-05	0.64	1	18	34	53	1.56	28.13	53.13	82.81
	K2	21-Jul-05	2.24	10	53	73	136	4.46	23.66	32.59	60.71
	K3	21-Jul-05	2.27	15	15	80	110	6.61	6.61	35.24	48.46
	K4	21-Jul-05	2.15	1	0	5	6	0.47	0.00	2.33	2.79
	K5	21-Jul-05	2.21	0	0	2	2	0.00	0.00	0.90	0.90
	K6	18-Jul-05	2.76	2	0	18	20	0.72	0.00	6.52	7.25
Outer Bay	K7	19-Jul-05	2.42	4	0	27	31	1.65	0.00	11.16	12.81
	K8	19-Jul-05	3.53	2	0	31	33	0.57	0.00	8.78	9.35
	K9	19-Jul-05	3.71	1	0	21	22	0.27	0.00	5.66	5.93
	K10	20-Jul-05	4.00	8	1	96	105	2.00	0.25	24.00	26.25
	K11	20-Jul-05	5.82	18	5	110	133	3.09	0.86	18.90	22.85
	K12	22-Jul-05	5.89	23	1	61	85	3.90	0.17	10.36	14.43
			37.64	85	93	558	736	2.26	2.47	14.82	19.55

July 2006				**No. of observed murrelets**				**Murrelet Density (birds/km²)**			
Region	Transect	Date	Area (km²)	Unid.	Kittliz's	Marbled	Total Murrelets	Unid	Kittliz's	Marbled	Total Murrelets
Inner Bay	K1	20-Jul-06	1.11	3	7	4	14	2.7	6.3	3.6	12.6
	K2	20-Jul-06	2.16	9	79	24	112	4.2	36.6	11.1	51.9
	K3	20-Jul-06	2.65	9	12	86	107	3.4	4.5	32.4	40.3
	K4	18-Jul-06	2.32	0	0	2	2	0.0	0.0	0.9	0.9
	K5	18-Jul-06	2.38	1	0	6	7	0.4	0.0	2.5	2.9
	K6	18-Jul-06	2.84	0	2	2	4	0.0	0.7	0.7	1.4
Outer Bay	K7	19-Jul-06	3.09	0	0	22	22	0.0	0.0	7.1	7.1
	K8	19-Jul-06	3.47	1	0	27	28	0.3	0.0	7.8	8.1
	K9	19-Jul-06	3.70	2	0	11	13	0.5	0.0	3.0	3.5
	K10	20-Jul-06	3.90	5	18	18	41	1.3	4.6	4.6	10.5
	K11	21-Jul-06	5.81	5	15	152	172	0.9	2.6	26.1	29.6
	K12	21-Jul-06	5.93	5	26	198	229	0.8	4.4	33.4	38.6
			39.37	40	159	552	751	1.02	4.04	14.02	19.08

Appendix C-2. Murrelet numbers and densities during Kachemak Bay surveys in July of 2005-2007.

Appendix C-2 - continued. Murrelet numbers and densities during Kachemak Bay surveys in July of 2005 - 2007.

July 2007				**No. of observed murrelets**				**Murrelet Density (birds/km^2)**			
Region	Transect	Date	Area (km^2)	Unid.	Kittliz's	Marbled	Total Murrelets	Unid	Kittliz's	Marbled	Total Murrelets
Inner Bay	K1	25-Jul-07	1.08	0	0	2	2	0.00	0.00	1.86	1.86
	K2	22-Jul-07	2.00	18	42	45	105	9.00	21.00	22.50	52.49
	K3	22-Jul-07	2.47	6	5	44	55	2.43	2.03	17.85	22.31
	K4	22-Jul-07	2.46	1	2	6	9	0.41	0.81	2.44	3.66
	K5	22-Jul-07	2.35	2	0	1	3	0.85	0.00	0.43	1.28
	K6	22-Jul-07	2.72	0	0	8	8	0.00	0.00	2.94	2.94
Outer Bay	K7	24-Jul-07	2.83	4	1	114	119	1.41	0.35	40.22	41.98
	K8	24-Jul-07	3.55	0	0	188	188	0.00	0.00	52.92	52.92
	K9	24-Jul-07	3.69	3	0	15	18	0.81	0.00	4.06	4.87
	K10	23-Jul-07	3.77	1	0	6	7	0.27	0.00	1.59	1.86
	K11	23-Jul-07	5.72	3	1	23	27	0.52	0.17	4.02	4.72
	K12	23-Jul-07	5.95	9	3	17	29	1.51	0.50	2.86	4.87
			38.59	47	54	469	570	1.22	1.40	12.15	14.77

August 2004						No. of observed murrelets				Murrelet Density (birds/km^2)			
Region	Transect Group	Date	No. Trans	Transect	Total Area (km^2)	Unid.	Kittliz's	Marbled	Total Murrelets	Unid	Kittliz's	Marbled	Total Murrelets
Inner Bay	Inner South Shore	8-Aug	3	XYZ	8.12	61	41	373	475	7.51	5.05	45.94	58.50
		16-Aug	3	XYZ	8.23	182	16	440	638	22.11	1.94	53.46	77.52
		23-Aug	3	XYZ	8.19	33	9	266	308	4.03	1.10	32.48	37.61
		3-Aug	1	8801	1.47	1	1	18	20	0.68	0.68	12.24	13.61
		5-Aug	4	8801-8804	4.11	8	14	196	218	1.95	3.41	47.69	53.04
		10-Aug	4	8801-8804	4.23	17	24	150	191	4.02	5.67	35.46	45.15
		14-Aug	4	8801-8804	4.21	22	18	233	273	5.23	4.28	55.34	64.85
		6-Aug	2	6 & 14	5.2	3	7	155	165	0.58	1.35	29.81	31.73
		11-Aug	2	6 & 14	5.56	6	3	98	107	1.08	0.54	17.63	19.24
		15-Aug	2	6 & 14	5.27	4	3	132	139	0.76	0.57	25.05	26.38
	Inner Zigzag	7-Aug	1	5	13.06	47	21	260	328	3.60	1.61	19.91	25.11
		21-Aug	1	5	12.33	9	9	266	284	0.73	0.73	21.57	23.03
Outer Bay	Eldredge Passage	4-Aug	5	8805-8809	3.81	5	0	254	259	1.31	0.00	66.67	67.98
		9-Aug	5	8805-8809	3.82	13	3	103	119	3.40	0.79	26.96	31.15
		12-Aug	5	8805-8809	3.98	5	3	41	49	1.26	0.75	10.30	12.31
	Outer South Shore	4-Aug	4	7-9, 10A	8.99	1	0	225	226	0.11	0.00	25.03	25.14
		9-Aug	4	7-9, 10A	10.47	9	9	189	207	0.86	0.86	18.05	19.77
		12-Aug	4	7-9, 10A	10.84	5	6	137	148	0.46	0.55	12.64	13.65
		22-Aug	3	7, 9, 10A	8.09	10	0	50	60	1.24	0.00	6.18	7.42
	Outer Zigzag	6-Aug	1	10	6.24	15	0	97	112	2.40	0.00	15.54	17.95
		17-Aug	1	10	6.83	2	0	64	66	0.29	0.00	9.37	9.66
	Outer North Shore	20-Aug	1	3	5.3	6	0	15	21	1.13	0.00	2.83	3.96
		20-Aug	1	2	1.94	3	3	15	21	1.55	1.55	7.73	10.82
Total numbers, average densities					150.29	467	190	3777	4434	3.11	1.26	25.13	29.50

Appendix C-3. Adult murrelet numbers and densities during Kachemak Bay surveys in August of 2004-2007.

Append. C-3 continued. Adult murrelet numbers and densities during Kachemak Bay surveys in August of 2004-2007.

August 2005						No. of observed murrelets				Murrelet Density (birds/km^2)			
Region	Transect Group	Date	No. Trans	Transect	Total Area (km^2)	Unid.	Kittliz's	Marbled	Total Murrelets	Unid	Kittliz's	Marbled	Total Murrelets
Inner Bay	Inner South Shore	9-Aug	3	XYZ	8.13	46	53	330	429	5.66	6.52	40.59	52.77
		16-Aug	3	XYZ	8.03	21	51	237	309	2.62	6.35	29.51	38.48
		4-Aug	4	8801-8804	4.21	13	22	221	256	3.09	5.23	52.49	60.81
		15-Aug	4	8801-8804	4.13	17	24	84	125	4.12	5.81	20.34	30.27
		22-Aug	4	8801-8804	4.24	22	10	107	139	5.19	2.36	25.24	32.78
		3-Aug	2	6 & 14	5.32	8	4	239	251	1.50	0.75	44.92	47.18
		10-Aug	2	6 & 14	5.45	3	2	69	74	0.55	0.37	12.66	13.58
		20-Aug	2	6 & 14	5.34	3	1	41	45	0.56	0.19	7.68	8.43
	Inner Zigzag	8-Aug	1	5	12.72	10	2	136	148	0.79	0.16	10.69	11.64
Outer Bay	Eldredge Passage	5-Aug	5	8805-8809	3.7	0	0	11	11	0.00	0.00	2.97	2.97
		14-Aug	5	8805-8809	3.75	3	0	35	38	0.80	0.00	9.33	10.13
	Outer South Shore	3-Aug	4	7-9, 10A	10.87	4	0	85	89	0.37	0.00	7.82	8.19
		10-Aug	4	7-9, 10A	11.11	2	2	62	66	0.18	0.18	5.58	5.94
		18-Aug	3	7, 9, 10A	7.93	8	0	93	101	1.01	0.00	11.73	12.74
		22-Aug	2	7, 9	4.89	0	0	12	12	0.00	0.00	2.45	2.45
	Outer Zigzag	6-Aug	1	10	6.06	1	0	22	23	0.17	0.00	3.63	3.80
		10-Aug	1	10	6.13	1	0	42	43	0.16	0.00	6.85	7.01
	Outer North Shore	7-Aug	1	3	5.01	3	0	2	5	0.60	0.00	0.40	1.00
		17-Aug	1	3	5.4	7	1	39	47	1.30	0.19	7.22	8.70
		7-Aug	1	2	1.74	5	0	35	40	2.87	0.00	20.11	22.99
		17-Aug	1	2	1.7	2	0	38	40	1.18	0.00	22.35	23.53
Total numbers, average densities					125.86	179	172	1940	2291	1.42	1.37	15.41	18.20

Append. C-3 continued. Adult murrelet numbers and densities during Kachemak Bay surveys in August of 2004-2007.

August 2006						No. of observed murrelets				Murrelet Density (birds/km²)			
Region	**Transect Group**	**Date**	**No. Trans**	**Transect**	**Total Area (km²)**	**Unid.**	**Kittliz's**	**Marbled**	**Total Murrelets**	**Unid**	**Kittliz's**	**Marbled**	**Total Murrelets**
Inner Bay	Inner South Shore	9-Aug	3	XYZ	8.13	46	53	330	429	5.66	6.52	40.59	52.77
		16-Aug	3	XYZ	8.03	21	51	237	309	2.62	6.35	29.51	38.48
		4-Aug	4	8801-8804	4.21	13	22	221	256	3.09	5.23	52.49	60.81
		15-Aug	4	8801-8804	4.13	17	24	84	125	4.12	5.81	20.34	30.27
		22-Aug	4	8801-8804	4.24	22	10	107	139	5.19	2.36	25.24	32.78
		3-Aug	2	6 & 14	5.32	8	4	239	251	1.50	0.75	44.92	47.18
		10-Aug	2	6 & 14	5.45	3	2	69	74	0.55	0.37	12.66	13.58
		20-Aug	2	6 & 14	5.34	3	1	41	45	0.56	0.19	7.68	8.43
	Inner Zigzag	8-Aug	1	5	12.72	10	2	136	148	0.79	0.16	10.69	11.64
Outer Bay	Eldredge Passage	5-Aug	5	8805-8809	3.7	0	0	11	11	0.00	0.00	2.97	2.97
		14-Aug	5	8805-8809	3.75	3	0	35	38	0.80	0.00	9.33	10.13
	Outer South Shore	3-Aug	4	7-9, 10A	10.87	4	0	85	89	0.37	0.00	7.82	8.19
		10-Aug	4	7-9, 10A	11.11	2	2	62	66	0.18	0.18	5.58	5.94
		18-Aug	3	7, 9, 10A	7.93	8	0	93	101	1.01	0.00	11.73	12.74
		22-Aug	2	7, 9	4.89	0	0	12	12	0.00	0.00	2.45	2.45
	Outer Zigzag	6-Aug	1	10	6.06	1	0	22	23	0.17	0.00	3.63	3.80
		10-Aug	1	10	6.13	1	0	42	43	0.16	0.00	6.85	7.01
	Outer North Shore	7-Aug	1	3	5.01	3	0	2	5	0.60	0.00	0.40	1.00
		17-Aug	1	3	5.4	7	1	39	47	1.30	0.19	7.22	8.70
		7-Aug	1	2	1.74	5	0	35	40	2.87	0.00	20.11	22.99
		17-Aug	1	2	1.7	2	0	38	40	1.18	0.00	22.35	23.53
Total numbers, average densities					125.86	179	172	1940	2291	1.42	1.37	15.41	18.20
		08/19/06	1	2	0.53	0	0	6	6	0.00	0.00	11.32	11.32
Total numbers, average densities					252.25	358	344	3886	4588	1.42	1.36	15.41	18.19

Appendix C-3 - continued. Murrelet numbers and densities during Kachemak Bay surveys in August of 2004 - 2007.

August 2007						No. of observed murrelets				Murrelet Density (birds/km^2)			
Region	**Transect Group**	**Date**	**No. Trans**	**Transect**	**Total Area (km^2)**	**Unid.**	**Kittliz's**	**Marbled**	**Total Murrelets**	**Unid**	**Kittliz's**	**Marbled**	**Total Murrelets**
Inner Bay	Inner South Shore	10-Aug	3	XYZ	7.95	24	98	342	464	3.02	12.33	43.02	58.36
		13-Aug	3	XYZ	8.12	47	90	336	473	5.79	11.08	41.38	58.25
		16-Aug	3	XYZ	7.84	10	60	263	333	1.28	7.65	33.55	42.47
		8-Aug	4	8801-8804	4.2	11	59	129	199	2.62	14.05	30.71	47.38
Outer Bay	Outer South Shore	9-Aug	4	7-9, 10A	10.54	8	0	68	76	0.76	0.00	6.45	7.21
		12-Aug	4	7-9, 10A	10.74	2	3	87	92	0.19	0.28	8.10	8.57
		15-Aug	4	7-9, 10A	10.28	2	1	164	167	0.19	0.10	15.95	16.25
Total numbers, average densities					59.67	104	311	1389	1804	1.74	5.21	23.28	30.23

Appendix C-4. Counts and densities of juvenile murrelets recorded during August surveys of Kachemak Bay of 2004. The number of adults is given for reference to juvenile:adult ratios, and adult densities are available in Appendix C-3. Unk = birds observed that could not be definitively identified as juveniles or adults. A map of labeled August transects is in Appendix A-2.

August 2004				**Counts**						**Densities**			
				Kittlitz's			**Marbled**			**Kittlitz's**		**Marbled**	
Region	**Transect Set**	**Date**	**Transects**	Adult	Juv	Unk	Adult	Juv	Unk	Juv	Unk	Juv	Unk
Inner Bay	Inner South Shore	8-Aug	XYZ	38	3		371	2		0.37	0.00	0.25	0.00
		16-Aug	XYZ	13	3		434	6		0.36	0.00	0.73	0.00
		23-Aug	XYZ	9			260	5	1	0.00	0.00	0.61	0.12
		3-Aug	8801	1			18				0.00	0.00	0.00
		5-Aug	8801-8804	13	1		194		2	0.24	0.00	0.00	0.49
		10-Aug	8801-8804	24			150				0.00	0.00	0.00
		14-Aug	8801-8804	17	1		232	0	1	0.24	0.00	0.00	0.24
		6-Aug	6 & 14	7			154	1		0.00	0.00	0.19	0.00
		11-Aug	6 & 14	3			96	2		0.00	0.00	0.36	0.00
		15-Aug	6 & 14	3			127	5		0.00	0.00	0.95	0.00
	Inner Zigzag	7-Aug	5	20	1		254	1	5	0.08	0.00	0.08	0.38
		21-Aug	5	7	1	1	260	5	1	0.08	0.08	0.41	0.08
Outer Bay	Eldredge Passage	4-Aug	8805 - 8809				254			0.00	0.00	0.00	0.00
		9-Aug	8805 - 8809	3			99	3	1	0.00	0.00	0.79	0.26
		12-Aug	8805 - 8809	3			28	12	1	0.00	0.00	3.02	0.25
	Outer South Shore	4, 6-Aug	7-9, 10A				219	4	2	0.00	0.00	0.45	0.22
		9, 11-Aug	7-9, 10A	7	2		176	13		0.19	0.00	1.24	0.00
		12, 15-Aug	7-9, 10A	2	4		111	26		0.37	0.00	2.40	0.00
		22-Aug	7, 9, 10A				40	10		0.00	0.00	1.24	0.00
	Outer Zigzag	6-Aug	10				93	4		0.00	0.00	0.64	0.00
		17-Aug	10				42	22		0.00	0.00	3.22	0.00
	Outer N.Shore	20-Aug	3				15			0.00	0.00	0.00	0.00
		20-Aug	2	3			15			0.00	0.00	0.00	0.00

Appendix C-4. Counts and densities of juvenile murrelets recorded during August surveys of Kachemak Bay in 2005. The number of adults is given for reference to juvenile:adult ratios, and adult densities are available in Appendix C-3. Unk = birds observed that could not be definitively identified as juveniles or adults. A map of labeled August transects is in Appendix A-2.

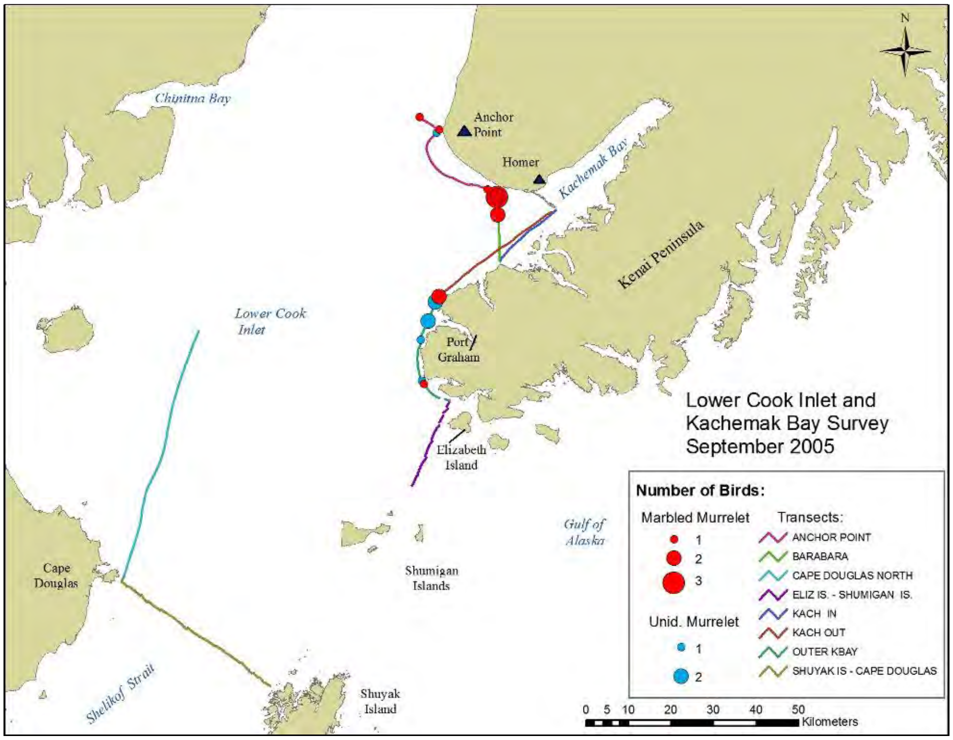
August 2005				**Counts**						**Densities**			
				Kittlitz's			**Marbled**			**Kittlitz's**		**Marbled**	
Region	**Transect Set**	**Date**	**Transects**	Adult	Juv	Unk	Adult	Juv	Unk	Juv	Unk	Juv	Unk
Inner Bay	Inner South Shore	9-Aug	XYZ	53			328	2	0	0.00	0.00	0.25	0.00
		16-Aug	XYZ	49	2		237			0.25	0.00	0.00	0.00
		4-Aug	8801-8804	22			217	4		0.00	0.00	0.95	0.00
		15-Aug	8801-8804	24			84			0.00	0.00	0.00	0.00
		22-Aug	8801-8804	10			105	2		0.00	0.00	0.47	0.00
		3-Aug	6 & 14	4			237	1	1	0.00	0.00	0.19	0.00
		10-Aug	6 & 14	2			69			0.00	0.00	0.00	0.00
		20-Aug	6 & 14	1			38	3		0.00	0.00	0.56	0.00
	Inner Zigzag	8-Aug	5	2			136			0.00	0.00	0.00	0.00
Outer Bay	Eldredge Passage	5-Aug	8805-8809				10	1		0.00	0.00	0.27	0.00
		14-Aug	8805-8809				33	2		0.00	0.00	0.53	0.00
	Outer South Shore	3-Aug	7-9, 10A				68	13	4	0.00	0.00	1.20	0.00
		10-Aug	7-9, 10A	1	1		47	15		0.09	0.00	1.35	0.00
		18-Aug	7, 9, 10A				73	20		0.00	0.00	2.52	0.00
		22-Aug	7, 9				8	4		0.00	0.00	0.82	0.00
	Outer Zigzag	6-Aug	10				18	4		0.00	0.00	0.66	0.00
		10-Aug	10				42			0.00	0.00	0.00	0.00
	Outer N.Shore	7-Aug	3				2			0.00	0.00	0.00	0.00
		17-Aug	3		1		38	1		0.19	0.00	0.19	0.00
		7-Aug	2				26	6	3	0.00	0.00	3.45	0.00
		17-Aug	2				38			0.00	0.00	0.00	0.00

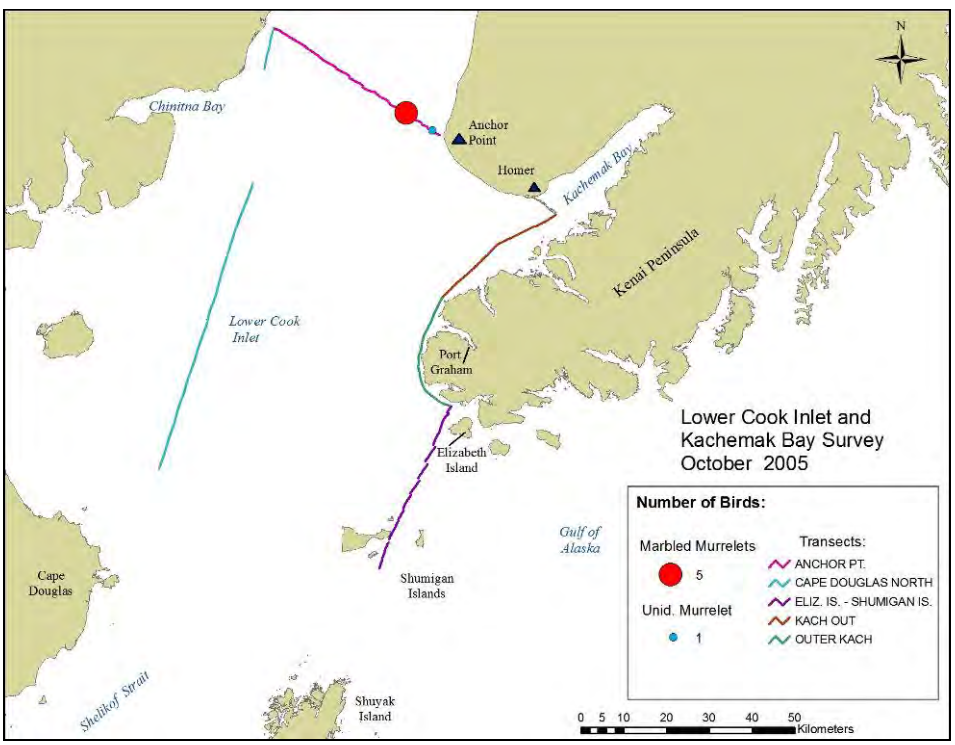
Appendix C-4. Counts and densities of juvenile murrelets recorded during August surveys of Kachemak Bay in 2006. The number of adults is given for reference to juvenile:adult ratios, and adult densities are available in Appendix C-3. Unk = birds observed that could not be definitively identified as juveniles or adults. A map of labeled August transects is in Appendix A-2.

August 2006				**Counts**						**Densities**			
Region	**Transect Set**	**Date**	**Transects**	**Kittlitz's**			**Marbled**			**Kittlitz's**		**Marbled**	
				Adult	Juv	Unk	Adult	Juv	Unk	Juv	Unk	Juv	Unk
Inner Bay	Inner South Shore	6-Aug	XYZ	343	3	2	285	1		0.37	0.25	0.12	0.00
		12-Aug	XYZ	180	3	3	859	2		0.37	0.37	0.24	0.00
		21-Aug	XYZ	32		2	311	2		0.00	0.25	0.25	0.00
		1-Aug	8801-8804	158			82			0.00	0.00	0.00	0.00
		8-Aug	8801-8804	219			114	2		0.00	0.00	0.47	0.00
		15-Aug	8801-8804	26	7	1	255	1		1.63	0.23	0.23	0.00
		3-Aug	6 & 14	5			126			0.00	0.00	0.00	0.00
		10-Aug	6 & 14	1			71	1		0.00	0.00	0.18	0.00
		20-Aug	6 & 14	1			100	3		0.00	0.00	0.58	0.00
Outer Bay	Eldredge Passage	2-Aug	8805-8809	0			182	3		0.00	0.00	0.79	0.00
		9-Aug	8805-8809	0			25	1		0.00	0.00	0.26	0.00
		17-Aug	8805-8809	0			23	9	1	0.00	0.00	2.29	0.25
		23-Aug	8805-8809	0			23	1	2	0.00	0.00	0.26	0.52
	South outer shore	2-Aug	7-9, 10A	0	1		259	1		0.10	0.00	0.10	0.00
		9-Aug	7-9, 10A	1			91	3		0.00	0.00	0.29	0.00
		17-Aug	7-9, 10A	2			69	22	2	0.00	0.00	2.15	0.20
		23-Aug	10A	0			7	12		0.00	0.00	4.74	0.00
		5-Aug	10	0			37	1		0.00	0.00	0.17	0.00
		15-Aug	10	0			11	1		0.00	0.00	0.17	0.00
	N.Outer shore	7-Aug	3	0			14			0.00	0.00	0.00	0.00
		19-Aug	3	0			5	1		0.00	0.00	0.20	0.00
		7-Aug	2	0			2			0.00	0.00	0.00	0.00
		19-Aug	2	0			6			0.00	0.00	0.00	0.00

Appendix C-4. Counts and densities of juvenile murrelets recorded during August surveys of Kachemak Bay in 2007. The number of adults is given for reference to juvenile:adult ratios, and adult densities are available in Appendix C-3. Unk = birds observed that could not be definitively identified as juveniles or adults. A map of labeled August transects is in Appendix A-2.

August 2007				**Counts**						**Densities**			
				Kittlitz's			**Marbled**			**Kittlitz's**		**Marbled**	
Region	**Transect Set**	**Date**	**Transects**	Adult	Juv	Unk	Adult	Juv	Unk	Juv	Unk	Juv	Unk
Inner Bay	Inner South Shore	10-Aug	XYZ	97		1	339	2	1	0.00	0.13	0.25	0.13
		13-Aug	XYZ	88	1	1	335	1		0.12	0.12	0.12	0.12
		16-Aug	XYZ	60			261	2		0.00	0.00	0.26	0.00
		8-Aug	8801-8804	59			128	1		0.00	0.00	0.24	0.00
Outer Bay	Outer South Shore	9-Aug	7-9, 10A	0			61	6	1	0.00	0.00	0.57	0.00
		12-Aug	7-9, 10A	1	2		86	1		0.19	0.00	0.09	0.00
		15-Aug	7-9, 10A	1			160	4		0.00	0.00	0.39	0.00





Appendix D. Observations of marbled murrelets and unidentified *Brachyramphus* murrelets in outer Kachemak Bay and Cook Inlet during transits in the *F/V Columbia* in September and October of 2005.

Appendix E-1. Population estimates for all species observed in Kachemak Bay during June surveys of 1993, 2005, and 2006.

Taxon		**June 1993**		**June 2005**		**June 2006**	
		N	*95% CI*	*N*	*95% CI*	*N*	*95% CI*
Common Name	Latin name						
BIRDS							
Common Loon	*Gavia immer*	234	233	93	110	217	223
Northern Fulmar	*Fulmaris glacialis*	-	-	55	105	-	-
Short-tailed Shearwater	*Puffinus tenuirostris*	53	102	602	798	-	-
Sooty Shearwater	*Puffinus griseus*	158	223	47,568	45,641	990	1,224
Unidentified Shearwater	*Puffinus* sp.	-	-	3,832	7,164	521	703
Double-crested Cormorant	*Phalacrocorax auritus*	3	5	3	5	13	21
Pelagic Cormorant	*Phalacrocorax pelagicus*	248	243	370	345	146	209
Pelagic or Red-faced Cormorant	*Phalacrocorax pelagicus OR urile*	-	-	-	-	93	147
Common Eider	*Somateria mollissima*	63	100	64	106	-	-
Harlequin Duck	*Histrionicus histrionicus*	225	158	1,815	1,804	1,180	585
Long-tailed Duck	*Clangula hyemalis*	-	-	-	-	3	5
Surf Scoter	*Melanitta perspicillata*	516	713	57	68	598	1,014
Black Scoter	*Melanitta americana*	-	-	83	118	6	10
White-winged Scoter	*Melanitta fusca*	14	12	67	107	309	319
Unidentified Scoter	*Melanitta* sp.	-	-	87	114	313	604
Barrow's Goldeneye	*Bucephala islandica*	-	-	-	-	732	1,333
Unidentified Duck	Family Anatidae	-	-	-	-	10	12
Black Oystercatcher	*Haematopus bachmani*	-	-	3	5	10	12
Red-necked Phalarope	*Phalaropus lobatus*	-	-	109	212	-	-
Bald Eagle	*Haliaeetus leucocephalus*	135	39	266	179	152	110
Parasitic Jaeger	*Stercorarius parasiticus*	-	-	55	106	-	-
Unidentified Shorebird		-	-	3	5	52	102
Bonaparte's Gull	*Larus philadelphia*	161	258	113	148	-	-
Mew Gull	*Larus canus*	452	472	138	218	42	36
Herring Gull	*Larus argentatus*	-	-	41	38	55	100
Glaucous-winged Gull	*Larus glaucescens*	12,036	13,197	7,117	3,786	6,048	4,226
Sabine's Gull	*Xema sabini/Larus sabini*	-	-	-	-	3	5
Black-legged Kittiwake	*Rissa tridactyla*	21,943	12,449	12,925	4,804	9,656	3,550
Unidentified Gull	Family Laridae	-	-	102	152	13	12
Aleutian Tern	*Onychoprion aleuticus*	53	102	109	211	55	101

Appendix E-1, continued. Population estimates for all species observed in Kachemak Bay in June of 1993, 2005, and 2006.

Taxon		**June 1993** *N*		**June 2005** *N*		**June 2006** *N*	
Common Name	Latin name						
BIRDS (Cont'd)							
Pigeon Guillemot	*Cepphus columba*	1,588	702	1,365	1,294	1,482	879
Kittlitz's Murrelet	*Brachyramphus brevirostris*	328	447	-	-	319	435
Marbled Murrelet	*Brachyramphus marmoratus*	984	1,336	3,651	1,823	7,312	4,376
Brachyramphus Murrelet (Unidentified)	*Brachyramphus* spp.	4,354	4,617	-	-	365	351
Brachyramphus Murrelet (Total)	*Brachyramphus* spp.	5,666	5,784	3,651	1,823	7,989	4,703
Ancient Murrelet	*Synthliboramphus antiquus*	-	-	55	105	-	-
Common Murre	*Uria aalge*	82,505	146,865	29,192	40,767	10,369	11,587
Unidentified Murre	*Uria* sp.	-	-	-	-	417	377
Horned Puffin	*Fratercula corniculata*	111	208	3	5	-	-
Tufted Puffin	*Fratercula cirrhata*	487	738	1,040	1,511	1,305	1,415
Northwestern Crow	*Corvus caurinus*	179	110	430	295	318	184
Tree Swallow	*Tachycineta bicolor*	-	-	3	5	-	-
MAMMALS							
Harbor Porpoise	*Phocoena phocoena*	-	-	3	5	10	11
Harbor Seal	*Phoca vitulina*	187	168	195	153	110	116
Sea Otter	*Enhydra lutris*	3,053	2,262	2,071	1,768	1,991	1,512

Appendix E-2. Population estimates for all species observed in Kachemak Bay during July surveys, 2005 – 2007.

Taxon	**July 2005**			**July 2006**			**July 2007**		
	birds/km²	*N*	*95% CI*	*birds/km²*	*N*	*95% CI*	*birds/km²*	*N*	*95% CI*
BIRDS									
Aleutian Tern	0.29	238	208	0.08	62	77	0.16	127	203
Ancient Murrelet	0.27	217	338	0.00	-	-	0.00	-	-
Arctic Tern	2.98	2,427	1,117	1.09	891	1,116	0.47	380	478
Bald Eagle	0.03	22	43	0.00	-	-	0.05	42	61
Black-legged Kittiwake	9.56	7,801	3,817	10.44	8,516	2,424	11.92	9,722	4,601
Brachyramphus *Murrelet (Unidentified)*	2.26	1,842	856	1.02	829	468	1.22	993	757
Brachyramphus *Murrelets (Total)*	19.55	15,949	6,811	19.08	15,561	8,112	14.77	12,047	8,840
Common Loon	0.03	22	41	0.05	41	81	0.18	148	138
Common Murre	13.04	10,640	9,678	6.81	5,553	3,362	23.19	18,916	12,161
Fork-tailed Storm Petrel	0.53	433	389	0.10	83	148	0.00	-	-
Glaucous-winged Gull	1.67	1,365	1,186	3.91	3,191	1,361	7.75	6,319	6,509
Harlequin Duck	0.13	108	207	0.00	-	-	0.00	-	-
Herring Gull	0.03	22	42	0.05	41	50	0.34	275	199
Hooded Merganser	0.00	-	-	0.00	-	-	0.00	-	-
Horned Puffin	0.29	238	245	0.00	-	-	0.05	42	52
Kittlitz's Murrelet	2.47	2,015	2,474	4.04	3,294	3,171	1.40	1,141	1,759
Leach's Storm Petrel	0.05	43	82	0.00	-	-	0.00	-	-
Long-tailed Jaeger	0.00	-	-	0.03	21	39	0.00	-	-
Marbled Murrelet	14.82	12,092	4,506	14.02	11,437	6,895	12.15	9,912	8,201
Mew Gull	0.16	130	117	0.10	83	121	0.03	21	41
Northern Fulmar	0.03	22	41	0.00	-	-	0.00	-	-
Northwestern Crow	0.21	173	309	0.00	-	-	0.03	21	38
Pacific Loon	0.08	65	83	0.13	104	105	0.08	63	83
Pelagic Cormorant	0.21	173	259	0.00	-	-	0.03	21	41
Pelagic or Red-faced Cormorant	0.03	22	43	0.00	-	-	0.00	-	-
Pigeon Guillemot	1.49	1,213	1,254	1.17	953	892	1.43	1,162	464
Red-faced Cormorant	0.16	130	254	0.00	-	-	0.00	-	-
Red-necked Grebe	0.03	22	39	0.00	-	-	0.00	-	-
Red-necked Phalarope	2.44	1,994	1,977	1.50	1,222	1,068	1.35	1,099	1,304

Taxon	July 2005			July 2006			July 2007		
	birds/km²	*N*	*95% CI*	*birds/km²*	*N*	*95% CI*	*birds/km²*	*N*	*95% CI*
BIRDS (cont'd)									
Sooty Shearwater	18.68	15,234	10,818	13.92	11,354	17,948	0.65	528	681
Surf Scoter	0.58	477	635	0.30	249	251	0.05	42	59
Thick-billed Murre	0.11	87	96	0.00	-	-	0.00	-	-
Tufted Puffin	0.24	195	261	0.18	145	244	0.26	211	166
White-winged Scoter	0.24	195	273	0.61	497	545	0.26	211	280
Unidentified Alcid	0.05	43	55	0.00	-	-	0.00	-	-
Unidentified Duck	0.05	43	58	0.00	-	-	0.00	-	-
Unidentified Gull	0.19	152	175	0.08	62	118	0.00	-	-
Unidentified Loon	0.03	22	38	0.00	-	-	0.26	211	431
Unidentified Murre	1.51	1,235	946	3.91	3,191	5,707	0.44	359	278
Unidentified Phalarope	0.35	282	492	0.00	-	-	0.00	-	-
Unidentified Puffin	0.05	43	77	0.00	-	-	0.00	-	-
Unidentified Scoter	0.00	-	-	0.08	62	123	0.03	21	42
Unidentified Shearwater	1.89	1,539	1,559	0.00	-	-	0.00	-	-
Unidentified Shorebird	0.32	260	462	0.10	83	169	0.00	-	-
Unidentified Storm-petrel	0.05	43	82	0.00	-	-	0.00	-	-
Unidentified Tern	0.50	412	313	0.05	41	45	0.31	254	436
MAMMALS									
Harbor Porpoise	0.00	-	-	0.03	21	41	0.00	-	-
Harbor Seal	0.08	65	98	0.23	186	223	0.08	63	71
Minke Whale	0.00	-	-	0.03	21	37	0.00	-	-
Sea Otter	2.87	2,340	833	3.99	3,253	2,382	3.32	2,705	959

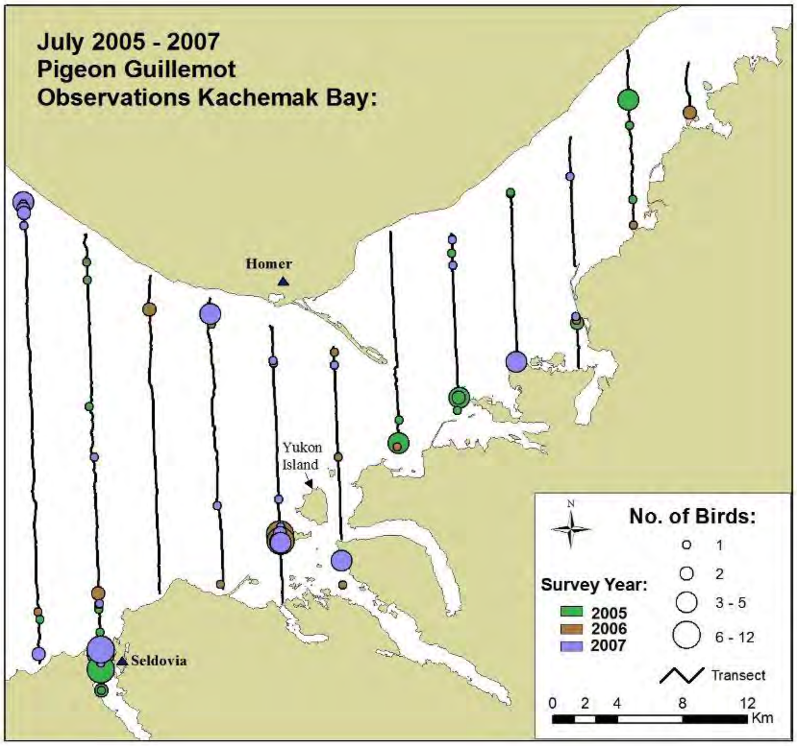
Appendix E-2 continued. Population estimates for all species observed during Kachemak Bay surveys in July, 2005 – 2007.

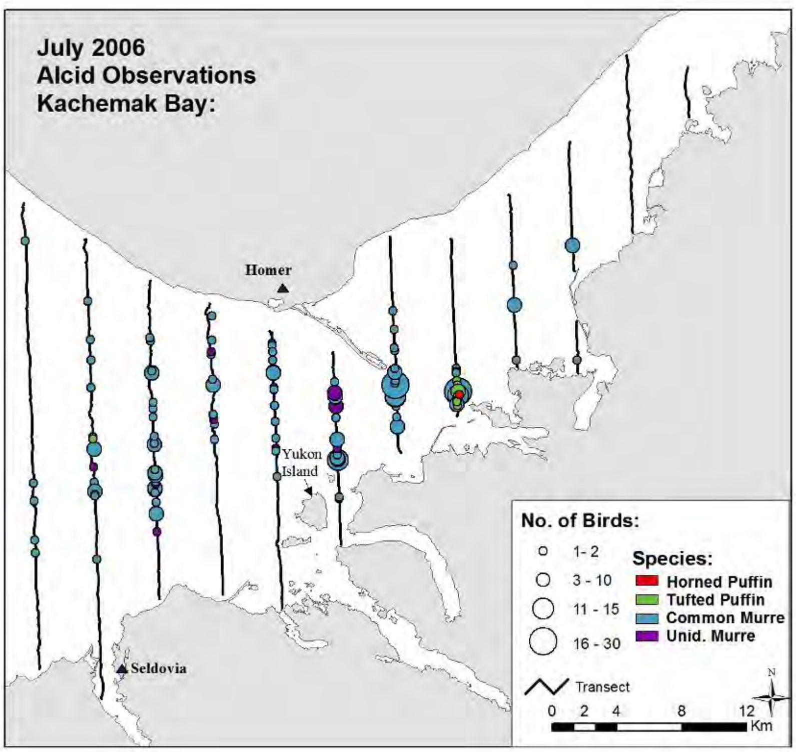
Appendix E-3. Densities of seabirds and marine mammals recorded during transits on the F/V Columbia, 4-5 September, 2005. Densities are given for different legs of the cruise, as shown in Appendix D-2. In September 253 km of transects were surveyed (38.1 km^2 with 150 m transect width).

September	Anchor Pt.	Barabara line	Cape Douglas North	Eliz. Is - Barren Is.	Into Kach	Out of Kach	Outer Kach	Shuyak Is.- Cape Douglas
Ancient Murrelet	3.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Black-legged Kittiwake	26.08	16.74	0.76	6.26	4.74	5.89	23.11	1.38
Brachyramphus Murrelet	0.20	0.80	0.00	0.00	0.00	0.00	1.40	0.00
Common Loon	2.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Common Murre	1.42	11.16	2.07	4.29	5.83	10.76	1.63	0.46
Dall's Porpoise	0.00	0.00	0.00	1.65	0.00	0.00	0.00	0.00
Fork-tailed Storm-petrel	0.00	0.00	0.65	0.00	0.36	0.00	0.00	0.00
Glaucous-winged Gull	0.81	0.00	0.11	0.99	0.36	1.22	1.40	1.84
Harbor Porpoise	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31
Harlequin Duck	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Harbor Seal	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00
Herring Gull	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.15
Horned Puffin	5.46	0.00	0.00	0.66	0.00	0.00	0.70	0.46
Marbled Murrelet	0.61	3.59	0.00	0.00	0.00	0.00	0.70	0.00
Northern Fulmar	0.00	0.00	3.71	1.98	0.00	0.00	0.00	3.53
Pacific Loon	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pelagic Cormorant	0.81	3.19	0.00	0.00	0.00	0.20	0.00	0.00
Pigeon Guillemot	12.54	1.99	0.00	0.00	0.00	0.00	0.47	0.00
Red Phalarope	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00
Rhinoceros Auklet	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.00
Red-necked Grebe	0.00	0.00	0.00	0.00	0.00	0.00	0.70	0.00
Red-necked Phalarope	0.00	1.20	0.00	0.00	3.28	0.81	0.00	0.77
Sea Otter	2.83	0.80	0.00	0.33	0.00	0.41	0.00	0.15
Sooty Shearwater	4.85	0.40	0.22	0.66	0.00	0.00	0.93	1.23
Thick-billed Murre	0.20	0.40	0.22	0.00	0.00	0.20	0.00	0.00
Tufted Puffin	0.00	0.00	0.00	19.78	0.00	1.22	14.94	0.77
Unid. Alcid	0.00	0.00	0.00	0.66	0.36	0.00	0.00	0.31
Unid. Bird	0.00	0.00	0.00	0.99	0.00	0.00	0.00	0.00
Unid. Gull	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00
Unid. Loon	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unid. Murre	0.00	0.00	0.33	1.98	0.00	0.00	0.00	0.00
Unid. Passerine	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unid. Phalarope	1.01	0.00	0.00	0.33	0.00	0.00	0.00	0.00
Unid. Shearwater	5.66	0.00	0.55	1.65	0.00	2.03	0.93	0.61
White-winged Scoter	0.61	0.00	0.00	0.00	0.00	0.00	0.23	0.00

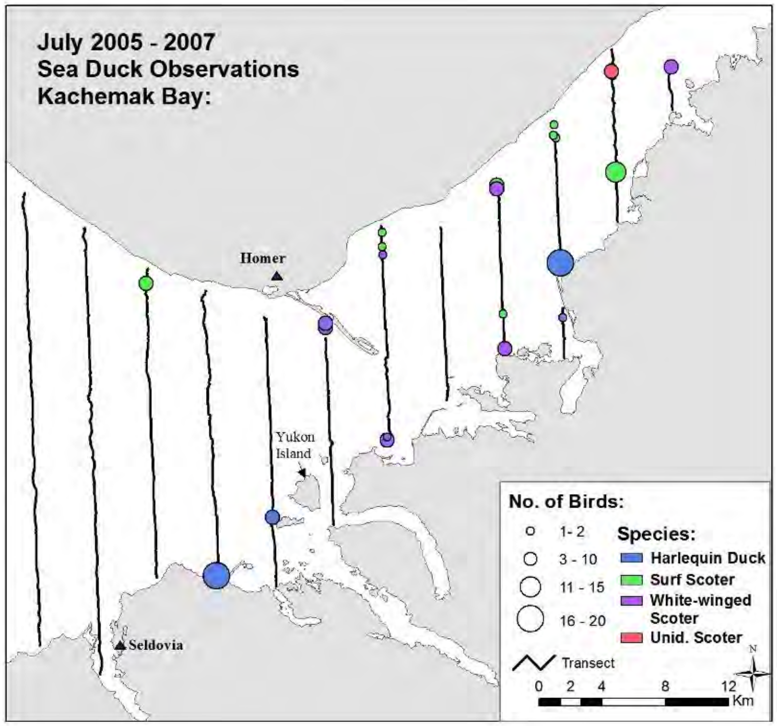
Appendix E-3, continued. Densities of seabirds and marine mammals recorded during transits onboard the F/V Columbia, 13-14 October 2005. Densities are given for different legs of the cruise, as shown in Appendix D-2. In October 228 km were surveyed (34.3 km^2 with 150 m transect width).

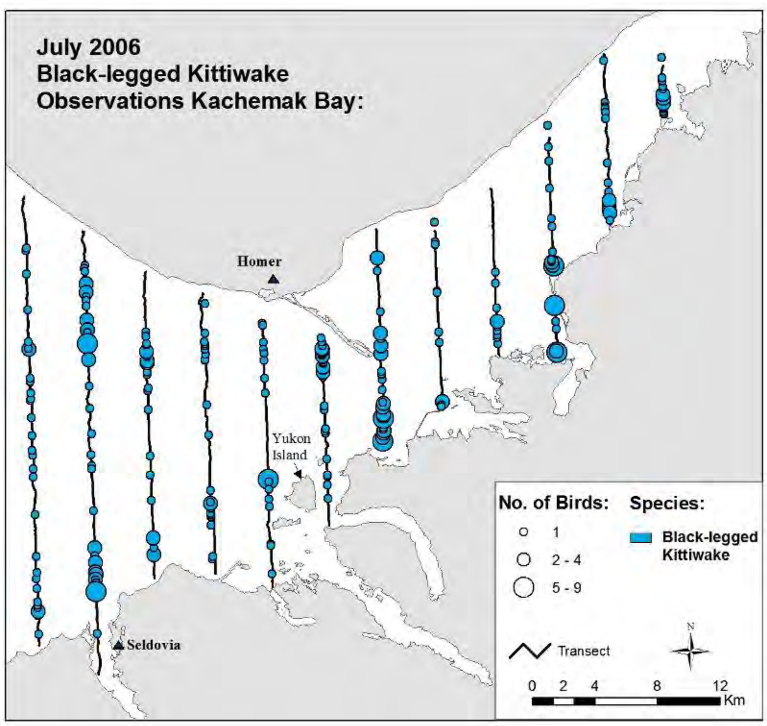
October	Anchor Pt.	Cape Douglas	Eliz. Is. - Barren Is.	Out of Kach	Outer Kach
Black-legged Kittiwake	2.80	0.00	1.01	0.40	1.99
Bonaparte's Gull	0.00	0.08	0.00	0.00	0.00
Brachyramphus Murrelet	0.15	0.00	0.00	0.00	0.00
Canada Goose	0.00	0.08	0.00	0.00	0.00
Common Eider	0.00	0.25	0.00	0.00	0.00
Common Murre	0.74	1.33	0.00	6.78	6.41
Glaucous-winged Gull	4.42	2.33	8.28	2.39	7.30
Herring Gull	0.15	0.17	0.00	0.20	0.44
Horned Puffin	0.00	0.25	0.00	0.00	0.44
Marbled Murrelet	0.74	0.00	0.00	0.00	0.00
Mew Gull	0.00	0.00	0.00	4.78	1.11
Northern Fulmar	1.91	0.00	0.00	0.00	0.00
Pelagic Cormorant	0.00	0.00	0.17	0.00	1.77
Pigeon Guillemot	0.15	0.00	0.00	0.20	0.00
Red-necked Grebe	0.00	0.00	0.00	0.00	0.22
Surf Scoter	0.00	0.00	0.00	0.20	0.00
Thick-billed Murre	0.00	0.08	0.00	0.00	0.22
Tufted Puffin	0.15	0.08	0.17	0.60	2.21
Unid. Alcid	0.00	0.17	0.00	0.40	0.44
Unid. Gull	0.15	0.00	0.00	0.20	0.00
Unid. Loon	0.29	0.00	0.00	0.00	0.22
Unid. Shorebird	0.00	0.17	0.00	0.00	0.00
White-winged Scoter	0.29	0.00	0.00	1.40	4.20



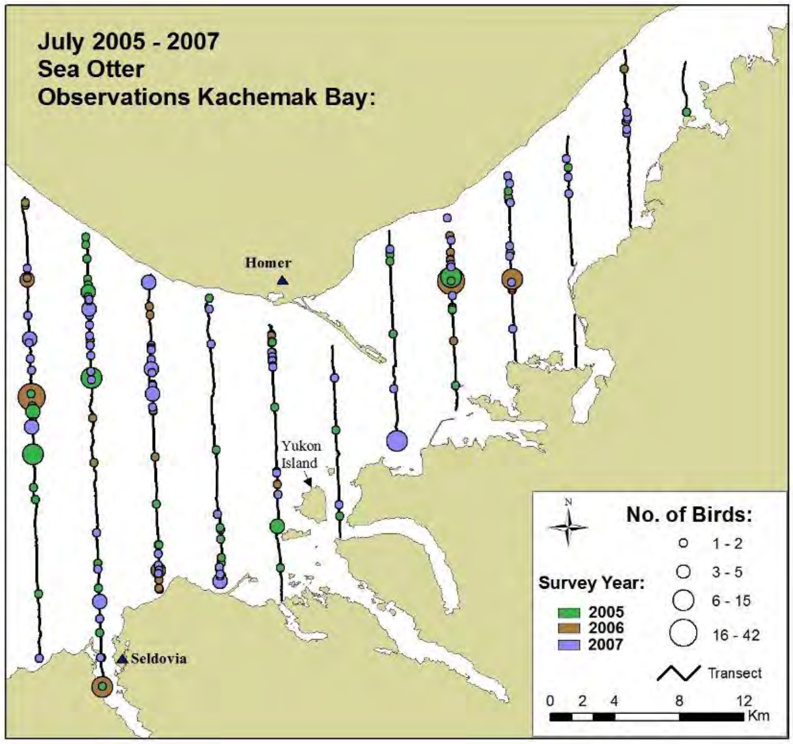


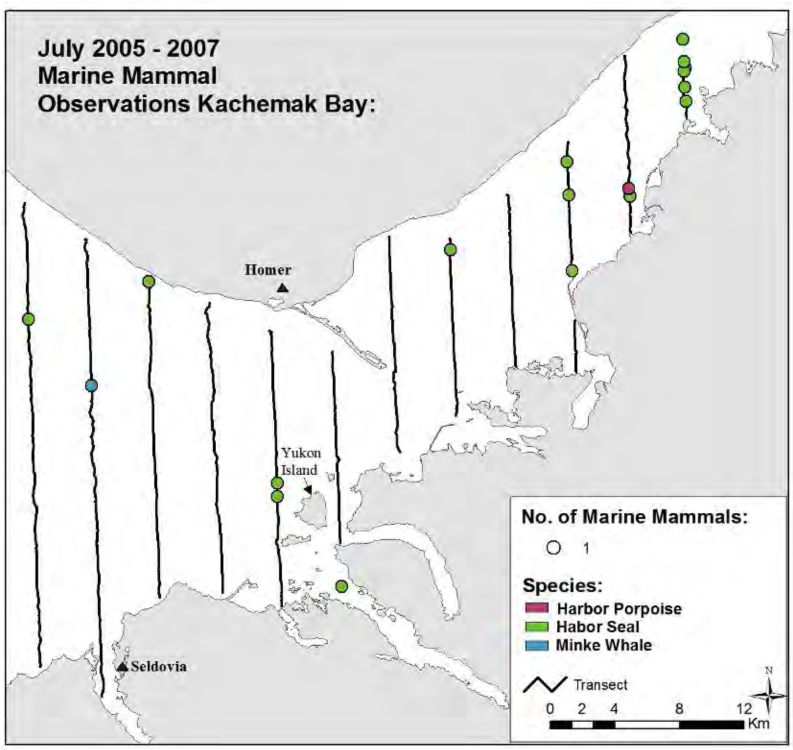
Appendix F. Distribution of pigeon guillemots (top) during July surveys of Kachemak Bay, 2005 - 2007. Distribution of other alcids (bottom) is shown for July 2006 only.



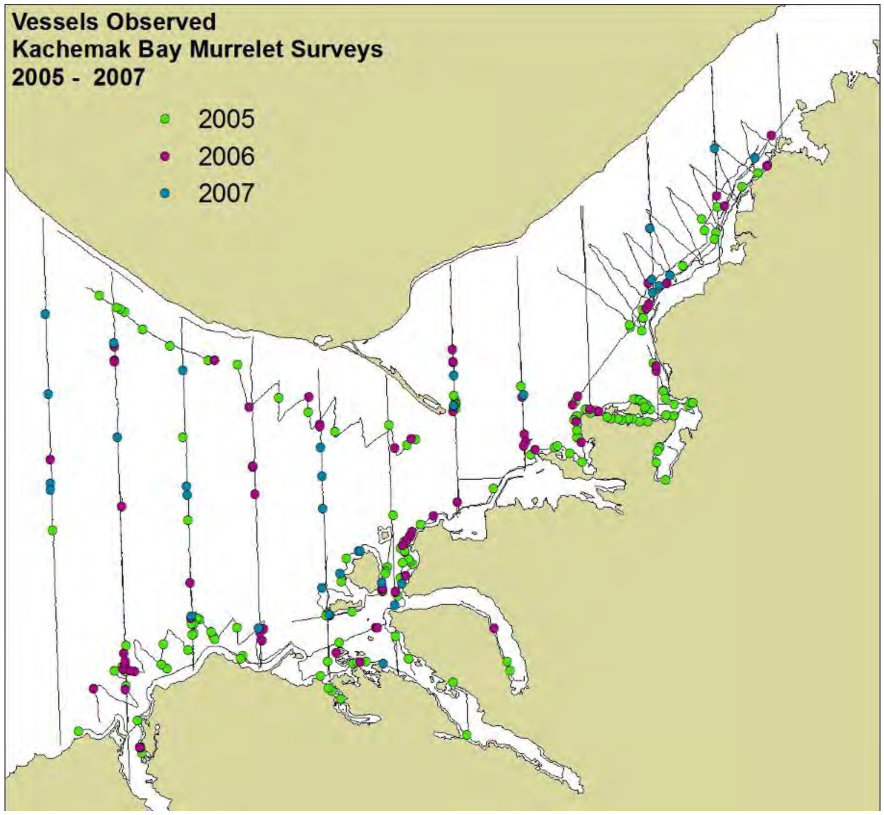


Appendix F. Distribution of sea ducks (top) recorded during July surveys of Kachemak Bay, 2005-2007, and black-legged kittiwakes (bottom) in July of 2006.





Appendix F. Distribution of sea otters (top) and other marine mammals (bottom) during July surveys of Kachemak Bay, 2005-2007.



Appendix F. Distribution of boats encountered during July and August surveys, 2005 – 2007. Figure includes all boats within 500 m of transects.

Location	Latitude	Longitude	CTD Station
June Casts			
Inner Bay	59 37.9	-151 20.1	5L
Inner Bay	59 39.5	-151 16	4L
Inner Bay	59 41.2	-151 12	3L
Inner Bay	59 43.1	-151 08	2L
Inner Bay	59 44.3	-151 05.7	1L
Outer Bay	59 32.1	-151 43.9	11L
Outer Bay	59 33.3	-151 40.2	10L
Outer Bay	59 33.7	-151 36	9L
Outer Bay	59 34	-151 32	8L
Outer Bay	59 34.9	-151 28	7L
Outer Bay	59 35.9	-151 24	6L
July Casts			
Inner Bay	59 44.2	-151 04	1A
Inner Bay	59 43	-151 08	2B
Inner Bay	59 41	-151 08	2C
Inner Bay	59 42	-151 12	3A
Inner Bay	59 39	-151 12	3B
Inner Bay	59 40.4	-151 16	4A
Inner Bay	59 39	-151 16	4B
Inner Bay	59 36	-151 16	4C
Inner Bay	59 39.2	-151 20	5A
Inner Bay	59 37	-151 20	5B
Inner Bay	59 35	-151 20.2	5C
Inner Bay	59 37	-151 24	6B
Inner Bay	59 33.6	-151 24	6C
Inner Bay	59 39	-151 16	4X
Inner Bay	59 40	-151 12	3-1
Inner Bay	59 41	-151 12	3-2
Inner Bay	59 42	-151 08	2-2
Inner Bay	59 43.9	-151 08	2-3
Outer Bay	59 36	-151 28	7A
Outer Bay	59 34	-151 28	7B
Outer Bay	59 32	-151 28	7C
Outer Bay	59 37	-151 36	9A
Outer Bay	59 34	-151 36	9B
Outer Bay	59 30	-151 36	9C
Outer Bay	59 38	-151 44	11A
Outer Bay	59 34	-151 44	11B
Outer Bay	59 29.1	-151 43.9	11C
Outer Bay	59 40.0	-151 48	12A
Outer Bay	59 37.0	-151 48	12B
Outer Bay	59 34.0	-151 48	12C
Outer Bay	59 30.0	-151 48	12D
Outer Bay	59 27.4	-151 48	12E

Appendix G. Location of CTD Casts in Kachemak Bay.