Exxon Valdez Oil Spill
Restoration Project Annual Report

Status and Ecology of Kittlitz's Murrelet in Prince William Sound

Restoration Project 96142
Annual Report

This annual report has been prepared for peer review as part of the *Exxon Valdez* Oil Spill Trustee Council restoration program for the purpose of assessing project progress. Peer review comments have not been addressed in this annual report.

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Status and Ecology of Kittlitz's Murrelet in Prince William Sound

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Study History: This project, which was initiated in 1996, investigated aspects of the ecology of Kittlitz's murrelet (*Brachyramphus brevirostris*) in four glaciated fjords in northern Prince William Sound during 3-week cruises in early (May–June) and late summer (July–August). This year was the first of a 3-year project.

Abstract: We studied populations, habitat use, reproduction, and feeding of Kittlitz's murrelets in four bays in Prince William Sound, Alaska. Kittlitz's murrelets were common in nearshore and offshore areas and rare on pelagic surveys. In early summer, they still were arriving in two bays, whereas numbers in two bays were stable; in late summer, numbers decreased rapidly as birds abandoned bays. Populations collectively totaled ~1,425 ± 1,700 (95% CI) birds. Habitat use varied among bays and cruises but generally was consistent within bays. At a large scale, murrelets used greater mean ice cover than was available overall, but at a fine scale, they used open water within the heavier ice. They occurred in sea-surface temperatures that were available to them in early summer but moved into cooler waters in late summer. The percentage of breeding-plumaged birds in early summer decreased through time. Reproductive output was extremely low. Feeding frequency was highest in nearshore areas, when tidal currents were weak-moderate, and in glacial affected habitats; it was lowest when currents were moderate-strong. Feeding frequency did not differ by time of day or overall tidal stage. The few birds seen feeding ate fishes, probably sandlance, capelin, and/or herring.

Key Words: *Brachyramphus brevirostris*, *Exxon Valdez*, feeding ecology, habitat use, Kittlitz's murrelet, population size, reproduction.

Project Data: (will be addressed in the final report)

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EXECUTIVE SUMMARY

Introduction

This project investigated aspects of the basic ecology of Kittlitz's murrelet (*Brachyramphus brevirostris*) in four glaciated fjords in northern Prince William Sound in 1996. The Kittlitz's murrelet is perhaps the most poorly known seabird that commonly nests in North America. The small size of its world population, its restricted distribution, and uncertainty over impacts to its Prince William Sound population from the *Exxon Valdez* oil spill all result in concern over the conservation of this species. The specific objectives of this study were (1) to conduct population surveys for Kittlitz's murrelets in four bays in northern Prince William Sound where Kittlitz's murrelets are known to concentrate; (2) to estimate population sizes of Kittlitz's murrelets in each bay and the northern Prince William Sound area as a whole; (3) to determine distribution and habitat use of Kittlitz's murrelets in each bay; (4) to develop and measure indices of reproductive performance of Kittlitz's murrelets in each bay; and (5) to describe trophic levels and the feeding ecology of Kittlitz's murrelets in each bay.

Methods

The four study bays were located in the northern and northwestern part of Prince William Sound and included the upper ends of Unakwik Inlet, College Fjord, Harriman Fjord, and Blackstone Bay. All four bays have at least one tidewater glacier and substantial amounts of habitat that is affected by glaciers to various degrees. We conducted multiple surveys in these bays during two 3-week cruises in early (May–June) and late summer (July–August) 1996.

We studied Kittlitz's murrelets on nearshore (in bays, ≤200 m from shore) surveys, offshore (in bays, >200 m from shore) surveys, and pelagic (>200 m from shore and in open parts of the Sound between bays) surveys. During surveys, we counted Kittlitz's murrelets and recorded their plumage (breeding, molting, winter, juvenile, unknown), location (in the air, on the water), and activity (e.g., flying, sitting/resting, feeding). We also characterized the habitat in which they were found by classifying the survey segments in terms of the level of effect by glaciers (glacial affected, glacial stream affected, marine sill affected, glacial unaffected), the percent ice cover (both by overall survey segment and transect and within 50 m of individual birds), and sea-surface temperatures (by overall survey segment). To study feeding ecology, we compared frequencies of birds that were feeding by time of day, rising vs. falling tide, tidal strength, and habitat type. We also attempted to catch juvenile Kittlitz's murrelets to study residence times and to catch juveniles and after-hatching-year (AHY) birds to study trophics.

Results

In early summer, Kittlitz's murrelets still were arriving in Unakwik Inlet and College Fjord, whereas their densities in Harriman Fjord and Blackstone Bay were stable, indicating that essentially their entire populations in these latter two bays had arrived by the time we began our surveys. In the former two bays, arrival during early summer seemed to be synchronous between nearshore and offshore surveys, suggesting that movements into the two zones were synchronous. Kittlitz's murrelets were distributed extensively throughout Harriman Fjord and Blackstone Bay (the two bays where populations were stable) but were restricted to the central and outer parts of Unakwik Inlet and College Fjord (where birds were still arriving). Numbers decreased rapidly in late summer as Kittlitz's murrelets abandoned the bays, and two of the four bays had been abandoned by the time we began our late summer surveys. Kittlitz's murrelets were common on nearshore and offshore surveys and rare on pelagic surveys. Populations in all four bays collectively totaled 1,409 ± 1,683 (95% CI) birds.

Preferred habitat type were consistent between cruises for both Unakwik Inlet (glacial stream affected habitat) and College Fjord (glacial affected), whereas habitat preference differed between cruises in Harriman Fjord (glacial unaffected in early summer, glacial affected in late summer). The preferred habitat in Blackstone Bay in early summer was glacial affected; however, no birds were present in late summer, so habitat use could not be evaluated. Reflecting this highly variable pattern of habitat use among bays and (to some extent) between cruises, mean densities of Kittlitz's murrelets did not differ by habitat type among bays. At a large scale, Kittlitz's murrelets used areas having significantly more ice than generally was available to them overall; at a fine scale, however, they used areas of open water that occurred within these zones of heavier ice. For nearshore and offshore surveys combined, 95% of all Kittlitz's murrelets occurred in waters 3–9°C in early summer, and 90% occurred in waters 3–6°C in late summer. Kittlitz's murrelets did not use waters of significantly different sea-surface temperatures than generally were available to them overall in early summer, but they used significantly colder waters in late summer, as they moved into areas near glaciers and in cooler parts of bays.

For nearshore and offshore surveys combined, the percentage of breeding-plumaged birds in early summer decreased through time, with the percentage during the final visit to Unakwik Inlet exhibiting a dramatic decline, suggesting that something was unusual about this population. The extreme variation in plumages of Kittlitz's murrelets, even birds that were classified as being in "breeding" plumage, suggested that either (1) many of these birds were breeding in what was not a "standard" breeding plumage or (2) if a "standard" breeding plumage is required for these birds to breed, many of these birds were not breeding. Ratios of juveniles to AHY birds indicated that reproductive output in all four bays was extremely low or absent during 1996: only one juvenile was recorded. Other evidence suggested that birds spent such short periods in two of the bays that we doubt that they reproduced successfully. We were unable to catch newly fledged juveniles to study their residence times and turnover rates.

We were unable to catch Kittlitz's murrelets with floating mist nets, so we were unable to collect samples for trophics studies. We were, however, able to examine other aspects of feeding ecology. In both early and late summer, a significantly higher percentage of Kittlitz's murrelets fed in nearshore areas than in offshore areas. There was, however, no difference between morning and afternoon in the percentage of Kittlitz's murrelets that were feeding; in fact, they were seen feeding throughout the day and even in the middle of the night. Kittlitz's murrelets exhibited few patterns of feeding with respect to tidal stage; feeding frequency in early summer/offshore was significantly higher on a rising than a falling tide, but the very low overall percentage of birds feeding in offshore areas makes us doubt the biological significance of this result. Kittlitz's murrelets preferred to feed when tidal currents were weak and/or moderate and avoided feeding when currents were moderate-strong. They also preferred to feed in glacial affected habitats and in shallow areas, particularly over shallow areas of sediments left by the retreat of glaciers. The few prey seen were fishes, probably sandlance, capelin, and/or Pacific herring, and primarily from 0- or 1-yr age classes.

Discussion

The timing of movements of populations of Kittlitz's murrelets differed markedly among bays in 1996, with birds arriving early and being distributed throughout the entire bays in Harriman Fjord and Blackstone Bay but arriving late and exhibiting a restricted distribution in Unakwik Inlet and College Fjord. We speculate that the later arrival and restricted distribution in the latter two bays was related to their heavier ice cover and colder sea-surface temperatures; indirect evidence suggest that food was not limiting their distribution in early summer.

Populations of Kittlitz's murrelets in these bays were fairly small. Interpretation of the meaning of these results, however, is hampered by a lack of good baseline data on population sizes in these study bays. There is an earlier estimate of as many as 63,000 Kittlitz's murrelets in Prince William Sound in 1972; if correct, the population in these four bays, which form the core of this species' abundance in the Sound, has declined dramatically since then. There also is a claim that as many as 10,000 Kittlitz's murrelets occurred in Unakwik Inlet during those 1972 surveys; if so, the population in that bay has declined dramatically to the present population of ~675 ± ~1,050 birds. Both of these earlier estimates, however, suffer from numerous questions about their quality and meaning. Further, 61% of the total count of Kittlitz's murrelets on the 1972 survey occurred on one offshore survey segment, thus strongly biasing the total population estimate for the Sound. Finally, post-spill survey estimates for the entire Sound have varied by up to 82% among years, suggesting that these large-scale surveys may not be appropriate for estimating population size of this highly clumped species.

Although patterns of habitat use were not entirely clear, it appeared that Kittlitz's murrelets were attracted to glacial affected habitats. In early summer, Kittlitz's murrelets appeared to avoid areas with heavy ice cover and cold sea-surface temperatures, thus appearing to have been prevented from having access to all habitats in two of the bays. When conditions ameliorated by late summer, Kittlitz's murrelets occurred in 100% of the available glacial affected habitats in College and Harriman fjords. Kittlitz's murrelets exhibited a shift to slightly higher ice cover later in the summer as they moved into parts of the bays where high cover previously had excluded the birds. This shift was corroborated by the distributional maps and the cooler sea-surface temperatures that were used later in the summer.

It is unclear what the plumage variation in Kittlitz's murrelets actually means. It appears, however, that closely related marbled murrelets exhibit similar variation in plumages, and some of them breed in what is not a "standard" breeding plumage. A thorough analysis of plumage variation and its relationship to breeding could be done with museum skins. All evidence suggested that reproductive output was extremely low in 1996. An earlier reference to a widespread lack of reproduction in this species in Glacier Bay suggests that breeding failures may not be uncommon in this species. Consistently low reproductive performance, however, would result in population declines if adult survival was non-compensatory.

Kittlitz's murrelets avoided feeding in strong tidal currents and preferred feeding in weak or moderate currents. Perhaps their preference for feeding in glacially affected habitats, which probably make food available on a continuous basis, frees them from a need to forage in strong tidal currents. Both the characteristics of their feeding apparatus (bill shape, size, and relative proportions) and our limited visual observations of food items suggested that Kittlitz's murrelets ate primarily the common forage fishes that occur in this area, although they also have been recorded taking large amounts of macrozooplankton at times. Further, studies that have examined food habits of other birds feeding near tidewater glaciers have found that they feed primarily on macrozooplankton.

Conclusions and Recommendations

We recommend that this study be continued in 1997 and 1998. Such additional sampling will enable us to collect additional data to confirm that the numerous patterns that we saw in 1996 were repeatable and important to this species. It also will enable us to collect additional data on topics of great interest to wildlife managers, such as those on population size and reproductive output. Finally, additional cruises will enable us to describe habitat characteristics and feeding ecology of Kittlitz's murrelets better. We have learned a great deal about the basic biology of Kittlitz's murrelet that may be useful in the conservation of this species, but there still is much to learn before we have a thorough understanding of its biology.

INTRODUCTION

The Kittlitz's murrelet (*Brachyramphus brevirostris*) is perhaps the most poorly known seabird commonly nesting in North America. The small size of its world population, its restricted distribution, and uncertainty over the impacts to its Prince William Sound population from the *Exxon Valdez* oil spill all result in concern about this species. This concern was recognized by the U.S. Fish and Wildlife Service (USFWS) when it classified the Kittlitz's murrelet as a Species of Special Concern under the Endangered Species Act. This classification means that Kittlitz's murrelets might qualify for protection under the Act but that additional information on vulnerability and threats is needed before a determination about listing is possible. So little is known about the biology of Kittlitz's murrelet that any new information will help wildlife managers and scientists define conservation goals and research needs for this species.

The primary justifications for this study are (1) the small global population size and restricted distribution of this seabird and (2) uncertainty about impacts from the *Exxon Valdez* oil spill and the species' population trends, both before and after the spill. The world population of Kittlitz's murrelets has been estimated to be as low as 20,000 birds, with most of the population residing in Alaska (van Vliet 1993). Within Alaska, Prince William Sound is believed to be one of two population centers for this species (Gabrielson and Lincoln 1959, Isleib and Kessel 1973). The magnitude of mortality of this species as a result of the oil spill is unknown, but one estimate was that 5–10% of the total world population may have been killed (van Vliet and McAllister 1994). Although we question the accuracy of this estimate, the species' small total world population makes mortality of concern to wildlife managers. Because of both the estimated spill-caused mortality and a general lack of information on this species, the *Exxon Valdez* Oil Spill Trustee Council (1996) listed Kittlitz's murrelet as "injured with recovery unknown" and funded this study on its ecology.

This study investigates the population status and distribution, habitat use, reproductive performance, and trophic characteristics of Kittlitz's murrelet in four bays in northwestern Prince William Sound. In this first year, we evaluated the distribution and abundance, at-sea habitat use, productivity, and trophic position and feeding ecology of this little-known seabird. The data on population trends will help in evaluating population changes in the center of its range in the Sound, and investigating habitat use, reproductive performance, and trophics and feeding will help us to understand how this species interacts with its environment and will enable us to measure some basic parameters of the life history of this poorly known species.

Background

The Kittlitz's murrelet is a small alcid that nests solitarily in remote areas of Alaska and the Russian Far East (American Ornithologists' Union 1983, Day et al. 1983, Day 1995). Because of its low nesting density, the extreme difficulty of finding its nests, and the paucity of surveys in its preferred nesting habitat, only 22 known or probable nests of this species have ever been located (Day et al. 1983, Piatt et al. 1994, Day 1995, Day and Stickney 1996). Based on the small sample of nests, it appears that the Kittlitz's murrelet is adapted to nesting primarily in rocky, sparsely vegetated scree slopes that occur at high elevations in the southern part of its range and at lower elevations in the northern part of its range (Day et al. 1983, Piatt et al. 1994, Day 1995).

Knowledge about the nesting phenology and breeding biology of Kittlitz's murrelet anywhere within its range is poor. For example, the incubation period is not known (but probably ~30 days, as in the closely related marbled murrelet *Brachyramphus marmoratus*; Sealy 1974), and the fledging period has been determined (for only one nest) to be ~24 days (J. F. Piatt, U.S. Geological Survey—Biological Research Division, Anchorage, AK, pers. comm.), or slightly shorter than that for the marbled murrelet (27–28 days; Simons 1980; Hirsch et al. 1981). Synthesizing records of eggs in birds, eggs and young in nests, laying and hatching dates, and first fledging dates, Day (1996) has derived estimates of nesting phenology in south-coastal Alaska (including Prince William Sound): known or probable egg-laying dates are 22 May–17 June, hatching dates are 22 June–17 July, and fledging dates are 15 July–10 August. It is unknown whether relaying occurs and, if it does, how much it protracts the nesting phenology described here.

Information on habitat use by Kittlitz's murrelet is nearly nonexistent. In southeastern Alaska, the species is restricted in distribution almost entirely to glaciated fjords: Glacier Bay, glaciated fjords on the mainland between the Stikine and Taku rivers, and probably in very low numbers around Baranof Island, which is the only glaciated island in the Alexander Archipelago (Day, manuscript in preparation). In Prince William Sound, it is found primarily in the glaciated fjords of the northern and northwestern Sound (Gabrielson and Lincoln 1959, Isleib and Kessel 1973; Nigro, pers. obs.), although it also occurs in very low numbers in non-glaciated fjords with scree slopes along their margins (Day et al., unpubl. data). Unakwik Inlet, and the vicinity of its marine sill (a former terminal moraine of a glacier that now is submarine in location) in particular, has been reported in the past to be used by large numbers of Kittlitz's murrelets (Isleib and Kessel 1973).

Food habits and feeding ecology of Kittlitz's murrelet also are poorly known. The few specimens that have been examined in the Gulf of Alaska (all from one collection on Kodiak Island) fed on forage fishes (Pacific sandlance *Ammodytes hexapterus*, capelin *Mallotus villosus*, Pacific herring *Clupea pallasi*, Pacific sandfish *Trichodon trichodon*, and unidentified fishes; Sanger 1987, Vermeer et al. 1987) and macrozooplankton (the euphausiids *Thysanoessa inermis* and *T. spinifera*). Elsewhere within the Kittlitz's murrelet's range, a bird collected at Cape Chaplina (in the northwestern Bering Sea) contained 10–20 crustaceans, and a bird collected at Wrangel Island (in the western Chukchi Sea) contained 24 (probably zoeae) *Spirontocaris* shrimp (Portenko 1973). Information on food habits thus far suggests that the Kittlitz's murrelet is primarily a secondary carnivore (Sanger 1987). The few samples of isotope ratios (naturally occurring variations in the elements Carbon and Nitrogen) in Kittlitz's murrelets examined from Kachemak Bay (Hobson et al. 1994), which is partially glaciated, also suggest that the species' trophic level is 3.8 (i.e., a secondary carnivore), or identical to that estimated from food habits in a non-glaciated area (Sanger 1987).

OBJECTIVES

1. To conduct population surveys for Kittlitz's murrelets in four glaciated fjords (hereafter called bays) in northern Prince William Sound.
2. To estimate population sizes of Kittlitz's murrelets in each bay and the northern Prince William Sound area as a whole.
3. To determine distribution and habitat use of Kittlitz's murrelets in each bay.
4. To develop and measure indices of reproductive performance of Kittlitz's murrelets in each bay.
5. To describe trophic levels and the feeding ecology of Kittlitz's murrelets.

METHODS

Study Area

Prince William Sound is a large embayment of the northern Gulf of Alaska (Fig. 1). Most of the central and northern Sound is either glaciated or recently deglaciated and contains numerous fjords and complex, rocky shorelines with abundant islands, islets, and reefs. In contrast, much of the southern Sound has wide, finer-grained beaches (Isleib and Kessel 1973). Waters within the Sound generally are >200 m deep, even within many bays. The high volume of fresh water that enters the Sound seasonally from glaciers, rivers, and precipitation mixes with the Alaska Coastal Current to form an "inland sea" (Niebauer et al. 1994). A branch of this current enters the Sound through a pass in the southeastern Sound, and most outflow leaves through passes in the southwestern Sound (Royer et al. 1990, Galt et al. 1991, Niebauer et al. 1994). Biologically, the Sound has an oceanic marine community, rather than a shallow, neritic community (Cooney 1986, Sambrotto and Lorenzen 1986). The region has cool temperatures and frequent precipitation, cloud cover, fog, and strong winds (Wilson and Overland 1986). Although most deglaciated areas are ice-free all year, the glaciated fjords may be substantially covered with sea ice during the coldest months and are partially covered during all except the warmest months.

The four study bays were located in the northern and northwestern part of Prince William Sound (Fig. 1). These four bays were selected because they are believed to contain most of the Kittlitz's murrelets in Prince William Sound (Gabrielson and Lincoln 1959, Isleib and Kessel 1973). Unakwik Inlet is the only study bay in the northern part of the Sound, whereas the other three study bays lie in the northwestern part of the Sound. All four are glaciated fjords generally being deep and generally having fairly straight shorelines that are a mixture of bedrock, boulders, rocks, cobbles, gravel, and sand in various proportions. Supratidal areas are well vegetated with conifers (primarily Sitka spruce *Picea sitchensis* and western hemlock *Tsuga heterophylla*) in the lower halves of the bays and moderately vegetated with conifers in the upper halves of the bays. Shrubs (primarily Sitka alder *Alnus crispa sinuata* and willows *Salix* spp.) form the other dominant woody plants at lower elevations. The vegetation undergoes altitudinal succession to forbs at moderate elevations and bare rock and permanent snowfields above ~750 m elevation. In addition, large areas that recently were deglaciated (e.g., around Yale Glacier) tend to be completely devoid of vegetation, even at low elevations.

Unakwik Inlet is long and narrow and is bordered by several hanging glaciers in the upper part of the bay (Fig. 2). Its only tidewater glacier (Meares), which has been advancing rapidly in recent years (Lethcoe 1987), occurs at the head of the bay. The bay is bisected ~$^2/_3$ of the distance toward its head by a shallow marine sill ~5 m deep at its deepest spot. Consequently, a large expanse of mudflats is exposed in this area, particularly in the eastern half of the bay, at low tide. The Prince William Sound Aquaculture Corporation's Cannery Creek Hatchery for salmon (*Oncorhynchus* spp.) is located at the eastern edge of this sill. Other than this hatchery, salmon appear to be produced in the upper end of this bay (i.e., in the area where we sampled) only at Miners Lake, whose outflow enters the bay ~5 km north of the cannery.

College Fjord is the largest of the four study bays, forming a deep, wide fjord ~30 km long (Fig. 3). It is bordered by several hanging glaciers (Holyoke, Barnard, and several unnamed glaciers), three advancing tidewater glaciers (Wellesley, Bryn Mawr, and Harvard), one fairly stable tidewater glacier (Smith), one stable glacier just above tidewater (Vassar), and one dramatically retreating tidewater glacier (Yale) that probably is approaching its stable retreated position (Lethcoe 1987, Sturm et al. 1991). Except for the large salmon runs at Coghill Lake, whose outflow lies at the mouth of College Fjord, we saw no evidence of spawning by salmon in this bay; however, two small salmon runs have been recorded at small outflow streams from Holyoke and Barnard glaciers (Roy 1987).

Harriman Fjord/Barry Arm (hereafter, Harriman Fjord) is a long, convoluted fjord entering the upper end of Port Wells near the mouth of College Fjord (Fig. 4). It is bordered by several hanging glaciers (Detached, Baker, Cataract, Roaring, Toboggan, Dirty, Wedge, and several unnamed glaciers), several advancing tidewater glaciers (Surprise, Barry, Coxe, and Harriman), one stable glacier just above tidewater (Serpentine), and one slightly retreating glacier (Cascade; Lethcoe 1987). We saw no evidence of spawning by salmon in this bay.

Blackstone Bay, which lies southwest of Port Wells, is the smallest of our study bays (Fig. 5). It is bordered by several hanging glaciers (Ripon, Concordia, Northland, and several unnamed glaciers), two slowly retreating glaciers just above tidewater (Marquette and Lawrence), and two slowly retreating tidewater glaciers (Beloit and Blackstone; Lethcoe 1987). A marine sill runs to the mainland from both sides of Willard Island, which occupies much of the head of the bay. This sill is fairly deep (~15 m deep) west of this island but only ~6 m deep at the deepest spot east of this island. Consequently, a large expanse of mudflats is exposed in this eastern area at low tide. We saw no evidence of spawning by salmon in this bay.

Data Collection

In 1996, we sampled during two research cruises that were conducted from 25 May to 14 June (early summer cruise) and from 28 July to 15 August (late summer cruise). Unless indicated otherwise, we sampled the 4 bays 2 times each during each cruise: Unakwik Inlet (3 samples in early summer), College Fjord (3 samples in late summer), Harriman Fjord (3 samples in late summer), and Blackstone Bay (Tables 1 and 2). During each cruise, we conducted both nearshore and offshore surveys in each study bay. These surveys measured population size, population trends within and between cruises, habitat use, and reproductive performance. While traveling between bays, we also sampled open waters with pelagic surveys (Fig. 1).

During each nearshore, offshore, and pelagic survey (described in "Distribution and Abundance," below), we recorded the following environmental information at the beginning of each survey segment and transect: time; segment (nearshore or offshore) or transect (pelagic) number; habitat type (see "Habitat Use," below); observation conditions (a five-point scale of poor, fair, good, very good, and excellent); swell height (Beaufort scale for the appropriate swell height); sea state (Beaufort scale for the appropriate wave height); wind speed (Beaufort scale for the appropriate wind speed); precipitation (12 possible types of precipitation, from none to various types of rain and snow and mixed precipitation); air temperature (measured to the nearest 1°C); sea-surface temperature (measured ~0.5 m below the sea's surface; to the nearest 1°C); and percent ice cover for the segment as a whole (see "Habitat Use," below). During each nearshore, offshore, and pelagic survey, we recorded the following information on each Kittlitz's murrelet: observation number; time of observation; total number of birds in that record; plumage (see "Reproductive Performance," below); location (in the air, on the water); activity (flying, sitting/resting, feeding [as indicated by diving, except for escape dives and other dives that did not appear to represent feeding behavior; also included birds holding prey in their bills], courting, preening/comfort, and sleeping); and ice cover (see "Habitat Use," below). On nearshore surveys, we assigned observation numbers to sightings and plotted all sightings on high-resolution maps of each bay. Because we were unable to map locations accurately on offshore and pelagic surveys, we simply counted birds on each survey segment and did not map their exact locations.

Abundance and Distribution.—We determined the abundance and distribution of Kittlitz's murrelets with nearshore, offshore, and pelagic surveys. Each survey type was designed to examine the abundance of Kittlitz's murrelets in each bay and in each geographic stratum (i.e., nearshore vs. offshore vs. more exposed pelagic waters).

Nearshore surveys sampled Kittlitz's murrelets that occurred in the nearshore zone (i.e., ≤200 m from the shoreline) and flying above it. This technique has been used for studies of birds in Prince William Sound by D. Irons, D. Nysewander, and J. Trapp (USFWS, Anchorage, AK, unpubl. data), Klosiewski and Laing (1994), Agler et al. (1994, 1995), Day et al. (1995, in press), and Murphy et al. (1997). In each bay, we drove a small boat slowly ($\bar{x}$ = 10.4 km/h; n = 19 surveys) along the shoreline ~100 m from the beach and identified, counted, and mapped locations of all Kittlitz's murrelets seen ≤200 m from the shoreline, including the area ≤300 m ahead of the boat (to detect and count birds flushing at a great distance), or flying over this zone. We calculated densities of Kittlitz's murrelets by dividing the count on a segment by the area of nearshore waters sampled on that segment; these calculations were made for each segment-visit (i.e., a sample of each nearshore segment during a visit to that bay; see Figs. 2–5). Nearshore segments were small sections of the total nearshore zone into which we had stratified the bays' waters for habitat analyses, with each segment's boundaries usually being determined by the presence of easily locatable geographic characteristics. Areas of nearshore waters in each segment were measured with GIS analyses from digitized maps (Table 3).

Offshore surveys sampled Kittlitz's murrelets that occurred in the centers (offshore zone) of bays, >200 m from shore (i.e., beyond the 200-m-wide nearshore survey zone). Following Day et al. (1995, in press), we modified the general strip-transect sampling technique used by the USFWS (Gould and Forsell 1989) to sample a transect line that was fixed in space, rather than in duration of time. On a predetermined survey trackline in each bay, we drove the boat slowly ($\bar{x}$ = 11.0 km/h; n = 19 surveys) and identified and counted all Kittlitz's murrelets seen ≤100 m from either side of the boat and ≤300 m ahead of it. Survey routes represented a compromise between a need to maximize the area sampled and a difficulty in navigating in a small boat to landmarks that were easily seen from a distance. (Because the amount of glacial ice was heavy in parts of these bays, particularly during the early summer cruise, we were unable to use the larger ship and its GPS navigational system to conduct offshore surveys. Hence, we had to sample from a small boat and had to lay out segment lines by eye to large geographic features on the bay's far sides.) We calculated densities of Kittlitz's murrelets by dividing the count on a segment by the area of offshore waters sampled on that segment; these calculations were made for each segment-visit (i.e., a sample of each offshore segment during a visit to that bay). Offshore segments were individual sections of survey trackline (Figs. 2–5). Lengths of offshore survey segments used in calculations of areas were measured with GIS from digitized maps, and areas sampled were calculated as segment length × 200 m total width (Table 3).

Pelagic surveys sampled Kittlitz's murrelets that occurred in more open waters of Prince William Sound, outside of the bays (Fig. 1). These surveys also were sampled as lines that were fixed in space and were sampled as we were running between bays. On a predetermined survey trackline, we identified and counted all Kittlitz's murrelets seen ≤150 m from either side of the boat and ≤300 m ahead of it during a 10-min period while the ship was traveling forward at a known and fixed speed (Gould and Forsell 1989). Transects <7 min in length at the end of a pelagic survey line were discarded. We then calculated densities of birds for each transect on each survey line by dividing the total count by the total area sampled (trackline length [determined from ship's speed, to the nearest 0.1 kt] × 300 m total width). Survey areas are ~1 km^2 at a speed of ~11 kt and normally were ~0.7–0.9 km^2 at speeds run in this study (~13 km/h).

On nearshore, offshore, and pelagic surveys, we checked for numbers of Kittlitz's murrelets possibly missed while sampling by operating the boat slowly and watching for birds diving or flushing well ahead of us or popping up behind us, by timing mean dive times (feeding dives, escape dives, and other dives) and comparing those with our boat's speeds, and by conducting diel activity surveys to see the time of day when most birds were present on the water. We were able to conduct one diel activity survey on the early summer cruise (in Blackstone Bay on 8 June), but numbers of Kittlitz's murrelets on the late summer cruise were so low and declining rapidly that we did not conduct those surveys at that time (see "Results," below). On the one diel activity survey we did run, we repeatedly subsampled throughout the day the bay's nearshore and offshore segments that were contiguous or nearly contiguous and that had contained Kittlitz's murrelets on earlier surveys. Each survey took 2.0–2.25 hr to sample, so we conducted each survey on a 3-hr basis, at 0600, 0900, 1200, 1500, and 1800. On each activity survey, total numbers of Kittlitz's murrelets were recorded for each nearshore and offshore segment.

Habitat Use.—We examined habitat use by Kittlitz's murrelets with respect to primary characteristics of nearshore and offshore zones. Individual survey segments examined on nearshore and offshore surveys (and, hence, individual records of Kittlitz's murrelets seen on those nearshore and offshore surveys) were classified into one of four standardized habitat-type categories that reflected the general effect of glaciers on the nearby marine habitat (Table 3):

- glacial affected (≤200 m from the face of a tidewater glacier);
- glacial stream affected (≥1 glacial meltwater streams entered the segment);
- marine sill affected (≤200 m from a sill); and
- glacial unaffected (>200 m from the glacier face or its ice edge or in a segment having <75% ice cover overall, and not in an area affected by a sill or glacial streams—in effect, having none of the other characteristics).

We considered the above categories to represent (from top to bottom) a trend of decreasing strength of effect by glaciers. Hence, if a segment had two characteristics of different strengths, it was classified as that of the stronger characteristic. For example, if glacial streams entered the bay under a tidewater glacier, the segment was categorized as "glacial affected," rather than "glacial stream affected." Likewise, a segment with a marine sill but also having a glacial stream entering it was classified as "glacial stream affected," rather than "marine sill affected." The number of segments having such multiple characteristics was small, so misclassification did not significantly affect the results of statistical tests.

The amount of ice cover determined whether a segment's classification changed over visits from these standardized categories, so we also recorded the actual habitat occurring during each segment-visit. Hence, a nearshore or an offshore segment could be classified as glacial unaffected on one visit but glacial affected on the next visit if it was covered with ≥75% ice on the second visit. On the other hand, a segment with a tidewater glacier (i.e., glacial affected) always was glacial affected. Offshore survey segments basically were categorized only as glacial affected or glacial unaffected, depending on the amount of ice covering the segment during that visit.

Because of heavy ice cover in some locations during the first cruise, we were unable to sample 15 (6.9%) of 218 total nearshore segments thoroughly. We did, however, survey as much of these segments as we could from the edges with binoculars, to see if Kittlitz's murrelets inhabited these areas of heavy ice cover. Because we saw no evidence on this cruise that they used areas of such heavy ice cover (see the section on ice in "Results"), we assumed for calculations and testing of mean density by habitat category that these 15 unsampled nearshore segments also had no Kittlitz's murrelets.

We also examined habitat use with respect to the relationship between the distribution of Kittlitz's murrelets and ice cover. Ice cover, however, was highly variable both spatially and temporally, depending on the amount of ice calved, the sea-surface temperature (which affected melting rates), and daily variations in winds and currents (which moved the ice in different directions). Consequently, percent ice cover was determined both for each segment as a whole (i.e., at a large scale) and for individual records of birds (i.e., at a fine scale), with ice cover for each survey segment being estimated for the segment as a whole (0%, <1%, 1%, 3%, and 5–100% in 5% units) and for individual birds being estimated as that in the area <50 m from each bird (with the categories the same as those for segments). We did not begin categorizing ice cover for individual bird records until partially through the early-summer cruise, however, and we occasionally forgot to record ice cover for individual birds after that time. Consequently, sample sizes for examining fine-scale ice relationships were not as large as were sample sizes for examining the more large-scale relationships.

We also examined habitat use with respect to the relationship between the distribution of Kittlitz's murrelets and sea-surface temperatures. We assigned the sea-surface temperature recorded for the beginning of that nearshore or offshore survey segment or pelagic transect as the temperature of the water in which the birds were found. Although this method was more crude than measuring the temperature at the exact location where each bird was seen, it was the only method that was logistically feasible to use.

Reproductive Performance.—During nearshore, offshore, and pelagic surveys, we classified Kittlitz's murrelets into five possible plumage categories:

- breeding (alternate) plumage (bird looks more brown than white underneath at a distance; may be fully brown or at a late molting stage with some white speckling);
- molting plumage (bird undergoing extensive molt, so that its exact plumage cannot be determined with certainty; bird is speckled brown-and-white and looks more white than brown underneath at a distance);
- winter (basic) plumage (bird is black-and-white);
- juvenal plumage (new black-and-white plumage, including flight feathers; bird is small, has an egg-tooth and a faint breast band, and avoids flying, preferring to dive instead); and
- unknown plumage (unsure of exact plumage).

Because juvenile/winter plumaged birds on the late summer cruise were so wary that we might be unable to classify with certainty the plumage of these birds, we classified them by the probability that they were juveniles. The categories reflecting our level of certainty about age were:

- definite juvenile (bird was small; had egg tooth and/or breast band);
- probable juvenile (we were unable to confirm either definitive character, but the bird was small and appeared to have a plumage similar to that seen on other juveniles); and
- possible juvenile (bird dove and escaped so quickly that we were unable to determine whether it was in juvenal plumage or in after-hatching-year [AHY] winter plumage).

We attempted to determine residency time of juveniles. Corrections for residency time and turnover rates of juveniles in each bay were to be generated by capturing juveniles alive with a dip-net and color-marking them with brightly-colored dyes. We were going to map locations of these birds on a regular basis after searching the bays for these brightly-colored birds.

Trophics and Feeding.—We attempted to capture Kittlitz's murrelets alive with floating mist nets (Burns et al. 1994, 1995; Kaiser et al. 1995) and to sample them for trophics studies. We intended to take samples from these living birds for examination of stable-isotope ratios (Hobson 1990, Hobson et al. 1994, Thompson and Furness 1995). Samples taken from each captured bird would include (1) ≥0.5 cc of blood for information on the trophic position of foods eaten recently; (2) a piece of primary or secondary feather for information on the trophic position of foods eaten while the bird was undergoing the fall molt; (3) a gray or brown body contour feather for information on the trophic position of foods eaten while the bird was undergoing the spring molt; and (4) any prey items that we acquired opportunistically while we were examining birds. We also were going to take standard measurements of, examine for reproductive status, and band all Kittlitz's murrelets caught. We were able to conduct four nights of mist-netting on the early summer cruise, but numbers of Kittlitz's murrelets in all of the bays on the late summer cruise were so low that we did not attempt to capture birds at that time (see "Abundance and Distribution," below).

Any food items that we acquired opportunistically (either dropped by live birds that were mist-netted or from birds that died accidentally) would be preserved, identified to the lowest possible taxon, counted, and weighed. We then were going to calculate an Index of Relative Importance (IRI) for each prey taxon, following Day and Byrd (1989).

In addition to trophic studies, we examined characteristics of those Kittlitz's murrelets classified as feeding by using the "activity" column of data collected as part of each nearshore, offshore, and pelagic survey. We converted the time of all records of feeding birds to hours after the previous low tide (to the nearest 0.01 hr) with uncorrected tide-tables for Valdez.

We opportunistically timed lengths of feeding dives of Kittlitz's murrelets to the nearest 1 sec. In addition, we recorded off-transect feeding data of interest, such as records of Kittlitz's murrelets holding fishes and records of mixed-species assemblages of feeding birds that contained Kittlitz's murrelets.

Data Analysis

Statistical summarization and analytical techniques are described by topic. Statistical tests were conducted with the software Microsoft Excel (v. 7.0) and SPSS (v. 7.0). All statistical tests are two-tailed, and the level of significance (α) is 0.05. When possible, power to detect a real difference at $\alpha = 0.05$ is presented. We used ranked (rather than actual) densities in tests involving densities because of large numbers of zeroes on some site-visits. Such data were not normally distributed, and their distributions could not be normalized by transformation. The use of ranked values in parametric tests, however, is essentially identical computationally to conducting nonparametric tests (Conover and Iman 1981) and provides more complete and informative statistical tests and output (e.g., multiple comparisons, observed power) than normally is available for nonparametric tests. In most cases, statistical comparisons are presented by cruise; in a few cases, comparisons also are made between cruises or for all cruises combined.

Abundance and Distribution.—We used the summarized count data from nearshore, offshore, and pelagic surveys (as densities by segment-visit or pelagic transect-visit) to calculate mean density by bay, bay-visit, and segment or transect-visit on each cruise. We also ranked these segment-visit estimates of densities, then used the ranks in a series of 3- and 4-factor ANOVAs that examined differences in mean densities among cruises, sites (i.e., bays), visits, and habitats. The null hypothesis was that mean densities did not differ between cruises or among sites or visits. We then tested the ranked density data for nearshore and offshore surveys to see whether mean density differed by survey type with a 3-factor ANOVA. Because the nearshore surveys consisted of four habitat types but the offshore surveys consisted of only one habitat type, we also filtered the nearshore data by habitat type, then again ranked and tested for differences between survey types in mean density in this one habitat type with a 3-factor ANOVA. In both cases, the null hypothesis was that mean densities did not differ between survey types.

For each cruise, we calculated the mean density of Kittlitz's murrelets on each nearshore and offshore survey segment. We then plotted these values and visually interpreted the patterns of distribution within each bay and compared these patterns of distribution between cruises. All comparisons of within-bay distribution were qualitative, in that they did not involve statistical tests of differences in distribution.

We estimated overall population sizes of Kittlitz's murrelets in each bay during each bay-visit by considering the nearshore survey to be a census and the offshore survey to be a sample. Thus, to estimate the total population on a particular bay-visit, we added the total number of birds seen on the nearshore survey during that visit to the estimated population in the offshore zone during that visit. This latter value was calculated as the mean offshore density × total area of offshore zone in the part of the bay that was sampled; SDs of the mean offshore densities were converted to 95% confidence intervals (CIs). Thus, the ensuing population estimate included an estimate of both the number of birds and the 95% CI of that estimate.

Habitat Use.—To examine use of particular habitat types, we calculated mean densities of Kittlitz's murrelets by standardized habitat type for nearshore and offshore surveys and compared ranked densities by habitat type and cruise with a 4- (nearshore) or 3-factor (offshore) ANOVA. Because all offshore segments were of one standardized habitat type, we were unable to include that factor in the model. The null hypothesis was that mean densities of Kittlitz's murrelets did not differ among cruise, site, visit, and standardized habitat type. We also calculated mean densities of Kittlitz's murrelets by actual (as opposed to standardized) habitat type encountered during each bay-visit for nearshore and offshore surveys and compared ranked densities by habitat type and cruise with a 4-factor ANOVA. The null hypothesis was that mean densities of Kittlitz's murrelets did not differ among cruise, site, visit, and actual habitat type.

To examine availability versus use of large-scale ice cover, we tabulated numbers of Kittlitz's murrelets by ice cover of each nearshore and offshore segment and compared mean ice covers by survey type and cruise with a series of 1-factor ANOVAs; data were pooled among all bays and visits during a cruise. Because we were examining comparisons within the factors cruise, species, and survey type, these issues were best tested by a series of 1-factor ANOVAs, rather than a 3-factor ANOVA. The null hypotheses were that the mean ice cover that was available did not differ from the mean ice cover used by Kittlitz's murrelets, that the mean ice cover that was available did not differ between cruises, and that the mean ice cover that was used did not differ between cruises. We also conducted a fine-scale comparison of ice availability versus use by comparing the total ice cover available in each segment with the ice cover recorded within 50 m around each bird; only those segments in which we had fine-scale ice data were used. We then tested for availability versus use of fine-scale ice cover with a series of 1-factor ANOVAs, as above. Again, data were pooled among all bays and visits during a cruise. The null hypotheses were that the mean ice cover that was available did not differ from the mean fine-scale ice cover used by Kittlitz's murrelets and that the mean ice cover that was used did not differ between cruises.

To examine availability versus use of sea-surface temperatures, we tabulated numbers of Kittlitz's murrelets by each nearshore and offshore segment's sea-surface temperature and compared mean sea-surface temperatures by survey type and cruise with a series of 1-factor ANOVAs. As for the ice comparisons, data were pooled among all bays and visits during a cruise. The null hypotheses were that the mean sea-surface temperature that was available did not differ from the mean sea-surface temperature used by Kittlitz's murrelets, that the mean sea-surface temperature that was available did not differ between cruises, and that the mean sea-surface temperature that was used did not differ between cruises.

Reproductive Performance.—We compiled the counts of birds of each plumage type by bay-visit on both cruises and plotted trends in percentages of birds in breeding plumage through time. We then followed the technique that had been developed by Kuletz et al. (1995; pers. comm.) to estimate reproductive performance of marbled murrelets in the Sound. We compiled densities of juveniles in each bay by our level of certainty about whether they actually were juveniles (i.e., definite, probable, possible). Because densities in some bays were changing through time, we also calculated the maximal density of juveniles in each bay during each visit. We calculated mean densities of AHY birds recorded in each bay; because densities in some bays were increasing through time, we also calculated the maximal density in each bay. We then estimated reproductive performance by calculating juvenile:AHY ratios for each bay, with uncertainty in the estimates being incorporated by calculating ratios from the mean densities of juveniles and AHY birds on all visits to a particular bay and the maximal densities of juveniles and AHY birds on any visit to a particular bay.

Trophics and Feeding.—We used the nearshore and offshore data on birds classified as feeding to test for variation in feeding frequency by survey zone, time of day, tidal stage, and habitat type. To determine the percentage of birds that were feeding, we recoded the activity data into two categories: numbers of birds "feeding" and numbers "not feeding" (i.e., all other activities combined). The stratification and pooling depended on the analysis done (e.g., time of day, tidal stage, habitat type).

To examine variation in feeding frequency by survey zone, we used a Chi-square test of row-by-column independence to test whether the frequency of feeding Kittlitz's murrelets differed between survey type (i.e., nearshore vs. offshore surveys). The null hypothesis was that feeding frequency did not differ between survey types.

To examine temporal variation in feeding frequency of Kittlitz's murrelets, we summarized total numbers of Kittlitz's murrelets that were and were not feeding by 1-hr blocks of time (e.g., 0800–0859, 0900–0959) and examined whether feeding frequency varied among time of day. Because of frequently small sample sizes in individual hourly periods, we had to stratify the data into larger time periods. Thus, we used a Chi-square test for row-by-column independence to determine whether the percentage of Kittlitz's murrelets that were feeding differed between morning (0800–1159) and afternoon (1200–1859) periods. The null hypothesis was that the feeding frequency did not differ between time periods.

To examine variation in feeding frequency by tidal stage, we converted the time of each record to hours after low tide, summarized numbers of Kittlitz's murrelets classified as feeding and not feeding by 1-hr blocks of tidal stage (e.g., 6.00–6.99 hr after low tide, 7.00–7.99 hr after low tide), and determined whether the frequency of feeding Kittlitz's murrelets varied among tidal stages. We used a Chi-square goodness-of-fit test, with the expected number of birds in each hour determined by the number of hours after the previous low tide. From a low tide to its following high tide ~6 hr later, the tide rises and falls in a sinusoidal fashion (Pond and Pickard 1983), with the hourly changes approximated as $^1/_{12}$, $^2/_{12}$, $^3/_{12}$, $^3/_{12}$, $^2/_{12}$, and $^1/_{12}$ of the total height. A tide falls from a high tide to a low tide in the same fashion. This sinusoidal curve of rising and falling tides is approximated by the bar graph shown in Figure 6 (top) and shows that the strongest tidal currents occur in the middle two hours of a rising or falling tide, moderate-strength currents occur in the second and fifth hours, and the weakest currents occur around the low and high tides (Pond and Pickard 1983). This sinusoidal curve's hourly values then were changed to values of relative strength of the tidal current (Fig. 6, bottom); it was these values of relative tidal strength that were used to generate the expected feeding frequencies with respect to current strength.

Because one tidal cycle actually is longer than 12 hr (it actually may be up to ~12.7 hr), we recoded the tidal data into 12 1-hr categories of similar size. Thus, the recoded categories were 0–1.05 hr after low tide (recoded as 1 hr), 1.06–2.10 hr after low tide (recoded as 2 hr), and so forth. The final 1-hr recoded category was only slightly larger (by a few hundredths of an hour) than the other categories, but this slight difference would have had little effect on the final results.

Because of frequently small sample sizes in each 1-hr tidal-stage category, we had to pool the data into larger categories. First, we pooled the data by rising (0–6 hr after low tide) and falling (7–12 hr after low tide) tides and tested whether the frequency of feeding differed between the two tidal stages with a Chi-square test for row-by-column independence. The null hypothesis was that feeding frequencies did not differ between tidal stages. We also examined whether feeding frequency was proportional to strength of the tidal current with a Chi-square goodness-of-fit test. The expected frequencies were based on relative tidal strength per hour (Fig. 6, bottom) and would be 0.167 for weak currents (1, 6, 7, and 12 hr after low tide), 0.333 for moderate-strength currents (2, 5, 8, and 11 hr after low tide), and 0.500 for strong currents (3, 4, 9, and 10 hr after low tide). The null hypothesis was that feeding frequencies did not differ from expected values by strength of tidal current.

To examine variation in feeding frequency by habitat type, we compiled the data by standardized habitat type (i.e., glacial affected, glacial stream affected, glacial unaffected) and used a Chi-square test for row-by-column independence to evaluate whether birds fed at a similar frequency in all habitat types. We were able to do such tests only for nearshore data, because all offshore segments occurred in one habitat type (see Table 3) The null hypothesis was that feeding frequency did not differ among habitat types.

RESULTS

Environmental conditions during the two cruises in 1996 were favorable for sampling (Table 4). Mean observation conditions averaged 4–5 on a scale of 1–5 (with 1 being poor and 5 being excellent). Mean sea heights, swell heights, and wind speeds (as indicated by Beaufort scale scores) were low, with seas of Beaufort 1 being ≤8 cm and of Beaufort 2 being ≤15 cm; mean sea conditions exceeded Beaufort 1 only on pelagic surveys during late summer. Precipitation was light in early summer but occurred considerably more often in late summer, when we lost one day of work because it was so heavy. Mean percent ice cover in late summer was only 9–34% that measured in early summer; no ice was recorded on any pelagic surveys. As might be expected, air and sea-surface temperatures averaged 1–2°C warmer in late summer than they did in early summer and reflected the decrease in ice cover. On both cruises, sea-surface temperatures were considerably higher on pelagic surveys than in the study bays.

Abundance and Distribution

Patterns of Abundance and Distribution.—In early summer, Kittlitz's murrelets were not recorded on nearshore surveys during the first two visits to Unakwik Inlet and on the first visit to College Fjord, whereas their densities in these two bays increased later in this cruise (Fig. 7, top). This temporal change in densities suggests that the populations in these bays still were arriving at that time. In contrast, Kittlitz's murrelets occurred in essentially stable densities in Harriman Fjord and Blackstone Bay, suggesting that essentially the entire populations essentially had arrived by the time we began our surveys. Once entire populations had arrived, these murrelets occurred in densities of 1–3 birds/km^2 in all bays. A similar pattern of delayed arrival in Unakwik Inlet and College Fjord during early summer was seen on the offshore surveys (Fig. 7, bottom), suggesting that these birds were moving into offshore areas at about the same time as they moved into nearshore areas. On the offshore surveys, mean densities generally ranged between ~1 and ~6 birds/km^2, although a high mean density of ~18 birds/km^2 was recorded during the final visit to Unakwik Inlet.

In late summer, Kittlitz's murrelets exhibited declines in abundance on both nearshore and offshore surveys through time, with the greatest declines occurring on offshore surveys (Fig. 7). In fact, these birds had completely abandoned Blackstone Bay by the time of our first visit and had abandoned Unakwik Inlet by our second visit. Kittlitz's murrelets were absent on all offshore surveys except for the first two in College Fjord, indicating that those murrelets that were present at this time were concentrated in nearshore waters.

Kittlitz's murrelets essentially were absent from pelagic waters during both cruises (Fig. 8). The only record was of a single bird on one sample of the Port Wells even lines during early summer. Hence, these birds did not appear to occur in pelagic waters during the breeding season.

When we tested the ANOVA model for nearshore surveys to determine whether densities of Kittlitz's murrelets differed among cruises, sites, visits, and habitat types, the overall model was significant but the only significant factor was site: overall densities were higher in College and Harriman fjords than they were in Blackstone Bay and Unakwik Inlet (Table 5). Overall abundance did not differ between cruises, and the significant cruise × site interaction simply reflected the change in abundance in ≥1 bay between cruises (e.g., the disappearance of Kittlitz's murrelets from Blackstone Bay in late summer; Fig. 7, top). On offshore surveys, however, the overall model was significant and there were significant differences both among sites and between cruises, with overall densities being higher in early summer than in late summer (Table 5). Again, the significant cruise × site interaction simply reflected the change in abundance in ≥1 bay between cruises (Fig. 7, bottom). Because there was only one habitat type on offshore surveys, we were unable to include habitat type in the ANOVA model for this survey type.

The plots of densities in Fig. 7 suggested a possible differences in overall densities between nearshore and offshore zones, so we tested for such a difference (Table 6). This model was significant overall but indicated that densities did not differ between the two survey types. Because the nearshore data set included four habitat types but the offshore data set contained only one, we considered it possible that our including more habitat types in the nearshore data set was adding additional variation that made it impossible to detect a difference between the two survey types. Hence, we re-ran the ANOVA with data from the one habitat type that was found in both nearshore and offshore surveys. The results of this reanalysis, which are not shown here, were similar to those shown in Table 6.

As a check to ensure that we were sampling for these birds at an appropriate time of day, we conducted a diel activity survey of some nearshore and offshore survey segments in Blackstone Bay on 8 June, during the early summer cruise (Table 7). On the nearshore component of these surveys, Kittlitz's murrelets showed essentially no change in abundance from early morning until mid–late afternoon (~1500) or possibly evening. The data for the offshore component suggested that the abundance of these birds was similar through most of the day but tapered off in the evening. Unfortunately, excessive disturbance caused by boats probably caused numbers in the afternoon surveys to be abnormal; our impression from other surveys in this area on other days was that these offshore counts would be about the same as they were in the morning. It is possible that the nearshore count for 1500–1700 also was negatively affected by boat-caused disturbance. If our impression was correct, the best hours to conduct nearshore and offshore surveys for this species would be between ~0600 and ~1500 (and possibly as late as 1700). On nearshore surveys, 84% of our sampling effort (by time) was concentrated in this period in both early and late summer. On offshore surveys, 79% and 83% of our sampling effort was concentrated in this period in early and late summer, respectively. If the optimal sampling period for offshore surveys actually is 0600–1700, we concentrated 90% of our overall sampling effort during that period in both early and late summer. Hence, it appeared that we sampled at the appropriate time of the day.

Because Kittlitz's murrelets were absent from Blackstone Bay when we began sampling in late summer, and because their abundance was decreasing rapidly in the other bays during this cruise (Fig. 7), we were unable to conduct a similar diel activity survey during the late summer cruise. Our impression, however, was that activity patterns were similar to those seen in early summer.

In early summer, Kittlitz's murrelets exhibited two main patterns of distribution within each of the four bays. In Unakwik Inlet and College Fjord, they were distributed in the central and/or lower parts of the areas sampled in these bays (Figs. 9 and 10). They were absent from the upper end of Unakwik Inlet and were nearly absent from both Harvard and Yale arms in College Fjord. In contrast, they were widely distributed throughout Harriman Fjord and Blackstone Bay in early summer (Figs. 11 and 12). They were distributed particularly widely throughout Harriman Fjord, although they appeared to avoid nearshore segments on the southern shore of the bay, whereas they were most common at the glaciated head of Blackstone Bay and occurred sporadically throughout the rest of the bay.

The early summer difference in abundance and distribution of Kittlitz's murrelets within bays probably reflected differences in ice cover and/or sea-surface temperatures within the bays (Table 8). The two bays with late arrival and restricted distribution of Kittlitz's murrelets (Unakwik Inlet and College Fjord) had both high percent ice cover and cool sea-surface temperatures on nearshore surveys. In contrast, the two bays with early arrival and widespread distribution (Harriman Fjord and Blackstone Bay) had lower (Blackstone Bay) to similar (Harriman Fjord) percent ice cover and warmer sea-surface temperatures (both bays) on nearshore surveys. A stronger difference between the two types of bays was seen on offshore surveys, in which substantially greater ice cover was seen in Unakwik Inlet and College Fjord than in Harriman Fjord and Blackstone Bay. Offshore sea-surface temperatures followed a similar pattern of being substantially cooler in Unakwik Inlet and College Fjord than in Harriman Fjord and Blackstone Bay.

In late summer, Kittlitz's murrelets were recorded only near the glaciated head of Unakwik Inlet (and only on nearshore surveys), were distributed fairly widely in both College and Harriman fjords, and were not recorded in Blackstone Bay (Figs. 9–12). They were recorded primarily on and near glacial affected nearshore segments in College and Harriman fjords and occurred sporadically elsewhere in nearshore segments. For example, they were present in all five nearshore segments in College Fjord and all four in Harriman Fjord that included tidewater glaciers. They also exhibited a general shift in distribution in Unakwik Inlet and College Fjord toward the central and upper parts of these bays, whereas they had been concentrated in the central and lower parts of these bays in early summer. During late summer, they also were rare on offshore segments in all bays except College Fjord.

The data on ice cover and sea-surface temperatures together suggest that these environmental characteristics were considerably less severe in late summer than they had been in early summer (Table 8). Hence, these environmental characteristics probably did not limit the distribution of

Kittlitz's murrelets within bays in late summer, particularly within the two bays with late arrival and restricted distribution (Unakwik Inlet and College Fjord). For example, ice cover within these two bays decreased between cruises by 79–87% on nearshore surveys and by 92–94% on offshore surveys. Likewise, sea-surface temperatures within these two bays increased between cruises by 27–38% on nearshore surveys and by 8–38% on offshore surveys. We suspect that this general amelioration of both environmental characteristics between cruises allowed Kittlitz's murrelets to penetrate into the upper ends of these bays in late summer.

In broad perspective, then, the overall pattern of distribution of Kittlitz's murrelets in Unakwik Inlet and College Fjord was from central and lower parts of the bays in early summer to central and upper parts of the bays in late summer and a general attraction to areas near or at tidewater glaciers in late summer. They were widely distributed throughout Harriman Fjord in early summer but were less abundant and concentrated near tidewater glaciers there in late summer. They were concentrated near tidewater glaciers in Blackstone Bay in early summer but had abandoned the bay entirely by late summer, making a seasonal comparison impossible. There also was a general late-summer movement of Kittlitz's murrelets from offshore areas to nearshore areas or an abandonment of offshore areas first, as populations in the bays declined.

Population Size.—In early summer, estimated populations of Kittlitz's murrelets were increasing through time in Unakwik Inlet and College Fjord but appeared to be stable across visits in Harriman Fjord and Blackstone Bay (Table 9). Hence, populations in the former two bays were still arriving as we began our surveys but in the latter two bays essentially were completely present by the beginning of our surveys. In Unakwik Inlet, the eventual population was 679 ± 1,045 birds, although this large an estimate would not have been generated if we had not added a third visit to see if any birds actually arrived in this bay. The estimated population in College Fjord was small but doubled between visits, to a maximum of 107 ± 72 birds; however, data from the late summer cruise suggest that this number probably was an underestimate and, hence, that the entire population had not arrived by the date of our final survey (see following paragraph). The estimated population in Harriman Fjord increased by <3% between visits, to 325 ± 192 birds, and the estimated population in Blackstone Bay increased by ~16% between visits, to 221 ± 302 birds. Together, the estimated population of Kittlitz's murrelets in all 4 bays combined during early summer was 1,332 ± 1,611 birds and was higher by at least 77 ± 72 birds if the estimate for College Fjord was low, for a corrected total of 1,409 ± 1,683 birds.

By the time of our first surveys in late summer, populations of Kittlitz's murrelets had disappeared or nearly disappeared in Unakwik Inlet and Blackstone Bay, were present but nearly gone in Harriman Fjord, and were present and decreasing through time in College Fjord (Table 9). In Unakwik Inlet, the population was down to 9 ± 0 birds in late July, and none were seen afterward. In College Fjord, numbers were decreasing rapidly (by ~85% over a 2-week period) through time. The population estimate for the first visit to this bay was ~80% higher than the largest estimate for the early summer cruise, suggesting that a significant number of birds had arrived after we had completed our surveys for that cruise. In Harriman Fjord, the estimated population on our first visit was only ~10% of that seen on the early summer cruise, and it decreased rapidly to essentially zero birds by the last visit. Birds had completely abandoned Blackstone Bay by our first visit there.

Habitat Use

Patterns of Habitat Use.—On nearshore surveys, Kittlitz's murrelets used a variety of habitats except for marine sill-affected ones (Table 10). Highest mean densities occurred in glacial affected habitats in 4 of the 7 bays/cruises in which Kittlitz's murrelets occurred on nearshore surveys. (Murrelets were absent from Blackstone Bay in late summer, as discussed above.) There was consistency between cruises in highest mean densities in one particular habitat type for both Unakwik Inlet (glacial stream affected habitat) and College Fjord (glacial affected habitat), whereas habitat preference differed between cruises in Harriman Fjord (glacial unaffected habitat in early summer, glacial affected habitat in late summer). Finally, Kittlitz's murrelets in Blackstone Bay occurred in highest densities in glacial affected habitats in early summer but were absent in late summer. Reflecting this highly variable pattern of habitat use among bays and (to some extent) between cruises, habitat type was not a significant factor in the 4-factor ANOVA discussed under "Abundance and Distribution," above (Table 5).

In spite of the results of the ANOVA incorporating habitat type (Table 5), another line of evidence suggests that Kittlitz's murrelets were attracted to glacial affected habitats. Although Kittlitz's murrelets had essentially abandoned Unakwik Inlet and Blackstone Bay by the beginning of the late summer cruise, they still were common in College and Harriman Fjords at that time (Figs. 10 and 11). On that cruise, Kittlitz's murrelets were recorded off the faces of nine of nine possible tidewater glaciers in those two bays, whereas they showed much lower affinity for the other habitat types. Hence, it is possible that the among-cruise variation seen in these two bays and the lack of birds seen in the other two bays during late summer affected the results of the habitat component of the ANOVA.

On offshore surveys, only glacial unaffected habitats were available to Kittlitz's murrelets (Table 10). Within that one habitat, however, mean densities varied widely among bays and cruises, with highest overall densities being recorded in early summer and being reflected in the significant "cruise" factor in the 3–factor ANOVA discussed under "Abundance and Distribution," above (Table 5).

Because habitat type could be affected to some extent by intrusions of large amounts of ice into nearshore or offshore segments that were not normally glacial affected habitats, we recalculated mean densities by actual habitat types encountered during each visit and tested for differences the same way we had done for the standardized habitat types, above. This series of recalculations, however, resulted in no differences in overall patterns of mean densities by habitat types and few differences in the ANOVA models (results not shown here). The few differences that did occur were in the offshore analyses, which showed cruise and site effects in the 3-factor ANOVA that became non-significant when habitat type was added as a fourth factor. The earlier analysis, however, did not include standardized habitat as a factor (all offshore segments were of the same standardized habitat type), so it is unclear if this model would have had as many significant effects if it had been able to contain habitat as a factor. Such a similarity between the two sets of results reflects the fact that habitat type (both standardized and actual) was not a significant factor in any of the ANOVA models and may reflect the possibility that the intrusion of ice onto individual segments was not significant or widespread enough to have had a significant effect on the distribution of Kittlitz's murrelets.

Relationship to Ice.—At a large scale, Kittlitz's murrelets generally showed pronounced relationships to ice cover (Figs. 13 and 14). In these cumulative figures, if the curve for Kittlitz's murrelet use of ice lies above the curve for ice availability, the murrelets are distributed in ice cover that is less than the amount that is available overall (i.e., across all nearshore or offshore segments sampled within a cruise): they are avoiding areas of heavier ice cover. Conversely, if the curve for Kittlitz's murrelet use of ice lies below the curve for ice availability, the murrelets are distributed in ice cover that is greater than the amount that is available overall: they are concentrating in areas of heavier ice cover.

In early summer, ice cover ranged from 0% to 100% on both nearshore and offshore surveys, although few segments had substantial amounts of ice: 75% of all nearshore and 73% of all offshore segments had ≤5% ice cover, whereas only 12% of nearshore and 14% of offshore segments had >50% ice cover (Figs. 13 and 14). In late summer, ice cover ranged from 0% to 90% on nearshore surveys and from 0% to 50% on offshore surveys; 86% of all nearshore and 96% of all offshore segments had ≤5% ice cover, and only 3% of nearshore and 0% of offshore segments had >50% ice cover.

In early summer, Kittlitz's murrelets occurred in 0–75% ice cover on nearshore surveys and in 0–35% ice cover on offshore surveys. They occurred in ≤5% ice cover on 85% of nearshore and 69% of offshore segments, whereas they occurred in >50% ice cover on only 2% of nearshore and 0% of offshore segments (Figs. 13 and 14). The abrupt jump on the use plot for the offshore surveys was caused by a flock seen in 35% ice cover. The one record of a Kittlitz's murrelet on pelagic surveys was in 0% ice cover. In late summer, Kittlitz's murrelets occurred in 0–90% ice cover on nearshore surveys and in 0.5–5% ice cover on offshore surveys. They occurred in ≤5% ice cover on 52% of nearshore and 100% of offshore segments, whereas they occurred in >50% ice cover on only 7% of nearshore and 0% of offshore segments (Figs. 13 and 14).

In most cases, these patterns of availability versus use of ice were statistically significant. In late summer/nearshore surveys and in offshore surveys for both cruises, Kittlitz's murrelets occurred in ice cover that was significantly greater than its overall availability; only the pattern for early summer/nearshore surveys was not significant (Table 11). When cruises were pooled within a survey type, Kittlitz's murrelets occurred in ice cover that was significantly heavier than its overall availability on both nearshore and offshore surveys (Table 11). Surprisingly, even though ice availability on nearshore surveys was significantly less in late summer than in early summer, Kittlitz's murrelets used areas with significantly greater (not less) ice cover in late summer than in early summer (Table 12). Such an increase probably reflects the change in distribution of Kittlitz's murrelets from central and lower parts of bays in early summer to central and upper parts of bays in late summer and in the general movement toward glacial affected habitats in late summer (Figs. 9–11). On offshore surveys, ice availability did not differ between cruises, as was seen on nearshore surveys, and ice use by Kittlitz's murrelets did not differ between cruises (Table 12).

At a fine scale, Kittlitz's murrelets essentially always showed pronounced relationships to ice cover (Figs. 15 and 16). These plots compare the large-scale ice cover for entire nearshore or offshore segments with the fine-scale ice cover seen in 50-m radius circles around each Kittlitz's murrelet within those segments. On nearshore surveys during both cruises, the murrelets always occurred in significantly less ice cover than was available overall at a large scale (Fig. 15, Table 13). On offshore surveys in early summer, they also occurred in significantly less ice than was available overall at a large scale; only the pattern for late summer was not significant, probably because of the small sample size (Fig. 16, Table 13). When cruises were pooled within a sampling type, Kittlitz's murrelets occurred in ice cover that was significantly less than its large-scale overall availability on both nearshore and offshore surveys (Table 13). Finally, Kittlitz's murrelets used ice at a fine scale that was significantly greater in cover in late summer than it was in early summer. Such a difference in pattern from the large-scale use of ice seen above suggests that Kittlitz's murrelets were able to penetrate into areas having slightly greater overall ice cover in late summer by seeking out localized areas of open or nearly open water at a fine scale.

Relationship to Sea-surface Temperatures.—Sea-surface temperatures ranged widely on both cruises (Figs. 17 and 18). In early summer, they ranged from 1°C to 13°C on nearshore surveys and from 3°C to 12°C on offshore surveys. In late summer, they ranged from 1°C to 13°C on nearshore surveys and from 2°C to 13°C on offshore surveys. On both cruises, sea-surface temperatures on both nearshore and offshore surveys were warmer at the outer edges of the bays.

Kittlitz's murrelets occurred in a wide range of sea-surface temperatures on both nearshore and offshore surveys. In early summer, they occurred in waters 2–13°C on nearshore surveys and in waters 3–10°C on offshore surveys; 2 of the nearshore records were outliers at 13°C, with all other birds in that zone being recorded in waters 2–10°C (Figs. 17 and 18). The one record of a Kittlitz's murrelet on pelagic surveys occurred as an outlier in water 13°C. In late summer, they occurred in waters 1–8°C on nearshore surveys and in waters 2–8°C on offshore surveys (Figs. 17 and 18). For nearshore and offshore surveys combined, 95% of all Kittlitz's murrelets occurred in waters 3–9°C in early summer, and 90% occurred in waters 3–6°C in late summer.

On both early summer nearshore and offshore surveys, Kittlitz's murrelets did not use waters of significantly different sea-surface temperatures than what were available to them overall; however, they did use significantly cooler water than was available to them overall on both late summer nearshore and offshore surveys (Tables 14 and 15). When the data were pooled among cruises, Kittlitz's murrelets used significantly cooler water than was available to them overall on both nearshore and offshore surveys. Early summer sea-surface temperatures were significantly cooler than were late summer sea-surface temperatures for nearshore surveys (Tables 14 and 16). Although nearshore sea-surface temperatures in early summer were cooler than they were in late summer, Kittlitz's murrelets used significantly warmer sea-surface temperatures in early summer than in late summer, suggesting some avoidance of the coolest waters in early summer. On offshore surveys, there were no differences among cruises in sea-surface temperatures that were available overall and in sea-surface temperatures that were used by Kittlitz's murrelets.

Reproductive Performance

Plumages.—Four plumage categories could be recorded on both cruises (breeding, molting, winter, and unknown); in addition, a juvenile plumage category was possible on the late summer cruise. In early summer, ~92% of all Kittlitz's murrelets seen were classified as breeding-plumaged birds on both nearshore and offshore surveys (Table 17). Another 6–8% of all birds still were molting during this cruise, and only ~1% were in winter plumage. For all surveys having samples of ≥10 birds (excluding the final visit to Unakwik Inlet), nearshore surveys had a slightly lower percentage of breeding-plumaged birds (106/114, or 93%) than did offshore surveys (114/115, or 99%). Addition of the final data for Unakwik Inlet, however, resulted in a similar percentage of breeding-plumaged birds on nearshore (121/130, or 93%) and offshore surveys (207/225, or 92%). For nearshore and offshore surveys combined, the percentage of breeding-plumaged birds decreased slightly through time, from ~95–98% on the first visit to 93–98% on the second visit (Fig. 19). The percentage of breeding-plumaged birds recorded during the third visit to Unakwik Inlet, however, exhibited a dramatic decline to ~83%, suggesting that something was unusual about this late-arriving population.

In late summer, ~96% of all Kittlitz's murrelets seen were classified as breeding-plumaged birds on both nearshore and offshore surveys (Table 18). Another ~4% of all birds were molting during this cruise, and none were in complete winter plumage. For all surveys having samples ≥10 birds, a slightly higher percentage of breeding-plumaged birds occurred on nearshore (164/172, or 95%) than on offshore surveys (14/15, or 93%). For nearshore and offshore surveys combined, the percentage of breeding-plumaged birds decreased through time, from ~98–100% on the first visit to 83–97% on the second visit and ~83% on the third visit (Fig. 19). The high percentage of birds in breeding plumage at the beginning of this cruise suggests either that those birds that were not in complete or nearly complete breeding plumage in early summer had molted into complete breeding plumage by late summer or that essentially all of them had left the study bays by the beginning of our surveys in late summer.

Patterns of Production.—We saw only one juvenile Kittlitz's murrelet during the late summer cruise, a solitary bird seen just off the shore on a nearshore survey in College Fjord on 30 July. This bird was a definite juvenile, and we saw no birds that were classified as either probable or possible juveniles. We saw no juveniles of any category on offshore surveys. We had no problem with misclassification between juveniles and winter-plumaged AHY birds, for we saw no AHY birds in a complete winter (basic) plumage on this cruise (Table 18). In addition, we saw numerous marbled murrelets that we classified as juveniles based on our criteria for Kittlitz's murrelets, suggesting that our classification system worked well. Because juvenile Kittlitz's and marbled murrelets are easily separated in the field, there was no misclassification between the two species.

The calculation of juvenile:AHY ratios indicated that reproductive output was extremely low or zero in all four bays during 1996 (Table 19). Again, only one definite juvenile was recorded on both nearshore and offshore surveys combined, so ratios in all except nearshore surveys in College Fjord were 0:1.

Evidence from the timing of movement of most of the four bays' populations also suggests that Kittlitz's murrelets experienced poor reproduction in 1996. By using dates by which most of the population was present (Table 9), we estimate that most of the Unakwik Inlet population was present from ≥2 June to ≤28 July, or a total of ≤57 days. In College Fjord, the estimate was from ≤27 May to ≥14 August, or a total of ≥80 days. Estimates were ≤29 May to ≤14 August (a total of ≥78 days) for Harriman Fjord and ≤31 May to ≤4 August (a total of ≥66 days) for Blackstone Bay. Because Kittlitz's Murrelets need ≥54 days after the egg is laid to incubate the egg and raise a chick to fledging (Day 1996), and because newly fledged juvenile marbled murrelets, which appear to behave similarly to juvenile Kittlitz's murrelets, remain at sea in the general vicinity of the nest for ≥14 days after fledging (Kuletz et al. 1995; also see Beissinger 1995), it is highly doubtful that enough time was available for successful breeding to have occurred in Unakwik Inlet and questionable whether there was enough time for it to have occurred in Blackstone Bay in 1996.

Residency Times of Juveniles.—Both the lack of juvenile Kittlitz's murrelets and the diving abilities of juveniles prevented us from catching any young for color-marking to determine residence times in bays. We even spent numerous hours attempting to catch juvenile marbled murrelets with a long-handled net from our small skiff, so that we could develop the expertise for catching juvenile Kittlitz's murrelets in 1997, but we were unable to catch even one juvenile marbled murrelet with this technique. These birds generally dove when the boat was ≥5 m away, so we were unable to get within net-range of them.

Trophics and Feeding

Mist-netting for Trophic Studies.—In early summer, we attempted to catch Kittlitz's murrelets with floating mist nets on four nights in Harriman Fjord and Blackstone Bay (Tables 1 and 20). We were going to sample any birds we caught for evaluation of trophics through a study of stable isotope ratios in blood and feathers. We generally deployed the nets in the evening and retrieved them in the middle of the night or in the morning; we were able to deploy 2–3 12-m-long nets each night. In Harriman Fjord, we deployed the net system in a fairly shallow area off the mouth of Surprise Inlet (Fig. 3). In Blackstone Bay, we deployed the net off the point between the two arms at the head of the bay (Fig. 4). We did not sample in Unakwik Inlet because Kittlitz's murrelets did not arrive there until late in the season and did not sample in College Fjord because of the heavy ice encountered in the upper end of that bay. Nets were deployed in areas having little ice and where we had seen substantial numbers of Kittlitz's murrelets during our nearshore surveys. The presence and location of ice, however, were the limiting factors that determined where we were able to deploy the nets.

We had to cancel mist-netting on one of our four evenings (10 June), because water currents changed direction as we were about to begin working and began moving several tons of ice toward and into the net system. Consequently, to avoid having the entire system destroyed, we had to pull it completely out of the water. Heavy movement of ice into that location prevented us from sampling the rest of that night.

Sampling effort over the 3 remaining nights was 12 net-hours/night, for a total of 36 net-hours (Table 20). During that time, we caught no Kittlitz's murrelets, for a mean catch rate of 0 birds/net-hour. Our qualitative observations indicated that birds generally avoided the area of the net system. Further, we were unable to deploy the net in locations where the highest local densities of Kittlitz's murrelets occurred: anything greater than small amounts of small pieces of ice tended to get caught in the spacer lines that held the net poles at a fixed distance, and even single large pieces of ice caught on the anchor lines, the spacer lines, and/or the bottoms of the mist nets themselves. The result was that the net system always was in danger of being destroyed by ice. In addition, we saw no pronounced up/down-bay movements of Kittlitz's murrelets, as one commonly sees with marbled murrelets, making it difficult to locate the net system in areas where a large number of Kittlitz's murrelets flew regularly.

Although we had planned on mist-netting in late summer, we did not attempt it because Kittlitz's murrelets had left two of the four bays by the time our second cruise began, and numbers in the remaining two bays were declining rapidly (see "Distribution and Abundance," above). Consequently, we reallocated the time that had been planned for mist-netting to other activities.

Patterns of Feeding.—Kittlitz's murrelets exhibited pronounced patterns of feeding by location and survey type (Table 21). The percentage of birds in early summer that were feeding was significantly higher in nearshore areas (24%) than in offshore areas (6%; Table 22). Similarly, the percentage of birds in late summer that were feeding was significantly higher in nearshore areas (54%) than in offshore areas (4%).

Kittlitz's murrelets did not exhibit pronounced patterns of feeding with respect to time of day (Tables 21 and 22). Percentages of birds that were feeding in the morning and afternoon were highly similar in all data sets. We were unable to conduct a test on the late summer/offshore data set, because we recorded no Kittlitz's murrelets in the afternoon part of the surveys. Matching these non-significant results, we not only saw Kittlitz's murrelets feeding throughout the morning and afternoon while surveying, but opportunistically saw them feeding in the evening and the middle of the night (at ~0430), after our regular surveys were completed.

Kittlitz's murrelets exhibited few patterns of feeding with respect to tidal stage, and probably none that were biologically significant (Tables 22 and 23). Percentages of birds that were feeding were similar in the two tidal stages for both the early and late summer nearshore data sets. The percentage of birds that were feeding was higher on a rising tide in early summer/offshore, but, because only ~6% of all birds seen in early summer/offshore were feeding, we doubt that this statistically significant result is biologically significant. We were unable to test the late summer/offshore data set because expected values were too low.

Kittlitz's murrelets exhibited strong patterns of feeding with respect to strength of tidal current (Tables 22 and 24). In all three data sets that were examined, they fed more often than expected when tidal currents were weak and/or moderate and strongly avoided feeding when tidal currents were strong and (to some extent) moderate. Thus, they were not extensively using strong tidal currents to concentrate prey or to make prey more available. We were unable to test the late summer/offshore data set because expected values were too low.

Kittlitz's murrelets also exhibited strong patterns of feeding by habitat type (Tables 22 and 25). On both cruises, they fed most frequently in glacial affected habitats (i.e., off the faces of tidewater glaciers), whereas feeding frequencies in the other two habitat types were similar and lower than those in glacial affected habitats. We were unable to test the offshore data sets because all habitats were of one type.

Other Aspects of Feeding.—Kittlitz's murrelets exhibited fairly long dive times while feeding. These dive times averaged 31.0 sec (SD = 11.0; range = 10–58; n = 41), or about the length of feeding dives by marbled murrelets in the same area ($\bar{x}$ = 28.2 sec; SD = 9.1; range = 8–48; n = 19).

Although we have no access to bathymetric data, it appeared that many Kittlitz's murrelets fed in fairly shallow water, particularly over shallow areas of sediments left by the retreat of the glaciers. For example, most of the nearshore areas along the northern side of Harriman Fjord where Kittlitz's murrelets were seen feeding in early summer (Fig. 11) were shallow. The shallow area off the mouth of Surprise Inlet, in particular, was used by feeding Kittlitz's murrelets; its depth was in the range 5–30 m on nautical charts and the ship's fathometer.

Surprisingly, Kittlitz's murrelets did not appear to forage extensively in tide rips, as marbled murrelets did. These tide rips were formed at "bottlenecks," such as the outflow of Jonah Bay into the main part of Unakwik Inlet, and at shoals, such as the tide rips that regularly formed over the shoal at Point Doran in Harriman Fjord. This lack of regular observations of Kittlitz's murrelets feeding in tide rips matched our feeding data for tidal stage, above (Table 24).

Kittlitz's murrelets feeding off the faces of the glaciers also did not forage in the way that black-legged kittiwakes (*Rissa tridactyla*), arctic terns (*Sterna paradisaea*), and mew (*Larus canus*) and glaucous-winged (*L. glaucescens*) gulls did. These birds primarily appeared to be foraging on prey that were pushed to the surface by large pieces of falling ice or that were upwelled by strong input of fresh water under the glacier faces. Instead, Kittlitz's murrelets appeared to forage by pursuit diving and capturing prey underwater.

We saw only a few Kittlitz's murrelets holding prey items. All four birds seen holding prey were holding fishes. One Kittlitz's murrelet held a Pacific sandlance that was 6–8 cm long, and two birds held unidentified fishes that were 8–10 cm long. Although we believe that these latter fishes were either capelin or Pacific herring, we were unable to confirm the identifications at a distance. If these three fishes were of those species, they all would be from 0- or 1-year age classes, given those lengths. The fourth feeding Kittlitz's murrelet was seen holding a fish of unknown species and length.

In one case, we saw Kittlitz's murrelets in a mixed-species feeding flock. At ~2020 on the evening of 30 July, we watched a feeding flock forming around ~20–30 black-legged kittiwakes that were plunge-diving near the mouth of Yale Arm in College Fjord. These birds presumably were diving on a school of fish (presumably a ball of herring), although we never saw any fish being brought to the surface. Approximately 25–40 Kittlitz's murrelets and ~100–110 marbled murrelets were attracted to this feeding flock, moving into a tight area of ~100 × 100 m and diving repeatedly among the plunging kittiwakes. Although we saw several other mixed-species feeding flocks involving kittiwakes and marbled murrelets in late summer, we did not see Kittlitz's murrelets in those flocks; not all of those flocks were seen in areas where Kittlitz's murrelets occurred, however.

One other aspect of Kittlitz's murrelet feeding should be mentioned. We noticed that Kittlitz's murrelets have large eyes—ones that are unusually large. The large size of the eyes suggests an adaptation to foraging in low-light conditions, either for feeding at night (as in a red-legged kittiwake *Rissa brevirostris* foraging on nocturnally-migrating myctophid fishes) or for feeding low light levels that occur at high latitudes in winter (e.g., Ross' gull *Pagophila eburnea*; Storer 1987). It is unclear at this time whether the abnormally large eyes in Kittlitz's murrelets represents an adaptation to either of these environmental adaptations or if they are an adaptation to poor visibility in glacially affected waters.

DISCUSSION

Abundance and Distribution

Kittlitz's murrelets differed substantially in abundance and distribution among and within the four study bays. The various ANOVAs indicated that overall densities in Harriman and College Fjords were greater than overall densities in Blackstone Bay and Unakwik Inlet. Although offshore densities during one visit to Blackstone Bay were the highest of all bays, overall densities there generally were low during both cruises combined.

There were pronounced differences among bays in the timing of movements of populations of Kittlitz's murrelets in early summer 1996. Essentially the entire populations were present in Harriman Fjord and Blackstone Bay by the time of our first visits in early June. In contrast, populations were still arriving in both Unakwik Inlet and College Fjord at that time. We speculate that the later arrival in these latter bays was related somehow to the considerably greater ice cover and/or colder sea-surface temperatures in these bays than occurred in Harriman Fjord and Blackstone Bay, rather than a temporal difference in food availability (see below). There is no known oceanographic or glaciological characteristic that would differ systematically like this among the four bays (R. T. Cooney, Institute of Marine Sciences, University of Alaska, Fairbanks, pers. comm.; C. S. Benson, Geophysical Institute, University of Alaska, Fairbanks, AK, pers. comm.), so it is probable that a different pattern will be seen in subsequent years.

This among-bay variation in the amount of ice cover also affected the distribution of Kittlitz's murrelets within bays during early summer. Following the pattern seen above, birds were distributed widely throughout Harriman Fjord and Blackstone Bay, whereas they were restricted to the central and lower parts of Unakwik Inlet and College Fjord. A movement toward glacier faces in late summer was seen in this study (College and Harriman fjords), suggesting again that ice cover and/or sea-surface temperature or the location of food limited the distribution of Kittlitz's murrelets within bays in early summer. Bailey (1927) also recorded Kittlitz's murrelets ~16 km (10 mi) away from the face of Muir Glacier (in Glacier Bay) on 19 June but found on 12 August that they had moved farther up the bay, to the glacier face. Because the nature of ice calving and the distribution of ice that has calved in these bays is highly dynamic, both temporally and spatially, generalization of these patterns with respect to ice, sea-surface temperatures, and food will require interpretable and similar patterns in subsequent years.

The evidence suggests that ice was the dominant factor affecting the distribution of Kittlitz's murrelets in 1996. In early summer, we saw no Kittlitz's murrelets in areas of heavy ice cover, but we did see them off-transect in nearby areas of open water, even if these locations were cold because of their proximity to the glaciers. Further, the feeding data showed a clear preference for feeding in glacial affected habitats in early summer, suggesting that food was not in short supply near glaciers at that time. Finally, the frequency of feeding birds in glacial affected habitats varied little between cruises, again suggesting little variation in food availability between cruises. We emphasize at this point, however, that ice cover, sea-surface temperatures, and the availability of food all may be intercorrelated to some extent, so all may exert some influence on the distribution of Kittlitz's murrelets in early summer.

It is clear that, during the summer, Kittlitz's murrelets occur primarily in nearshore and offshore waters in bays and only rarely occur in pelagic waters outside of the bays. The pattern of use of bays by Kittlitz's murrelets that we saw this year reflects both a preference for bays described earlier by Sanger (1987) and a pattern seen on pelagic surveys in open waters throughout the Sound in 1990–1991 (Day et al., ABR, Inc., Fairbanks, AK; unpubl. data). Although we were unable to measure and plot exact locations of Kittlitz's murrelets on the offshore surveys, our impression was that nearly all birds occurred within 1,000 m of the shore. Kittlitz's murrelets were extremely rare beyond that distance and occurred only as sporadic individuals or small flocks. A significant percentage of the population might occur beyond that distance only during late summer, when Kittlitz's murrelets occasionally occur in the sporadic mixed-species feeding flocks that prey on schools of small fishes.

Population Size.—Population sizes of Kittlitz's murrelets in these four bays are fairly small, forming a total population of ~1,425 ± 1,700 birds. Hence, possibly as many as ~3,000, but probably about half that many, Kittlitz's murrelets occur collectively in these four bays. The primary previous estimate of population sizes of Kittlitz's murrelets in this region is from Isleib and Kessel (1973), who stated that July–August 1972 surveys estimated ~57,000 total Kittlitz's murrelets in Prince William Sound. These authors also reported seeing ~10,000 Kittlitz's murrelets, including a flock of ~2,500 just north of the marine sill, in the upper end of Unakwik Inlet on 30 July 1972. Later, Klosiewski and Laing (1994) recalculated the overall estimate from the same data to be 63,229 ± 80,122 birds. There are uncertainties about these numbers, and we have several reservations about their accuracy.

Our first reservation with the estimates for July 1972 is that one or a few offshore samples with abnormally high densities would result in a greatly inflated overall population estimate, because the multiplication factor for that stratum was high. Indeed, the data from one offshore survey sample from Unakwik Inlet on 30 July represented 76% of all Kittlitz's murrelets seen on all offshore surveys and 61% of all Kittlitz's murrelets seen on all surveys of all types (data provided by S. J. Kendall, USFWS, Anchorage, AK, *in litt.*). In reality, 31 of 61 total shoreline and offshore survey segments sampled by that study had no Kittlitz's murrelets, and only 6 of the 61 had ≥10 Kittlitz's murrelets. Hence, this one abnormal data point dramatically inflated the total population estimate for 1972. Second, most of the population of Kittlitz's murrelets within Prince William Sound is so restricted to a few glaciated fjords that we find it difficult to believe that they occurred at that time on ~50% of all surveys throughout the Sound—a pattern suggested by the raw data file. In other words, we suspect that the random sampling done in 1972 somehow selected a high percentage of segments within the specific habitat preferred by Kittlitz's murrelets, thereby greatly inflating the overall density estimate and, hence, the overall population estimate. (We hope to examine maps of sampling locations from that 1972 survey; they are archived at the USFWS office in Anchorage.) Finally, Pete Isleib regularly fished in Unakwik Inlet during that period, yet Isleib and Kessel (1973) mention seeing large numbers of Kittlitz's murrelets there only during this one survey. Hence, if this flock actually was composed entirely of Kittlitz's murrelets, it probably was exceptional, although Isleib and Kessel did not describe it that way.

Data presented in Agler et al. (1994; Appendix A) also can be examined to see what inferences can be made about whether has there been a population decline of Kittlitz's murrelets in Prince William Sound. Their Sound-wide estimates for July since the *Exxon Valdez* oil spill have varied by ~82% among years, from a high of 6,436 in 1989 to a low of 1,184 in 1991. We question whether the total population of Kittlitz's murrelets in Prince William Sound actually did vary by this amount over these years. On the other hand, our estimate, which is for ~50% of the bays that contain most of the Sound's population for Kittlitz's Murrelets, is ~50% of the 3,368 estimated in PWS during summer (Kendall and Agler 1997). However, the extensive interannual variation in estimated population size seen in that study, coupled with the extreme variation in abundance and distribution among bay-visits and bays (depending on ice cover and sea-surface temperatures) that we have seen in this study, suggests either that (1) for some reason, these birds really do exhibit dramatic interannual changes in population size in a broad region such as Prince William Sound (and, if so, where are they in those years when they do not visit the Sound?), or (2) these broad-scale surveys are not adequate for estimating accurate Sound-wide populations of this highly clumped species. At this time, it is unclear which case is true.

Given these reservations about the 1972–1973 data set, we do not believe that those data should be used as a baseline for subsequent comparison of Kittlitz's murrelet populations. Also, given the large post-spill variation in estimated population size of this species, it is unclear whether this Sound-wide survey method can estimate the total population of this highly clumped species accurately. Consequently, we consider it still to be an unresolved question whether this species has experienced a population decline in Prince William Sound.

Habitat Use

Although Kittlitz's murrelets exhibited consistent use of a particular habitat type in most of the bays, the "preferred" habitat type was not completely consistent across all bays and between cruises. (Actually, the only consistent pattern was a lack of use of marine sill affected habitats.) To some extent, however, this lack of consistency was driven by external factors that appeared to override the preference of these birds for some habitat types. First, it appeared that excessive ice cover, excessively cold sea-surface temperatures, or a combination of the two in early summer prevented Kittlitz's murrelets from spreading throughout and having equal access to all habitats in Unakwik Inlet and College Fjord. Second, the heaviest ice cover and coldest temperatures in early summer occurred off the faces of the tidewater glaciers, making many of the segments with this specific habitat type unavailable to Kittlitz's murrelets. Once ice cover declined and sea-surface temperatures increased in these glacial affected habitats later in the summer, Kittlitz's murrelets moved into them, occurring in 100% of the glacial affected segments in College and Harriman fjords in late summer. A third reason why the ANOVA did not detect a consistent use of a particular habitat types was that densities in Unakwik Inlet and Blackstone Bay had declined to zero or nearly zero by the beginning of the late summer cruise, thereby decreasing the effect of any pattern seen there in early summer. A final reason why the pattern of habitat use was not consistent may be related to variations in freshwater input from glaciers in glacial affected and glacial stream affected habitats. We noticed substantial variation in rates of input and in water clarity and mixing among segments of these habitat types, and we believe that it is possible that these extreme variations may have had an as-yet-unquantified effect on the habitat use and distribution of Kittlitz's murrelets within bays.

Although this year's research suggests that the pattern is not strong, glacial affected habitats appear to be the habitat type most highly preferred by Kittlitz's murrelets. The shift in distribution in College and Harriman fjords from early to late summer resulted in a high frequency of use of this habitat, and densities in these two bays were highest in this habitat type during late summer. A similar seasonal shift in the distribution of Kittlitz's murrelets to glacier faces was recorded off Muir Glacier in Glacier Bay in 1919 (Bailey 1927). In addition, densities in Blackstone Bay in early summer (when birds were still present) were much higher in this habitat type than in the others.

Kittlitz's murrelets showed stronger and clearer relationships to ice cover and sea-surface temperature than they did to habitat types. In general, they used a greater ice cover (at a large scale) than was available to them overall and cooler sea-surface temperatures (at a large scale) than were available overall. At a fine scale, however, they occurred in localized areas of low ice cover (i.e., open water) within the zones of heavier overall ice cover, indicating that heavy ice cover somehow affected their distribution or dispersion within the bays. The shift to increased ice cover in late summer, contrary to expectation, may have occurred as a result of a change in the size, shape, and/or dispersion of ice between cruises; however, we have no data to prove that ice characteristics, other than percent cover, changed between cruises.

It may seem inconsistent to conclude that ice limited the distribution of Kittlitz's murrelets within bays in early summer but that they used areas having more ice than was available to them overall at that time. Such conclusions are not in conflict, however: although Kittlitz's murrelets used areas having higher ice cover than was available to them overall, they still avoided areas having extensive ice cover. In reality, only a small percentage of birds in early summer were recorded in ice cover >35% (<5% of birds on nearshore surveys; 0% on offshore surveys), yet 15–20% of all survey segments at that time had >35% ice cover. These segments were the ones that occurred in the upper ends of Unakwik Inlet and College Fjords and off the faces of the tidewater glaciers in Harriman Fjord. Consequently, ice cover did limit the distribution of Kittlitz's murrelets, even though they did use a greater ice cover than was available to them overall.

Reproductive Performance

Plumage Variation.—Because of uncertainty about the actual age-structure of the population and because of often great plumage differences among individual Kittlitz's murrelets, it is unclear what the number of adults that were present in each bay actually was. No information on the age-structure of any Kittlitz's murrelet population is available, and we could not address that uncertainty in this study. It is clear, however, that both Kittlitz's and marbled murrelets exhibit unusual plumage characteristics that confuse the issue of just exactly what is a "breeding-plumaged bird." A substantial percentage (>>50% by our recollection) of these "breeding-plumaged birds" exhibited non-standard breeding plumage characteristics, from white under-tail coverts to white mandibular patches, white scapulars, and a whitish collar on the neck and significant amounts of white on the breast and throat. Indeed, based on our experience with other alcids, we would have considered most of the birds seen in 1996 to have been non-breeders, based solely on their incompletely expressed breeding plumages until sometime in the middle of the summer.

In late summer, most breeding-plumaged birds were completely brown early in the cruise, but they began developing whitish speckling underneath and on their faces late in the cruise, as they entered the prealternate molt. Although a thorough evaluation of Kittlitz's murrelet plumages was beyond the scope of this study, the complexity and extensive variation in plumages of this species that we observed in the field this year suggest that either many of these birds were breeding in what was not a "standard" breeding plumage or, if a "standard" breeding plumage is required for these birds to breed, many of these birds were not breeding. Similar variation in the plumage of the marbled murrelet has been recorded (Burns et al. 1994, Kuletz et al. 1995); some of those "non-standard" birds were found to be breeding, however (K. J. Kuletz, USFWS, Anchorage, AK, pers. comm.). Clearly, a thorough analysis of Kittlitz's murrelet plumages from a series of museum skins would greatly enhance our understanding of this extensive plumage variation, would help us to learn how frequently Kittlitz's murrelets actually breed in such non-standard plumages, and would enable us to determine whether some field-recognizable plumage characteristics are seen only in breeders or non-breeders, thereby increasing our ability to estimate accurate percentages of breeding birds in a population.

Reproduction.—All available evidence suggests to us that reproductive output by Kittlitz's murrelets in the four study bays was essentially zero in 1996. The juvenile:AHY ratio was zero in three of the four bays and was extremely low in the fourth. In addition, the bays' populations were present for too short a time for successful reproduction to have occurred without our detecting it in Unakwik Inlet and may have been present for too short a time in Blackstone Bay. Finally, newly fledged juvenile marbled murrelets remain at sea in the general vicinity of the nest for ≥14 days (Beissinger 1995, Kuletz et al. 1995). Hence, if all juvenile Kittlitz's murrelets (which appear to be similar in behavior to marbled murrelets) had left the bays by our first visit, all of them would have had to have fledged on the earliest date ever recorded in this region for this species and would have had to have spent ≤14 days at sea in the vicinity of the nest after they had fledged.

Although no information is available on the population dynamics of this or any other Kittlitz's murrelet population, one can use results from a recent modeling exercise on the reproductively similar marbled murrelet (Beissinger 1995) to examine the implications of such poor reproductive performance. Body mass and annual reproductive effort are good predictors of annual survivorship in alcids; marbled murrelets, which are similar in size to Kittlitz's murrelets and which also lay one egg/year, are estimated to have an annual adult survivorship of ~85%. Further, like marbled murrelets, Kittlitz's murrelets also exhibit geographic asynchrony in the timing of movements that, presumably, reflect asynchrony in the timing of reproduction. Unfortunately, the age at first breeding is unknown for both species, so Beissinger constructed his models for a range of ages. Given these model parameters, a Kittlitz's murrelet population with 85% annual survivorship would need to have an annual (female) fecundity of 0.39/pair to remain stable, based on an average age at first breeding of 3 years. An average annual survivorship of 90% would drop the annual (female) fecundity needed to maintain a stable population to 0.23/pair for birds first breeding at 3 years of age. Such fecundity levels would require juvenile:AHY ratios of ~0.15–0.20:1, or about 8–10 times the ratio that we measured in the only bay that appeared to produce young in 1996.

The implication of Beissinger's modeling (1995) is that, if it occurs regularly in Kittlitz's murrelets, such a low fecundity level will result in substantial annual declines in population size. Although we have not constructed such models, we estimate from the information discussed in Beissinger that the low levels of fecundity recorded in this study would result in annual population declines of 10% or more if maintained over several years. At this time, no information is available for evaluating the frequency of such reproductive failures in this species. Failures, however, have been recorded previously. During a collecting trip to Glacier Bay in 1907, Grinnell (1909) and others found no evidence of breeding in a series of 38 Kittlitz's murrelets that were collected between 28 June and 17 July, at what should be the height of the breeding season (Day 1996). Although it is possible that these experienced collectors somehow missed collecting any breeding birds (which they would be trying to collect), the large number of birds collected without any showing evidence of breeding suggests that the probability is low that these collectors missed *any* evidence of reproduction. The true frequency and meaning of such breeding failures in the population dynamics and population trends of this species are, however, unknown at this time and will require further investigation.

Trophics and Feeding

Our inability to catch Kittlitz's murrelets alive prevented us from measuring their trophic levels. Deployment of the net system went smoothly and was modeled after that described in Burns et al. (1994, 1995) and Kaiser et al. (1995). Unfortunately, the tendency for Kittlitz's murrelets to occur in the vicinity of floating ice made mist-netting difficult, dangerous for the nets, and unproductive in terms of catching birds. We saw numerous spots where we felt we could have deployed the nets and caught marbled murrelets, but the heavy ice often occurring near Kittlitz's murrelets made it very difficult to deploy the nets in a location where we could catch them. Perhaps ice characteristics were dramatically different this year from those seen in previous years, for Burns et al. (1994) caught a Kittlitz's murrelet in 1993 in a part of Unakwik Inlet where we never saw any in 1996. Nevertheless, catching Kittlitz's murrelets alive will require, in our opinion, a major, stand-alone effort that is dedicated solely to that task: the difficulty of capture is so great that part-time efforts will not yield significant amounts of data.

Kittlitz's murrelets exhibited no preference for feeding by time of day and little or no preference by tidal stage. (We question the biological significance of the statistically significant offshore pattern, given the low percentage of birds that actually were feeding on offshore surveys.) They did feed much more often in nearshore areas than in offshore areas and more often than expected in and around slack tide, rather than when tidal currents were strong. The latter result was surprising to us, because marbled murrelets foraging in the same bays seemed to have a strong preference for feeding when tidal currents were strongest. For example, one would always see them feeding in the tide rips (i.e., tidal fronts) at the outflow of Jonah Bay into Unakwik Inlet and in tidal fronts that formed over shoal areas and around marine sills as the tide was flowing strongly. Perhaps the preference of Kittlitz's murrelets for feeding in glacial affected habitats (i.e., near tidewater glaciers) has caused this lack of preference for fast tidal speeds: if the birds had a steady supply of food being upwelled off the faces of the glaciers, there would be no need to depend on strong tidal currents to upwell and concentrate prey.

Although tidal-oriented feeding was not preferred this year, some Kittlitz's murrelets did feed during periods of strong tidal currents—they simply did not feed in tidal fronts. The use of tidal fronts by feeding Kittlitz's murrelets has, however, been recorded both in (Walker 1922) and off the mouth of (Day, pers. obs.) Glacier Bay. The latter observation, however, represented a mixed-species feeding flock with marbled murrelets in mid-late summer, so perhaps that aspect of feeding was more important to the Kittlitz's murrelets than was the presence of tidal fronts.

Although we were unable to measure the trophic level of Kittlitz's murrelets, our limited visual data indicated that they ate fishes. It appears that they primarily eat the common schooling fishes in Prince William Sound that form a major part of the diet of other nearshore bird species. A preference for fishes is to be expected from the morphology and proportions of the mouth and bill of this species (Bédard 1969), and that preference has been documented in the few birds that have been collected for feeding studies (Sanger 1987, Vermeer et al. 1987, Piatt et al. 1994). At this point, it is unclear how important walleye pollock are in the diet of this species in Prince William Sound. That fish species was not important to Kittlitz's murrelets off Kodiak Island (Sanger 1987) but was important to them in Kachemak Bay (Piatt et al. 1994). A shift in species-composition of the nearshore nekton community in the northern Gulf of Alaska had occurred between the sampling of Sanger and that of Piatt et al., however (Piatt and Anderson 1996), so the observed differences in the importance of pollock may reflect this community shift much more than it does geographic variation.

Although our visual observations suggested that Kittlitz's murrelets fed on fishes, these results are limited and may be biased by the large size of fishes and the small size of macrozooplankton that would have made the latter difficult or impossible to see from a distance. Alternatively, because prey are eaten underwater, the smaller zooplankton would be eaten easily without our detecting it, whereas at least the larger fishes were brought to the surface (presumably for manipulation) before they were eaten underwater during a subsequent dive. Summer foods of Kittlitz's murrelets from a non-glaciated area off Kodiak Island consisted by volume of ~30% euphausiids and traces of gammarid amphipods (Sanger 1987, Vermeer et al. 1987), so a substantial amount of zooplankton is eaten by this species in the Gulf of Alaska. Elsewhere, large amounts of zooplanktonic crustaceans (e.g., *Spirontocaris* shrimp, unidentified crustaceans) may be eaten (Portenko 1973). Indeed, Kittlitz's murrelets may avoid competition with marbled murrelets by foraging on both fishes and substantial amounts of crustaceans and foraging in protected bays, whereas marbled murrelets forage primarily on fishes and both in bays and in more exposed waters (Sanger 1987).

The preference of Kittlitz's murrelets for feeding in glacial affected habitats also suggests that macrozooplankton may form a significant part of their diet in Prince William Sound. In Aialik Bay on the Kenai Peninsula, Murphy et al. (1984) found that glaucous-winged gulls were attracted to the face of Aialik Glacier, where they fed on euphausiids and mysids that were upwelled in meltwater flowing out under the glacier. This upwelling appeared to coincide with a dramatic increase in the rate of flow of meltwater from under the glacier face. Similar glacier-face feeding by seabirds on macrozooplankton has been recorded at the Nordenskjold Glacier in western Svalbard, where large numbers of black-legged kittiwakes and northern fulmars (*Fulmarus glacialis*) repeatedly fed off the glacier face on the euphausiid *Thysanoessa inermis*, the mysid *Mysis oculata*, and the hyperiid amphipod *Parathemisto libellula* (Hartley and Fisher 1936). Further, an input of large amounts of fresh water at or near the surface of a fjord should result in positive estuarine flow as salt water rises under the freshwater lens while mixing occurs (Cooney, pers. comm.). This positive estuarine flow should result in the upwelling of macrozooplankton such as euphausiids and mysids, which occur at depth during the day. In addition, the mixing process itself should form microscale patches of isopycnal water that are neutrally buoyant and, hence, are easily moved vertically (as either upwelling or downwelling) by local density instabilities and winds.

In addition to the mixing and vertical movement of salt and fresh water in glacial affected habitats, similar mixing was seen in some of the glacial stream affected habitats examined in this study. The amount of mixing and turbidity of the water in some of these segments was highly variable, depending on both the amount of fresh water entering the system and the sediment load of that water. As a result, water clarity over much of the study bays was highly variable, both spatially and temporally. We speculate at this point that the unusually large eye size of Kittlitz's murrelets reflect an adaptation for foraging in this highly turbid water.

CONCLUSIONS AND RECOMMENDATIONS

We believe that we were able to learn much about the ecology of this rare and poorly known seabird in 1996. Although some components of the study were not executed successfully, we still were able to learn far more than ever was known previously. We will make some recommendations here for 1997 and 1998 research. Because the 1997 budget already is fixed, recommendations that will cost additional money are suggested for 1998.

The abundance and distribution surveys went smoothly and yielded good, valuable, and interesting information. We recommend continuing them, especially to collect additional data for tracking estimates of population size within a year and to confirm the patterns that we saw this year. Although the addition of Blackstone Bay to have four bays being surveyed resulted in extra effort and sometimes inconsistent results, we believe that having that many bays sampled allows us to see consistencies across all bays, inconsistencies that may be interpretable in light of among-bay differences in characteristics (e.g., ice cover), and inconsistencies that were strictly random. We recommend using the extra days of 1997 ship time that will not be used in mist-netting (see below) to cover the added Blackstone surveys and additional surveys in some bays; however, we will attempt to cover all four bays again in 1997 with the existing money—unless the Chief Scientist recommends that we drop Blackstone Bay. Now that we have a better feel for the timing of population movements, we recommend adjusting the sampling schedule slightly, with the early summer cruise occurring during the period ~1–20 June and the late summer cruise occurring during the period ~15 July–10 August. We also recommend an additional, short cruise in late June-early July 1998 that would enable us to determine how stable and representative our population estimates from the early summer cruise are. We also recommend a cruise in June 1998 having additional, intensive nearshore and offshore surveys, similar to what we are doing at this time, in the few other glaciated fjords that are known or are believed to have substantial numbers of Kittlitz's murrelets: Port Nellie Juan, Icy Bay, Nassau Fjord, and Columbia Bay. Such a cruise would enable us to estimate with some confidence the overall size of the majority of Prince William Sound's population of Kittlitz's murrelets.

The habitat studies also are yielding useful and interesting information. We suggest continuing them while attempting further quantification of habitat associations of Kittlitz's murrelets, with the eventual goal at the end of this study some sort of regression analysis (e.g., logistic regression) that would include all habitat variables in a model that would partition the effect of each habitat variable in determining the abundance and distribution of Kittlitz's murrelets within these bays. In 1997, we will attempt to collect data on secchi disk readings of water clarity, so that we can quantify further the at-sea habitat characteristics of Kittlitz's murrelets and to examine fine-scale patterns of distribution. We also hope to take salinity measurements and possibly depth measurements, if we can locate a hand-held fathometer. Redirecting some of the money that otherwise would be spent on telemetry and mist-netting (see below) would enable us to rent a secchi disk, a good salinometer, and possibly a fathometer for this recommended, additional habitat sampling in 1997.

The studies on plumages and reproductive performance are interesting and of great importance, especially considering the apparently poor reproductive performance seen in 1996. We already have budgeted four additional days for late summer surveys in 1997, to give us a larger temporal window for searching for juveniles. One problem we encountered in 1996 was our inability to capture fledged juveniles. We recommend not buying transmitters for the juveniles in 1997 until we are certain that we actually can capture juveniles in substantial numbers. After discussing this capture problem with marbled murrelet biologists who have experience in attempting to capture juveniles on the water, it is clear that capturing juveniles on the water is very difficult. Hence, we want to be assured of success before we spend the money on transmitters. We also recommend addition of a component in 1998 that studies plumage variation in Kittlitz's murrelets. Such a study could be done on the 200+ specimens that we have located in major museum collections around the country. We could arrange to have all of these specimens sent to one museum (e.g., the Museum of Vertebrate Zoology in Berkeley, which has a major collection of Kittlitz's murrelets as museum skins), then could describe plumages and determine which birds showed evidence of breeding (e.g., bare brood patch, notes on the collection label of eggs in the oviduct). Such a study would enable us to understand better what these variations in plumages mean, in terms of breeding capability and effort and possible field-recognizable age categories (e.g., adult vs. subadult).

The mist-netting was unsuccessful in catching Kittlitz's murrelets for trophic studies in 1996. It also required a major investment in time and was quite dangerous when large pieces of ice moved into the nets. On the other hand, we found out several other interesting and important aspects of feeding ecology that were not known previously, simply by recording the occurrence of feeding during our abundance and distribution surveys. We suggest eliminating the mist-netting component in 1997 and investing the time and money into additional abundance and distribution surveys (which also provide information on feeding ecology) and into additional, in-depth observations of feeding birds and quantification of other aspects of feeding.

Not purchasing telemetry transmitters and renting a telemetry receiver in 1997 will save money. Deleting the mist-netting task in 1997 will save money on equipment, ship time, and personnel. Hence, changing or deleting these tasks in 1997 will make available money that either can be returned to the Trustee Council or can be redirected to the other tasks recommended here. We will wait for suggestions from the Chief Scientist on these recommendations and on recommendations for the 1998 research.

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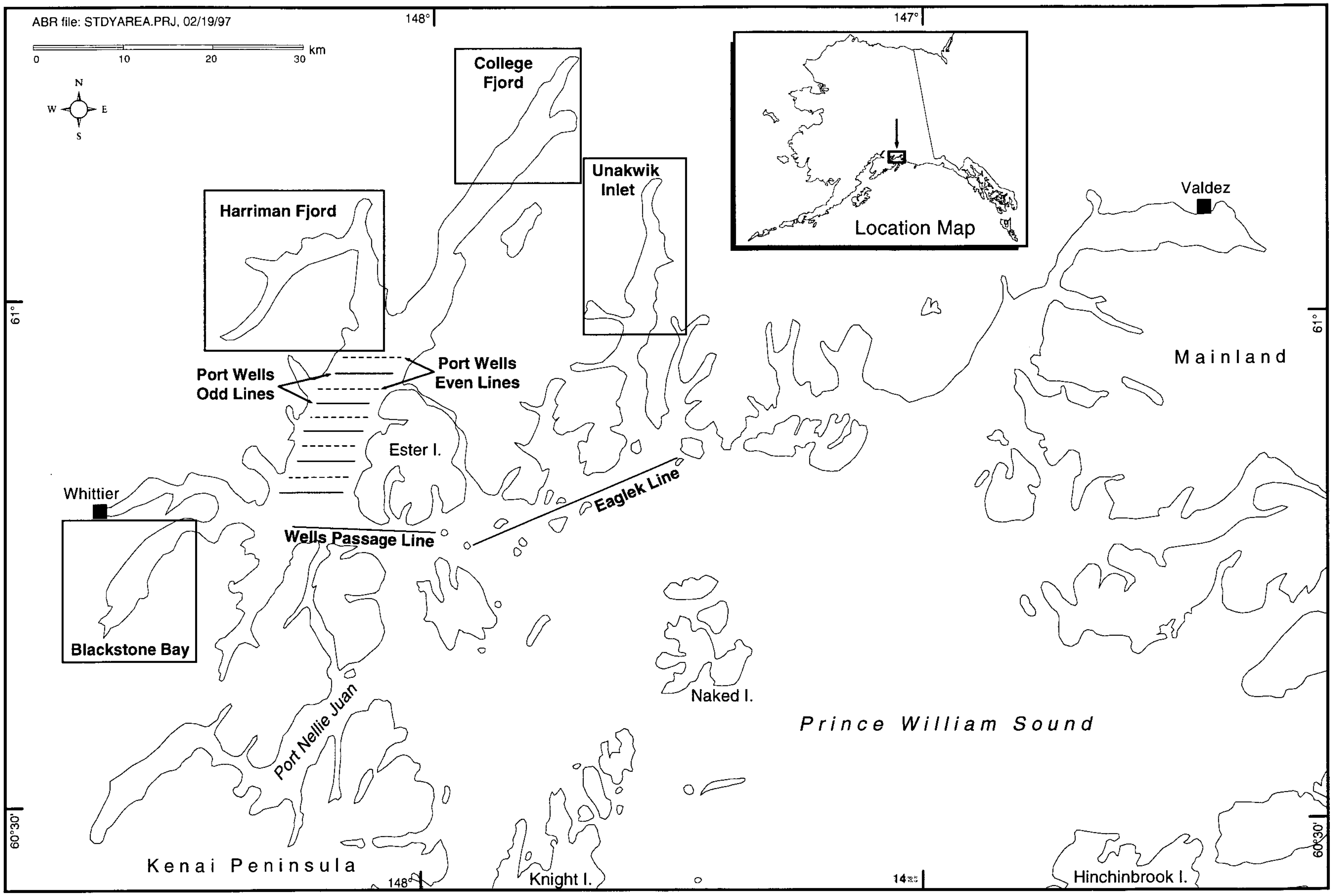

Fig. 1. Locations of study bays and pelagic survey lines sampled in Prince William Sound, Alaska, in 1996.

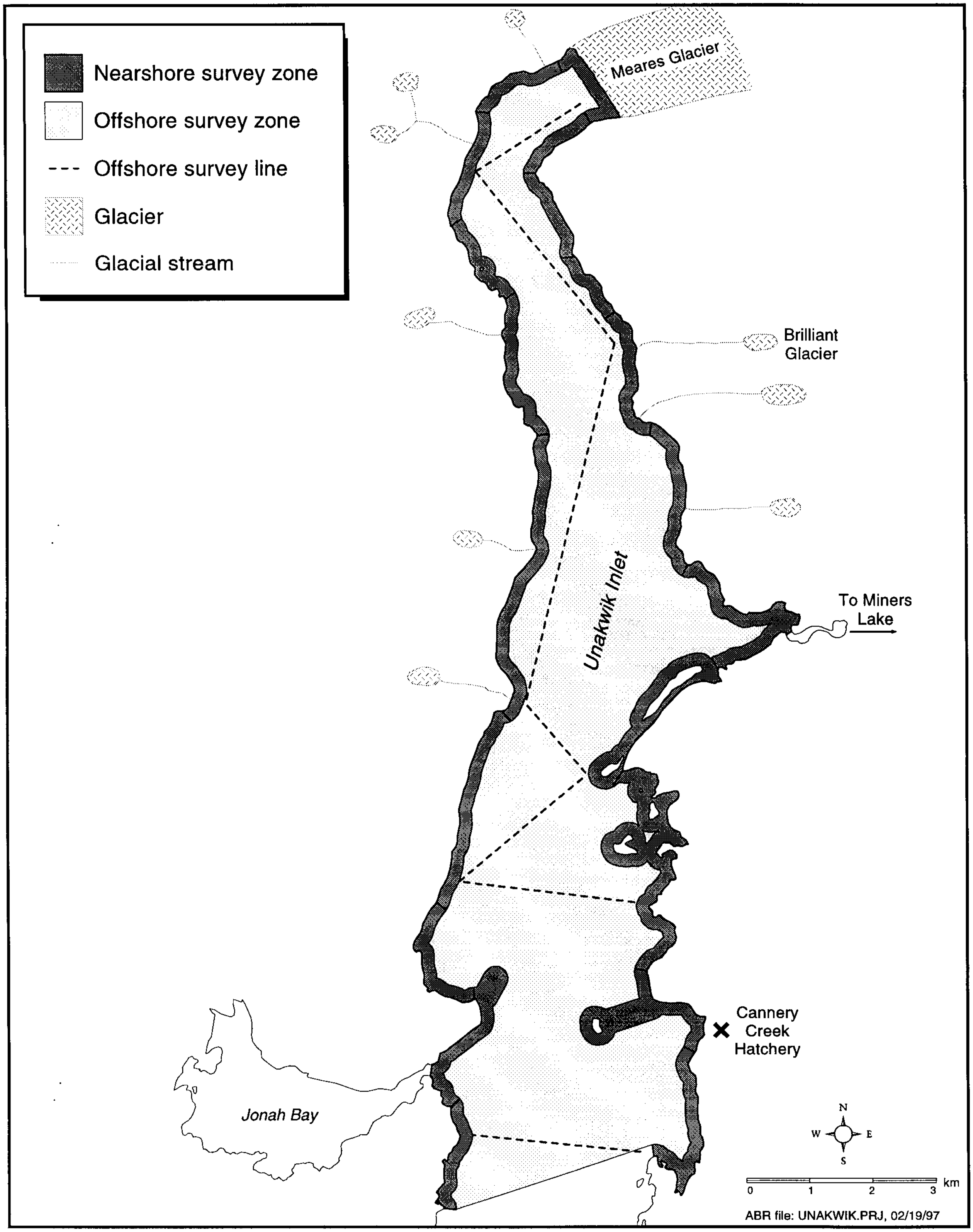

Fig. 2. Locations of nearshore and offshore survey segments and the extent of the offshore zone that was used in the estimation of population size of Kittlitz's murrelets in Unakwik Inlet, Alaska, in 1996.

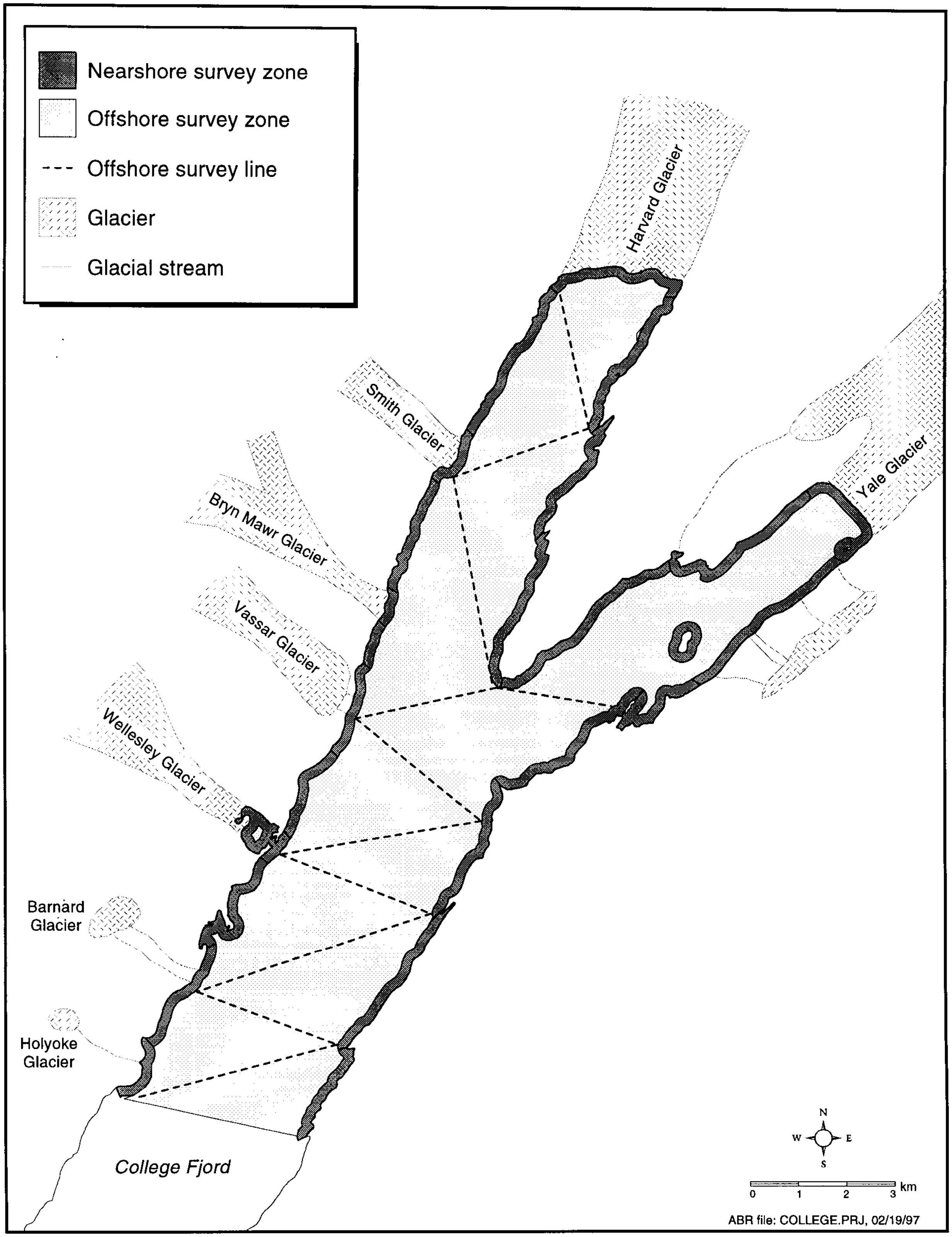

Fig. 3. Locations of nearshore and offshore survey segments and the extent of the offshore zone that was used in the estimation of population size of Kittlitz's murrelets in College Fjord, Alaska, in 1996.

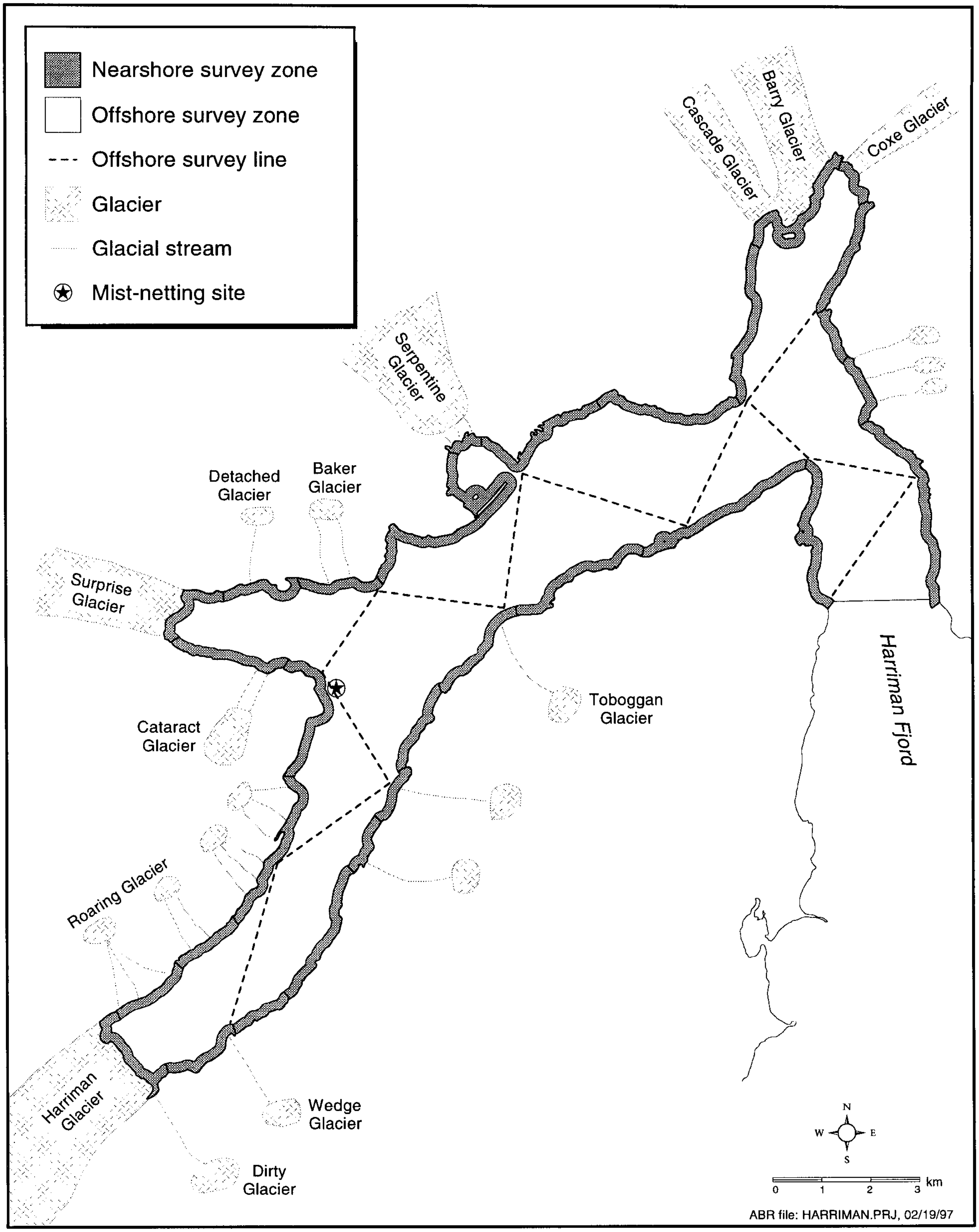

Fig. 4. Locations of nearshore and offshore survey segments and the extent of the offshore zone that was used in the estimation of population size of Kittlitz's murrelets in Harriman Fjord, Alaska, in 1996. The location of the mist-netting site also is marked.

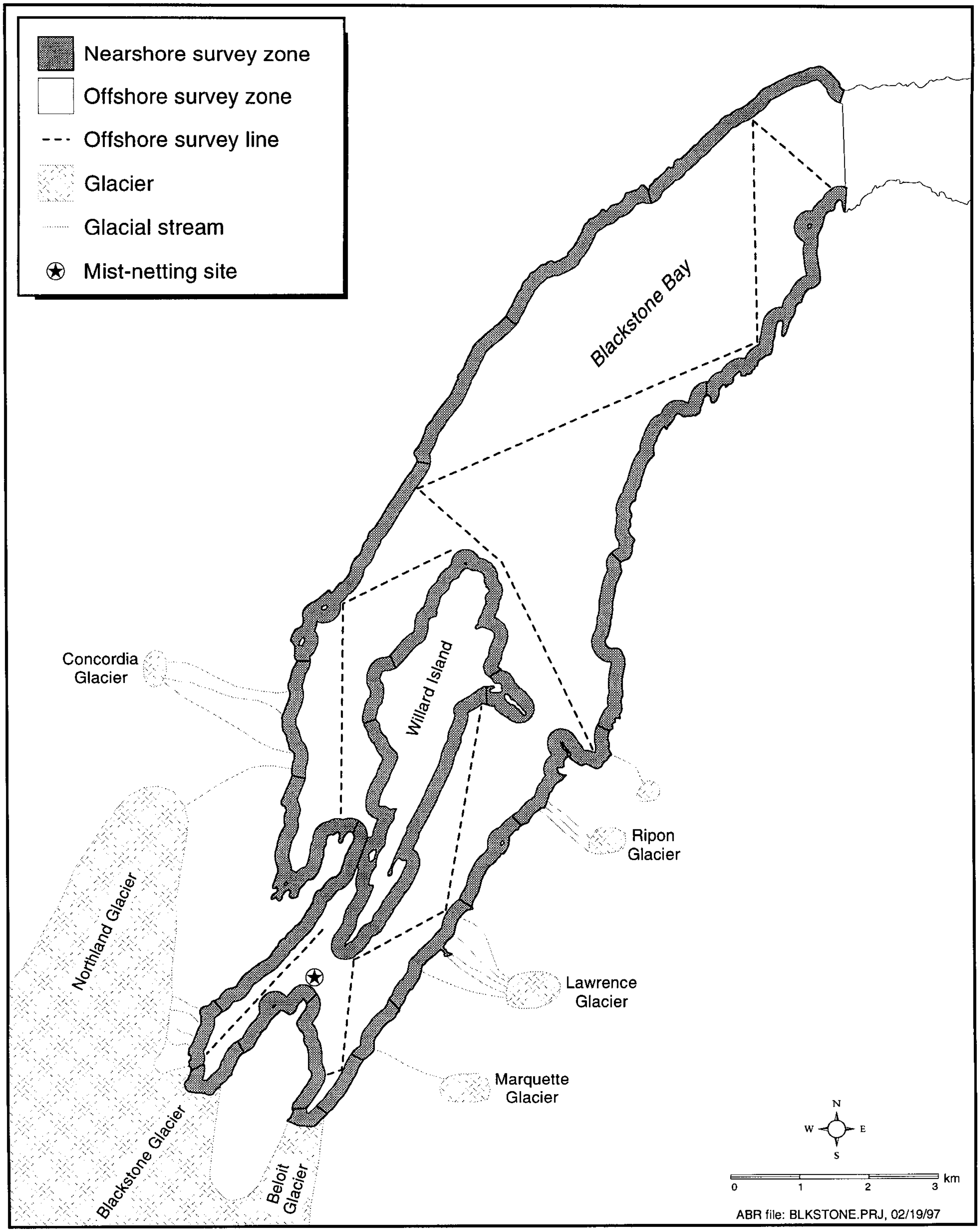

Fig. 5. Locations of nearshore and offshore survey segments and the extent of the offshore zone that was used in the estimation of population size of Kittlitz's murrelets in Blackstone Bay, Alaska. The location of the mist-netting site also is marked.

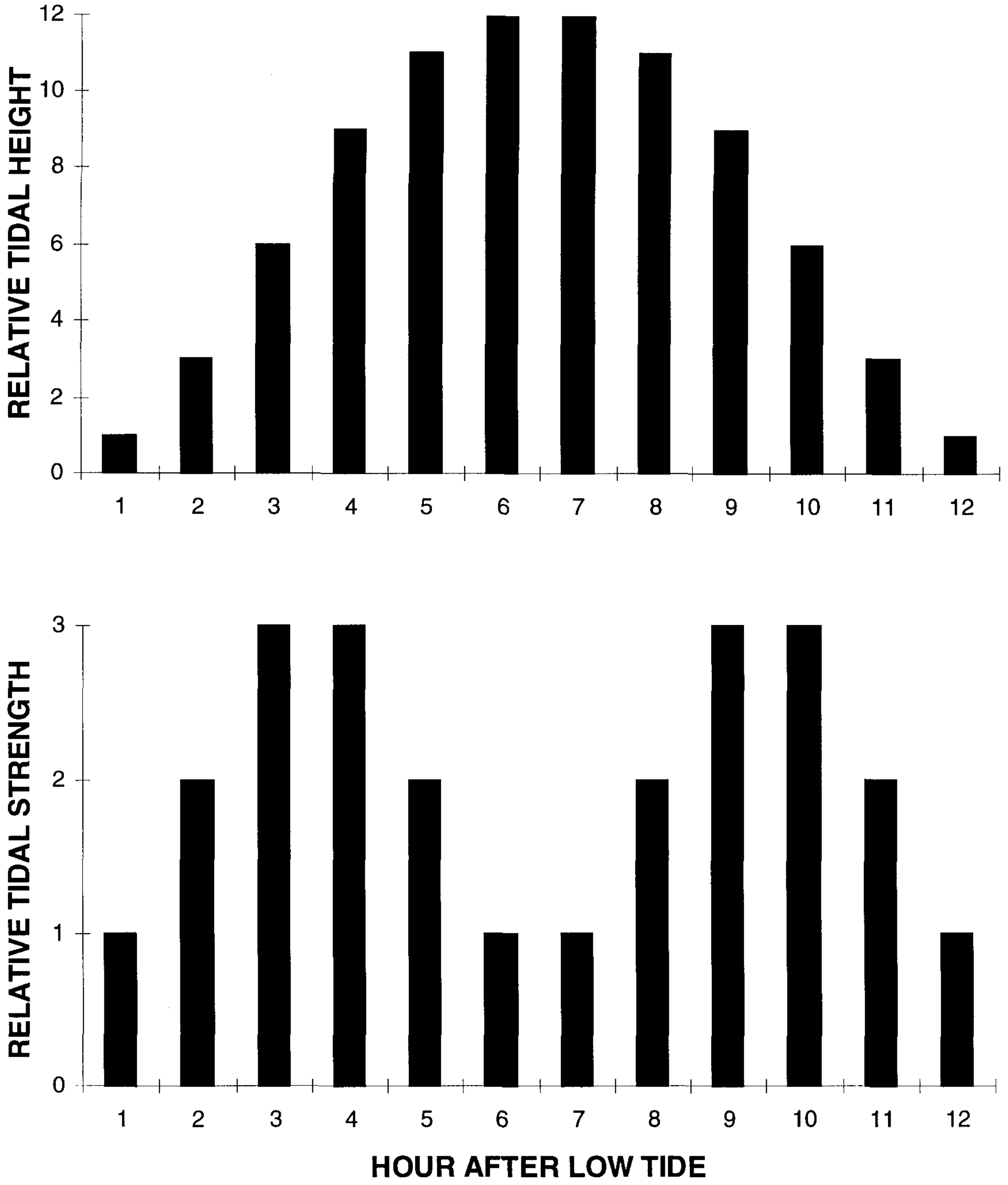

Fig. 6. Relative height of tide (top) and relative strength of tidal current (bottom) during one tidal cycle, by hour after low tide. Tidal strength is indicated by the hourly change in tidal height.

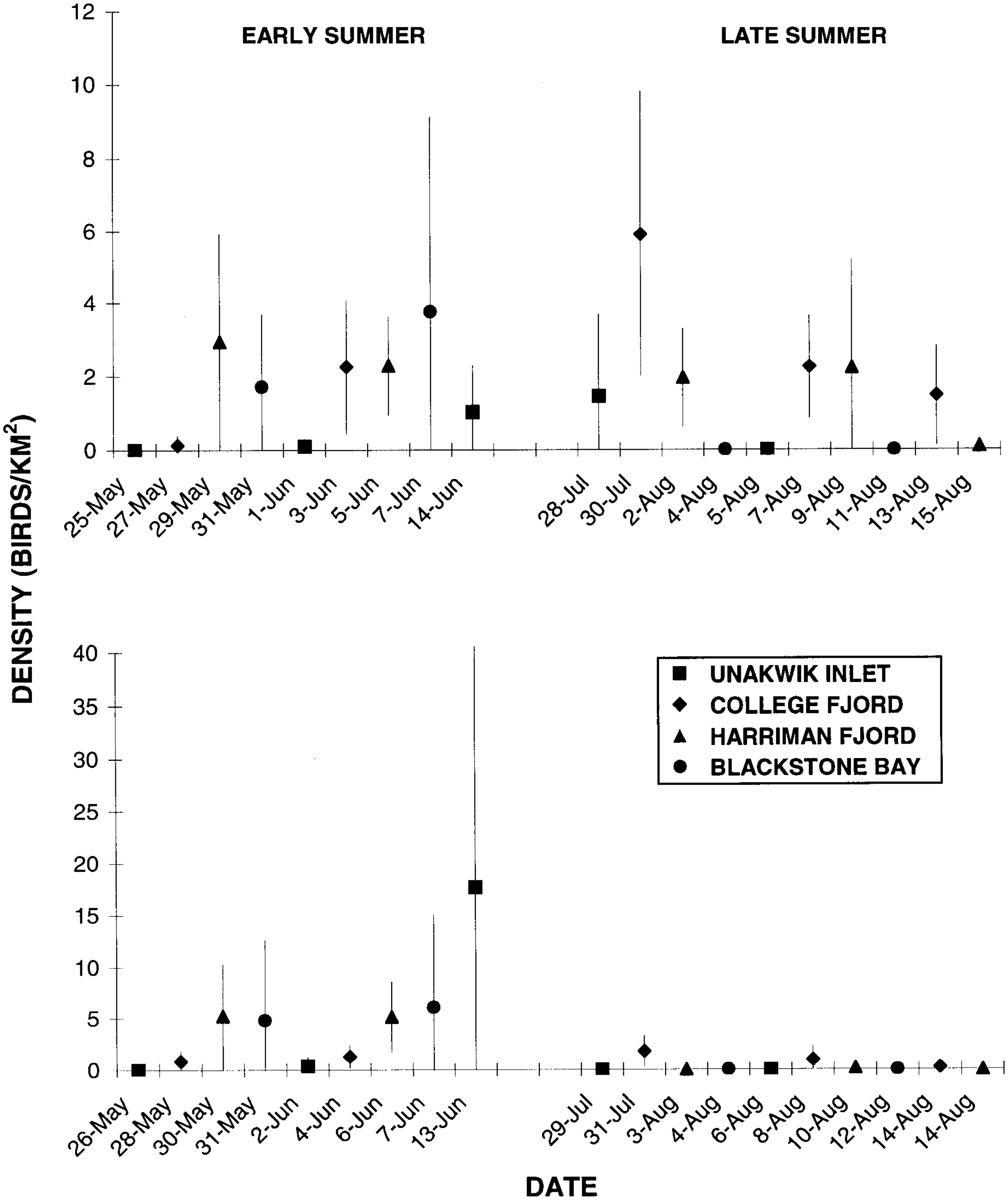

Fig. 7. Densities (birds/km^2) of Kittlitz's murrelets on nearshore (top) and offshore (bottom) surveys in four study bays in Prince William Sound, Alaska, in early and late summer 1996. Vertical bars represent 95% CIs.

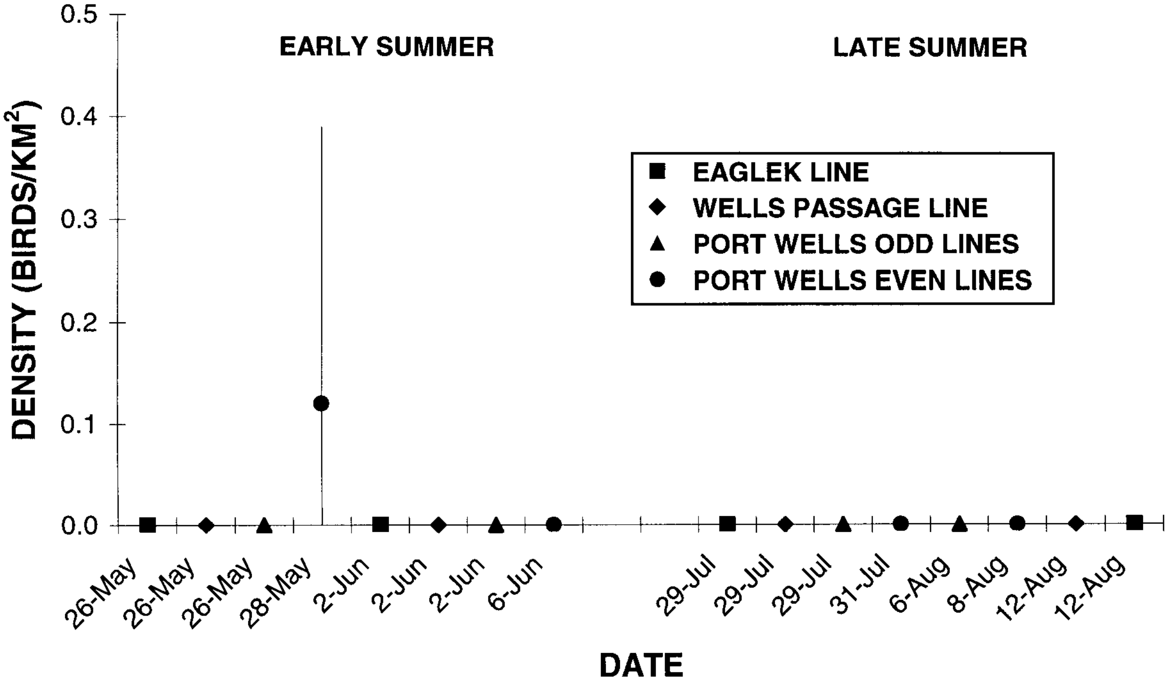

Fig. 8. Densities (birds/km^2) of Kittlitz's murrelets on pelagic surveys in Prince William Sound, Alaska, in early and late summer 1996. Vertical bars represent 95% CIS.

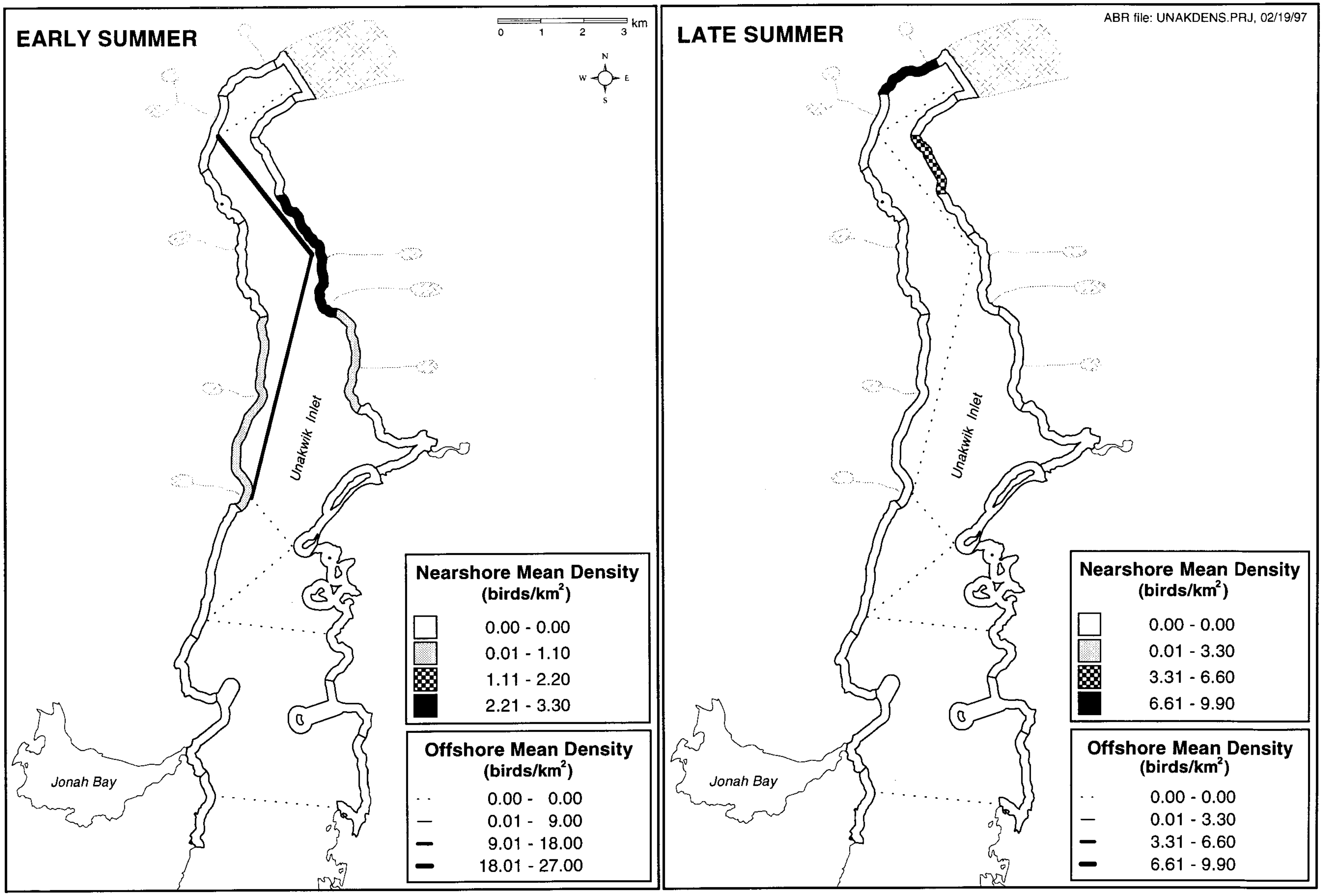

Fig. 9. Abundance and distribution of Kittlitz's murrelets on nearshore and offshore surveys in Unakwik Inlet in early (left) and late (right) summer 1996. Data are expressed as the mean density (birds/km^2) on all visits to each survey segment during a cruise.

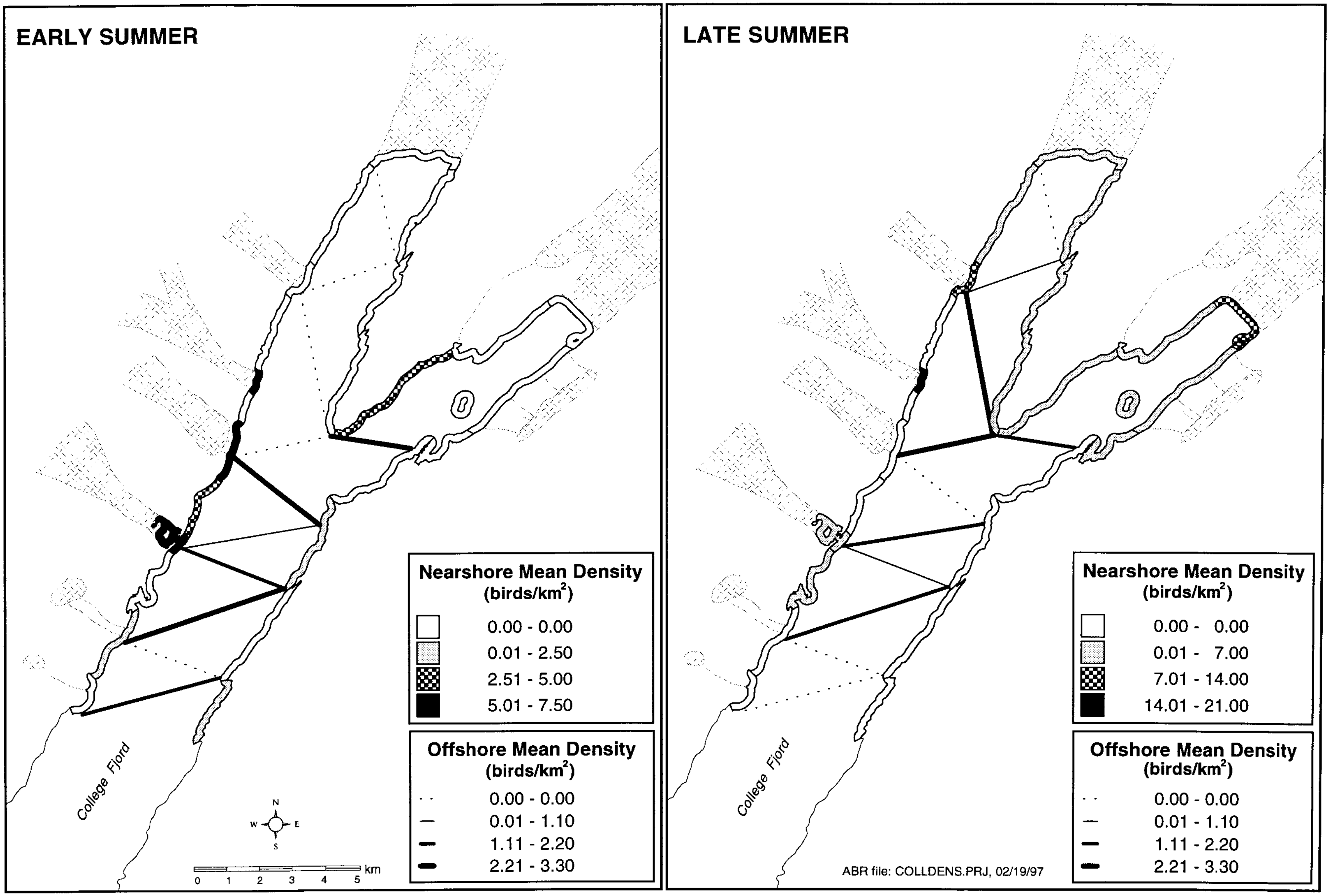

Fig. 10. Abundance and distribution of Kittlitz's murrelets on nearshore and offshore surveys in College Fjord in early (left) and late (right) summer 1996. Data are expressed as the mean density (birds/km^2) on all visits to each survey segment during a cruise.

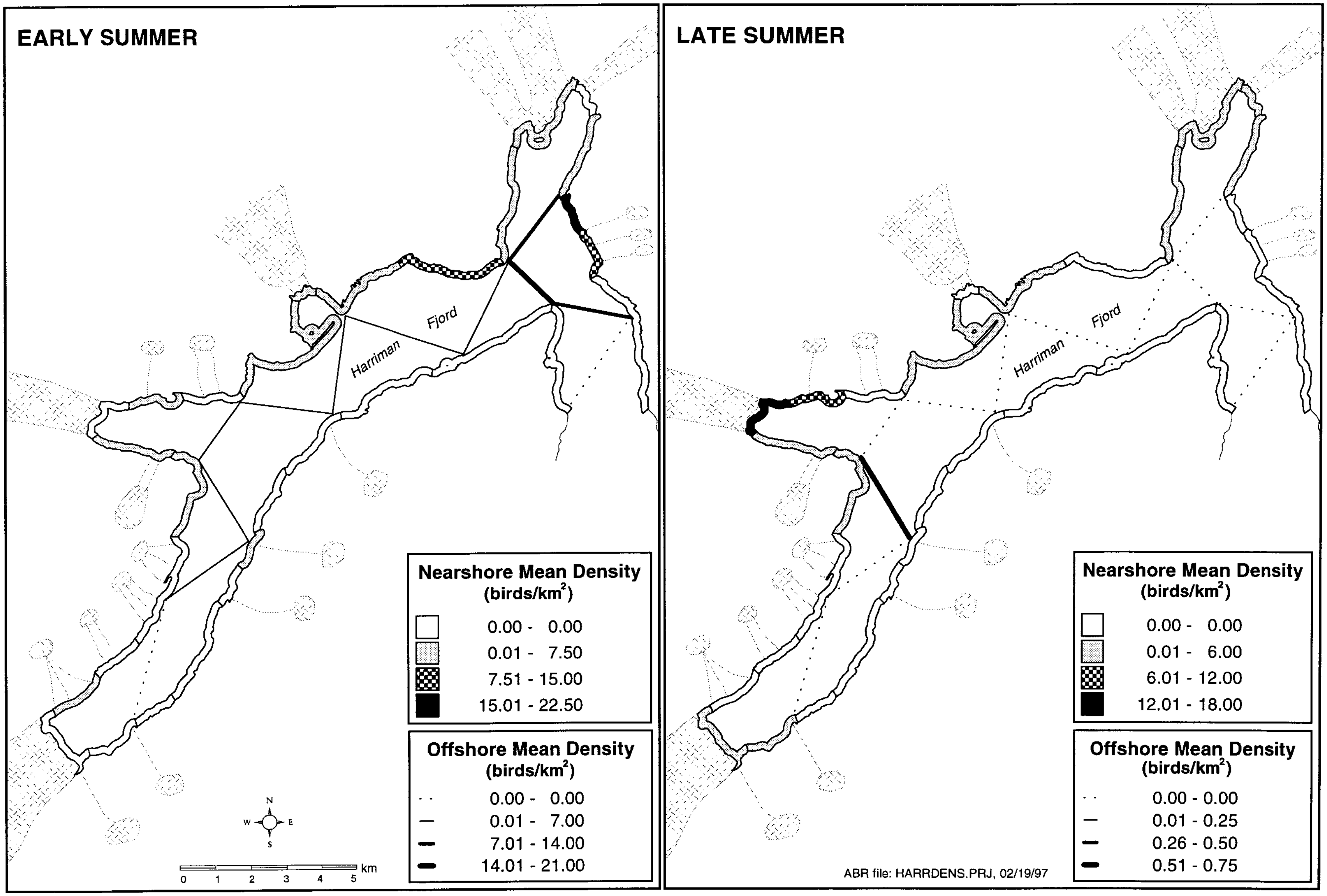

Fig. 11. Abundance and distribution of Kittlitz's murrelets on nearshore and offshore surveys in Harriman Fjord in early (left) and late (right) summer 1996. Data are expressed as the mean density (birds/km^2) on all visits to each survey segment during a cruise.

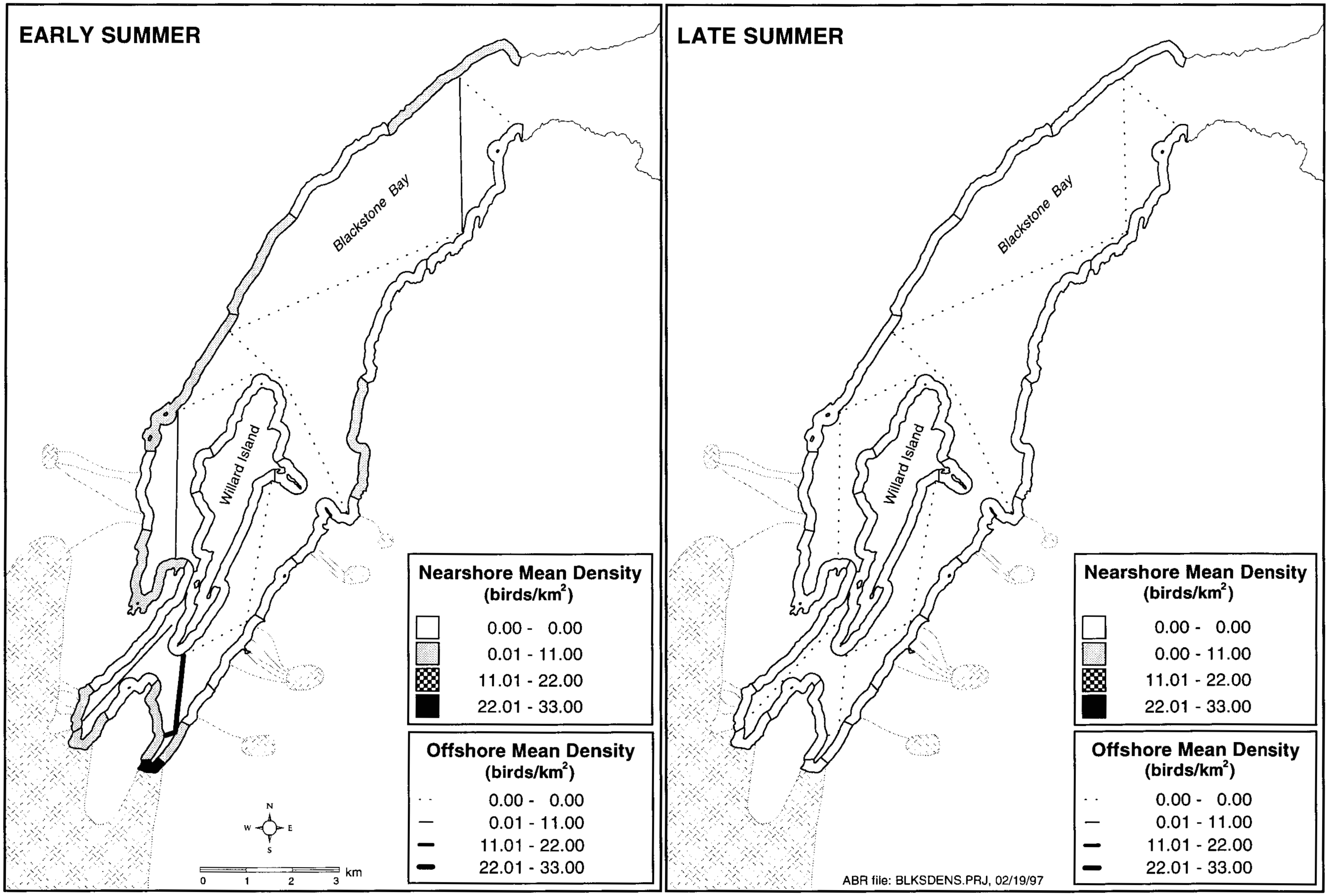

Fig. 12. Abundance and distribution of Kittlitz's murrelets on nearshore and offshore surveys in Blackstone Bay in early (left) and late (right) summer 1996. Data are expressed as the mean density (birds/km^2) on all visits to each survey segment during a cruise.

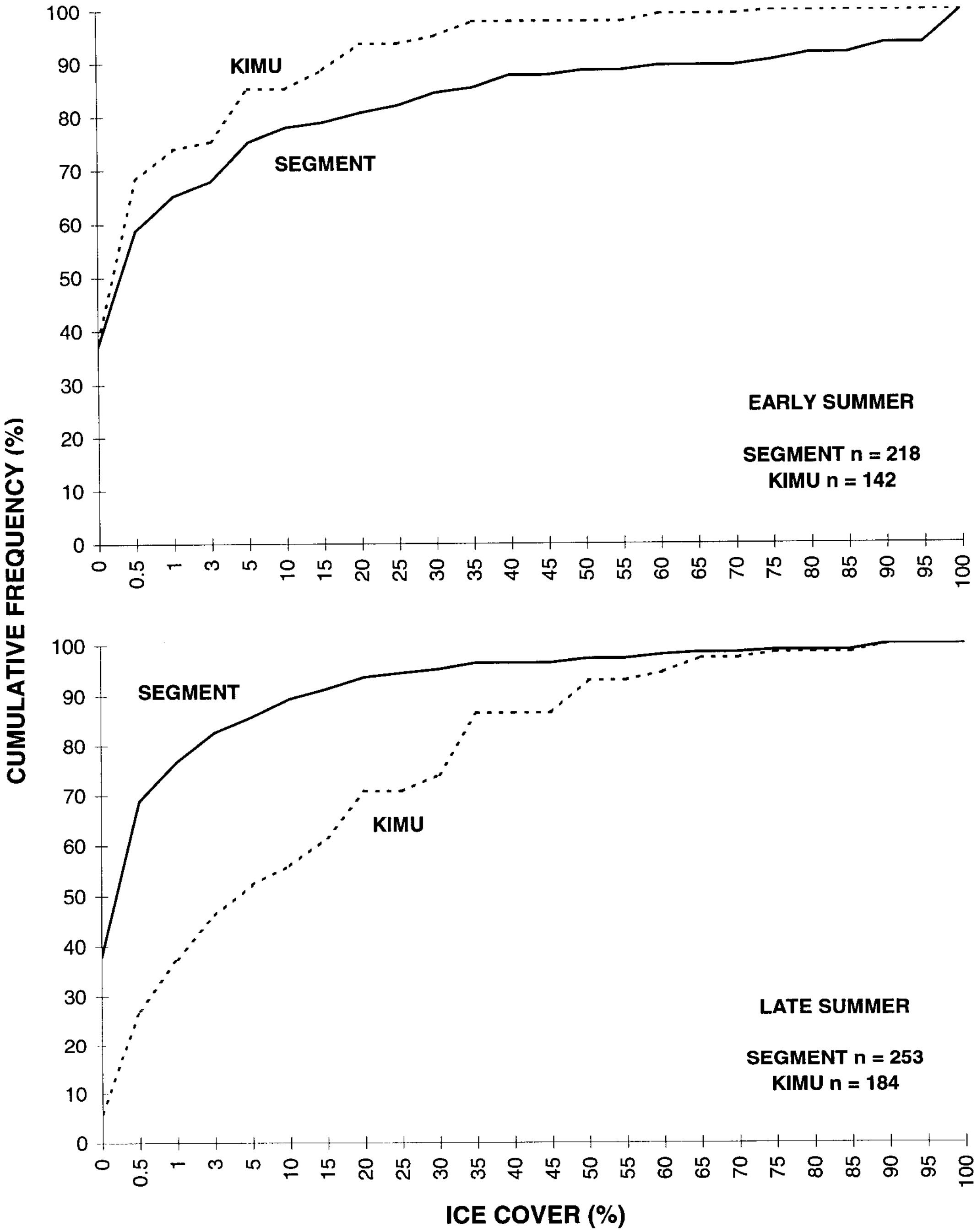

Fig. 13. Large-scale availability (SEGMENT) and use of ice by Kittlitz's murrelets (KIMU) on nearshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1996. Scale is expanded at lower end of x-axis.

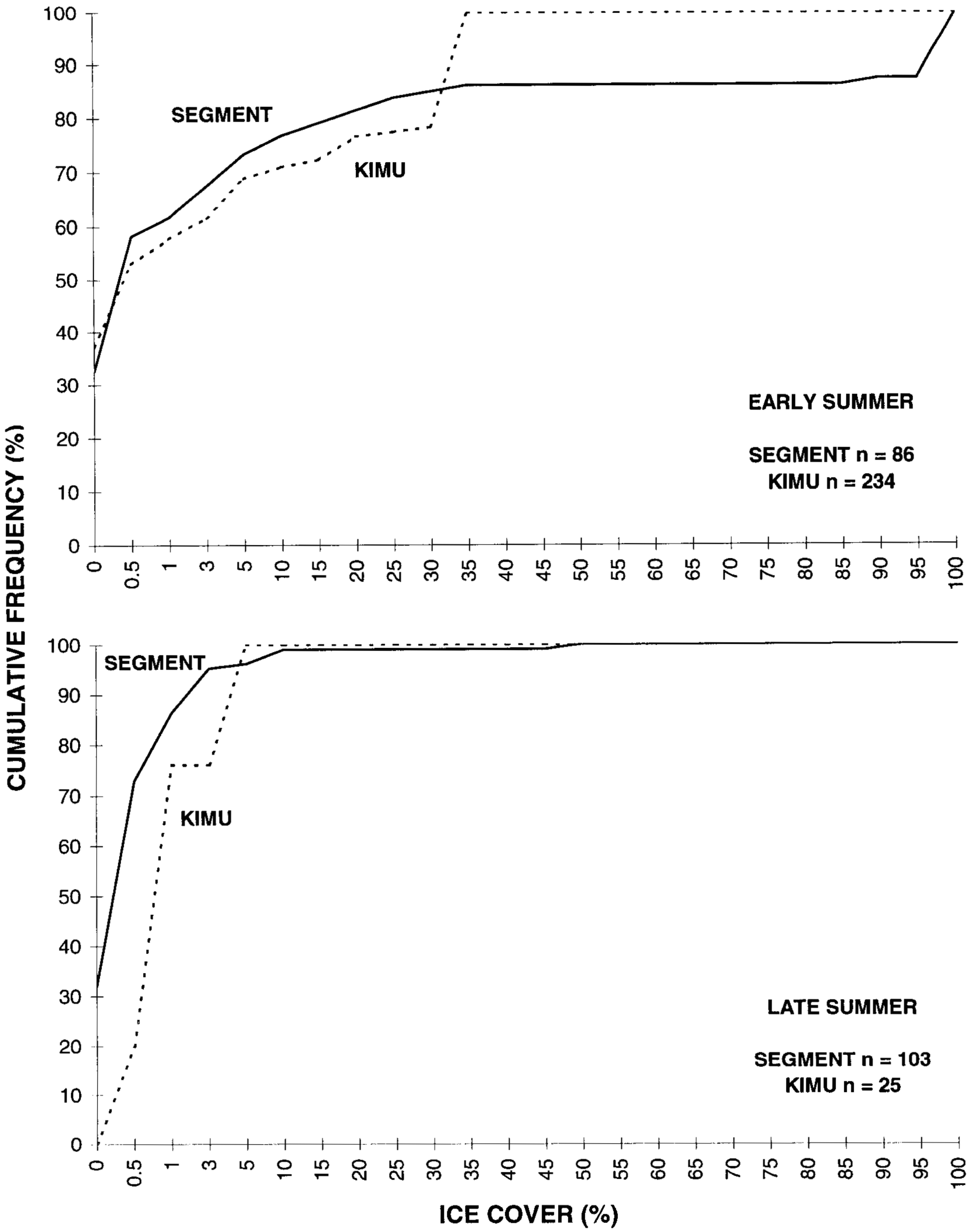

Fig. 14. Large-scale availability (SEGMENT) and use of ice by Kittlitz's murrelets (KIMU) on offshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1996. Scale is expanded at lower end of x-axis.

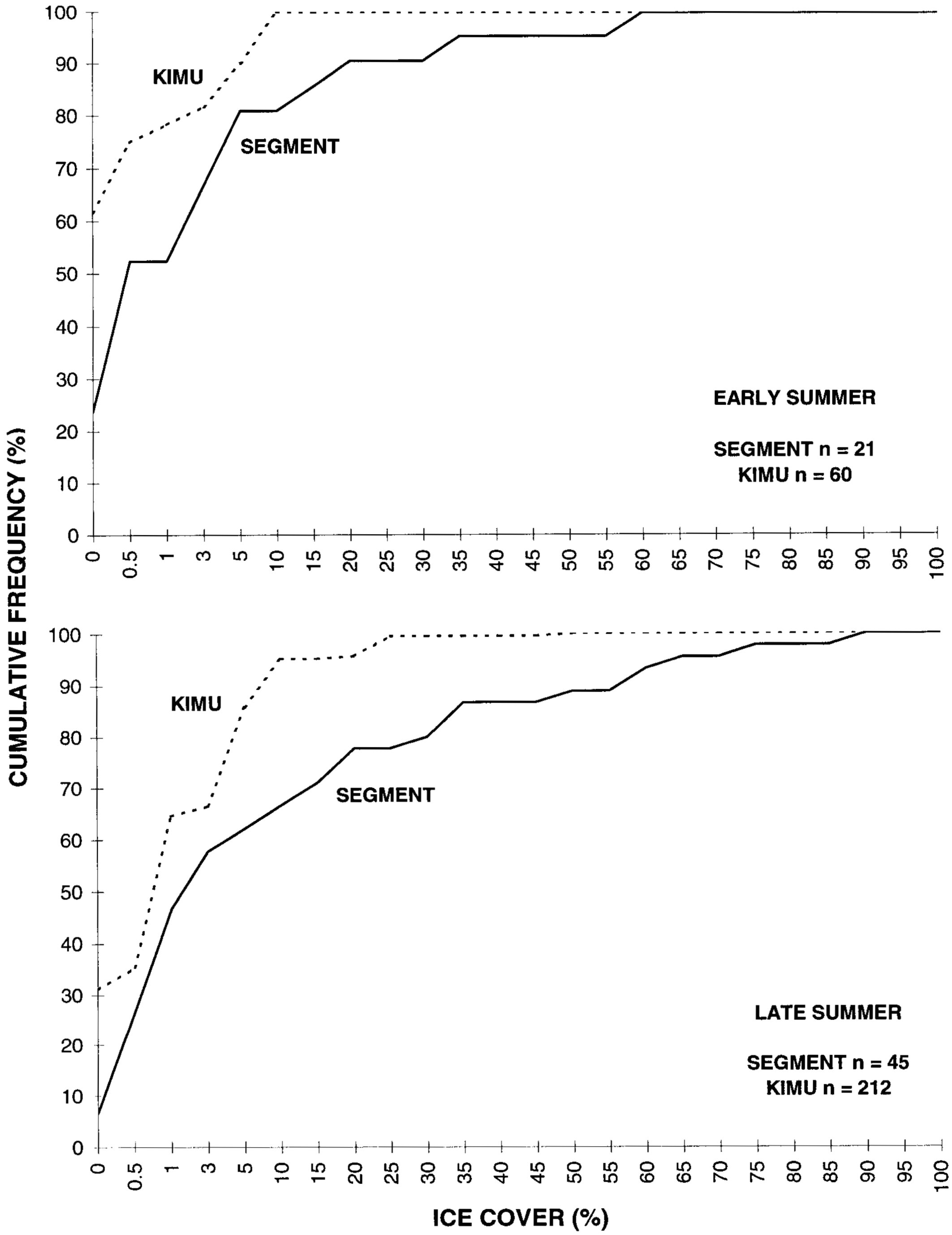

Fig. 15. Large-scale availability (SEGMENT) and fine-scale use of ice by Kittlitz's murrelets (KIMU) on nearshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1996. Scale is expanded at lower end of x-axis.

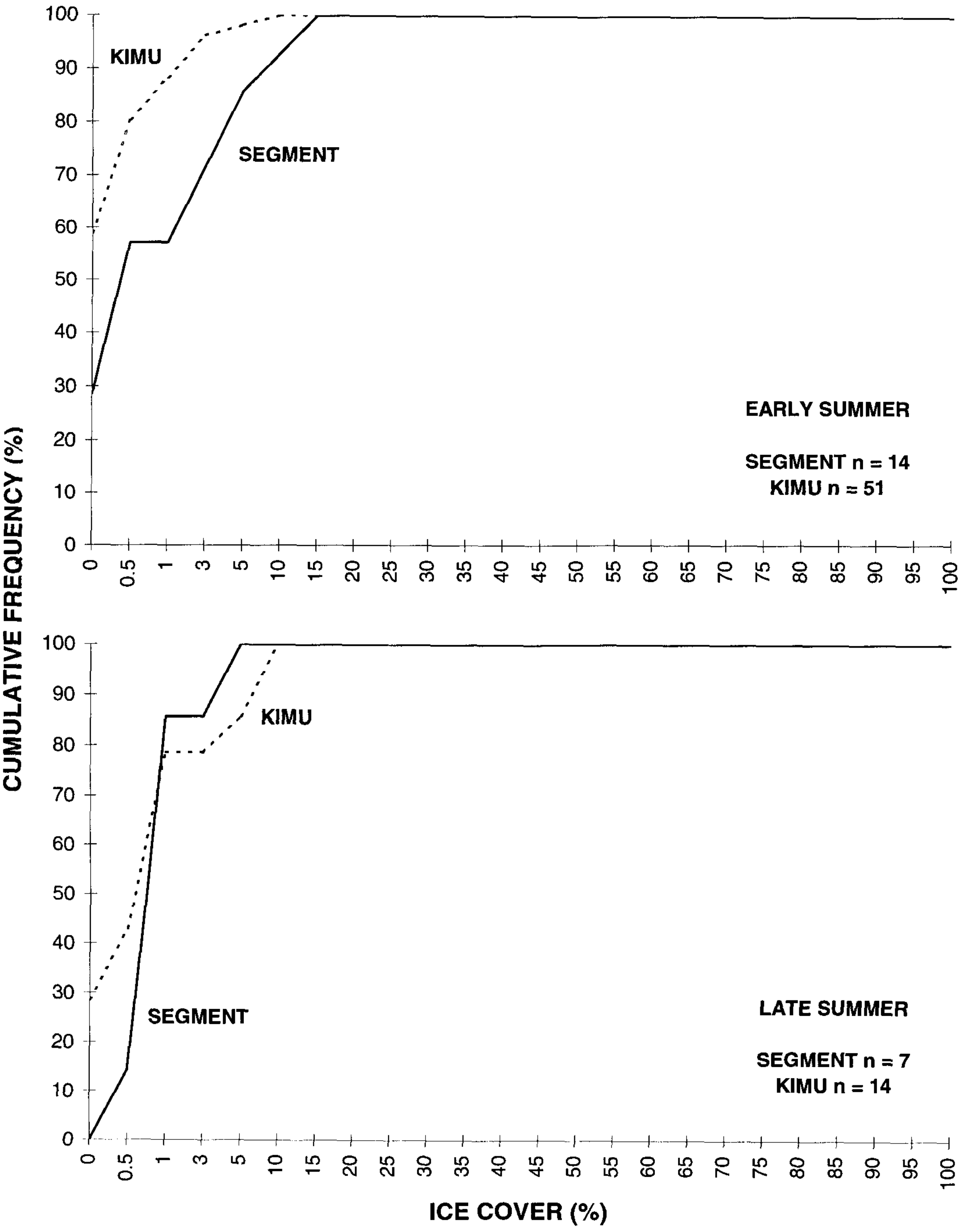

Fig. 16. Large-scale availability (SEGMENT) and fine-scale use of ice by Kittlitz's murrelets (KIMU) on offshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1996. Scale is expanded at lower end of x-axis.

Table 25. Number (percentage) of Kittlitz's murrelets recorded feeding in nearshore waters of four bays in Prince William Sound, Alaska, in 1996, by cruise and standardized habitat type. No analyses were done for offshore surveys, because all sampling there occurred in only one habitat type.

	Habitat type								
	Glacial affected			Glacial stream affected			Glacial unaffected		
Cruise	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total
Early summer	9	6	15	4	25	29	21	77	98
(Percent)	(60.0)	(40.0)	(–)	(13.8)	(86.2)	(–)	(21.4)	(78.6)	(–)
Late summer	45	24	69	17	23	40	37	38	75
(Percent)	(65.2)	(34.8)	(–)	(42.5)	(57.5)	(–)	(49.3)	(50.7)	(–)

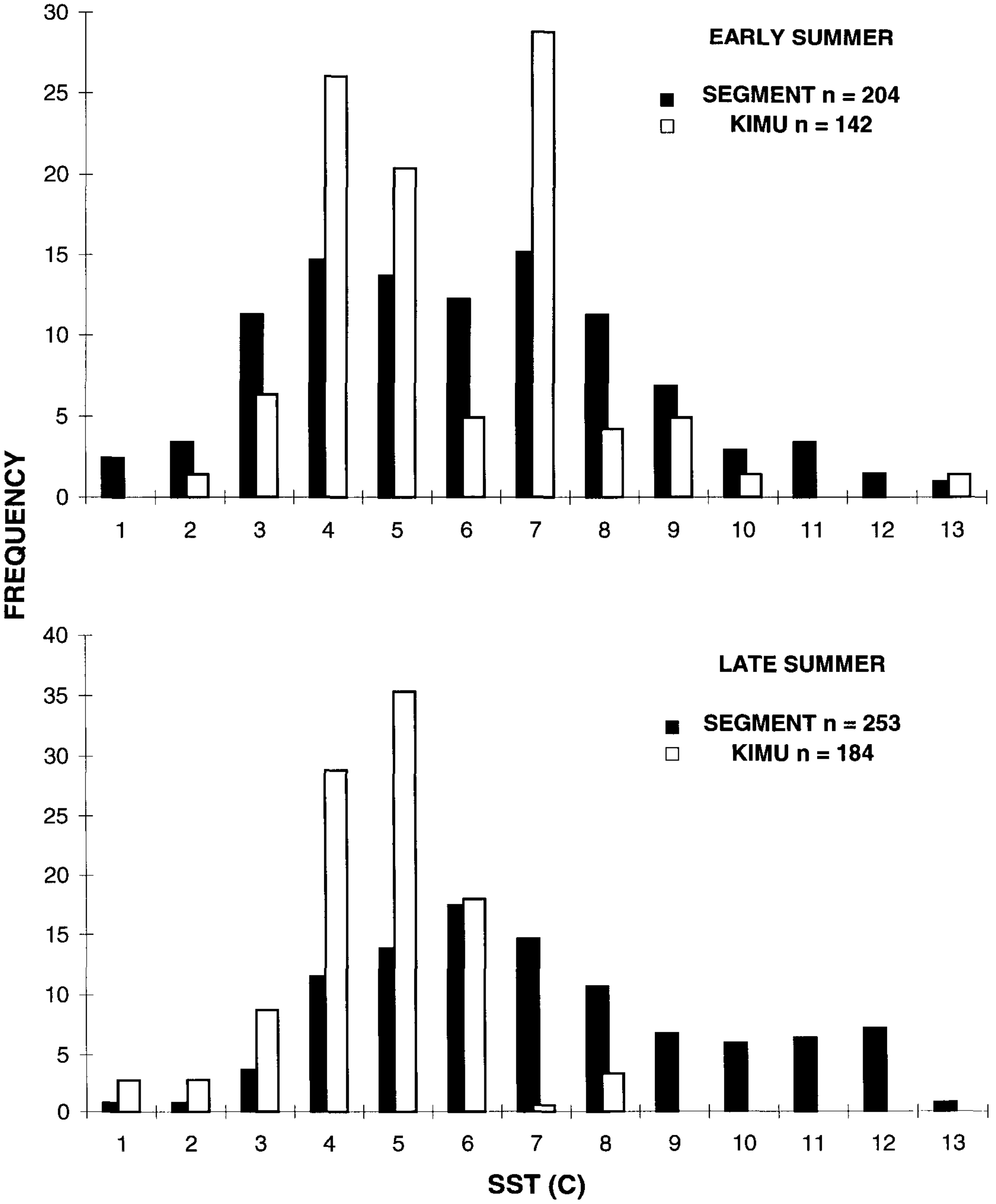

Fig. 17. Large-scale availability (SEGMENT) and use of sea-surface temperatures (SST) by Kittlitz's murrelets (KIMU) on nearshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1996.

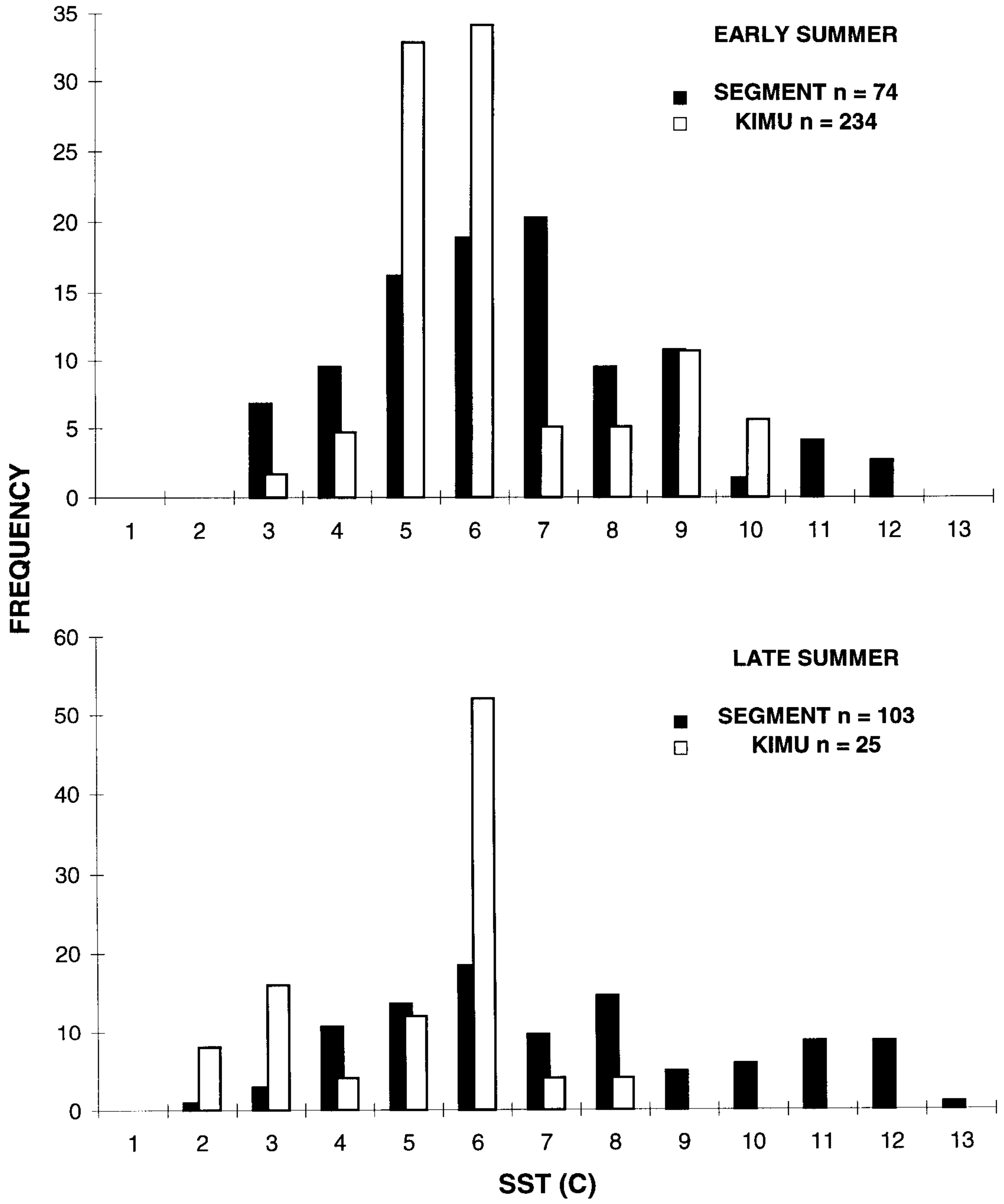

Fig. 18. Large-scale availability (SEGMENT) and use of sea-surface temperatures (SST) by Kittlitz's murrelets (KIMU) on offshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1996.

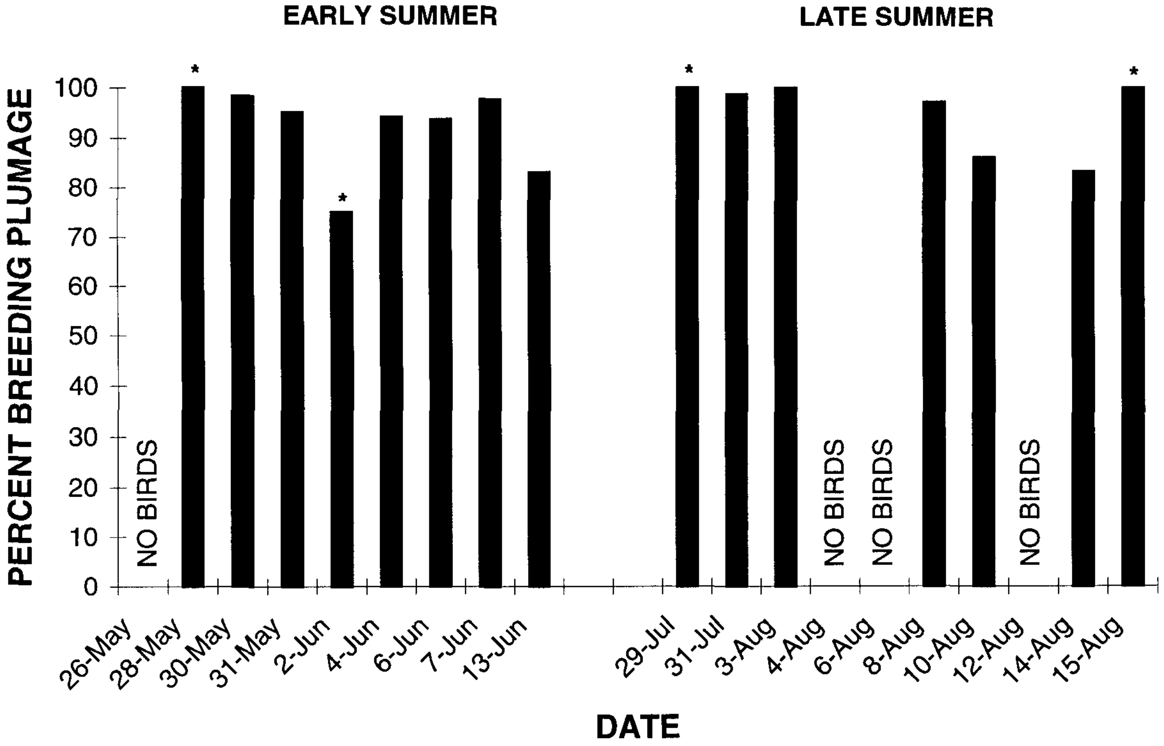

Fig. 19. Changes in the percentage of after-hatching-year (AHY) Kittlitz's murrelets that were in breeding plumage in four bays in Prince William Sound, Alaska, in early and late summer 1996. Data are for nearshore and offshore surveys combined; asterisks represent samples of <10 birds.

Table 1. Sampling activities conducted in Prince William Sound, Alaska, in early summer (25 May–14 June) 1996.

	Activity				
Date	Nearshore surveys	Offshore surveys	Pelagic survey lines	Mist-netting for trophic studies	Other
25 May	Unakwik Inlet				
26 May		Unakwik Inlet	26, 27, 31, 33, 35, 37, 39		
27 May	College Fjord				
28 May		College Fjord	40, 38, 36, 34, 32		
29 May	Harriman Fjord				
30 May		Harriman Fjord			
31 May	Blackstone Bay	Blackstone Bay			
1 June	Unakwik Inlet				
2 June		Unakwik Inlet	26, 27, 31, 33, 35, 37, 39		
3 June	College Fjord				
4 June		College Fjord			
5 June	Harriman Fjord				
6 June		Harriman Fjord	40, 38, 36, 34, 32		
7 June	Blackstone Bay	Blackstone Bay[a]			
8 June					Activity surveys (Blackstone Bay)
9 June		Blackstone Bay[a]		Blackstone Bay	
10 June				Blackstone Bay[b]	
11 June				Harriman Fjord	
12 June				Harriman Fjord	
13 June		Unakwik Inlet			
14 June	Unakwik Inlet				

[a] Partial survey conducted each day.

[b] Sampling canceled because of intrusion of large amount of ice into mist net system.

Table 2. Sampling activities conducted in Prince William Sound, Alaska, in late summer (28 July–15 August) 1996.

	Activity		
Date	Nearshore surveys	Offshore surveys	Pelagic survey lines
28 July	Unakwik Inlet		
29 July		Unakwik Inlet	26, 27, 31, 33, 35, 37, 39
30 July	College Fjord		
31 July		College Fjord	40, 38, 36, 34, 32
1 August	weather day (no work)	weather day (no work)	weather day (no work)
2 August	Harriman Fjord		
3 August		Harriman Fjord	
4 August	Blackstone Bay	Blackstone Bay	
5 August	Unakwik Inlet		
6 August		Unakwik Inlet	31, 33, 35, 37, 39
7 August	College Fjord		
8 August		College Fjord	40, 38, 36, 34, 32
9 August	Harriman Fjord		
10 August		Harriman Fjord	
11 August	Blackstone Bay		
12 August		Blackstone Bay	27, 26
13 August	College Fjord		
14 August		College Fjord, Harriman Fjord	
15 August	Harriman Fjord		

Table 3. Areas sampled, total areas of sampling zones, and total areas by habitat types in the four study bays in Prince William Sound, Alaska, in 1996.

	Total area (km^2)		Area (km^2) by habitat type			
Survey type/bay	Sampled	In zone	Glacial affected	Glacial stream affected	Marine sill affected	Glacial unaffected
NEARSHORE						
Unakwik Inlet	11.33	11.33	0.34	3.51	1.55	5.93
College Fjord	13.69	13.69	2.16	2.77	0	8.76
Harriman Fjord	15.57	15.57	1.92	4.42	0	9.23
Blackstone Bay	12.42	12.42	0.37	1.70	0.51	9.84
Total	53.01	53.01	4.79	12.40	2.06	33.76
OFFSHORE						
Unakwik Inlet	4.19	37.92	0	0	0	4.19
College Fjord	7.78	64.28	0	0	0	7.78
Harriman Fjord	6.40	56.54	0	0	0	6.40
Blackstone Bay	5.67	33.75	0	0	0	5.67
Total	24.04	192.49	0	0	0	24.04

Table 4. Environmental characteristics recorded during nearshore, offshore, and pelagic surveys in Prince William Sound, Alaska, during summer 1996 cruises. Values were calculated from environmental measurements taken at the beginning of each sampling segment (nearshore and offshore surveys) and transect (pelagic surveys).

	Characteristic															
Cruise/	Observation conditions		Sea height		Swell height		Wind speed		Frequency of precipitation		Air temperature		Ice cover (%)		Sea-surface temperature	
survey type	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	No.	%	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
EARLY SUMMER																
Nearshore[a]	4.6	0.7	0.3	0.5	0.1	0.4	0.3	0.5	26	12.7	7.8	2.4	14.5	29.5	6.0	2.6
Offshore[b]	4.3	0.6	0.6	0.4	0.2	0.6	0.4	0.6	7	9.5	7.9	2.0	16.0	33.0	6.6	2.2
Pelagic[c]	4.0	0.7	0.6	0.6	0.9	0.7	0.9	0.7	0	0	10.9	1.5	0	0	11.0	1.7
LATE SUMMER																
Nearshore[d]	4.8	0.5	0.4	0.6	0.0	0.2	0.4	0.6	25	9.9	9.1	2.9	5.0	14.3	7.1	2.6
Offshore[e]	4.4	0.7	0.6	0.5	0.1	0.3	0.4	0.6	22	21.4	8.2	2.4	1.4	5.2	7.3	2.7
Pelagic[f]	3.9	0.6	1.5	0.6	1.2	0.8	1.5	0.5	13	20.3	12.4	1.5	0	0	12.7	1.2

[a] n = 205 for observation conditions and swell height; n = 218 for ice cover; n = 204 for all others.

[b] n = 74 for all.

[c] n = 64 for all.

[d] n = 253 for all.

[e] n = 103 for all.

[f] n = 64 for all.

Table 5. Results of 4- (nearshore surveys) and 3- (offshore surveys) factor ANOVAs on ranked densities (birds/km^2) of Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1996. For nearshore surveys, analysis was by cruise, site (bay), visit, and standardized habitat type; for offshore surveys, analysis was by cruise, site, and visit.

Survey type/source	SS	df	F	*P*-value[a]	Observed power[b]	Multiple comparisons[c]
NEARSHORE						
Overall model	28,000,000.0	66	56.072	<0.001***	1.000	
Cruise	12,607.2	1	1.697	0.193	0.255	
Site	207,059.0	3	9.288	<0.001***	0.997	CF = HF > BB = UI
Visit	41,080.5	2	2.764	0.064	0.544	
Habitat type	15,624.8	3	0.701	0.552	0.199	
Cruise × site	185,767.0	3	8.333	<0.001***	0.993	
Cruise × visit	34,085.0	1	4.587	0.033*	0.570	
Cruise × habitat type	43,043.2	3	1.931	0.124	0.498	
Site × visit	42,114.5	4	1.417	0.228	0.441	
Site × habitat type	52,131.4	7	1.002	0.429	0.434	
Visit × habitat type	61,174.4	6	1.372	0.225	0.537	
OFFSHORE						
Overall model	1,706,490.0	19	1,880.737	<0.001***	1.000	
Cruise	18,730.9	1	14.880	<0.001***	0.970	early summer > late summer
Site	23,877.5	3	6.323	<0.001***	0.964	CF > HF = BB = UI
Visit	1,123.1	2	0.446	0.641	0.122	
Cruise × site	24,794.6	3	6.566	<0.001***	0.970	
Cruise × visit	3,430.4	1	2.725	0.101	0.375	
Site × visit	3,610.5	4	0.717	0.581	0.229	

[a] * = significant at $\alpha = 0.05$; ** = significant at $\alpha = 0.01$; *** = significant at $\alpha = 0.001$.

[b] Power to detect a real difference at $\alpha = 0.05$.

[c] UI = Unakwik Inlet; CF = College Fjord; HF = Harriman Fjord; BB = Blackstone Bay.

Table 6. Results of 3-factor ANOVA on ranked densities (birds/km^2) of Kittlitz's murrelets on nearshore and offshore surveys in four bays in Prince William Sound, Alaska, in 1996, by cruise, site (bay), and survey type.

Source	SS	df	F	*P*-value[a]	Observed power[b]	Multiple comparisons[c]
Overall model	74,000,000.0	16	291.083	<0.001***	1.000	
Cruise	336,344.0	1	21.177	<0.001***	0.996	early summer > late summer
Site	574,256.0	3	12.052	<0.001***	1.000	CF = HF > BB = UI
Survey type	16,229.6	1	1.022	0.312	0.172	
Cruise × site	587,571.0	3	12.332	<0.001***	1.000	
Cruise × survey type	197,480.0	1	12.434	<0.001***	0.941	
Site × survey type	4,607.9	3	0.097	0.962	0.067	

[a] * = significant at $\alpha = 0.05$; ** = significant at $\alpha = 0.01$; *** = significant at $\alpha = 0.001$.

[b] Power to detect a real difference at $\alpha = 0.05$.

[c] UI = Unakwik Inlet; CF = College Fjord; HF = Harriman Fjord; BB = Blackstone Bay.

Table 7. Numbers of Kittlitz's murrelets counted during diel activity surveys in Blackstone Bay, Prince William Sound, Alaska, on 8 June 1996, by time of survey and survey type.

	Survey type		
Time of survey	Nearshore	Offshore	Total
0600–0800	12	18	30
0900–1100	12	18	30
1200–1400	13	7[a]	20[a]
1500–1700	3[a]	9[a]	12[a]
1900–2100	0	11	11

[a] Disturbance caused by tour and/or private boats probably decreased counts.

Table 8. Mean ice cover (%) and sea-surface temperature (°C) in four study bays in Prince William Sound, Alaska, in 1996, by habitat variable, bay, cruise, and survey type.

	Early summer						Late summer					
	Nearshore			Offshore			Nearshore			Offshore		
Habitat variable/bay	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n
ICE COVER												
Unakwik Inlet	10.0	23.5	60	18.0	35.2	20	1.3	3.4	40	1.0	2.6	14
College Fjord	33.6	40.9	50	41.4	45.7	22	7.1	16.5	75	3.4	8.7	33
Harriman Fjord	11.1	26.3	60	3.2	8.0	24	6.7	17.7	90	0.5	0.7	36
Blackstone Bay	4.7	13.5	48	0.7	1.5	19	1.8	5.1	48	0.2	0.3	20
SEA-SURFACE TEMPERATURE												
Unakwik Inlet	5.8	2.1	57	5.8	1.4	18	9.3	2.2	40	9.4	1.7	14
College Fjord	4.5	1.9	41	4.8	1.5	13	5.7	1.9	75	5.2	1.5	33
Harriman Fjord	6.1	2.2	58	6.0	1.3	24	5.9	1.7	90	6.6	1.7	36
Blackstone Bay	7.5	3.1	48	9.2	1.7	19	9.5	2.3	48	10.7	1.9	20

Table 9. Estimated population sizes of Kittlitz's Murrelets in four study bays, Prince William Sound, Alaska, in 1996, by cruise, bay, and visit.

			Total nearshore	Offshore density (birds/km^2)		Offshore area	Total offshore		Overall total	
Cruise/bay	Visit	Date[a]	count	$\bar{x}$	95% CI	(km^2)	Population	95% CI	Population	95% CI
EARLY SUMMER										
Unakwik Inlet	1	25 MY	0	0	0	37.92	0	0	0	0
	2	1 JN	1	0.37	0.87	37.92	14	33	15	33
	3	13 JN	9	17.66	27.55	37.92	670	1,045	679	1,045
College Fjord	1	27 MY	2	0.83	0.99	64.28	53	64	55	64
	2	3 JN	24	1.29	1.12	64.28	83	72	107	72
Harriman Fjord	1	2 MY9	35	4.98	5.34	56.54	282	302	317	302
	2	5 JN	35	5.13	3.39	56.54	290	192	325	192
Blackstone Bay	1	31 MY	20	5.05	7.59	33.75	170	256	190	256
	2	7 JN	16	6.06	8.95	33.75	205	302	221	302
LATE SUMMER										
Unakwik Inlet	1	29 MJL	9	0	0	37.92	0	0	9	0
	2	6 AU	0	0	0	37.92	0	0	0	0
College Fjord	1	31 JL	70	1.78	2.24	64.28	114	144	184	144
	2	8 AU	29	0.93	1.36	64.28	60	87	89	87
	3	14 AU	16	0.20	0.29	64.28	13	19	29	19
Harriman Fjord	1	3 AU	30	0	0	56.54	0	0	30	0
	2	10 AU	28	0.16	0.34	56.54	9	19	37	19
	3	15 AU	2	0	0	56.54	0	0	2	0
Blackstone Bay	1	5 AU	0	0	0	33.75	0	0	0	0
	2	12 AU	0	0	0	33.75	0	0	0	0

[a] MY = May; JN = June; JL = July; AU = August.

Table 10. Mean densities (birds/km2) of Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1996, by survey type, cruise, bay, and standardized habitat type.

		Habitat type											
Survey type/ cruise	Bay	Glacial affected			Glacial stream affected			Marine sill affected			Glacial unaffected		
		$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n
NEARSHORE													
Early summer	Unakwik Inlet	0	0	3	0.68	2.09	21	0	0	6	0.28	1.52	30
	College Fjord	2.38	5.06	10	0.99	2.49	10	–	–	0	0.86	2.81	30
	Harriman Fjord	0.31	0.88	8	2.29	4.06	24	–	–	0	3.54	8.16	28
	Blackstone Bay	16.32	30.11	4	0.96	3.04	10	0	0	4	1.88	4.79	30
Late summer	Unakwik Inlet	0	0	2	1.40	5.22	14	0	0	4	0.49	2.18	20
	College Fjord	9.62	10.77	15	1.77	4.15	15	–	–	0	1.57	2.83	45
	Harriman Fjord	5.61	11.20	12	1.21	4.08	36	–	–	0	0.44	1.37	42
	Blackstone Bay	0	0	4	0	0	10	0	0	4	0	0	30
OFFSHORE													
Early summer	Unakwik Inlet	–	–	0	–	–	0	–	–	0	6.01	18.88	21
	College Fjord	–	–	0	–	–	0	–	–	0	1.06	1.58	22
	Harriman Fjord	–	–	0	–	–	0	–	–	0	5.06	6.96	24
	Blackstone Bay	–	–	0	–	–	0	–	–	0	5.58	11.22	19
Late summer	Unakwik Inlet	–	–	0	–	–	0	–	–	0	0	0	14
	College Fjord	–	–	0	–	–	0	–	–	0	0.97	1.84	33
	Harriman Fjord	–	–	0	–	–	0	–	–	0	0.05	0.32	36
	Blackstone Bay	–	–	0	–	–	0	–	–	0	0	0	20

Table 11. Results of 1-factor ANOVAs on large-scale use of ice by Kittlitz's murrelets with respect to large-scale availability in four bays in Prince William Sound, Alaska, in 1996, by cruise and survey type.

Cruise/survey type/source	SS	df	F	*P*-value[a]	Observed power[b]	Results of multiple comparisons
EARLY SUMMER/NEARSHORE SURVEYS						
Model	25,559.2	1	2.547	0.111	0.356	
LATE SUMMER/NEARSHORE SURVEYS						
Model	1,526,989.0	1	128.247	<0.001***	1.000	KIMU ice use > ice availability
EARLY SUMMER/OFFSHORE SURVEYS						
Model	42,638.1	1	5.376	0.021*	0.637	KIMU ice use > ice availability
LATE SUMMER/OFFSHORE SURVEYS						
Model	25,876.5	1	24.095	<0.001***	0.998	KIMU ice use > ice availability
NEARSHORE SURVEYS						
Model	1,830,187.0	1	37.887	<0.001***	1.000	KIMU ice use > ice availability
OFFSHORE SURVEYS						
Model	453,524.0	1	30.726	<0.001***	1.000	KIMU ice use > ice availability

[a] * = significant at $\alpha = 0.05$; ** = significant at $\alpha = 0.01$; *** = significant at $\alpha = 0.001$.

[b] Power to detect a real difference at $\alpha = 0.05$.

Table 12. Results of 1-factor ANOVAs on large-scale availability of ice and use of ice by Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1996, by cruise and survey type.

Availability or use/ survey type/source	SS	df	F	*P*-value[a]	Observed power[b]	Results of multiple comparisons[c]
ICE AVAILABILITY/NEARSHORE SURVEYS						
Model	74,872.2	1	4.388	0.037*	0.552	ES ice availability > LS ice availability
ICE AVAILABILITY/OFFSHORE SURVEYS						
Model	10,276.5	1	3.769	0.054	0.489	
ICE USE/NEARSHORE SURVEYS						
Model	591,280.0	1	86.337	<0.001***	1.000	ES ice use < LS ice use
ICE USE/OFFSHORE SURVEYS						
Model	1,482.7	1	0.283	0.595	0.083	

[a] * = significant at $\alpha = 0.05$; ** = significant at $\alpha = 0.01$; *** = significant at $\alpha = 0.001$.

[b] Power to detect a real difference at $\alpha = 0.05$.

[c] ES = early summer; LS = late summer.

Table 13. Results of 1-factor ANOVAs on fine-scale use of ice by Kittlitz's murrelets with respect to large-scale availability in four bays in Prince William Sound, Alaska, in 1996, by cruise, survey type, and use.

Cruise/survey type/use/source	SS	df	F	*P*-value[a]	Observed power[b]	Results of multiple comparisons[c]
EARLY SUMMER/NEARSHORE SURVEYS						
Model	3,922.0	1	9.142	0.003**	0.848	KIMU ice use < ice availability
LATE SUMMER/NEARSHORE SURVEYS						
Model	56,366.6	1	11.118	0.001***	0.913	KIMU ice use < ice availability
EARLY SUMMER/OFFSHORE SURVEYS						
Model	1,771.6	1	6.366	0.014*	0.700	KIMU ice use < ice availability
LATE SUMMER/OFFSHORE SURVEYS						
Model	21.4	1	0.619	0.441	0.116	
NEARSHORE SURVEYS						
Model	130,231.0	1	14.958	<0.001***	0.971	KIMU ice use < ice availability
OFFSHORE SURVEYS						
Model	4,695.6	1	9.175	0.003**	0.850	KIMU ice use < ice availability
ICE USE/NEARSHORE SURVEYS						
Model	96,606.0	1	17.897	<0.001***	0.988	LS ice use > ES ice use
ICE USE/OFFSHORE SURVEYS						
Model	1,771.6	1	6.346	0.014*	0.699	LS ice use > ES ice use

[a] * = significant at $\alpha = 0.05$; ** = significant at $\alpha = 0.01$; *** = significant at $\alpha = 0.001$.

[b] Power to detect a real difference at $\alpha = 0.05$.

[c] ES = early summer; LS = late summer.

Table 14. Mean sea-surface temperature (°C) on survey segments and use of sea-surface temperatures by Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1996, by cruise and survey type.

	Sea-surface temperature					
Cruise/	Segments			Kittlitz's murrelets		
survey type	$\bar{x}$	SD	n	$\bar{x}$	SD	n
EARLY SUMMER						
Nearshore	6.0	2.6	204	5.7	2.0	142
Offshore	6.6	2.2	74	6.3	2.0	234
LATE SUMMER						
Nearshore	7.1	2.6	253	4.6	1.3	184
Offshore	7.3	2.7	103	5.1	1.6	25

Table 15. Results of 1-factor ANOVAs on large-scale use of sea-surface temperatures (SSTs) by Kittlitz's murrelets with respect to large-scale availability in four bays in Prince William Sound, Alaska, in 1996, by cruise and survey type.

Cruise/survey type/source	SS	df	F	*P*-value[a]	Observed power[b]	Results of multiple comparisons
EARLY SUMMER/NEARSHORE SURVEYS						
Model	9,728.6	1	0.995	0.319	0.169	
LATE SUMMER/NEARSHORE SURVEYS						
Model	1,675,419.0	1	142.868	<0.001***	1.000	KIMU SST use < SST availability
EARLY SUMMER/OFFSHORE SURVEYS						
Model	14,908.0	1	1.996	0.159	0.291	
LATE SUMMER/OFFSHORE SURVEYS						
Model	16,837.5	1	13.775	<0.001***	0.958	KIMU SST use < SST availability
NEARSHORE SURVEYS						
Model	3,459,036.0	1	75.705	<0.001***	1.000	KIMU SST use < SST availability
OFFSHORE SURVEYS						
Model	186,689.0	1	12.586	<0.001***	0.943	KIMU SST use < SST availability

[a] * = significant at $\alpha = 0.05$; ** = significant at $\alpha = 0.01$; *** = significant at $\alpha = 0.001$.

[b] Power to detect a real difference at $\alpha = 0.05$.

Table 16. Results of 1-factor ANOVAs on large-scale availability of sea-surface temperatures (SSTs) and use of SSTs by Kittlitz's murrelets with respect to gross availability in four bays in Prince William Sound, Alaska, in 1996, by availability or use and survey type.

Availability or use/ survey type/source	SS	df	F	*P*-value[a]	Observed power[b]	Results of multiple comparisons[c]
SST AVAILABILITY/NEARSHORE SURVEYS						
Model	275,550.0	1	16.566	<0.001***	0.982	ES SSTs < LS SSTs
SST AVAILABILITY/OFFSHORE SURVEYS						
Model	6,523.1	1	2.548	0.112	0.355	
SST USE/NEARSHORE SURVEYS						
Model	180,168.0	1	22.767	<0.001***	0.997	ES KIMU SST use > LS SST use
SST USE/OFFSHORE SURVEYS						
Model	19,461.3	1	3.799	0.052	0.493	

[a] * = significant at $\alpha = 0.05$; ** = significant at $\alpha = 0.01$; *** = significant at $\alpha = 0.001$.

[b] Power to detect a real difference at $\alpha = 0.05$.

[c] ES = early summer; LS = late summer.

Table 17. Plumage characteristics of after-hatching-year Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in early summer 1996, by survey type, bay, and visit.

			Plumage					Percent
Survey type/bay	Visit	Date	Breeding	Molting	Winter	Unknown	Total	breeding plumage
NEARSHORE								
Unakwik Inlet	1	25 May	0	0	0	0	0	–
College Fjord	1	27 May	2	0	0	0	2	100.0
Harriman Fjord	1	29 May	34	0	1	0	35	97.1
Blackstone Bay	1	31 May	18	1	1	0	20	90.0
Unakwik Inlet	2	1 June	1	0	0	0	1	100.0
College Fjord	2	3 June	22	2	0	0	24	91.7
Harriman Fjord	2	5 June	32	1	0	2	35	91.4
Blackstone Bay	2	7 June	15	1	0	0	16	93.8
Unakwik Inlet	3	14 June	6	3	0	0	9	66.7
Total			130	8	2	2	142	
Percent			91.5	5.6	1.4	1.4		
OFFSHORE								
Unakwik Inlet	1	26 May	0	0	0	0	0	–
College Fjord	1	28 May	6	0	0	0	6	100.0
Harriman Fjord	1	30 May	25	0	0	0	25	100.0
Blackstone Bay	1	31 May	22	0	0	0	22	100.0
Unakwik Inlet	2	2 June	2	1	0	0	3	66.7
College Fjord	2	4 June	11	0	0	0	11	100.0
Harriman Fjord	2	6 June	28	1	0	0	29	96.6
Blackstone Bay	2	7 June	28	0	0	0	28	100.0
Unakwik Inlet	3	13 June	93	16	1	0	110	84.5
Total			215	18	1	0	234	
Percent			91.9	7.7	0.4	0		

Table 18. Plumage characteristics of after-hatching-year Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in late summer 1996, by survey type, bay, and visit.

			Plumage					Percent
Survey type/bay	Visit	Date	Breeding	Molting	Winter	Unknown	Total	breeding plumage
NEARSHORE								
Unakwik Inlet	1	28 July	9	0	0	0	9	100.0
College Fjord	1	30 July	69	0	0	0	69	100.0
Harriman Fjord	1	2 August	30	0	0	0	30	100.0
Blackstone Bay	1	4 August	0	0	0	0	0	–
Unakwik Inlet	2	5 August	0	0	0	0	0	–
College Fjord	2	7 August	28	1	0	0	29	96.6
Harriman Fjord	2	9 August	24	4	0	0	28	85.7
Blackstone Bay	2	11 August	0	0	0	0	0	–
College Fjord	3	13 August	13	3	0	0	16	81.3
Harriman Fjord	3	15 August	2	0	0	0	2	100.0
Total			175	8	0	0	183	
Percent			95.6	4.4	0	0		
OFFSHORE								
Unakwik Inlet	1	29 July	0	0	0	0	0	–
College Fjord	1	31 July	14	1	0	0	15	93.3
Harriman Fjord	1	3 August	0	0	0	0	0	–
Blackstone Bay	1	4 August	0	0	0	0	0	–
Unakwik Inlet	2	6 August	0	0	0	0	0	–
College Fjord	2	8 August	7	0	0	0	7	100.0
Harriman Fjord	2	10 August	1	0	0	0	1	100.0
Blackstone Bay	2	12 August	0	0	0	0	0	–
College Fjord	3	14 August	2	0	0	0	2	100.0
Harriman Fjord	3	14 August	0	0	0	0	0	–
Total			24	1	0	0	25	
Percent			96.0	4.0	0	0		

Table 19. Density (birds/km^2) of juvenile (July–August) and after-hatching-year (AHY; May–June) Kittlitz's murrelets and juvenile:AHY ratios in four bays in Prince William Sound, Alaska, in 1996, by survey type and bay.

Survey	Juvenile density			AHY density			Juvenile:AHY ratio	
type/bay	$\bar{x}$	n	Maximal	$\bar{x}$	n	Maximal	$\bar{x}$	Maximal
NEARSHORE								
Unakwik Inlet	0	2	0	0.38	3	1.03	0:1	0:1
College Fjord	0.02	3	0.07	1.19	2	2.26	0.02:1	0.03:1
Harriman Fjord	0	3	0	2.61	2	2.94	0:1	0:1
Blackstone Bay	0	2	0	2.73	2	3.76	0:1	0:1
OFFSHORE								
Unakwik Inlet	0	2	0	6.01	3	17.66	0:1	0:1
College Fjord	0	3	0	1.06	2	1.29	0:1	0:1
Harriman Fjord	0	3	0	5.06	2	5.13	0:1	0:1
Blackstone Bay	0	2	0	5.58	2	6.06	0:1	0:1

Table 20. Sampling effort and catch rates of Kittlitz's murrelets with floating mist nets in Prince William Sound, Alaska, in early summer 1996.

				Number of		
Date	Bay	Time of sampling	Number of nets deployed	Net-hours of sampling	Kittlitz's murrelets caught	Catch rate (birds/net-hour)
9 June	Blackstone Bay	2300–0500	2	12.0	0	0
10 June	Blackstone Bay	–[a]	–	0	–	–
11 June	Harriman Fjord	2130–0130	3	12.0	0	0
12 June	Harriman Fjord	2015–0015	3	12.0	0	0

[a] Sampling was canceled at the last minute because of an intrusion of a large amount of ice into the net system about the time sampling was to begin.

Table 21. Number (percentage) of Kittlitz's murrelets recorded feeding in four bays in Prince William Sound, Alaska, in 1996, by cruise, survey type, and time of day.

	Time of day								
	Morning[a]			Afternoon[a]			Total		
Cruise/ survey type	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total
EARLY SUMMER									
Nearshore	19	71	90	15	37	52	34	108	142
(Percent)	(21.1)	(78.9)	(–)	(28.8)	(71.2)	(–)	(23.9)	(76.1)	(–)
Offshore	6	66	72	9	153	162	15	219	234
(Percent)	(8.3)	(91.7)	(–)	(5.6)	(94.4)	(–)	(6.4)	(93.6)	(–)
LATE SUMMER									
Nearshore	70	60	130	29	25	54	99	85	184
(Percent)	(53.8)	(46.2)	(–)	(53.7)	(46.3)	(–)	(53.8)	(46.2)	(–)
Offshore	1	24	25	0	0	0	1	24	25
(Percent)	(4.0)	(96.0)	(–)	(–)	(–)	(–)	(4.0)	(96.0)	(–)

[a] Morning = 0800–1159; afternoon = 1200–1859.

Table 22. Results of statistical tests on percentages of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996.

Comparison	χ^2	df	*P*-value[a]	Conclusion
NEARSHORE VS. OFFSHORE				
Early summer	23.989	1	<0.001***	nearshore % feeding > offshore % feeding
Late summer	22.026	1	<0.001***	nearshore % feeding > offshore % feeding
MORNING VS. AFTERNOON[b]				
Early summer/nearshore	1.040	1	0.331	
Early summer/offshore	0.656	1	0.442	
Late summer/nearshore	0.000	1	0.990	
RISING VS. FALLING TIDE[c]				
Early summer/nearshore	1.052	1	0.328	
Early summer/offshore	11.883	1	<0.001***	rising % feeding > falling % feeding
Late summer/nearshore	0.196	1	0.683	
STRENGTH OF TIDAL CURRENT[c]				
Early summer/nearshore	37.427	2	<0.001***	prefer weak; avoid strong
Early summer/offshore	13.133	2	0.002**	prefer weak; avoid moderate
Late summer/nearshore	47.324	2	<0.001***	prefer weak and moderate; avoid strong
HABITAT TYPE[d]				
Early summer/nearshore	12.608	2	0.002**	prefer glacial affected
Late summer/nearshore	6.295	2	0.045*	prefer glacial affected

[a] * = significant at $\alpha = 0.05$; ** = significant at $\alpha = 0.01$; *** = significant at $\alpha = 0.001$.

[b] We were unable to test late summer/offshore because no Kittlitz's murrelets were recorded in the afternoon part of the surveys.

[c] We were unable to test late summer/offshore because expected values were <1.

[d] We were unable to test offshore because all surveys were of one habitat type.

Table 23. Number (percentage) of Kittlitz's murrelets recorded feeding in four bays in Prince William Sound, Alaska, in 1996, by cruise, survey type, and tidal stage.

Cruise/ survey type	Tidal stage					
	Rising tide[a]			Falling tide[a]		
	Feeding	Not feeding	Total	Feeding	Not feeding	Total
EARLY SUMMER						
Nearshore	13	52	65	21	56	108
(Percent)	(20.0)	(80.0)	(–)	(27.3)	(72.7)	(–)
Offshore	10	56	66	5	163	168
(Percent)	(15.2)	(84.8)	(–)	(3.0)	(97.0)	(–)
LATE SUMMER						
Nearshore	48	44	92	51	41	92
(Percent)	(52.2)	(47.8)	(–)	(55.4)	(44.6)	(–)
Offshore	1	18	19	0	6	6
(Percent)	(5.3)	(94.7)	(–)	(0)	(0)	(–)

[a] 0–6 hr after low tide; 7–12 hr after low tide.

Table 24. Number (percentage) of Kittlitz's murrelets recorded feeding in four bays in Prince William Sound, Alaska, in 1996, by cruise, survey type, and strength of tidal current.

	Current strength								
	Weak[a]			Moderate[a]			Strong[a]		
Cruise/ survey type	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total
EARLY SUMMER									
Nearshore	19	32	51	5	18	23	10	58	68
(Percent)	(37.3)	(62.7)	(–)	(21.7)	(78.3)	(–)	(14.7)	(85.3)	(–)
Offshore	7	46	53	0	29	29	8	144	152
(Percent)	(13.2)	(86.8)	(–)	(0)	(100.0)	(–)	(5.3)	(94.7)	(–)
LATE SUMMER									
Nearshore	23	26	49	60	42	102	16	17	33
(Percent)	(46.9)	(53.1)	(–)	(58.8)	(41.2)	(–)	(48.5)	(51.5)	(–)
Offshore	0	14	14	0	2	2	1	8	9
(Percent)	(0)	(100.0)	(–)	(0)	(100.0)	(–)	(11.1)	(88.9)	(–)

[a] Weak = 1, 6, 7, and 12 hr after low tide; moderate = 2, 5, 8, and 11 hr after low tide; strong = 3, 4, 9, and 10 hr after low tide.

Table 25. Number (percentage) of Kittlitz's murrelets recorded feeding in nearshore waters of four bays in Prince William Sound, Alaska, in 1996, by cruise and standardized habitat type. No analyses were done for offshore surveys, because all sampling there occurred in only one habitat type.

	Habitat type								
	Glacial affected			Glacial stream affected			Glacial unaffected		
Cruise	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total
Early summer	9	6	15	4	25	29	21	77	98
(Percent)	(60.0)	(40.0)	(–)	(13.8)	(86.2)	(–)	(21.4)	(78.6)	(–)
Late summer	45	24	69	17	23	40	37	38	75
(Percent)	(65.2)	(34.8)	(–)	(42.5)	(57.5)	(–)	(49.3)	(50.7)	(–)