Exxon Valdez Oil Spill
Restoration Project Annual Report

Status and Ecology of Kittlitz's Murrelet in Prince William Sound: Results of 1996 and 1997 Studies

Restoration Project 97142
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: Results of 1996 and 1997 Studies

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Study History: This project, which was initiated in 1996, investigated aspects of the ecology of Kittlitz's murrelet (*Brachyramphus brevirostris*), a rare seabird of some conservation concern, 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 second year 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, in 1996 and 1997. Kittlitz's murrelets were common on nearshore and offshore surveys and rare on pelagic surveys. In early summer, the arrival of murrelets was delayed by extensive ice cover and/or cold temperatures in some bays and years; in late summer, numbers decreased rapidly as birds abandoned bays. Populations collectively totaled ~1,420 ± 1,700 birds in 1996 and ~1,280 ± 650 birds in 1997. Glacial-affected habitats were most preferred by murrelets, and glacial-unaffected habitats were least preferred. Murrelet abundance was strongly related to ice cover, water clarity, and sea-surface temperatures. The percentage of breeding-plumaged birds in early summer decreased through time, as what probably were younger birds arrived. The low reproductive output in both years and the occurrence of mixed-species pairs are sources of concern. Feeding frequency was highest in late summer, in 1997, in nearshore areas, and when tidal currents were weak-moderate. Feeding frequency did not differ by time of day, overall tidal stage, or habitat type. Kittlitz's murrelets ate fishes, primarily sandlance and unidentified fishes, and Kittlitz's and marbled murrelets overlapped extensively in prey type, prey size, and dive times.

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

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

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

EXECUTIVE SUMMARY

Introduction

This project has investigated aspects of the basic ecology of Kittlitz's murrelet (*Brachyramphus brevirostris*) in four glaciated fjords in northern Prince William Sound, Alaska, in the summers of 1996 and 1997. 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 this species is known to concentrate; (2) to estimate population sizes and trends of Kittlitz's murrelets in each bay and the four bays as a whole; (3) to determine distribution and habitat use of Kittlitz's murrelets; (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.

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 and 1997.

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 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 radius of individual birds), and secchi depths (1997 only), sea-surface temperatures, and sea-surface salinities (1997 only) by overall survey segment. To study feeding ecology, we compared proportions of birds that were feeding by time of day, season, year, survey type, tidal stage (rising vs. falling), current strength, and habitat type. We also attempted to catch hatching-year (juvenile) Kittlitz's murrelets in 1996 to study residence times and to catch birds for studies of trophics. Finally, we observed feeding birds and examined prey type and size and measured dive times.

Results

Kittlitz's murrelets occurred in highest densities in College Fjord and Harriman Fjord and in lowest densities in Unakwik Inlet and Blackstone Bay. Although the ANOVAs indicated that overall densities on nearshore surveys (but not offshore surveys) differed significantly between years, a Before-After test of only those samples that overlapped by date indicated that the difference was significant only in early summer. Numbers decreased rapidly in late summer of both years, as Kittlitz's murrelets abandoned the bays after late July; however, numbers actually were declining slowly after mid-July. In both years, Kittlitz's murrelets were common on nearshore and offshore surveys and rare on pelagic surveys. Population estimates in all 4 bays varied dramatically between years but collectively totaled ~1,420 ± 1,700 (95% CI) birds in 1996 and ~1,280 ± 650 birds in 1997. In both years, early-summer populations in Harriman Fjord were stable through time, but the arrival of murrelets was delayed until sometime in mid-summer in College Fjord; populations in Unakwik Inlet and Blackstone Bay changed through time, indicating arrival sometime in early summer. These variations in arrival times tended to be determined, at least in part, by the presence of extensive ice cover, low sea-surface temperatures, or both.

Glacial-affected habitats were most preferred, glacial-stream-affected habitats were second in preference, and glacial-unaffected habitats were least preferred by Kittlitz's murrelets; marine-sill-affected habitats were avoided by Kittlitz's murrelets. At a large scale, the use of percent ice cover by Kittlitz's murrelets on nearshore surveys was less than availability in early summer but greater than availability in late summer, when birds concentrated near the faces of tidewater glaciers; in contrast, use on offshore surveys and at a fine scale always was less than availability. At both large and small scales, the use of percent ice cover did not differ between years but did differ between survey types and seasons. In 1997, Kittlitz's murrelets used water on nearshore surveys that was less clear than that available in both early and late summer (reflecting a preference for more turbid areas around glaciers) and on offshore surveys used water that was less clear than that available in early summer but greater than that available in late summer; most birds occurred in waters with secchi depths of ≤3 m. For nearshore and offshore surveys combined in 1996, most Kittlitz's murrelets occurred in waters 3–9°C; in 1997, most Kittlitz's murrelets occurred in waters 4–11°C. Kittlitz's murrelets used colder sea-surface temperatures than were available on average on all nearshore and offshore surveys except the offshore survey for early summer 1997. In 1997, Kittlitz's murrelets used sea-surface salinities that were less than available on average in late-summer nearshore surveys and in both seasons of offshore surveys.

For nearshore and offshore surveys combined, >90% of birds were in breeding plumage in early summer, but this proportion decreased through time, as what presumably were younger birds that had not yet completed the molt entered the bays; in contrast, in late summer, the proportion of breeding-plumaged birds was high (presumably after all birds had finished molting) and declined only at the end of that season, as birds began to enter the post-breeding (pre-basic) molt. The proportion of breeding-plumaged birds in early summer 1996 was the lowest of all four cruises. Seasonal patterns in the proportions of single-bird groups were pronounced; however, these seasonal patterns did not match the predicted pattern. Ratios of hatching-year (HY) to after-hatching-year (AHY) birds indicated that reproductive output in all four bays was extremely low or absent in both years: only one HY bird was recorded in 1996, and none were seen in 1997. 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 HY birds to study their residence times and turnover rates in 1996, and we saw no HY birds in 1997, so we also were unable to study residence times that year. We observed what appeared to be mixed-species "pairs" of Kittlitz's and marbled murrelets during all cruises except early summer 1996. From their behavior, these birds were paired; however, we heard no vocalizations in these "pairs."

Because we were unable to catch Kittlitz's murrelets with floating mist nets in 1996, we were unable to collect samples for trophic studies; the mist-netting was abandoned after that year. We were able to examine other aspects of feeding ecology, however. The proportion of birds seen feeding was significantly higher in 1997 than in 1996, in late summer than in early summer, and in nearshore waters than in offshore waters. In contrast, the proportion of birds seen feeding was not related to time of day, tidal stage, current strength, or habitat type. When observed feeding proportions was compared with that predicted by current strength, however, proportions generally were significantly higher than expected in weak and moderate currents and lower than expected in strong currents. Kittlitz's murrelets were seen eating fishes, especially sandlance (but also probably capelin and/or Pacific herring), and primarily from 0- or 1-yr age classes. Prey type and prey size overlapped extensively between Kittlitz's and marbled murrelets. Kittlitz's murrelets occasionally occurred in mixed-species feeding flocks, primarily with marbled murrelets. Kittlitz's murrelets often feed in shallow water, particularly over shallow banks of sediments that had been left by the retreat of the glaciers; however, depth and densities of birds were not closely related, indicating that the relationship was not strong. Dive times of Kittlitz's murrelets averaged 29.2 ± 10.4 (SD) sec, or nearly identical to the 29.5 ± 7.5 sec of marbled murrelets in the same bays. Kittlitz's murrelets seem to be more adapted to foraging in highly turbid water then marbled murrelets do.

Discussion

Kittlitz's murrelets arrive in these bays primarily in spring (April and/or May) and up to mid-June; they begin leaving the bays in mid-July, and most are gone by early August. The timing of movements of populations of Kittlitz's murrelets differed markedly among bays during both years. The only bay whose entire population was present by early June in both years was Harriman Fjord, the only bay whose entire population was present sometime after mid-June was College Fjord, and the timing of arrival differed between years in Unakwik Inlet and Blackstone Bay. We speculate that the later arrival and restricted distribution of murrelets in some bays and during some years were caused by the presence of extensive ice cover, low sea-surface temperatures, or both; indirect evidence suggests that food was not limiting their distribution in early summer. Ice cover seems to be the primary factor determining the distribution and abundance of Kittlitz's murrelets within bays in early summer.

Populations of Kittlitz's murrelets in these bays were fairly small, and the regional population in the four study bays combined differed by ~9% between years. Determination of whether populations have changed, however, is hampered by a lack of good baseline data on population sizes in these study bays. In 1972, the Prince William Sound population of Kittlitz's murrelets was estimated at ≤63,000 birds; if that estimate was accurate, the population in these four bays, which contain probably 50% of this species' abundance in the Sound, has declined dramatically since then. As many as 10,000 Kittlitz's murrelets were estimated to occur in Unakwik Inlet during those 1972 surveys; if so, the population in that bay has declined by 99% to the 1997 estimated size of ~130 ± ~60 birds. Both of these earlier estimates, however, suffer from numerous questions about their statistical appropriateness 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 129% among years, suggesting that these large-scale surveys may not be appropriate for estimating population size of this highly clumped species.

For argument's sake, however, we assumed that all of the available estimates were correct and calculated the rate of change that would be required for Kittlitz's murrelet populations in Prince

William Sound to have achieved the levels that are estimated today. These changes range from +5.82%/yr to –24.28%/yr, with most estimates suggesting that the population is declining; however, the suggestion of a declining trend is not consistent among all years. Our 2-year data set suggested a population change of –9.30%/yr, although 95% confidence intervals for the overall population in the 4 bays combined overlapped between years. Hence, the population *may* be declining, but it is unclear whether it actually is and, if so, what the actual rate of change may be. Conservation concerns about this species, however, mandate additional surveys to examine further the question of population declines.

Kittlitz's murrelets exhibited an overall preference for glacial-affected habitats and secondarily for glacial-stream-affected habitats; they used glacial-unaffected habitats at a lower rate and avoided marine-sill-affected habitats. In early summer, Kittlitz's murrelets appeared to avoid areas with heavy ice cover and cold sea-surface temperatures. When conditions ameliorated by late summer, Kittlitz's murrelets occurred in 100% of the available glacial-affected habitats. 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, the decreased water clarity, the cooler sea-surface temperatures, and the lower salinities of habitats that were used by murrelets later in the summer. The consistent interannual patterns of use of ice but significant interannual differences in use of sea-surface temperatures suggest that ice cover is more important in determining the within-bay distribution of this species.

It is unclear what the great range in plumage variation in Kittlitz's murrelets that we have seen in this study actually means. It appears, however, that closely related marbled murrelets exhibit similar variation in plumages, and some of them breed in "non-standard" breeding plumages. In addition, subadult alcids molt progressively later than adults do, suggesting that a substantial number of these birds may have been subadults. Temporal patterns of the frequency of single-bird flocks of Kittlitz's murrelets appear to have little explanatory power in the context of reproduction; however, these patterns are similar between years and are similar to those seen in marbled murrelets, suggesting that they reflect some previously unidentified aspect of the biology of this genus. All evidence suggested that reproductive output was extremely low in both years. 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. We observed mixed-species "pairs" of Kittlitz's and marbled murrelets. The occurrence of such interspecific pairing is cause for concern, because it suggests that reproductive isolating mechanisms between the two species may be breaking down in some cases because the populations of Kittlitz's murrelets are being swamped by populations of marbled murrelets.

Kittlitz's murrelets were seen feeding much more often in 1997 than in 1996, in late summer than in early summer, and in nearshore areas than in offshore areas; in contrast, they showed no preference for feeding by time of day, tidal stage, current strength, or habitat type. Although feeding frequencies did not differ significantly among current strengths, they were higher than expected during weak and moderate currents and less than expected in strong currents. Perhaps their preference for feeding in glacial-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 Prince William Sound, 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. Kittlitz's and marbled murrelets overlapped extensively in prey type, prey size, and dive times, raising the possibility of competition for food between the two species. The primary mechanism for ecological separation seems to be an adaptation of Kittlitz's murrelets for feeding in highly turbid water off and near tidewater glaciers and the avoidance of such areas by marbled murrelets. Kittlitz's murrelets often feed in waters ≤10 m deep; however, this relationship is not strong.

Conclusions and Recommendations

We recommend that this study be extended for two additional years (i.e., in FY 1999 and 2000). Such additional sampling will enable us to collect sufficient data to determine with more confidence whether the Kittlitz's murrelet population in these four study bays actually is declining and, if so, the rate of decline. It also will enable us to collect additional data on topics of great interest to wildlife managers, such as those on reproductive output and the occurrence of mixed-species "pairs." Additional cruises also will enable us to describe habitat characteristics and feeding ecology of Kittlitz's murrelets better. Finally, we recommend an addition cruise to estimate populations of Kittlitz's murrelets in the other four bays of Prince William Sound that probably contain significant populations of this species. 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 we still have 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. In addition, the species is listed in the *Red Book of the USSR* (that country's version of the Endangered Species List) as "rare, poorly studied (Category IV)," and collection of any birds requires special permits (Flint and Golovkin 1990). 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 throughout the species' entire range.

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 the accuracy of this estimate is unclear, 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 3-year 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 these first two years, 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 of this species 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 been located (Day et al. 1983, Piatt et al. 1994, Day 1995, Day and Stickney 1996). Based on the small sample of nests, Kittlitz's murrelets appear to be adapted to nesting primarily in rocky, sparsely vegetated scree slopes that occur at high elevations in the southern part of their range and at lower elevations in the northern part of their range (Day et al. 1983, Piatt et al. 1994, Day 1995).

Little is known about the nesting phenology and breeding biology of Kittlitz's murrelet anywhere within its range. For example, the incubation period is unknown (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.

Except for work conducted in 1996 (Day and Nigro 1997), 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 et al., in review). 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, Day and Nigro 1997), 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). Research in Prince William Sound in 1996 found that the species did not prefer one habitat type across all four bays, that it avoided areas of heavy ice cover, and that it moved into cooler waters near glacier faces in late summer as those locations became available with the more-rapid melting of calved ice (Day and Nigro 1997).

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 both 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 isotopes of 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). Research in the glaciated fjords of Prince William Sound in 1996 found that feeding frequencies were highest in nearshore areas, during periods when tidal currents were weak-moderate, and in glacial-affected habitats; that they did not differ by time of day or overall tidal stage; and that the few birds seen feeding ate fishes, probably sandlance, capelin, and/or herring (Day and Nigro 1997).

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.
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 both glacial and sea ice during the coldest months and are partially covered with glacial ice 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 that generally are deep and usually have fairly straight shorelines that are a mixture of bedrock, boulders, rocks, cobbles, gravel, and sand in various proportions. Terrestrial 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 both soil and 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 spawning occurs 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 1996 cruise) and from 28 July to 15 August (late summer 1996 cruise). In 1997, we sampled during two research cruises that were conducted from 1 to 21 June (early summer 1997 cruise) and from 16 July to 4 August (late summer 1997 cruise). Unless indicated otherwise, we sampled the 4 bays 2 times each during each cruise: Unakwik Inlet (3 samples in early summer both years), College Fjord (3 samples in late summer both years), Harriman Fjord (3 samples in late summer both years), and Blackstone Bay (3 samples in late summer 1997; Tables 1–4). 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 "Abundance and Distribution," below), we recorded the following 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; measured only in 1996);
- percent ice cover for the segment as a whole (see "Habitat Use," below);
- secchi depth (measured to the nearest 0.5 m; measured only in 1997);
- sea-surface temperature (measured ~0.5 m below the sea's surface, to the nearest 1°C); and
- sea-surface salinity (measured ~0.5 m below the sea's surface, to the nearest 0.1‰; measured only in 1997).

During each nearshore, offshore, and pelagic survey, we recorded the following information on each Kittlitz's murrelet observation:

- observation number;
- time of observation;
- total number of birds seen;
- 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 numbers of birds on each survey segment.

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). Based on our findings on the timing of occupation of the bays in 1996, we revised the sampling schedule in 1997. Because we needed temporal overlap for an appropriate comparison of numbers between years, we still overlapped the timing of one sampling visit to each bay on each cruise during both years.

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, 1997), Day and Nigro (1997), and Murphy et al. (1997). In each bay, we drove a small boat slowly ($\bar{x}$ = 10.1 km/h; n = 39 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 features. Area of nearshore waters in each segment was measured from digitized maps with GIS software (Table 5).

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, 1997) and Day and Nigro (1997), 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 ($\bar{x}$ = 10.6 km/h; n = 39 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 the need to maximize the area sampled and the 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 cruises, 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, so we laid 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 the survey trackline (Figs. 2–5). Lengths of offshore survey segments used in calculations of areas were measured from digitized maps with GIS software, and areas sampled were calculated as segment length × 200 m total width (Table 5).

Pelagic surveys sampled Kittlitz's murrelets that occurred in more open waters of Prince William Sound, outside of the bays (Fig. 1). Following Day and Nigro (1997), 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, Day and Nigro 1997). 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 ~0.7–1.0 km^2 at speeds run in this study (13–20 km/h).

On nearshore and offshore 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 by comparing those with our boat's speeds; later, we conducted diel activity surveys to determine the time of day when most birds were present on the water. We were able to conduct one diel activity survey in early summer 1996 (in Blackstone Bay on 8 June), but numbers of Kittlitz's murrelets in late summer 1996 and in 1997 were so low, so spread out as to make counting a reasonable number of birds unfeasible, and/or declining so 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, we recorded total numbers of Kittlitz's murrelets for each nearshore and offshore segment.

In addition to the activity sampling, we conducted a counting cross-check in early summer 1997 to determine our individual efficiency at detecting and counting Kittlitz's murrelets. Using a boat driver to operate the small boat while we counted, we cruised at normal sampling speeds and 100 m from shore and independently counted all murrelets seen (including marbled murrelets) in that zone. Each observer kept the hand-held counter in a coat pocket, to keep the other observer from knowing when birds were being counted. After surveying each small section of shoreline, we compared numbers and reconciled locations of birds that the other observer had missed. We then calculated the probability of each observer's missing an individual bird and the probability that both observers missed a particular bird.

Habitat Use.—We examined habitat use by Kittlitz's murrelets with respect to 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 (i.e., classified with categories that had been determined *a priori*) habitat-type categories that reflected the general effect of glaciers on the nearby marine habitat (Table 5):

- 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 marine sill); and
- glacial-unaffected (>200 m from the glacier face 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 probably would not significantly affect the results of statistical tests.

The amount of ice cover determined whether a segment's classification changed among visits from these standardized categories, so we also recorded the actual habitat category during each segment-visit. A segment having a tidewater glacier always was glacial-affected. On the other hand, a nearshore or 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. Offshore survey segments were categorized only as glacial-affected or glacial-unaffected, depending on the amount of ice covering the segment during a particular visit.

Because of heavy ice cover in some locations during the early summer cruises, we were unable to sample 15 (6.9%) of 218 total nearshore segments thoroughly in 1996 and portions of 5 (2.2%) of 218 segments in 1997. 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 any of the four cruises that murrelets 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 unsampled nearshore segments also had no Kittlitz's murrelets.

Starting in 1996, we 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 within a bay). Consequently, we determined percent ice cover both for each segment as a whole and for all of the birds in it (i.e., at a large scale) and for individual records of birds (i.e., at a fine scale). For the large scale, we estimated ice cover for each survey segment as a whole (0%, <1%, 1%, 3%, and 5–100% in 5% units); for the fine scale, we estimated for individual birds the percent of ice within a circle 50 m in radius around 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 1996 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 those for examining the large-scale relationships.

Starting in 1997, we examined habitat use by Kittlitz's murrelets with respect to water clarity, with secchi depth representing a measure of water clarity. We assigned the secchi depth recorded for the beginning of each nearshore or offshore survey segment or pelagic transect as the secchi depth of the water in which the birds were found. Although this method was cruder than measuring the secchi depth at the exact location where each bird was seen, it was the only method that was logistically feasible to use over a broad area.

Starting in 1996, we examined habitat use of Kittlitz's murrelets with respect to 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. Again, this was the only method that was logistically feasible to use over a broad area.

Starting in 1997, we examined habitat use of Kittlitz's murrelets with respect to sea-surface salinity. We assigned the sea-surface salinity recorded for the beginning of that nearshore or offshore survey segment or pelagic transect as the salinity of the water in which the birds were found. Again, this was the only method that was logistically feasible to use over a broad area.

In June 1997, we used the side-scanning sonar on the *Miss Kaylee* to measure the bathymetric depth of the nearshore zone in Harriman Fjord. To conduct these measurements, we cruised along the shoreline 200 m offshore and measured with the sonar the depth at a distance of 100 m from shore every 250-300 m along the shoreline. Because some areas were too shallow to take the ship into, we had to take a few measurements later with a weighted hand line that was calibrated in 1-m increments.

Reproduction.—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);
- hatching-year (HY; 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 some HY/winter plumaged birds on the late summer cruise were so wary that we could not classify with certainty the plumage of these birds, we classified them by the probability that they were HY birds. The categories reflecting our level of certainty about age were:

- definite HY bird (bird was small; had egg tooth and/or breast band; avoided flying, preferring to dive instead);
- probable HY bird (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; avoided flying, preferring to dive instead); and
- possible HY bird (bird dove and escaped so quickly that we were unable to determine whether it was in HY 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) to sample them for trophic 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) $\geq$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 1996 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). Following the recommendations of the Trustee Council's Chief Scientist (R. Spies) and head reviewer for avian studies (C. Haney), we discontinued mist-netting after 1996.

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, we recorded off-transect feeding data of interest, such as records of Kittlitz's murrelets holding fishes and the estimated sizes of those fishes (usually to the nearest 2 cm).

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.

When possible, we classified prey that were being held or being eaten by Kittlitz's murrelets as fish or invertebrate and identified those prey to the lowest possible taxon (e.g., Pacific sand lance, unidentified fish). When possible, we also estimated the size (i.e., maximal length) of prey items to the nearest cm or to a 2-cm range of estimated length (e.g., 8–10 cm).

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 mixed-species feeding flocks that contained Kittlitz's murrelets.

Data Analysis

Statistical summarization and analytical techniques are described by topic. Most statistical tests were conducted with the software Microsoft Excel (v. 7.0) and SPSS (v. 7.0). The multiway contingency tables with maximum-likelihood estimators were analyzed with the software JMP (v. 2.01). All statistical tests were 2-tailed, and the level of significance (α) was 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. We used a Tukey's HSD test in all multiple comparisons. In most cases, statistical comparisons are presented by year or cruise/season; in a few cases, comparisons also are made between years, cruises/seasons, or all cruises/seasons combined.

We summarized the characteristics that might affect our observation abilities by calculating mean observation conditions, sea height, swell height, and wind speed and by calculating the frequency of any type of precipitation for each cruise and survey type. We also summarized mean environmental characteristics by calculating mean ice cover, secchi depth, sea-surface temperature, and sea-surface salinity for each cruise and survey type. All values were calculated from measurements taken or estimates made at the beginning of each sampling segment (nearshore and offshore surveys) and transect (pelagic surveys).

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 and/or plot mean density by bay, bay-visit, and segment or transect-visit on each cruise. We calculated the relationship between nearshore and offshore densities for each bay-visit with a series of Pearson product-moment correlations by each season and for all data combined. In each test, the null hypothesis was that nearshore and offshore densities were not related during each bay-visit.

We ranked the segment-visit estimates of densities, then used the ranks in 5- (nearshore) and 4-factor (offshore) ANOVAs that examined differences in mean densities among years, seasons, sites (i.e., bays), visits, and habitats. For the nearshore test, the null hypothesis was that mean densities did not differ between year, season, site, visit, or standardized habitat type; the null hypothesis for the offshore test was similar, except it excluded habitat type.

Not all surveys were conducted at the same time in both years, so we also conducted a Before-After test (Wiens and Parker 1995) of just those abundance data that were collected on the same dates during both years. This analysis provided a cross-check of the above tests of differences in densities between years and seasons. Following Murphy et al. (1997), we subtracted 1997 densities from 1996 densities for those bay-visits that were conducted during the period of temporal overlap. Unlike Murphy et al., however, we conducted the analysis at the segment level, rather than the bay level, which would have resulted in too few samples for statistical power. These differences were used in a series of *t*-tests by survey type (nearshore and offshore) and by comparison (all data combined and early summer vs. late summer). For each test involving all data combined, the null hypothesis was that the overall change between years did not differ significantly from zero. For each test involving seasonal changes within a survey type, the null hypothesis was that the overall yearly change did not differ between seasons.

We tested the ranked density data for nearshore and offshore surveys to see whether mean density differed by survey type with a 5-factor ANOVA (year, season, site, visit, and survey type). 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 the one habitat type that occurred in both survey types, then again tested for differences between survey types in mean density in this one habitat type with a 5-factor ANOVA (year, season, site, visit, and survey type). In each test, 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 (also see Wiens et al. 1996). This latter value was calculated as the mean offshore density × total area of offshore zone in the part of the bay that was sampled; standard deviations (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. We summed the largest estimate of population size for each bay in each year to estimate the pooled population estimate in all four bays combined for each year.

Habitat Use.—To examine the use of particular habitat types, we calculated mean densities of Kittlitz's murrelets by standardized habitat type for nearshore surveys and compared ranked densities by habitat type and season with a 5-factor ANOVA that examined differences in mean densities among years, seasons, sites (i.e., bays), visits, and habitats (see "Distribution and Abundance," above). The null hypothesis was that mean densities did not differ between year, season, site, visit, or standardized habitat type. Because all offshore segments were of one standardized habitat type, we were unable to test that factor as we did in the nearshore model that was tested above.

We also calculated mean densities of Kittlitz's murrelets by actual (as opposed to standardized) habitat type (i.e., taking into account the influence of variable amounts of floating ice) encountered during each bay-visit for nearshore and offshore surveys and compared ranked densities by habitat type and cruise with 5-factor ANOVAs. For each test, the null hypothesis was that mean densities of Kittlitz's murrelets did not differ among year, cruise, site, visit, or actual habitat type.

To examine availability versus use of large-scale ice cover, water clarity (as indicated by secchi depth), sea-surface temperature, and sea-surface salinity, we tabulated numbers of Kittlitz's murrelets by each nearshore and offshore segment's ice cover, secchi depth, sea-surface temperature, and sea-surface salinity and calculated and compared means of each variable by survey type and season with a series of MANOVAs. These analyses were conducted to decrease the number of individual statistical tests and, hence, to decrease the chance of making one or more Type I errors by conducting a large number of single-factor analyses. For all analyses, data were pooled among all bays and visits during a cruise. The first analyses involved a set of 2-factor MANOVAs for 1997 data only. (Secchi and sea-surface salinity data were collected only in 1997, whereas ice and sea-surface temperature data were collected in both 1996 and 1997; hence, all four variables were measured contemporaneously only in 1997.) One MANOVA with ranked data compared availability (as indicated by the habitat measurements taken at the beginning of each nearshore and offshore survey's segment) of all four habitat variables by the factors survey type and season; another compared use (as indicated by the habitat measurements taken at the beginning of each nearshore and offshore survey's segment, with these measurements being considered to be the use attributes for all birds that were recorded in that segment) of all four habitat variables by the factors survey type and season. The null hypotheses for each habitat variable were that availability did not differ by survey type and season and that use did not differ by survey type and season. Then, a nested MANOVA with ranked data compared availability versus use with the factors survey type and season nested within availability and use. The null hypothesis for each habitat variable was that availability did not differ from use by survey type and season.

The second analyses involved a set of 3-factor MANOVAs only for the variables ice cover and sea-surface temperature. This second set of analyses had to be conducted because data on these habitat variables were collected over both years, thus allowing an examination of whether availability, use, and availability versus use also differed between years. One MANOVA with ranked data compared availability and another compared use of the two habitat variables by the factors year, survey type, and season. The null hypotheses for each habitat variable were that availability did not differ by year, survey type, and season and that use did not differ by year, survey type, and season. A nested MANOVA with ranked data compared availability versus use with the factors year, survey type, and season nested within availability and use. The null hypothesis for each habitat variable was that availability did not differ from use by year, survey type, and season.

In addition to the large-scale analyses of availability versus use, we conducted a finer-scale comparison of ice availability versus use by using a series of 3-factor ANOVAs to compare the total ice cover available in each segment with the ice cover recorded within 50 m around each bird (i.e., individual ice); only those segments in which we had individual ice data were used in the analyses. Again, for all analyses, data were pooled among all bays and visits during a cruise. One ANOVA with ranked data compared availability (as indicated by the ice cover for each nearshore and offshore survey's segment for which we also had individual data for birds), and another compared use (as indicated by the ice cover for an individual bird), by the factors year, survey type, and season. The null hypotheses were that availability did not differ by year, survey type, and season and that use did not differ by year, survey type, and season. Then, a nested ANOVA with ranked data compared availability versus use with the factors year, survey type, and season nested within availability and use. The null hypothesis was that availability did not differ from use by year, survey type, and season.

Reproduction.—To estimate reproductive performance of Kittlitz's murrelets, we followed the technique that had been developed by Kuletz and Kendall (in press) to estimate reproductive performance of marbled murrelets in the Sound. We compiled densities of HY birds in each bay by our level of certainty about whether they actually were HY birds (i.e., definite, probable, possible). Because densities in some bays were changing through time, we also calculated the maximal density of HY birds in each bay during all visits to that bay on a cruise. We calculated mean densities of AHY birds recorded in each bay; because densities in some bays were changing through time, we also calculated the maximal density of AHY birds in each bay during all visits to that bay on a cruise. We then estimated reproductive performance by calculating HY:AHY ratios for each bay, with uncertainty in the estimates being incorporated by calculating ratios from the mean densities of HY and AHY birds on all visits to a particular bay and the maximal densities of HY and AHY birds on any visit to a particular bay.

We compiled numbers of Kittlitz's murrelets of each plumage type by bay-visit on each cruise and plotted trends in percentages of birds in breeding plumage through time. We then used a series of Chi-square tests for row-by-column independence to test whether proportions of breeding-plumaged birds differed between survey types, seasons within a year, and years. To determine the proportion of birds that were in breeding plumage, we recoded the plumage data into two categories: numbers of birds in breeding plumage and numbers not in breeding plumage (i.e., all other plumages combined). We pooled nearshore and offshore data for the tests on seasons within a year and the same season between years. For each test, the null hypothesis was that the proportion of birds in breeding plumage did not differ by the stratification factor being considered.

We explored the data from both years to examine whether group size could be used as an indicator of reproduction in Kittlitz's murrelets. The conceptual model used for early summer was that the proportion of single-bird groups (i.e., group size = 1) should increase through time as additional birds began incubating eggs, leaving non-incubating individuals from nesting pairs to forage alone at sea. This model assumes (1) that non-incubating individuals have no behavioral tendency to flock while at sea and (2) that the non-breeding birds that arrive after egg-laying has been completed have no temporal pattern of flocking that would affect the above hypothesized pattern. The conceptual model used for late summer was that the proportion of single-bird groups should (1) be lower overall than that seen in early summer, because both members of a breeding pair could forage together at all times except when one is carrying food to the juvenile; and (2) should decrease through time, because both members of a pair probably spend time together reinforcing the strength of the pair bond prior to the end of the breeding season. This model assumes that non-breeding birds have no temporal pattern of flocking that would affect the above hypothesized pattern.

To examine temporal patterns of group size, we compiled numbers of Kittlitz's murrelets of each group size by bay-visit (with nearshore and offshore numbers being pooled) on each cruise and plotted trends in percentages of single-bird groups through time. To determine proportions of birds that were in single-bird groups, we summarized the total number data into two categories: numbers of birds in group size 1 and numbers in group size >1 (i.e., all other group sizes combined). We then used a series of Chi-square tests for row-by-column independence to test whether proportions of single-bird groups differed between survey type, seasons within a year, and the same season between years. We pooled nearshore and offshore data for the tests on seasons within a year and the same season between years. For each test, the null hypothesis was that the proportions of single-bird groups did not differ by the stratification factor being considered.

We infrequently recorded what appeared to be mixed-species "pairs" of Kittlitz's and marbled murrelets. In both years, we compiled all records of these mixed-species "pairs" during each bay-visit.

Trophics and Feeding.—We used the nearshore and offshore data on birds classified as feeding to test for variation in the proportion of birds that were feeding by survey zone, time of day, tidal stage, and habitat type. To determine the proportion 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).

We examined variations in the proportions of birds that were feeding by classifying all data by time of day (morning [0600–1159]; afternoon [1200–1930]), season (early summer, late summer), year (1996, 1997), survey type (nearshore, offshore), tidal stage (rising, falling), current strength (weak, moderate, strong; see following paragraph), and standardized habitat type (glacial-affected, glacial-stream-affected, glacial-unaffected). We then compiled these data by each of these variables and tested whether any of these variables were important in determining the proportion feeding with a multiway contingency table with maximum-likelihood estimators in the software JMP. The null hypothesis was that proportions feeding did not differ by time of day, season, year, survey type, tidal stage, current strength, and standardized habitat type.

To examine variation in the porportions of bird that were feeding by tidal stage and current strength, we first converted the time of each record to hours after low tide and summarized numbers of Kittlitz's murrelets classified as feeding and not feeding by recoded 1-hr blocks of tidal stage (e.g., 4 hr after low tide, 9 hr after low tide; see following paragraph). From a low tide to its following high tide ~6.6 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 (approximated in Fig. 6, top) indicates 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 may be up to nearly 13 hr on some days), we recoded the tidal data into 12 1-hr categories of similar size. Thus, the recoded categories were 0–1.08 hr after low tide (recoded as 1 hr after low tide), 1.08–2.16 hr after low tide (recoded as 2 hr), and so forth, so that the recoded numbers ran from 1 to 12 hr after low tide. 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 results of the analyses.

In addition to examining the effects of simple current strength on the proportions of birds that were feeding with the above multiway contingency table with maximum-likelihood estimators, we examined whether the number of birds feeding was proportional to strength of the tidal current with a multiway (for two years) Chi-square goodness-of-fit test. In this test, the expected numbers were based on relative tidal strength per hr after low tide (Fig. 6, bottom) and would be 0.167 for weak currents (recoded 1, 6, 7, and 12 hr after low tide), 0.333 for moderate currents (recoded 2, 5, 8, and 11 hr after low tide), and 0.500 for strong currents (recoded 3, 4, 9, and 10 hr after low tide). The null hypothesis was that the proportion feeding did not differ from expected values by strength of tidal current. This test differs from the earlier one in that it tested the null hypothesis that the proportion feeding did not differ by current strength; in contrast, this one tests whether the proportions feeding differs from a specific hypothesized pattern.

We summarized all data on prey that we observed Kittlitz's murrelets holding or eating during 1996 and 1997; because data were limited, we pooled them from both years. These data included both identification to lowest possible taxon and mean estimated size (maximal length). For sizes of those prey that had been estimated as a range of values (e.g., 8–10 cm), we used the midpoint of the range estimate (e.g., 9 cm for an item estimated at 8–10 cm) in the calculations and tests. For comparison, we summarized and compared prey species eaten and prey sizes between Kittlitz's and marbled murrelets from the same bays over the two years of the study and tested for differences with a 2-sample *t*-test that assumed unequal variances. The null hypothesis was that mean prey size did not differ between species.

We used bathymetric data that we had collected in Harriman Fjord in June 1997 to examine the relationship between depth and feeding in Kittlitz's murrelets. We calculated the mean depth of all measurements for each segment. We were able to measure depths off of the faces of Harriman, Surprise, and Coxe glaciers but not off of the face of Barry Glacier. Because depths off of the other three glaciers were so similar (means of 42–56 m), we estimated the mean depth off of Barry Glacier by calculating a mean of all measurements off of the other glaciers. For each cruise, we then calculated correlation coefficients between mean depth and mean density of Kittlitz's murrelets over all visits. Because Kittlitz's murrelets forage in equal frequencies in the various habitat types and because densities are highest in glacial-affected habitats (see "Results"), density was a good surrogate for the density of feeding birds. For each test, the null hypothesis was that depth was not related to density of Kittlitz's murrelets.

We calculated mean dive times for all Kittlitz's murrelets that had been measured in 1996 and 1997; to increase sample sizes, we pooled the data from both years. For comparison, we summarized and compared mean dive times between Kittlitz's and marbled murrelets from the same bays over the 2 years of the study and tested for differences with a 2-sample *t*-test that assumed unequal variances. The null hypothesis was that mean dive time did not differ between species.

RESULTS

Characteristics that could affect our observation abilities were favorable for sampling in both years and differed little between years (Table 6). Mean observation conditions averaged 4+ on a scale of 1–5 (with 1 being poor and 5 being excellent) on all except late-summer pelagic surveys in 1996. In general, observation conditions were better within the bays than on the pelagic surveys outside of bays and were better on nearshore surveys than on offshore surveys. 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 early summer 1997 and late summer 1996 and 1997. In 1996, 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. In contrast, precipitation in 1997 occurred more frequently in early than in late summer; we lost a day of work because of heavy rain only in late summer, however.

Overall environmental conditions differed between both seasons and years, being generally icier and cooler in 1996 than in 1997; no 1996 data on secchi depth and sea-surface salinity were available for comparison (Table 7). Mean percent ice cover in late summer was only 9–55% of that measured in early summer and always was higher within bays than outside of them. Ice was not recorded on any pelagic survey. Mean secchi depths were greater in late summer than in early summer, as the water cleared after the spring phytoplankton bloom. As might be expected, sea-surface temperatures averaged 1–2°C warmer in late summer than they did in early summer and reflected the seasonal decrease in ice cover. Sea-surface temperatures also were 1–2.5°C warmer overall in 1997 than in 1996 and were considerably lower in the study bays than on pelagic surveys outside of the bays in both years. Reflecting the input of substantial amounts of fresh water added to these bays by meltwater coming from the tidewater and hanging glaciers, mean sea-surface salinities decreased by 16–31% from early to late summer, depending on the survey type.

Abundance and Distribution

Patterns of Abundance and Distribution.—In early summer 1996, no Kittlitz's murrelets were seen 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 their entire 1996 populations 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. In late summer 1996, densities declined slowly through time, although a few birds still were present when we finished surveys in mid-August.

Although the timing of surveys was slightly later in early summer 1997 than in early summer 1996, Kittlitz's murrelets on nearshore surveys followed a similar pattern of increasing densities through time, as birds continued arriving in the bays (Fig. 7, top). Once entire populations had arrived, these murrelets occurred in densities of 2–10 birds/km^2 in all bays. In late summer 1997, densities declined slowly through time; although a few birds still were present when we finished surveys in early August, most were gone by the end of July. In addition, nearshore densities were higher in 1997 than in 1996 on 4 of 5 early-summer surveys and on 3 of 4 late-summer surveys that were paired in time.

On offshore surveys, a pattern of delayed arrival in Unakwik Inlet and College Fjord during early summer 1996 was similar to that seen on nearshore surveys that year (Fig. 7, middle) suggested that these birds were moving into offshore areas at about the same time as they moved into nearshore areas. 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 early summer 1997, the pattern of arrival on offshore surveys was not as clear as that seen in 1996. Densities on offshore surveys were higher in 1997 than in 1996 on only 1 of 5 early-summer surveys and on 2 of 3 late-summer surveys that were paired in time; one paired data set was zero in both cases.

In late summer of both years, Kittlitz's murrelets exhibited dramatic declines in abundance on offshore surveys through time, such that they essentially had completely abandoned the bays by the end of July (Fig. 7, middle). After 1 August, Kittlitz's murrelets were absent on all offshore surveys except for one in College Fjord in 1996 and one each in Harriman Fjord in 1996 and 1997, indicating that those Kittlitz's murrelets that were present after 1 August were concentrated in nearshore waters.

Although the timing of movements of Kittlitz's murrelets into and out of nearshore and offshore waters was generally similar, the relationship was not strong in all cases. The relationship was not significant for early summer (1996 and 1997 pooled; $r = 0.066$; n = 18; $P > 0.50$) but was for late summer (1996 and 1997 pooled; $r = 0.705$; n = 21; $P < 0.001$). When data were pooled among all seasons and years, the relationship was not statistically significant ($r = 0.245$; n = 39; $P = 0.128$).

Kittlitz's murrelets essentially were absent from pelagic waters during both cruises in both 1996 and 1997 (Fig. 7, bottom). The only records were of a single bird on one of the Port Wells even lines in early summer 1996 and a total of five birds scattered across the Port Wells even and odd lines in early summer 1997. Hence, these birds were not found in significant numbers in pelagic waters outside of the bays during early summer and were not found there at all in late summer.

On nearshore surveys, three main factors were significant in the ANOVA model: year, site, and habitat type (Table 8). Overall abundance was higher in 1997 than in 1996 and higher in College and Harriman fjords than in Unakwik Inlet and Blackstone Bay; habitat relationships are discussed later (see "Patterns of Habitat Use," below). Overall abundance did not differ between seasons and visits, probably because of high variability and, hence, low power (Fig. 7, top; Table 8). Two significant interactions were found, reflecting seasonal changes in densities in ≥1 bay among years and changes in ≥1 habitat type among years.

On offshore surveys, the main factors season and site both differed significantly; however, neither years nor visits were significantly different, again probably because of high variability and low power (Table 8). Overall abundance was higher in early summer than in late summer and higher in Harriman and College fjords than in Unakwik Inlet and Blackstone Bay. As was seen for nearshore surveys, most of the significant interactions simply reflected changes in abundance in ≥1 bay between cruises (Fig. 7, middle). Because only one standardized habitat type occurred on offshore surveys, we were unable to include habitat type in the ANOVA model for this survey type.

Not all surveys were conducted at the same time in both years, so a Before-After test of only those data that were collected on the same dates both years provided a cross-check of the above tests of differences in densities between years and seasons. For nearshore surveys, overall densities for both seasons combined were nearly, but not significantly, different between years

(Table 9), suggesting that the difference in timing of surveys between years probably was enough to provide significance in the above ANOVA, which used all data. When the Before-After data were examined by season, the relationship was significant, indicating that 1997 densities were significantly higher overall in early summer but were about the same between years in late summer. For offshore surveys, overall densities for both seasons combined did not differ between years (Table 9), a result similar to that seen in the above ANOVA. When the data were examined by season, they again were not related, although densities were considerably lower in early summer 1997 than 1996 and about the same between years in late summer.

The plots of densities in Fig. 7 suggested a possible difference in overall densities between nearshore and offshore zones, so we tested for such a difference (Table 10). 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 10.

Within-bay Distribution.—In early summer 1996, Kittlitz's murrelets exhibited two main patterns of distribution within each of the four bays. In Unakwik Inlet and College Fjord, these birds were distributed in the central and/or lower parts of the areas sampled in these bays (Figs. 8 and 9). 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 1996 (Figs. 10 and 11). 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 only sporadically elsewhere in the bay.

In late summer 1996, Kittlitz's murrelets were recorded only near the glaciated head of Unakwik Inlet, were distributed fairly widely in both College and Harriman fjords, and were absent from Blackstone Bay (Figs. 8–11). 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 late-summer 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 1996, they also were rare on offshore segments in all bays except College Fjord.

In early summer 1997, Kittlitz's Murrelets were recorded on all segments except those at the head of Unakwik Inlet, were distributed throughout essentially all of College Fjord, were distributed throughout Harriman Fjord (including all tidewater glacier faces and much of the southern shore), and were concentrated in the upper half of Blackstone Bay (Figs. 12–15). In Unakwik Inlet, we recorded the first birds that we have seen in this study seaward of the marine sill. In College Fjord, ice was light enough to enable us to sample off Yale Glacier for the first time during this season, and numerous Kittlitz's Murrelets were seen there; birds were seen off of all tidewater glaciers except for Harvard, but they were seen nearby. In Harriman Fjord, birds were seen off of all tidewater glaciers, including an extremely high density of 144 birds/km^2 off the face of Coxe Glacier. In Blackstone Bay, they were seen off of Blackstone Glacier but were not seen off of Beloit Glacier, although they were seen nearby.

In late summer 1997, Kittlitz's Murrelets in Unakwik Inlet were concentrated off and near Meares Glacier and occurred only sporadically elsewhere, were seen throughout College Fjord and Harriman Fjord, and in Blackstone Bay were concentrated off and near Blackstone and Beloit glaciers (Figs. 12–15). In all, they were seen off of all 12 tidewater glaciers in the 4 bays combined, suggesting a strong attraction to this habitat.

The difference in abundance and distribution of Kittlitz's murrelets within bays between early and late summer 1996 probably reflected differences in ice cover and/or sea-surface temperatures within the bays (Table 11). In early summer 1996, 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 both nearshore and offshore surveys. In contrast, the two bays with early arrival and widespread distribution (Harriman Fjord and Blackstone Bay) in early summer 1996 had lower (Blackstone Bay) to similar (Harriman Fjord) percent ice cover and warmer sea-surface temperatures (both bays) on these surveys. In contrast, the data on ice cover and sea-surface temperatures for late summer 1996 suggest that these environmental characteristics were considerably less severe than they had been in early summer 1996. For example, ice cover within these two bays decreased between cruises in 1996 by 79–87% on nearshore surveys and by 92–94% on offshore surveys. Likewise, sea-surface temperatures within these two bays increased between cruises in 1996 by 27–38% on nearshore surveys and by 8–38% on offshore surveys. Hence, these environmental characteristics probably did not limit the distribution of Kittlitz's murrelets within bays in late summer 1996, particularly within the two bays with late arrival and restricted distribution (Unakwik Inlet and College Fjord).

The data on ice cover and sea-surface temperatures in 1997 indicated a generally less icy and warmer environment than was seen in 1996 (Table 11). In early summer 1997 in particular, ice cover often was 50–70% of that seen in early summer 1996, and sea-surface temperatures often were 10–45% warmer than in early summer 1996. Surprisingly, ice cover in several bays often was higher in late summer 1997 than in late summer 1996; however, the small overall amounts of ice seen during late summer 1997 apparently were not enough to have a significant effect of the distribution of Kittlitz's murrelets, and sea-surface temperatures always were warmer than those recorded in late summer 1996.

Population Size.—In early summer 1996, estimated populations of Kittlitz's murrelets increased through time in Unakwik Inlet and College Fjord but were stable across visits in Harriman Fjord and Blackstone Bay (Table 12). 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 ± 866 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 here. The estimated population in College

Fjord was small but doubled between visits, to a maximum of 102 ± 64 birds; however, data from the late summer cruise suggest that this cruise probably underestimated the maximal number of birds there in 1996 by 82 ± 21 birds and, hence, that the entire population had not arrived by the date of our final early-summer survey. The estimated population in Harriman Fjord increased by only <3% between visits, to 325 ± 172 birds, and the estimated population in Blackstone Bay increased by ~16% between visits, to 222 ± 266 birds. Together, the maximal estimated population of Kittlitz's murrelets in all 4 bays combined during early summer was 1,328 ± 1,368 birds and was higher by at least 82 ± 21 birds because the estimate for College Fjord was low, for a corrected total of 1,410 ± 1,389 birds (Table 13).

By the time of our first surveys in late summer 1996, populations of Kittlitz's murrelets had disappeared or nearly disappeared in Unakwik Inlet and Blackstone Bay, were present but only 10% of early-summer numbers in Harriman Fjord, and were higher than what were estimated in early summer in College Fjord (Table 12). 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 1996 cruise, suggesting that a significant number of birds had arrived after we had completed our surveys for that cruise. After the first visit, estimated populations in all bays exhibited rapid declines of 100% (Unakwik Inlet), 84% (College Fjord), and 95% (Harriman Fjord) over the 2-week period; birds had completely abandoned Blackstone Bay by our first visit there, so the decline could not be calculated.

Because overall population estimates usually were higher in early summer, we usually (but not always) used the largest estimate for each bay during that season as the estimate of the population size for that year. In early summer 1997, estimated populations of Kittlitz's murrelets increased through time in Unakwik Inlet, College Fjord, and Blackstone Bay but appeared to be somewhat stable across visits in Harriman Fjord (Table 14). Estimated populations in Unakwik Inlet appeared to have leveled off by our third visit, however. In Unakwik Inlet, the maximal population was 133 ± 61 birds. In College Fjord, the estimated population increased through time and, as was seen in 1996, was higher in late summer by 352 ± 57 birds. The estimated population in Harriman Fjord was high and fairly stable between visits, although it did increase by ~16% on the second visit to 524 ± 253 birds. The estimated population in Blackstone Bay increased by 526% between visits to 119 ± 157 birds, indicating later arrival of birds. Together, the maximal estimated population of Kittlitz's murrelets in all 4 bays combined during early summer was 928 ± 591 birds and was higher by at least 352 ± 57 birds because the estimate for College Fjord did not peak until late summer, for a corrected total of 1,280 ± 648 birds (Table 13).

By the time of our first surveys in late summer 1997, populations of Kittlitz's murrelets had essentially disappeared in Blackstone Bay, were approximately 50% of early-summer numbers in Unakwik Inlet and Harriman Fjord, and were higher than what were estimated in early summer in College Fjord (Table 14). After the first visit, estimated populations in all bays exhibited rapid declines of 70% (Unakwik Inlet), 88% (College Fjord), 78% (Harriman Fjord), and 90% (Blackstone Bay) over the 2-week period.

The late-summer surveys were begun ~2 weeks earlier in 1997 than in 1996, so the late arrival in Blackstone Bay in early summer 1997 and the absence of birds there in mid-July 1997 indicates that those birds did not visit that bay for long. During the first week of August, estimated populations in all four bays combined were highly similar between years (Tables 12 and 14), suggesting that an overall departure from the bays occurred at about the same time each year.

Evaluation of Sampling Protocol.—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 1996, during the early summer cruise (Table 15). 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 offshore component also 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.

Because Kittlitz's murrelets were absent from Blackstone Bay when we began sampling in late summer, and because numbers of Kittlitz's murrelets in late summer 1996 and in 1997 were so low (especially in Blackstone Bay), so spread out as to make counting a reasonable number of birds unfeasible (other bays), and/or declining so rapidly in late summer, we did not conduct those surveys at that time (other bays). Our impression, however, was that activity patterns in late summer 1996 and during both cruises in 1997 were similar to those seen in early summer 1996.

On 16 June 1997, we conducted a counting cross-check experiment between the two observers to determine inter-observer sampling variability. One observer missed 1.9% of 158 birds seen by both observers, and the other observer missed 1.9–3.2% of all birds seen by both observers. (There was some uncertainty about how many birds the second observer missed, so a range of estimates is presented.) Hence, the probability that *both* observers missed a particular bird is somewhere between the product of these two percentages (i.e., 0.019 × 0.019 [0.019 to 0.032] = 0.00036–0.00061, or 0.04–0.06%) and the sum of these two percentages (i.e., 0.019 + [0.019 to 0.032] = 0.019–0.051, or 1.9–5.1%). Note that these estimates tell you the estimated percentage of birds that were missed by both observers *out of the birds that were seen by one or both of the observers*. Some unknown bias may mean that additional birds were missed by both observers without their knowing it or without their knowing how often such birds are missed.

Habitat Use

Patterns of Habitat Use.—On nearshore surveys, Kittlitz's murrelets used all habitats except for marine-sill-affected ones; highest overall mean densities occurred in glacial-affected habitats, with lower mean densities in glacial-stream-affected and glacial-unaffected habitats (Tables 8 and 16). Highest mean densities occurred in glacial-affected habitats in 9 (60%) of the 15 bays/seasons in which Kittlitz's murrelets occurred on nearshore surveys (primarily College and Harriman fjords and Blackstone Bay); murrelets were absent from Blackstone Bay in late summer 1996, as discussed above, so no preference was possible at that time. There was a particularly strongly attraction to glacial-affected habitats in late summer, when the highest densities were recorded there in 5 (72%) of 7 bay/season pairs. Highest mean densities occurred in glacial-stream-affected habitats in 4 (27%) of the 15 bay/season pairs (Unakwik Inlet in both early summer cruises and in late summer 1996 and College Fjord in early summer 1997). Highest mean densities occurred in glacial-unaffected habitats in only 2 (13%) of the 15 bay/season pairs; these highest mean densities occurred with no coherent pattern (Harriman Fjord in early summer 1996 and Unakwik Inlet in late summer 1997).

Between seasons within a year, the highest mean densities consistently occurred in one habitat type for 4 of 7 possible season/year pairs: Unakwik Inlet (glacial-stream-affected habitat in 1996), College Fjord (glacial-affected habitat in 1996), Harriman Fjord (glacial-affected habitat in 1997), and Blackstone Bay (glacial-affected habitat in 1997; Table 16). The use of glacial-unaffected habitats was not consistent between seasons within a year. Again, Blackstone Bay could not be compared between seasons in 1996.

Between years during the same season, the highest mean densities also occurred consistently in one particular habitat type for 4 of 7 year/season pairs (Table 16). Of these four pairs exhibiting consistency, three occurred in glacial-affected habitats and the fourth occurred in glacial-stream-affected habitats. The other three year/season pairs were not consistent between years during a particular season.

Two other lines of evidence suggest that Kittlitz's murrelets were attracted to glacial-affected habitats. First, in the ANOVAs for both nearshore and offshore data (Table 8), the highest densities of Kittlitz's murrelets were found in those bays that had the highest number of tidewater glaciers (College and Harriman fjords). These results suggest that some sort of selection for glacial-affected habitats may be occurring at a bay level of scale. Second, these murrelets were recorded frequently on glacial-affected segments (Figs. 8-15; also see above). They occurred on 5 (42%) of 12 glacial-affected segments during early summer 1996 (but the association probably was limited by the heavy ice and/or cold temperatures; see "Within-bay Distribution," above), 9 (90%) of 10 segments in late summer 1996 (no birds were recorded in Blackstone Bay, so those 2 segments could not be counted), 8 (67%) of 12 segments in early summer 1997, and 12 (100%) of 12 segments in late summer 1997.

On offshore surveys, glacial-unaffected habitats were the only standardized habitat types that were available to Kittlitz's murrelets (Table 16). Within that one habitat, however, mean densities varied widely among bays and cruises, with highest overall densities being recorded in early summer in both years and being reflected in the significant "season" factor in the 4–factor ANOVA discussed under "Abundance and Distribution," above (Table 8).

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 each data set for differences similarly to that for the standardized habitat types, above. This series of recalculations for nearshore surveys resulted in no major differences in overall patterns of mean densities by actual habitat types and few differences between the two types of ANOVA models incorporating standardized vs. actual habitat types (results are not shown here). Results of the analysis for offshore surveys indicated no difference between habitat types. Such a similarity between the two sets of nearshore results indicates that the intrusion of large amounts of calved ice onto individual non-glacial segments was not widespread enough to have altered the distribution and habitat use of Kittlitz's murrelets significantly or that ice cover is not the best measure of a glacial-affected habitat.

Relationship to Ice Cover.—At a large scale, Kittlitz's murrelets generally showed pronounced relationships to ice cover (Figs. 16 and 17). 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 1996, available 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 74% of all offshore segments had ≤5% ice cover, whereas only 12% of nearshore and 13% of offshore segments had >50% ice cover (Figs. 16 and 17). In late summer 1996, ice cover ranged from 0% to 90% on nearshore surveys and from 0% to 45% 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 1997, ice cover ranged from 0% to 95% on nearshore surveys and from 0% to 100% on offshore surveys; 80% of all nearshore and 79% of all offshore segments had ≤5% ice cover, and only 5% of nearshore and 7% of offshore segments had >50% ice cover. In late summer 1997, ice cover ranged from 0% to 100% on both nearshore and offshore surveys; 90% of all nearshore and 95% of all offshore segments had ≤5% ice cover, whereas only 3% of all nearshore and offshore segments had >50% ice cover. Hence, in both seasons for nearshore surveys and on offshore surveys in early summer only, available ice cover was lower in 1997 than in 1996; available ice coverage was greater in 1997 only for late-summer offshore surveys (Table 17).

Large-scale availability of ice did not differ significantly between survey types but did differ significantly between seasons (Table 18). Multiple comparisons indicated that availability was significantly higher in early summer than in late summer. When this analysis of availability was extended with the 3-factor MANOVA that added year (i.e., 1996 and 1997) to the model, availability did not differ significantly between survey types but did differ significantly between years and seasons (Table 19). Multiple comparisons indicated that availability was significantly higher in 1997 than in 1996 and higher in early summer than in late summer. The significant year effect actually was opposite that seen for mean percent ice cover in Table 17. This seemingly greater mean ice cover in 1996 than 1997 was driven primarily by the larger number of segments (both nearshore and offshore) in early summer 1996 that had significant amounts of ice (Figs. 16 and 17; Table 17). For example, ~7% more nearshore survey segments in 1996 than 1997 had ice cover ≥10%, and many more offshore survey segments in 1996 than 1997 had ice cover ≥35% (Figs. 16 and 17). In contrast, ice cover in late summer was similar between years for both survey types. Because larger amounts of ice within segments dramatically decrease their use by Kittlitz's murrelets (see "Within-bay Use," above; and results of ice use, below), especially in early summer, we believe that the greater ice cover in early summer 1996 was more biologically significant. Hence, we are ignoring the multiple comparisons in Table 19 and conclude that ice cover was higher in 1996 than in 1997.

In early summer 1996, Kittlitz's murrelets occurred in 0–75% ice cover on nearshore surveys and in 0–35% ice cover on offshore surveys (Figs. 16 and 17). 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. In late summer 1996, 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. In early summer 1997, Kittlitz's murrelets occurred in 0–60% ice cover on nearshore surveys and 0.5–40% ice cover on offshore surveys; they occurred in ≤5% ice cover on 76% of nearshore and 80% of offshore segments, whereas they occurred in >50% ice cover on only 1% of nearshore and 0% of offshore segments. In late summer 1997, Kittlitz's murrelets occurred in 0–75% ice cover on nearshore surveys and 0–10% ice cover on offshore surveys; they occurred in ≤5% ice cover on 75% of nearshore and 95% of offshore segments, whereas they occurred in >50% ice cover on only 2% of nearshore and 0% of offshore segments. The abrupt jumps on the use plot for the offshore surveys during both seasons were caused by flocks of Kittlitz's murrelets. The 1 record of a Kittlitz's murrelet on pelagic surveys in 1996 and the 5 records in 1997 occurred in 0% ice cover. Thus, Kittlitz's murrelets used segments with more ice in late summer than in early summer on both years' nearshore surveys, segments with more ice in early summer than late summer on both years' offshore surveys, segments with slightly more ice in 1997 for early summer nearshore but much more ice in 1996 for late summer nearshore surveys, and segments with more ice in 1996 than in 1997 for both seasons' offshore surveys (Table 17).

Large-scale use of ice by Kittlitz's murrelets in 1997 differed significantly between both survey types and seasons (Table 20). Multiple comparisons indicated that they occurred in water that had significantly greater ice cover on nearshore surveys than on offshore surveys and in greater ice cover in early summer than in late summer (Figs. 16 and 17, Table 17). When this analysis of use was extended with the 3-factor MANOVA that added year to the model, Kittlitz's murrelets occurred in ice cover that did not differ significantly between years but did differ between survey types and seasons, as above (Table 21). Multiple comparisons indicated that they occurred in ice cover that was significantly greater on nearshore surveys than on offshore surveys and greater in early summer than in late summer.

Large-scale availability versus use of ice in 1997 differed significantly by both survey type and season (Table 22). On nearshore surveys, Kittlitz's murrelets occurred in ice cover that was less than that available on average in early summer but greater than that available on average in late summer, when birds concentrated near the faces of tidewater glaciers (Table 17). In contrast, on offshore surveys, use almost always was less than availability. When this analysis was extended with the 3-factor MANOVA that added year to the model, ice use versus availability again differed significantly by survey type and season, plus it differed by year (Table 23). The year effect primarily reflected the difference between years in the relationship for late-summer offshore surveys, in that Kittlitz's murrelets occurred in ice cover that was greater than that available on average in 1996 but less than that available on average in 1997 (Table 17).

At a fine scale, Kittlitz's murrelets always showed pronounced avoidance of heavy ice cover, in that essentially all birds occurred in ≤10% ice cover, no matter what the availability was (Figs. 18 and 19). These plots compare the large-scale ice cover for nearshore or offshore segments with the fine-scale ice cover seen in 50-m-radius circles around each Kittlitz's murrelet within those segments. Ice availability on these segments differed between survey types but not between years and seasons (Tables 24 and 25). Multiple comparisons indicated that availability of ice was significantly higher on nearshore surveys than on offshore surveys. Use of ice by Kittlitz's murrelets did not differ by year but differed significantly by survey type and season (Tables 24 and 25). Multiple comparisons indicated that Kittlitz's murrelets occurred in ice cover that was significantly greater on nearshore surveys than on offshore surveys and greater in late summer than in early summer. Again, this increased use in late summer probably reflected the move at that season toward glacier faces (see above). Finally, use versus availability did not differ significantly by year but did differ by survey type and season (Table 25). Kittlitz's murrelets occurred in ice cover that was less than that available on average in all survey types, seasons, and years except for the late-summer offshore survey in 1996, when they occurred in ice cover that was slightly greater than that available on average. The difference between availability and use was significantly greater for nearshore surveys than offshore surveys and was greater in early summer than in late summer.

Relationship to Water Clarity.—Secchi depths, which were sampled only in 1997, had narrow ranges in early summer but ranged widely in late summer (Figs. 20 and 21). In early summer 1997, they ranged from 0 m to 6 m on nearshore surveys and from 1 m to 6 m on offshore surveys; 84% of all nearshore and 81% of all offshore segments had secchi depths of ≤3 m, whereas 0% of all nearshore and offshore segments were >6 m in depth. In late summer 1997, they ranged from 0 m to 13 m on nearshore surveys and from 0 m to 14 m on offshore surveys, reflecting the general clearing of the water in at least those segments that were glacial-unaffected after most primary production in these fjords had stopped; 84% of all nearshore and offshore segments were ≤3 m in depth, whereas only 6% of all nearshore and 9% of all offshore segments were >6 m in depth. On both cruises, secchi depths on both nearshore and offshore surveys were larger in glacial-unaffected habitats and smaller in glacial-affected habitats. Hence, available secchi depths occurred over a wider range in late summer than early summer on both nearshore and offshore surveys and were larger overall in late summer, probably because of the general clearing of the water column due to a decrease in phytoplankton concentrations (Table 17).

Large-scale availability of secchi depths in 1997 differed significantly between survey types (Table 18). Multiple comparisons indicated that availability was significantly higher on offshore surveys than on nearshore surveys (Figs. 20 and 21, Table 17), probably because most sediment that entered bays did so in the nearshore zone. Because we collected data on secchi depths only in 1997, the analysis of availability could not be extended with a 3-factor MANOVA that added year to the model.

In early summer 1997, Kittlitz's murrelets occurred in waters of 0–5 m secchi depths on nearshore and 0–6 m depths on offshore surveys (Figs. 20 and 21). They occurred in ≤3 m secchi depths on 80% of nearshore and 98% of offshore segments, whereas they occurred in >6 m depths on 0% of nearshore and offshore segments. In late summer 1997, Kittlitz's murrelets occurred in 0–5 m secchi depths on nearshore and 0–14 m depths on offshore surveys. They occurred in ≤3 m secchi depths on 97% of nearshore and 81% of offshore segments, whereas they occurred in >6 m depths on 0% of nearshore and 19% of offshore segments. Hence, Kittlitz's murrelets occurred in secchi depths of a wider range in late summer than early summer on offshore but not nearshore surveys and occurred in smaller secchi depths in late summer on nearshore surveys but in larger secchi depths in late summer on offshore surveys (Table 17).

Large-scale use of secchi depths in 1997 differed significantly between both survey type and season (Table 20). Multiple comparisons indicated that Kittlitz's murrelets occurred in water that was significantly clearer on offshore surveys than on nearshore surveys and clearer in early summer than in late summer (Figs. 20 and 21, Table 17). Kittlitz's murrelets used water that was clearer on average on offshore surveys than on nearshore surveys because the water actually was significantly clearer overall on offshore surveys. Kittlitz's murrelets occurred in water that was clearer on average in early summer than in late summer, despite lower standing stocks of phytoplankton in late summer, because many of them moved inshore to the vicinity of tidewater glaciers (i.e., areas with very low water clarity) in late summer, as discussed above. Because we collected data on secchi depths only in 1997, the analysis of use could not be extended with a 3-factor MANOVA that added year to the model.

Large-scale availability versus use of secchi depths in 1997 differed significantly between both survey type and season (Table 22). On nearshore surveys, Kittlitz's murrelets occurred in water that was less clear than that available on average in both early and late summer (Table 17). In contrast, on offshore surveys, Kittlitz's murrelets used water that was less clear than that available overall in early summer but more clear than that available on average in late summer. Again, this analysis of availability versus use could not be extended with a 3-factor MANOVA that added year to the model.

Relationship to Sea-surface Temperature.—Sea-surface temperatures ranged widely on both cruises in both years (Figs. 22 and 23). On all cruises, sea-surface temperatures on both nearshore and offshore surveys were warmer at the outer edges of the bays. In early summer 1996, temperatures ranged from 1°C to 13°C on nearshore surveys and from 3°C to 12°C on offshore surveys. In late summer 1996, they ranged from 1°C to 13°C on nearshore surveys and from 2°C to 13°C on offshore surveys. In early summer 1997, they ranged from 3°C to 12°C on nearshore surveys and from 0°C to 12°C on offshore surveys. In late summer 1997, they ranged from 2°C to 14°C on nearshore surveys and from 4°C to 17°C on offshore surveys. Hence, available sea-surface temperatures were warmer overall in late summer than in early summer, were warmer on offshore surveys than on nearshore surveys, and were warmer overall in 1997 than in 1996. The latter pattern goes hand-in-hand with the reduced overall amount of ice cover in 1997 (see "Relationship to Ice Cover," above).

Large-scale availability of sea-surface temperatures in 1997 differed significantly between both survey types and seasons (Table 18). Multiple comparisons indicated that temperatures were significantly higher on offshore surveys than on nearshore surveys (where tidewater glaciers and glacial-fed streams dumped cold water into the bays) and higher in late summer (as waters warmed overall) than in early summer (Figs. 22 and 23, Table 17). When this analysis of availability was extended with the 3-factor MANOVA that added year to the model, availability differed significantly by survey type and season, as above, plus by year (Table 19). Multiple comparisons indicated that temperatures were significantly higher in 1997 than in 1996, higher on offshore surveys than on nearshore surveys, and higher in late summer than in early summer.

Kittlitz's murrelets occurred in a wide range of sea-surface temperatures on both nearshore and offshore surveys in both years (Figs. 22 and 23). In early summer 1996, they occurred in waters 2–13°C on nearshore surveys and 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. In late summer 1996, they occurred in waters 1–8°C on nearshore surveys and 2–8°C on offshore surveys. For nearshore and offshore surveys combined, 95% of all Kittlitz's murrelets in 1996 occurred in waters 3–9°C in early summer, and 90% occurred in waters 3–6°C in late summer. In early summer 1997, they occurred in waters 3–12°C on nearshore surveys and 4–11°C on offshore surveys. In late summer 1997, they occurred in waters 2–12°C on nearshore surveys and 4–12°C on offshore surveys. For nearshore and offshore surveys combined, 94% of all Kittlitz's murrelets in 1997 occurred in waters 4–10°C in early summer, and 88% occurred in waters 5–11°C in late summer. The 1 Kittlitz's murrelet seen on pelagic surveys in 1996 occurred in water 13°C, and those seen in 1997 occurred in waters 11°C (2 birds) and 12°C (3 birds). Hence, Kittlitz's murrelets on both nearshore and offshore surveys occurred in warmer water overall in 1997 than in 1996, but a seasonal pattern was inconsistent between the two survey types and years.

Large-scale use of sea-surface temperatures in 1997 differed significantly between both survey types and seasons (Table 20). Multiple comparisons indicated that Kittlitz's murrelets occurred in water that was significantly warmer on offshore surveys than on nearshore surveys and warmer in late summer than in early summer (Figs. 22 and 23, Table 17). When this analysis of use was extended with the 3-factor MANOVA that added year to the model, use did not differ significantly between seasons but did differ between years and survey types (Table 21). Multiple comparisons indicated that Kittlitz's murrelets occurred in water that was significantly warmer on average in 1997 than in 1996 and warmer on offshore surveys than on nearshore surveys.

Large-scale availability versus use of sea-surface temperatures in 1997 differed significantly between both survey types and seasons (Table 22). On nearshore surveys, Kittlitz's murrelets occurred in water that was cooler than that available on average in both early and late summer (Table 17). In contrast, on offshore surveys, they occurred in water that was warmer than that available on average in early summer but cooler than that available on average in late summer, with the contrast suggesting a movement toward cooler, glacial-affected areas at that time. When this analysis of availability versus use was extended with the 3-factor MANOVA that added year to the model, use did differ significantly by year and by both survey type and season, as above (Table 23). Kittlitz's murrelets occurred in water that was significantly cooler than that available on average on all nearshore and offshore surveys except the offshore survey for early summer 1997.

Relationship to Sea-surface Salinity.—Sea-surface salinity, which was examined only in 1997, had a moderate range in early summer but ranged widely in late summer (Figs. 24 and 25). On both cruises, sea-surface salinity on both nearshore and offshore surveys was higher toward the outer edges of the bays. In early summer 1997, salinities ranged from 16‰ to 30‰ on nearshore surveys and from 17‰ to 29‰ on offshore surveys. In late summer 1997, they ranged from 7‰ to 25‰ on nearshore surveys and from 11‰ to 24‰ on offshore surveys. Hence, available sea-surface salinity was higher overall in early summer than in late summer, had a greater range in late summer than in early summer, and was lower in nearshore waters than in offshore waters in late summer.

Large-scale availability of sea-surface salinity in 1997 differed significantly between seasons but not survey types (Table 18). Multiple comparisons indicated that mean salinities were significantly greater in early summer than in late summer, when freshwater input into these bays decreased their overall salinities (Figs. 24 and 25, Table 17). Sea-surface salinities did not differ significantly between survey types. Because we collected data on sea-surface salinity only in 1997, the analysis of availability could not be extended with a 3-factor MANOVA that added year to the model.

In early summer 1997, Kittlitz's murrelets occurred in waters of 19–30‰ salinity on nearshore and 20–28‰ on offshore surveys (Figs. 24 and 25); however, 99% occurred in waters 21–29‰ on nearshore surveys, and 92% occurred in waters 22–28% on offshore surveys. In late summer 1997, Kittlitz's murrelets occurred in waters of 10–24‰ salinity on nearshore and 11–24‰ on offshore surveys; however, use was not concentrated in particular salinities on either nearshore or offshore surveys. Hence, the mean sea-surface salinity used by Kittlitz's murrelets was greater in early summer than in late summer but had a greater range in late summer.

Large-scale use of sea-surface salinity in 1997 differed significantly between both survey types and seasons (Table 20). Multiple comparisons indicated that Kittlitz's murrelets occurred in water that was significantly more saline on offshore surveys than on nearshore surveys(where freshwater input was greater) and more saline in early summer than in late summer, when many birds moved to the vicinity of glacier faces (Figs. 24 and 25, Table 17). Because we collected data on sea-surface salinity only in 1997, the analysis of use could not be extended with a 3-factor MANOVA that added year to the model.

Large-scale availability versus use of sea-surface salinity in 1997 differed significantly between both survey types and seasons (Table 22). On nearshore surveys, Kittlitz's murrelets occurred in water that was more saline than that available on average in early summer but less saline than that available on average in late summer (Table 17). In contrast, on offshore surveys, they occurred in water that was less saline than that available on average in both early and late summer. Again, this analysis of availability versus use could not be extended with a 3-factor MANOVA that added year to the model.

Reproduction

Plumages as an Indicator of Reproduction.—Four AHY plumage categories could be recorded during both seasons (breeding, molting, winter, and unknown); in addition, an HY (juvenile) plumage category was possible in late summer. On both nearshore and offshore surveys, the proportions of all Kittlitz's murrelets that were classified as breeding-plumaged birds ranged between 92% and 97% (Table 26, Appendices 1–4). On most cruises, however, the proportions were on the order 96–97%, with the one exception being early summer 1996. On both nearshore and offshore surveys, the proportions of all Kittlitz's murrelets that were classified as molting birds ranged between 3% and 8%, with most cruises having 3–4% molting. Winter-plumaged birds rarely were recorded, and only in early summer; birds had not completely molted back into winter plumage by the ends of the late-summer cruises (that molt occurs in August and September, with the peak probably from mid-August through late September; Day et al., in review). Only 2 of 1,753 birds were not seen well enough to identify the plumage.

The proportion of birds that were in breeding plumage did not differ between nearshore and offshore surveys during any of the four cruises (Table 27). Thus, we pooled data between survey type and conducted between-season and between-year tests. The proportion of birds that were in breeding plumage did not differ between seasons within a year for either year (Table 27). Surprisingly, the test for 1996 was not significant, given the substantial differences in proportions; perhaps power was low, however.

The proportions of birds that were in breeding plumage differed between years within the same season for early summer but not for late summer (Table 27). In early summer, the proportions of birds in breeding plumage was significantly less in 1996 than in 1997. These results suggest that the above lack of a significant difference between early and late summer 1996 was caused at least partially by small sample sizes in late summer 1996.

In both 1996 and 1997, the proportion of Kittlitz's murrelets that were in breeding plumage during each bay-visit generally ranged between 90% and 100% during both early and late summer (Fig. 26). In early summer, the percentage of birds in breeding plumage declined fairly quickly (from 95% to 83%) during the first 2 weeks of 1996, but the percentage declined at about two-thirds that rate during the same period in early summer 1997 (from 98% to 90%). These declines probably reflect the arrival of non-breeding adult and subadult birds, both of which undergo the prealternate molt later than do breeding adults (see "Discussion"). In late summer, the proportion of Kittlitz's murrelets that were in breeding plumage was high overall but declined after early August (in 1996), as significant numbers of birds began the prebasic molt; however, reasons for the dip and subsequent increase in percentages around 23 July in 1997 are unclear. The high proportion of birds in breeding plumage at the beginning of the late-summer cruises 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 birds not in breeding plumage had left the study bays by the beginning of our surveys in late summer.

Group Size as an Indicator of Reproduction.—The proportion of single-bird groups (i.e., group size = 1) showed few temporal patterns that could be interpreted to suggest that many birds were reproducing (Fig. 27). The proportion of single-bird groups declined through time in early summer 1996 but showed no pronounced temporal pattern in early summer 1997. Overall proportions were much higher in late summer than in early summer, and the proportion of single-bird groups increased slightly through time in late summer of both years.

There were pronounced seasonal patterns in the proportions of single-bird groups (Fig. 27). The proportion of single-bird groups did not differ significantly between survey type during any cruise (Table 28). Thus, we pooled data between survey type and conducted between-season and between-year tests. The overall proportion of single-bird groups was 46.4% (104/224) in early summer 1996, 83.9% (141/168) in late summer 1996, 62.2% (252/405) in early summer 1997, and 77.3% (320/414) in late summer 1997. The overall proportion of single-bird groups differed significantly between seasons in both years, with proportions in late summer always being significantly higher than those in early summer. The overall proportion of single-bird groups differed significantly between years in early summer but did not in late summer.

Patterns of Production.—During both years combined, we saw only one HY Kittlitz's murrelet, a solitary bird seen just off a rocky beach on a nearshore survey in College Fjord on 30 July 1996. This bird was a definite HY bird, and we saw no birds that were classified as either probable or possible HY birds. We saw no HY birds of any category on nearshore surveys in 1997 or on offshore surveys in both years. We had no problem with misclassification between HY birds and winter-plumaged AHY birds, for no AHY birds occurred in a complete winter (basic) plumage on late-summer cruises (Table 26). In addition, we saw numerous marbled murrelets (particularly in 1996) that we classified as HY birds based on our criteria for Kittlitz's murrelets, suggesting that our classification system worked well. Because HY Kittlitz's and marbled murrelets are easily separated in the field, we had no problem with misclassification between the two species.

The calculation of HY:AHY ratios indicated that reproductive output was extremely low or zero in all four bays during both 1996 and 1997 (Table 29). Again, only one definite HY bird was recorded on both nearshore and offshore surveys combined, so ratios in all bays 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 12), 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 and Marks 1997; 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.

In contrast, evidence from the timing of movement of most of the four bays' populations in 1997 sheds little light on Kittlitz's murrelet reproduction. By using dates by which most of the population was present (Table 14), we estimate that most of the populations were present for a total of ≥60 days in all four bays. This lack of good estimates in timing occurred because we used information collected in 1996 to revise the cruise schedules in 1997, so that we were present only when large numbers of birds were present. However, because we were present in the bays during the time when fledging is believed to occur, because newly fledged juvenile Kittlitz's murrelets probably remain at sea in the general vicinity of the nest for ≥14 days after fledging, and because Kittlitz's murrelets were not seen carrying fishes (presumably to nestlings), it is highly doubtful that they bred successfully in any of the bays in 1997.

Residence Times of HY birds.—The lack of HY Kittlitz's murrelets prevented us from catching any young for color-marking to determine residence times in bays. In 1996, we even spent numerous daylight hours attempting to catch HY marbled murrelets with a long-handled net from our small skiff so that we could develop the expertise for catching HY Kittlitz's murrelets in 1997, but we were unable to catch even one HY 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. In 1997, few HY marbled murrelets were produced before the cruise ended, so we were unable to attempt to catch them at night with spotlights.

Mixed-species "Pairs" of Murrelets.—We observed what appeared to be mixed-species "pairs" of Kittlitz's and marbled murrelets during three of the four cruises in 1996 and 1997 (Table 30). We were unable to determine whether these birds actually were of different sexes, so the term "pair" is being used in a general sense here. We recorded no mixed-species "pairs" in early summer 1996, although we may not have recognized them as such during that cruise, and we saw none in Blackstone Bay during any cruise. For some obscure reason, most "pairs" were seen in Harriman Fjord. In two cases, we recorded mixed-species groups of Kittlitz's and marbled murrelets that we suspected contained a "pair" of these birds, but we were unable to confirm the presence of "pairs." Those suspected "pairs" were seen on 12 June and 27 July 1997 (Table 30).

From their behavior, these birds appeared to be paired: they sat on the water near each other (usually ≤1 m apart), they stayed and swam near each other when we disturbed one member of the pair, they often searched for the other member of the "pair" when we disturbed one, and so on. We did not hear any vocalizations, however, to determine whether each species called with its own species-specific call or used a unique call common to both members of the "pair."

The call of the Kittlitz's murrelet is a hoarse, raspy *ah-ah*, *ah-ah-ah*, or *aaaaahhh*, which is of variable length (usually 1–3 sec) and which may be made once to several times in succession. It sounds somewhat like a hoarse Northwestern Crow (*Corvus caurinus*) or Oldsquaw (*Clangula hyemalis*) and is made without opening the mouth—the throat is seen moving, suggesting that the noise is resonating through the sides and bottom of the buccal cavity. Paired Kittlitz's murrelets of presumably different sexes were seen making identical vocalizations of this type to each other when separated, and we have heard them make no other vocalizations of any type.

The primary calls of the marbled murrelet are *keeeerrrr* and a high-pitched whistle (Nelson 1997). The call is made with the mouth open, rather than while resonating through the buccal cavity. Paired marbled murrelets of presumably different sexes were seen making identical vocalizations of this type to each other when separated, and we have heard them make no other vocalizations of any type.

Trophics and Feeding

Mist-netting for Trophic Studies.—In early summer 1996, we attempted to catch Kittlitz's murrelets with floating mist nets on four nights in Harriman Fjord and Blackstone Bay (Tables 1 and 31). 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 in 1996 because Kittlitz's murrelets did not arrive there until late in the season and did not sample in College Fjord in 1996 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 pulled 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 31). 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 vicinity of the net system. Further, we were unable to deploy the net system 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 impossible to locate the net system in spots that numerous Kittlitz's murrelets regularly traversed.

Although we had planned on mist-netting in late summer 1996, 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. Following the recommendations of the Trustee Council's Chief Scientist (R. Spies) and head reviewer for avian studies (C. Haney), we did not attempt mist-netting in 1997 and reallocated that time to other activities.

Patterns of Feeding.—Kittlitz's murrelets exhibited pronounced patterns of feeding by season, year, and survey type, but not by time of day (Table 32). The proportion of birds that were feeding was much higher overall in 1997 than in 1996, in late summer than in early summer, and in nearshore areas than in offshore areas. In contrast, the proportion of birds that were feeding showed no noticeable pattern by time of day, in that proportion of birds that were feeding were similar between the morning and afternoon.

Kittlitz's murrelets exhibited no patterns of feeding with respect to tidal stage (Table 33). Proportions of birds that were feeding were highly similar between years and tidal stages for nearly all season/survey type data sets and exhibited few dramatic differences within a year. The proportion 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 (Table 32), we doubt that this difference is biologically significant, whether or not it is statistically significant.

Kittlitz's murrelets exhibited no strong patterns of feeding with respect to strength of tidal current (Table 34). In early summer, the proportion of birds feeding tended to be greater when tidal currents were moderate and/or strong on nearshore surveys and when tidal currents were weak and/or moderate on offshore surveys; in late summer, the proportion of birds feeding tended to be greater when tidal currents were weak and/or strong on both nearshore and offshore surveys.

On nearshore surveys, Kittlitz's murrelets exhibited no strong patterns of feeding by habitat type other than avoiding marine-sill-affected habitats completely (Table 35). In early summer, more birds fed in glacial-stream-affected habitats, whereas, in late summer, more fed in glacial-affected habitats. This seasonal shift in proportions feeding actually follows the seasonal shift of murrelets to glacial-affected habitats described earlier and suggests that these glacier faces are extremely important at that time to feeding Kittlitz's murrelets. We did not compile numbers for the offshore data sets because all habitats were of one type.

As might be expected from the above discussion, the multiway contingency table analysis indicated that season, year, and survey type were significant in determining the proportion of Kittlitz's murrelets that were feeding (Table 36). Time of day, tidal stage, current strength, and habitat type all showed no relationship to the proportion feeding. In contrast, the proportion feeding was significantly higher in late summer than in early summer, in 1997 than in 1996, and in nearshore waters than in offshore waters.

We examined the relationship between the proportion of Kittlitz's murrelets that were feeding and current strength further because, rather than assuming that the three current strengths had an equal effect on the proportion feeding, it was possible that the proportion feeding would differ by current strength in another pattern. Hence, we used a multiway goodness-of-fit test to determine whether the proportion feeding differed from that expected by current strength as described in "methods," above: 16.7% in weak currents, 33.3% in moderate currents, and 50.0% in strong currents. These tests showed a significant deviation from expected proportions in all four season/survey type data sets (Table 37). Proportions feeding were significantly greater than expected in weak currents in 2 of the 4 tests, in moderate currents in 3 of the 4 tests, and in strong currents in 0 of the 4 tests. Proportions feeding were significantly less than expected in weak and moderate currents in 0 of the 4 tests and in strong currents in 3 of the 4 tests. Hence, the proportions feeding in weak and moderate currents generally was greater than expected and the proportion feeding in strong currents generally was less than expected.

Food Habits.—Although the data on food habits are limited, Kittlitz's murrelets primarily appeared to forage on fishes in these bays in 1996 and 1997 (Table 38). We were able to identify only about one-third of the fishes that Kittlitz's murrelets were seen holding, and all of them were Pacific sand lance. Although we believe that most of the unidentified fishes were Pacific herring and/or capelin, we were unable to confirm the identifications at a distance.

Prey items eaten by Kittlitz's murrelets were similar overall to those identified for marbled murrelets in the same bays in 1996 and 1997 (Table 39, Appendix 5). In both species, ~33% of the prey items were identified to species, with the remainder being unidentified. Of prey items that were identified to species, 100% of those taken by Kittlitz's murrelets and 89% of those eaten by marbled murrelets were Pacific sand lance. The remaining identified items eaten by marbled murrelets were Pacific herring.

Although mean prey sizes of Kittlitz's murrelets were smaller than those of marbled murrelets (Table 38), these mean sizes did not differ significantly between the two species ($t = -1.299$; df = 13; $P = 0.216$), indicating extensive overlap between the two species in the size of prey that are eaten. These prey sizes suggest that these fishes all are from 0- or 1-year age-classes.

Mixed-species Feeding Flocks.—We saw Kittlitz's murrelets in mixed-species feeding flocks on only a few occasions during the two years of research (Table 40). The limited information suggests that these mixed-species flocks were considerably more common in 1997 than in 1996, which matches our general impression that fishes were more available in 1997: considerably more Kittlitz's murrelets were seen holding fishes in 1997 than in 1996 (Table 38), as were marbled murrelets in 1997 (Appendix 5), and feeding frequencies were significantly higher overall in 1997 than in 1996 (Table 36). Mixed-species feeding flocks that contained Kittlitz's murrelets were seen throughout the day and were far more common in late summer than in early summer (Table 40). The marbled murrelet is the species that Kittlitz's murrelets most often associate with in these flocks, with black-legged kittiwakes (*Rissa tridactyla*) being next in frequency. Mew gulls (*Larus canus*) and arctic terns (*Sterna paradisaea*) appear to be uncommon in these feeding flocks.

Depth of Feeding.—Kittlitz's murrelets often feed in fairly shallow water, particularly over shallow banks of sediments that have been left by the retreat of the glaciers. For example, most of the nearshore areas along the southeastern and northwestern sides of Unakwik Inlet (Figs. 8 and 12), the western side of College Fjord (Figs. 9 and 13), and the northern side of Harriman Fjord (Figs. 10 and 14) where Kittlitz's murrelets were seen feeding appear to be shallow. In Harriman Fjord, shallow areas off of the mouths of Surprise and Barry inlets in particular were used by feeding Kittlitz's murrelets; most of the depths were in the range 1–10 m on the ship's sonar. Because feeding frequency and standardized habitat type were not related (Table 36), we investigated whether feeding frequency might be related to depth, with avian density as an indicator of feeding frequency. Mean water depth of a segment had a significant negative relationship with density of Kittlitz's murrelets in Harriman Fjord in early summer 1996 ($r = -0.397$; df = 28; $P = 0.033$). There was, however, no significant relationship between depth and density of Kittlitz's murrelets in late summer 1996 ($r = 0.195$; df = 28; $P = 0.322$), early summer 1997 ($r = 0.166$; df = 28; $P = 0.400$), and late summer 1997 ($r = 0.193$; df = 28; $P = 0.327$), indicating that the relationship between feeding frequency and depth is weak.

Other Aspects of Feeding.—Kittlitz's murrelets exhibited fairly long dive times while feeding. These dive times averaged 29.2 sec (SD = 10.4; range = 6–58; n = 76) and were almost identical to the mean length of dives by marbled murrelets feeding in the same bays ($\bar{x}$ = 29.5 sec; SD = 7.5; range = 8–48; n = 88). Not surprisingly, these mean dive times did not differ between species ($t = -0.186$; df = 134; $P = 0.853$).

Surprisingly, Kittlitz's murrelets did not 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 body of Unakwik Inlet, and at shoals, such as the tide rips that regularly formed over the shoal at Point Doran in Harriman Fjord and over the marine sills in Unakwik Inlet and Blackstone Bay. This lack of regular observations of Kittlitz's murrelets feeding in tide rips matched our feeding data for current strength, which showed a lack of feeding during strong currents (Table 37).

Kittlitz's murrelets feeding off the faces of the glaciers also did not forage in the same manner as black-legged kittiwakes, arctic terns, and mew and glaucous-winged (*L. glaucescens*) gulls. These three species primarily appeared to forage 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; this method of feeding is consistent with their inability to dive and their reliance on surface-seizing for catching prey. As a result, they often moved from area to area where pieces of glacier ice were being calved. In contrast, Kittlitz's murrelets appeared to forage by pursuit diving and capturing prey underwater.

During a bathymetric survey of Harriman Fjord on 19–21 June 1997, we used a side-scanning sonar to map the bathymetry of the nearshore zone; this sonar is used primarily to locate schools of fishes (Capt. R. Horton, Cordova, AK, pers. comm.). Off the face of Harriman and Surprise glaciers, this sonar recorded large numbers of fish-sized objects in the water-column; many Kittlitz's murrelets were feeding off of these glaciers in early summer 1997 (Fig. 14). Capt. Horton indicated that these fish densities compared well with some of the highest densities that he had seen during a forage-fish survey around Prince William Sound in 1996. It was unclear what fish species these sonar targets in 1997 represented, however.

We noticed that Kittlitz's murrelets appeared to have relatively larger eyes than marbled murrelets do. The large size of the eyes suggests an adaptation to foraging in low-light conditions—i.e., for feeding at night, for feeding in low light levels that occur at high latitudes in winter, or for feeding in highly turbid water where light is limited. We have examined ecological and morphological adaptations in both this species and marbled murrelets in a manuscript that is being prepared for submission to a peer-reviewed journal (Appendix 6). This manuscript suggests that the differences in relative eye size between the two species may result from adaptations to foraging in waters of different clarity, with Kittlitz's murrelets being adapted to foraging in highly turbid water and marbled murrelets being adapted to foraging in clear water.

DISCUSSION

Characteristics affecting observation conditions did not differ overall between years; hence, interannual differences in distribution and abundance, habitat use, reproduction, and feeding ecology of Kittlitz's murrelets could not be caused by interannual differences in sightability of birds. Characteristics were similar between years except for precipitation, which generally occurred more frequently in 1997 than 1996 during early summer but more frequently in 1996 than 1997 during late summer. Environmental characteristics exhibited substantial variation between seasons and years, with ice cover being greater in 1996 than 1997 in most cases. Conversely, sea-surface temperatures were considerably higher in 1997 than 1996, a pattern that is complementary to the reduced ice cover in 1997. No data were collected on secchi depth and sea-surface salinity in 1996, so no interannual comparisons were possible.

Abundance and Distribution

Kittlitz's murrelets differed substantially in abundance and distribution among and within the four study bays in both 1996 and 1997. The various ANOVAs, however, indicated that overall densities in Harriman and College Fjords were greater than overall densities in Blackstone Bay and Unakwik Inlet. These results suggest that this species exhibits a large-scale selection for those bays having the greatest numbers of tidewater glaciers. In addition, nearshore densities were higher overall in 1997 than in 1996, indicating that there may be substantial interannual variation in densities of Kittlitz's murrelets; however, no significant differences in offshore densities were seen, so these interannual differences apparently occur in only some locations.

Densities of Kittlitz's murrelets did not differ significantly between nearshore and offshore waters within bays. Densities in these two locations, however, clearly were much higher than they were in more open waters outside of bays (i.e., on pelagic surveys), suggesting that Kittlitz's murrelets rarely, if ever, leave the bays during the breeding season. (It is possible that the few Kittlitz's murrelets seen on pelagic surveys represented scattered birds that nest in some of the suitable habitat that is occurs sporadically along the edges of Port Wells and Passage Canal, rather than representing birds that had left the glaciated fjords.) This preference for bays by Kittlitz's murrelets is consistent both with that seen by Sanger (1987) and an avoidance of more open (less protected) waters throughout the Sound during the breeding season (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 ≤1 km from shore, also suggesting a preference for near-shoreline habitats. 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.

The timing of arrival of Kittlitz's murrelets differed among bays in early summer of both 1996 and 1997. In early summer 1996, densities were stable or increasing slightly in Harriman Fjord and Blackstone Bay, whereas they were increasing at a faster rate in both Unakwik Inlet and College Fjord. In early summer 1997, densities were stable or increasing slightly in Unakwik Inlet, increasing at a faster rate in College Fjord and Harriman Fjord, and increasing rapidly in

Blackstone Bay. Surprisingly, the highest nearshore and offshore densities in College Fjord always were seen in late summer, rather than early summer, suggesting that Kittlitz's murrelets may arrive there later than they do in other bays.

We speculate that the later arrival of Kittlitz's murrelets in Unakwik Inlet and College Fjord in early summer 1996 was related somehow to the considerably greater ice cover and/or colder sea-surface temperatures in those bays than occurred in Harriman Fjord and Blackstone Bay, rather than a temporal difference in food availability (see below). No known oceanographic or glaciological characteristic would differ systematically among the four bays, as was seen for the arrival of Kittlitz's murrelets (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.). In addition, the lack of a dramatically different pattern of arrival among bays in early summer 1997 is explained most easily by the more moderate environmental conditions occurring during that cruise. That ice cover and/or sea-surface temperatures may be limiting the time of arrival of birds is suggested further by the consistently late arrival of birds in College Fjord. Although nearshore ice cover in College Fjord in early summer declined dramatically between years, ice cover during that season was the highest of all bays and was 16.2% (nearshore) to 21.6% (offshore) overall in early summer 1997. These percentages still are in the range at which ice cover has a strong negative effect on densities of Kittlitz's murrelets (Figs. 16 and 17). In addition, sea-surface temperatures in College Fjord in early summer increased slightly from 1996 to 1997 in nearshore waters (but exhibited about the smallest percent increase of all four bays) and actually decreased slightly in offshore waters. Hence, the amelioration of environmental conditions in early summer 1997 was smallest in College Fjord, and the consistently later arrival of birds there probably reflected that smaller amount of amelioration.

This among-bay variation in the amount of ice cover also affected the distribution of Kittlitz's murrelets within bays during early summer 1996 but not during other cruises. Following the pattern seen above, in early summer 1996, birds were restricted to the central and lower parts of Unakwik Inlet and College Fjord, whereas they were distributed widely throughout Harriman Fjord and Blackstone Bay. In contrast, they were distributed essentially throughout all bays during the other three cruises (with the exception of a complete absence of birds in Blackstone Bay in late summer 1996). A movement toward glacier faces from both early to late summer 1996 and early to late summer 1997 was seen, 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) 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, also suggesting some sort of physical limitation of ice and/or sea-surface temperatures in early summer.

We believe that ice was the dominant factor affecting the distribution of Kittlitz's murrelets in both 1996 and 1997. In early summer of both years, we saw almost no Kittlitz's murrelets in areas of extensive 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 1996, and there was a high (67% of all glacial-affected segments) frequency of association with glacial-affected habitats in early summer 1997, suggesting that food was not in short supply near glaciers at that time. In contrast, amelioration of environmental characteristics by late summer allowed Kittlitz's to spread throughout all bays. We emphasize at this point, however, that ice cover, sea-surface temperatures, and the availability of food all may be interrelated to some extent, so all may exert some influence on the distribution of Kittlitz's murrelets in early summer.

One of the most interesting aspects of the comparative within-bay distributions was the concentration of Kittlitz's Murrelets off of the face of Harriman Glacier in 1997 (Fig. 14) but not in 1996 (Fig. 10). This glacier was inactive in 1996 and did almost no calving that year, and the little calving that did occur in 1996 was seen primarily in late summer. In 1997, however, this glacier was extremely active and calved nearly continuously during both cruises. In particular, an opening that appeared near the northern end of the glacier face in 1997 was a site of active calving and rapid retreat. It is possible that the glacier face has come off of the rear edge of the sill in this location; if so, further rapid retreat may occur in the near future. We are unclear why Kittlitz's Murrelets occurred in such high densities near this actively calving glacier in 1997, but there clearly was a sudden attraction to it.

Population Size.—Population sizes of Kittlitz's murrelets in these four bays are fairly small, representing a total population of ~1,400 ± 1,400 birds in 1996 and ~1,300 ± 650 birds in 1997. Maximal counts of numbers of birds during nearshore and offshore surveys combined indicate that 316 birds in 1996 and 427 in 1997 were counted in the four bays combined, putting the lower limit on the 2 years' population estimates at those levels. Hence, possibly as many as 2,600-2,800, but probably about half that many, Kittlitz's murrelets occur collectively in these 4 bays. Interannual variation in estimated population sizes was high in all four bays, although 95% confidence intervals overlapped between years for all bays except College Fjord. 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 Kittlitz's murrelets in Prince William Sound as a whole. 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) and Agler and Kendall (1997) recalculated the overall estimate from the same data to be 63,229 ± 80,122 birds. Some uncertainties exist about these estimates, however, and we have 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 pelagic survey (when within bays, equivalent to our 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.*). Because the multiplication factors for offshore surveys are high, this abnormal data point dramatically inflated the total population estimate for 1972. In addition, 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 in 1972. Hence, if this flock actually was composed entirely of several thousand Kittlitz's murrelets, it probably was exceptional, although Isleib and Kessel did not suggest that it was.

Data presented in Appendix A of Agler and Kendall (1997) also can be examined to see what inferences can be made about whether the Kittlitz's murrelet population has changed in Prince William Sound. Their Sound-wide estimates for July since the *Exxon Valdez* oil spill have varied from a high of 6,436 in 1989 to a low of 1,280 in 1996, or by –77% to +129% among samples from subsequent years. We question whether the total population of Kittlitz's murrelets in Prince William Sound actually did vary by this amount over these years. Further, our estimates (1,410 and 1,280 in 1996 and 1997, respectively), which are generated for ~50% of the bays that contain most of the Sound's population for Kittlitz's Murrelets, are equal to or greater than the population estimated by Agler and Kendall (1997) for all of Prince William Sound during summer 1996. (We do, however, emphasize that both our and Agler and Kendall's estimates are on the same order of magnitude—i.e., a few thousand birds.) The extensive interannual variation in estimated population size seen in Agler and Kendall's study, coupled with the extreme variation in abundance and distribution among bay-visits and bays (depending on ice cover and sea-surface temperatures) seen in this study, suggests either that (1) for some reason, these birds really do exhibit dramatic interannual changes in population size on a regional scale such as Prince William Sound (and, if so, where are they in those years when they do not visit the Sound?), or (2) the broad-scale surveys used by the U.S. Fish and Wildlife Service are not adequate for estimating accurate Sound-wide populations of this highly clumped species. At this time, it is unclear which case is true, although the latter appears to be more likely: random sampling does not estimate population sizes of highly clumped species accurately (Thompson 1992).

For argument's sake, we assumed that the 1972, 1989, and 1996 summer population estimates and the winter 1972, 1973, 1990, and 1996 population estimates for Kittlitz's murrelets in Prince William Sound (Agler and Kendall 1997) were accurate and modeled what sort of average annual population changes would be required for the population to have undergone such changes among years (Table 41). In the winter comparisons, we included data for both 1972 and 1973 because they both were available as starting points and because they differed by an order of magnitude from year to year. The models for changes in summer populations among time periods ranged from –12.58%/yr to –20.60%/year, and those for changes in winter populations ranged from +5.82%/yr to –24.28%/yr. Although one might reasonably assume that a change in summer should be matched by a similar change in winter, the two data sets are not related (Fig. 28; $r = 0.46$; df = 3; $P = 0.440$), indicating a lack of seasonal consistency in estimated population trends within the Agler and Kendall data sets. Our data for 1996 and 1997 suggest an interannual change of –9.30%, although we have only 2 years of data. For comparison, the spectacled eider (*Somateria fischeri*) population on the Yukon-Kuskokwim Delta underwent a "precipitous" (the term that usually has been applied for this large a rate of decline) ~7%/yr decline in numbers of birds seen on aerial surveys during the period 1957–1992 and a ~14%/yr decline in the number of nests seen on ground-based surveys recorded there during the period 1986–1992 (Stehn et al. 1993). The index population of red-legged kittiwakes (*Rissa brevirostris*) on St. George Island also exhibited a decline of ~50% overall (~5%/yr) during the period 1976–1989 (G. V. Byrd, USFWS, Homer, AK, pers. comm.), probably as a result of 10 consecutive years of low or no productivity. For Kittlitz's murrelets, the assumption of an estimated survivorship of ~85%/yr for an alcid of this size (Beissinger 1995) would yield a decline of 15%/yr if there had been no production of young Kittlitz's murrelets over the 25 years since the first population-level data were collected.

Evaluation of Sampling Protocol.—Our evaluation of the timing of sampling suggests that the best time for sampling occurs between 0600 and either 1500 or 1700. On nearshore and offshore surveys combined, 83.8% of our sampling effort (by time) over both years combined was concentrated in the period 0600–1500 (n = 22,651 min of sampling). If the optimal sampling period for surveys actually is 0600–1700, we concentrated 95.6% of our overall sampling effort during that period. Hence, it appeared that nearly all of our sampling effort occurred at the optimal time of the day.

The counting cross-check that we conducted in early summer 1997 indicated that the slow sampling rate, the constant checking for birds possibly missed, and the generally very good to excellent sampling conditions experienced in these bays results in a low to very low estimated inter-observer variability. Because this estimate of inter-observer variability is so low (we would be far more concerned about accuracy if this variation was, say, 30%), we consider our method to be highly accurate. On the other hand, there may be some unusual conditions under which we both miss a high percentage of birds (although we do not believe that we do under any circumstances). It would, however, be impossible without a major sampling effort to determine the actual percentage of birds that we both miss. That effort would be beyond the scope of this project. Thus, we suggest no changes to the sampling protocol at this time.

Habitat Use

Although Kittlitz's murrelets exhibited an overall preference for glacial-affected habitats and secondarily for glacial-stream-affected habitats and an avoidance of marine-sill-affected habitats, these "preferred" habitat types were not always preferred in all bays and during all cruises. 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 evenly throughout all bays (particularly in 1996). Second, the heaviest ice cover and coldest temperatures in early summer occurred off the faces of the tidewater glaciers, making some of the segments with this specific habitat type unused by Kittlitz's murrelets. This greater ice cover in early summer off these tidewater glaciers probably explains why their frequency of use was lower in early summer than late summer during both years (see "Patterns of Habitat Use" in "Results," above). Once ice cover declined and sea-surface temperatures increased in these glacial-affected habitats later in the summer, Kittlitz's murrelets spread throughout all habitats. A final reason why the pattern of habitat use was not consistent across all bays, seasons, and years may be related to variations in freshwater input from glaciers in glacial-affected and glacial-stream-affected habitats. We noticed substantial but unquantified variation in rates of freshwater input and in water clarity and mixing among segments of these two 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.

All evidence indicates that glacial-affected habitat is the habitat type that is most preferred by Kittlitz's murrelets. Densities in this habitat type often was the highest of all, and the shift in distribution of murrelets to this habitat from early to late summer resulted in a high frequency of use of this habitat in 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).

Kittlitz's murrelets showed stronger relationships to the four habitat variables that were examined (i.e., ice cover, secchi depth, sea-surface temperature, and sea-surface salinity) than they did to the standardized habitat types. In nearshore waters, where murrelets concentrated in late summer, they used less ice cover (at a large scale) than was available to them in early summer and greater ice cover than was available in late summer. This increase in use of ice cover probably occurred because ice cover in nearshore waters often was too high and/or sea-surface temperatures were too low in early summer for Kittlitz's murrelets to occur there at all or in large numbers; hence, they may have been forced into other areas that may not have been as preferred. In contrast, as overall ice cover decreased and overall sea-surface temperatures increased in late summer, Kittlitz's murrelets moved into areas near glacier faces, as discussed above. That such a move into the proximity of tidewater glaciers occurred in late summer also was seen in the distributional evidence presented above and in the significant decreases in secchi depth (which is lowest off the faces of glaciers) and sea-surface salinity (which decreases as a result of freshwater input) in late summer. At a fine scale, Kittlitz's murrelets occurred in localized areas of low ice cover (i.e., open water) within areas of heavier overall ice cover, indicating that heavy ice cover somehow affected their distribution or dispersion within the bays. The shift toward using increased ice cover in late summer at both large and small scales, contrary to expectation based on early-summer use, may have occurred as a result of a change in the size, shape, and/or dispersion of ice between seasons; however, we have no data to prove that ice characteristics, other than percent cover, changed between cruises.

Although Kittlitz's murrelets sometimes 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%, yet 15–20% of all survey segments at that time had >35% ice cover. These segments usually were those that occurred in the upper ends of the bays and off the faces of tidewater glaciers. In addition, Kittlitz's murrelets generally avoided most areas with fine-scale ice cover >10% and did not appear to penetrate into heavy ice in early summer, when overall ice cover is greater and, hence, there are fewer areas with ≤10% ice cover. Consequently, ice cover did limit the distribution of Kittlitz's murrelets, even though they sometimes did use a greater ice cover than was available to them on average. In addition, the fact that Kittlitz's murrelets did not vary annually in use of ice suggests that they tend to occur only in areas where the amount of ice is limited.

Kittlitz's murrelets showed a pronounced relationship to water clarity. In general, the water was clearer in the offshore zone than in the nearshore zone and in early summer than in late summer. Kittlitz's murrelets in offshore waters generally occurred in water of the average clarity that was available to them seasonally, probably because there was little within-bay variation in clarity. In nearshore waters, however, Kittlitz's murrelets experienced great spatial variation in available water clarity, with water turbidity consistently decreasing from glacial-affected habitats to glacial-stream-affected habitats and, finally, glacial-unaffected habitats. Because of the inshore movement to the vicinity of tidewater glaciers and glacial streams in late summer, secchi depths used by Kittlitz's murrelets actually decreased dramatically at that time.

Kittlitz's murrelets showed relationships to sea-surface temperature that, in a general sense, matched the seasonal and geographic variations in that habitat characteristic. Available temperatures were higher in offshore waters than in nearshore waters, higher in late summer than in early summer, and higher in 1997 than in 1996. Kittlitz's murrelets showed similar patterns of use. They used waters in 1997 that were slightly warmer than those in 1996, but this difference simply seemed to reflect a difference in availability. Overall, however, they tend to avoid waters greater than ~12°C.

Kittlitz's murrelets showed relationships to sea-surface salinity that, in a general sense, matched the seasonal and geographic variations in that habitat characteristic. Available salinities were higher in the offshore zone than in the nearshore zone and lower in late summer than in early summer. Kittlitz's murrelets followed this pattern in use except for early-summer nearshore surveys. At that time, Kittlitz's murrelets actually occurred in water that was more saline than that available to them on average. In other words, a substantial number of murrelets did not occur in locations, such as glacial-affected areas, that had large amounts of freshwater input. As environmental conditions ameliorated in late summer, these birds then were able to move into those areas having large freshwater inputs.

Reproduction

Plumage as an Indicator of Reproduction.—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. Information on the age-structure of any Kittlitz's murrelet population is not 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 a "breeding-plumaged bird" is. A substantial percentage (>50% by our recollection) of the birds that we had classified as "breeding-plumaged" in early summer 1996 exhibited some non-standard breeding plumage characteristics, including white under-tail coverts, white post-mandibular patches, white scapulars, a whitish collar on the neck, and/or significant amounts of white on the breast and throat. (In our classification system, any bird that was called breeding-plumaged simply had a plumage that was predominantly, rather than completely, breeding-plumaged.) Indeed, based on our experience with other alcids, we would have considered most of the birds seen in early summer 1996 to have been non-breeders or subadults, based solely on their incompletely expressed breeding plumages until sometime in the middle of the summer. In contrast, most birds in early summer 1997 exhibited more typical, complete breeding plumages, suggesting either that the prealternate molt in 1996 was delayed, that a large number of the birds seen in 1996 were subadults, or that Kittlitz's murrelets have a molting strategy that is different from that of other alcids.

In late summer 1996 and 1997, most breeding-plumaged birds were completely brown (i.e., in complete breeding plumages) early in the cruises, but they began developing whitish speckling underneath, on their faces, and in the collars on the napes of their necks late in the cruise, as they entered the prealternate molt. As might be expected from the slight difference in timing between the two late-summer cruises, the percentage of birds that had entered the molt was higher in late summer 1996, which extended further into August than the 1997 cruise did.

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 in early summer 1996 suggest that either many of these birds were breeding in what was not a "typical" breeding plumage or, if a "typical" breeding plumage is required for these birds to breed, many of these birds were not breeding. The opposite was true in early summer 1997, when nearly all birds were in complete breeding plumage by early June.

We believe that the difference between years may be related to age of the birds, rather than to a delay in the timing of the prealternate molt. The timing of molt is believed to be controlled by photoperiod, rather than by other extrinsic factors such as temperature (Payne 1972); hence, the timing should be constant interannually. On the other hand, subadult marbled murrelets and auklets arrive in the vicinity of the breeding grounds in incompletely molted plumages during the summer (Bédard and Sealy 1984, Flint and Golovkin 1990, Carter and Stein 1995). Although information on the timing of molt in subadults is limited in marbled murrelets, subadult auklets have specific molting schedules for each age-class and molt progressively earlier in successive years until their molt schedule matches that of adults (Bédard and Sealy 1984). Hence, it is more probable that the late-molting Kittlitz's murrelets that we observed in 1996 represented subadult birds produced in previous years than it represented interannual variation in molt schedules of breeding adults.

We also have seen great overall variation in plumage colors in the field and in museum specimens, suggesting that some plumage variation possibly related to reproductive status may be seen in the field. Similar variation in the plumage of the marbled murrelet has been recorded; however, some of those "non-typical" birds were found to be breeding (Burns et al. 1994, Kuletz et al. 1995). 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 reproductively related plumage characteristics are visible in the field, thereby increasing our ability to estimate accurate percentages of breeding birds in a population.

Group Size as an Indicator of Reproduction.—It appears that temporal patterns of the proportion of single-bird groups of Kittlitz's murrelets has little explanatory power in the context of reproduction. In effect, these results often were exactly opposite those that were predicted by the frequency models (see "Reproductive Performance" in "Methods," above). Although these patterns of group size appeared to have little explanatory power in the context of reproduction, they could if our predictive models are incorrect. These patterns certainly are consistent from year to year in Kittlitz's murrelets, and an identical pattern is seen in marbled murrelets (Day and Nigro, unpubl. data), suggesting that these patterns are reflecting some previously unidentified aspect of the biology or behavior of this genus.

Production.—Reproductive output by Kittlitz's murrelets in the four study bays was essentially zero in 1996 and was zero in 1997. In addition, the bays' populations were present for too short a time in 1996 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; data for 1997, however, were too uncertain for us to draw any conclusions about the probability of nesting.

Finally, if all HY Kittlitz's murrelets (which appear to be similar in behavior to marbled murrelets) had left the bays by our first visits in late summer 1996, 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 little time at sea in the vicinity of the nest after they had fledged. In 1997, we began surveys on the earliest fledging date ever recorded in this region for this species, yet we still saw no HY birds over the next ~20 days. On the other hand, the plumage data indirectly suggest that the large number of late-molting birds seen in early summer 1996 represented a cohort of subadults that had been produced in one or more previous years (see "Plumage as an Indicator of Reproduction," above), so it appears that successful reproduction may occur sporadically. Although it is possible that we left the field before fledging occurred, the latest estimated date of fledging in this region is 10 August (Day 1996), or ~5 days before we left the field in 1996 and ~5 days after we left it in 1997. Hence, we do not believe that we left the field too early in both years to locate fledglings.

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; *in litt.*) 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 1 egg/year, are estimated to have an annual adult survivorship of 85–90%. 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 HY:AHY ratios of ~0.18–0.28:1; correcting for the higher numbers of AHY birds seen in the bays in early summer, these ratios would be ~0.13–0.26 for Kittlitz's murrelets, or about 6–13 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, Beissinger (*in litt.*) estimates that the low levels of fecundity recorded in this study and average annual survival rates of 85–90% would result in annual population declines of 10–15% if maintained over many 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 in this region (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 *all* 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.

Mixed-species "Pairs."—We saw several of what appeared to be mixed-species "pairs" of Kittlitz's and marbled murrelets during three of the four cruises. From their behavior, these birds appeared to be paired, but we could not distinguish if they were actually male/female pairs. We also did not hear any vocalizations, so we were unable to determine whether each species called with its own species-specific call or used a unique call common to both members of the pair. At this time, we are unclear about the population-level implication of the occurrence of such "pairs." Clearly, however, if the birds remained paired, such "pairs" would remove individual Kittlitz's murrelets from the small pool of potential breeders occurring in each bay, thereby decreasing the total reproductive potential of a bay's population. Whether this number of birds lost to the potential breeding pool is significant at a population level is unclear, but we speculate that it may have a negative effect on the Kittlitz's murrelet population in Prince William Sound and/or that it is may be related to the low number of Kittlitz's murrelets in these bays.

The reasons for such mixed-species pairing are unclear. Individual species have specific plumages, vocalizations, and courtship displays that promote reproductive isolation and, hence, avoid the waste of reproductive effort on other species and on the production of eggs that may or may not result in reproductively fertile offspring (Mayr 1963, Welty 1982). Reproductive isolation is not, however, complete in all species and sometimes results in the production of interspecific hybrids. Such hybridization is common in some bird groups and rare in others, with hybrids being common in waterfowl, even across genera in some cases, and in gulls (Mayr 1963, Williamson and Peyton 1963, Bellrose 1976, Snell 1991, Bell 1996).

Hybridization in alcids appears to be rare, for it rarely is reported in the literature. The most common suggested alcid hybrids occur between the phenotypically similar and often geographically sympatric common (*Uria aalge*) and thick-billed (*U. lomvia*) murres (e.g., Cairns and DeYoung 1981, Friesen et al. 1993). Such a relationship between the occurrence of hybridization and phenotypic and geographic similarity in species raises the possibility of attempted hybridization in Kittlitz's and marbled murrelets, which also have such characteristics. In addition, interspecific hybridization (and, presumably, attempts at hybridization) occurs more frequently in situations in which one species is dramatically outnumbered by another (see Friesen et al. 1993 and discussion therein). Such attempts usually result in males of the common species pairing with females of the rare species, primarily because of an absence of mating stimuli for females of the rare species (Friesen et al. 1993). In our study area, Kittlitz's murrelets are outnumbered by marbled murrelets by a ratio of ~6:1 on nearshore surveys, ~5:1 on offshore surveys, and ~160:1 on pelagic surveys; ratios for nearshore and offshore surveys would be even higher if marbled murrelet populations in the outer parts of the study bays were included. Hence, the overall rarity of Kittlitz's murrelets may be resulting in these mixed-species pairs, possibly decreasing the reproductive output of Kittlitz's murrelets even further.

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. The distribution of Kittlitz's murrelets may differ dramatically from year to year, for Burns et al. (1994) caught a Kittlitz's murrelet in 1993 in a part of Unakwik Inlet where we saw none in 1996; however, we did see some there in 1997. 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, tidal stage, current strength, and habitat type. In contrast, the proportion feeding was much greater in late summer than in early summer, in 1997 than in 1996, and in nearshore areas than in offshore areas. Although proportions feeding did not differ significantly among current strengths, proportions were higher than expected during weak and moderate currents and lower than expected in strong currents. 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., because densities are highest there and proportions feeding are similar among habitats, the actual number of feeding birds is highest in this habitat) 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.

Even though 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 represented a mixed-species feeding flock with marbled murrelets in mid-late summer, so perhaps the presence of mixed-species feeding flocks was more important to the Kittlitz's murrelets than was the presence of tidal fronts.

Food Habits.—Although the data on food habits are limited, Kittlitz's murrelets appeared to forage primarily on fishes, with the identified species being Pacific sand lance, in these bays in 1996 and 1997. We believe that most of the unidentified fishes were Pacific herring and/or capelin. We do not know what the small schools of larval fishes that we saw in late summer 1997 were, although D. Irons (pers. comm.) collected some small (3–4 cm) age-0 herring and a few small capelin from a school that was being fed on by black-legged kittiwakes in Harriman Fjord on 8 August 1997. Apparently, spawning is delayed and/or growth rates of young fishes are much slower in these glaciated fjords than they are in the warmer parts of Prince William Sound (E. Brown, University of Alaska, Fairbanks, AK, *fide* D. Irons).

It appears that Kittlitz's murrelets 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 (Kistchinskiy 1968, cited in Flint and Golovkin 1990; 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 later importance of pollock may reflect this community shift much more than it does geographic variation.

Our visual observations suggesting that Kittlitz's murrelets fed on fishes 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 usually are eaten underwater, the smaller zooplankton would be eaten easily without our detecting them, whereas at least the larger fishes were brought to the surface (presumably for manipulation) before they were eaten at the surface or 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 almost entirely 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, 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 (Murphy et al. 1984). 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 *T. inermis*, the mysid *Mysis oculata*, and the hyperiid amphipod *Parathemisto libellula* (Hartley and Fisher 1936)—all taxa that occur in Alaska. Further, an input of large amounts of fresh water at or near the surface of a fjord should result in positive estuarine flow (i.e., surface outflow) as salt water rises under the freshwater lens while mixing occurs. 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. Finally, it is possible that cold temperatures near the faces of tidewater glaciers slow prey enough that they are caught more easily by Kittlitz's murrelets than they are elsewhere.

In addition to the mixing and vertical movement of salt and fresh water in glacial-affected habitats, 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 suggest that the slightly larger relative eye size of Kittlitz's murrelets and the preference of this species for glacial-affected and glacial-stream-affected habitats reflect an adaptation for foraging in this highly turbid water and a mechanism for avoiding competition with the closely related marbled murrelet, which appears to eat fishes of similar species and similar size but avoids such habitats (Appendix 6).

Mixed-species Feeding Flocks.—We saw Kittlitz's murrelets in mixed-species feeding flocks on only a few occasions over the two years of research. The limited information suggests that these mixed-species flocks are unimportant to Kittlitz's murrelet populations as a whole for securing food—most birds apparently forage singly or, at times, in groups of two birds. In these flocks, Kittlitz's murrelets most often associated with marbled murrelets, reflecting the similarity in diets between the two species.

Depth of Feeding.—Many Kittlitz's murrelets apparently feed in fairly shallow water, particularly over shallow banks left by the retreat of the glaciers. In Harriman Fjord, many areas used for feeding by Kittlitz's murrelets were 1–10 m in depth. Surprisingly, densities of birds were significantly related to depth (and this relationship indicated a preference for shallow water) in only one of four cruises. Hence, although densities and depth may be a related, the relationship is not consistent. The presence of a relationship during only early summer 1996 probably reflects the importance of fairly deep glacial-affected habitats for feeding and reflects the fact that Kittlitz's murrelets were prevented by excessive ice cover from being in those habitats during that cruise (see "Abundance and Distribution," above).

Other Aspects of Feeding.—Kittlitz's murrelets exhibited fairly long dive times while feeding. These dive times were almost identical to the mean length of dives by marbled murrelets that were feeding in the same bays. These results again indicate that there is extensive overlap in feeding characteristics between these two species, raising the possibility of interspecific competition for food.

CONCLUSIONS AND RECOMMENDATIONS

We believe that we were able to learn much about the ecology of this rare and poorly known seabird in 1996 and 1997. 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 1998 research and beyond.

The abundance and distribution surveys have gone smoothly and have yielded good, valuable, and interesting information. We recommend continuing them, especially to collect additional data for tracking estimates of population size within each bay and to confirm the overall patterns that we have seen. We believe that sampling the four bays 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. Now that we have a better feel for the timing of population movements, we recommend following the timing of the sampling schedule that was used in 1997, with the early summer cruise occurring during the period ~1–20 June and the late summer cruise occurring during the period ~15 July to ~5 August. We also reaffirm our earlier recommendation of an additional, short cruise in late June-early July 1998; that cruise has been funded and will occur in 1998.

Although it is possible that the Kittlitz's murrelet population in these four bays and in Prince William Sound as a whole is declining over time, the wide interannual variation in population estimates from the Sound-wide surveys of the USFWS and the limited number of data sets for tracking a trend makes it unclear whether a decline actually is occurring or if it simply is an artifact of sampling bias and limited data. Nevertheless, both our and Agler and Kendall's data sets independently suggest that a population decline *may* be occurring. Our level of certainty that a decline is occurring is, however, only moderate at best, and an accurate estimate of the rate of decline (if it actually is occurring) is unavailable at this time. We emphasize, however, that concern about the fate of this species (see "Introduction") mandates further geographically extensive and sampling-intensive population monitoring to evaluate better the possibility of a decline. We recommend two additional years of sampling (i.e., FY 1999 and 2000) to determine whether a declining trend in our data is apparent. The reproductive studies (see below) also suggest the importance of continued data collection on this species.

We also recommend a cruise in 1999 or 2000 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 an 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 addition to the five types of data that were collected in 1997, we hope to take depth measurements of both sampling segments and individual birds with a hand-held fathometer in 1998. Any remaining moneys left over at the end of these FY 1997 studies will be used to digitize point locations in the nearshore data set for additional habitat-level analyses, such as shoreline substrate, distance from nearest streams and other sources of fresh water, and distance from nearest shoreline.

The studies on plumages and on reproductive performance are interesting and of great importance, especially considering the apparently poor reproductive performance seen in both 1996 and 1997. One issue that needs to be discussed is the capturing and radio-marking of fledged HY birds. We recommend not buying transmitters for the HY birds until we are certain that the birds actually are produced in substantial numbers and, then, that we actually can capture them in substantial numbers. We simply want to be more confident of success before we spend the money on transmitters. We recommend redirection of this telemetry money that had been budgeted for FY 1998 to digitizing locations in the nearshore data set. Finally, we recommend eventual evaluation (i.e., in FY 1999 or 2000) of plumages and plumage variation in Kittlitz's murrelets through the use of museum skins. 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). Such a study cannot be done in FY 1998, because specimens at the U.S. National Museum are unavailable for a year during renovations to that building.

The possibility of a declining Kittlitz's murrelet population and the apparently poor productivity of this species raise concern about the long-term stability of these populations. In addition, the apparent pairing of some Kittlitz's murrelets with marbled murrelets suggests that populations of Kittlitz's murrelets in these bays *may be* becoming so small and/or that the marbled murrelet populations may be so large that they *may be* swamping the Kittlitz's murrelet populations. Either way, the effective swamping of the Kittlitz's murrelet populations *may be* leading to a breakdown in reproductive isolating mechanisms in some birds. Such a loss of Kittlitz's murrelets from the small pool of potentially available breeding birds would result in even further reductions in overall population size. Hence, we recommend two more years of sampling (in FY 1999 and 2000) to continue examining productivity, population trends, and the extent of such mixed-species "pairs."

Redirecting some money to increased examination of feeding ecology resulted in our learning a great deal about feeding in Kittlitz's murrelets so far. In FY 1998, we will attempt to measure bathymetry of the nearshore zone, which is where most Kittlitz's murrelets feed, with hand-held fathometers. Such information, when tied with the other feeding variables that we are examining, will enable us to understand better the habitat requirements for these birds to feed. The most tantalizing information that we have collected so far was from the side-scanning sonar survey in Harriman Fjord. On that sonar, we saw large numbers of fish-type targets off the faces of the tidewater glaciers that we were able to approach. It is, however, unclear what these fish species were and whether they occur off these glaciers at annual and interannual time scales. We recommend the development of an additional component of the study for FY 1999 and 2000 to use side-scanning sonar surveys for fishes at the same time that we are conducting our nearshore and offshore surveys. We also recommend continuation of our comparative studies of feeding between Kittlitz's and marbled murrelets. The limited data suggest that these two species overlap extensively in preferred prey and sizes of prey, raising the possibility of feeding-related competition. It appears that Kittlitz's murrelets have attempted to minimize this competition by specializing in feeding in highly turbid waters of glacial-affected habitats; however, extensive overlap in habitat use and, hence, possibly extensive competition for food in the other habitat types, still occurs between the two species.

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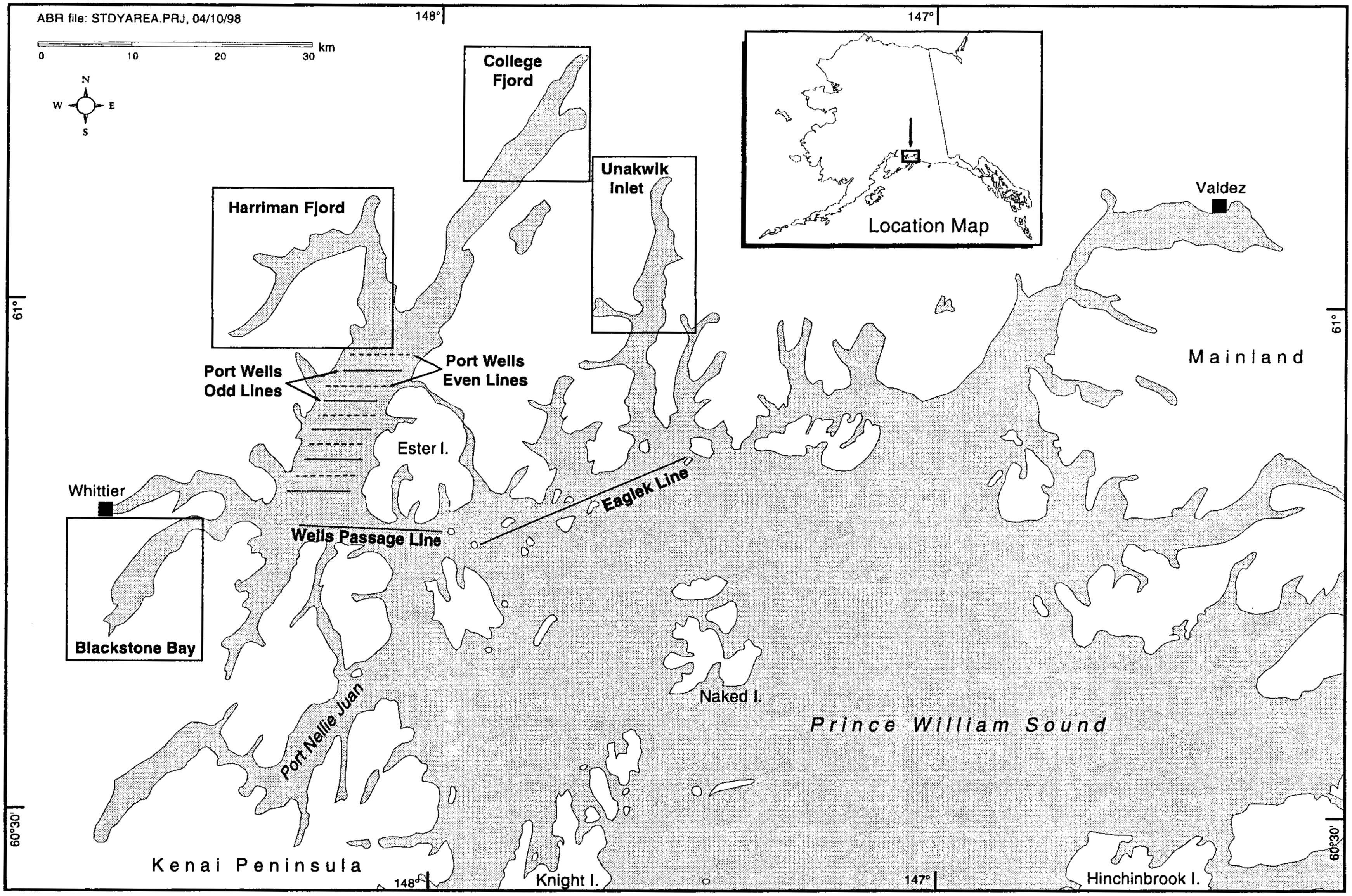

Fig. 1. Locations of study bays and pelagic survey lines sampled in Prince William Sound, Alaska, in 1996 and 1997.

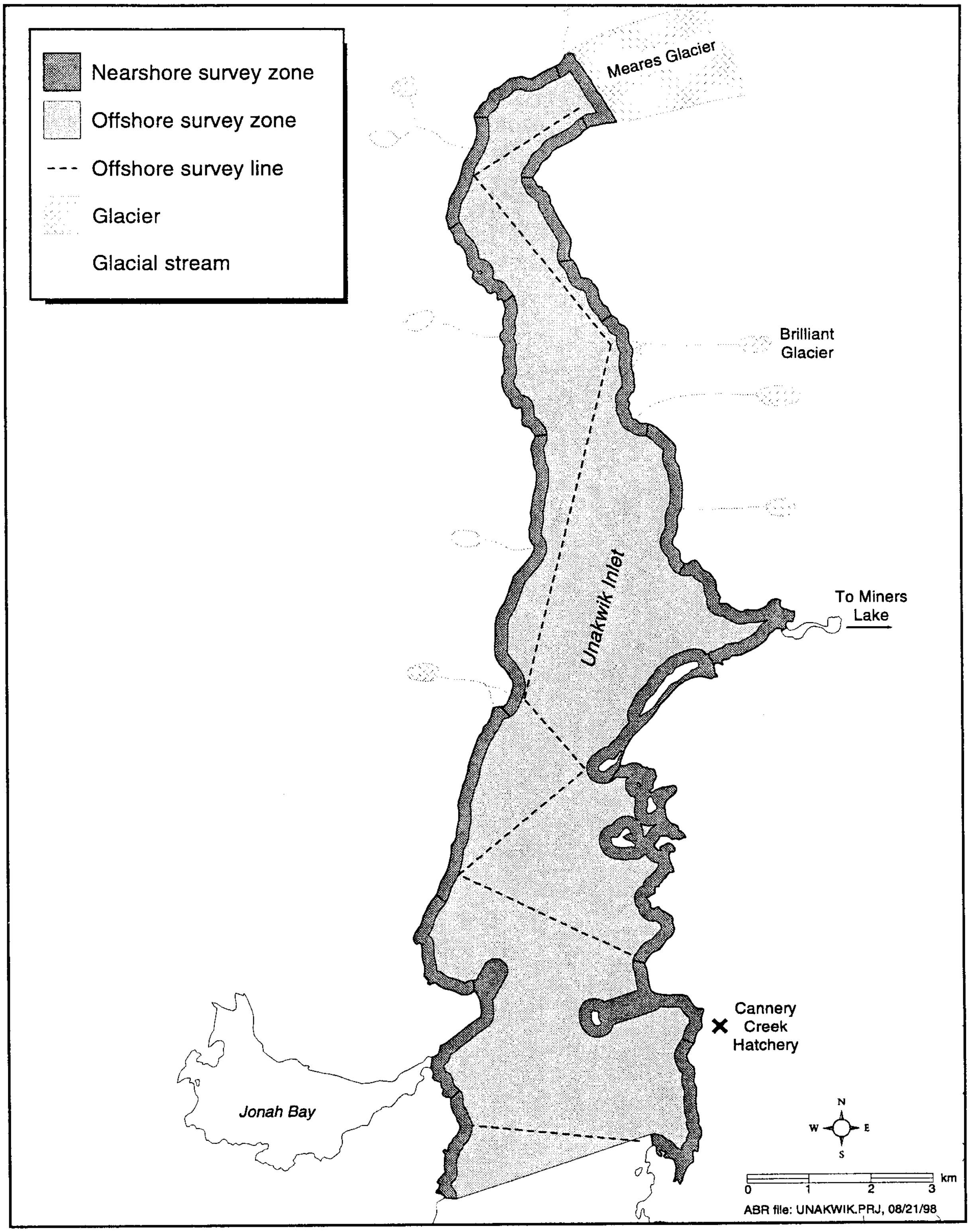

Fig. 2. Locations of nearshore and offshore survey segments and the extent of the offshore zone that was used to estimate the population size of Kittlitz's murrelets in Unakwik Inlet, Alaska, in 1996 and 1997.

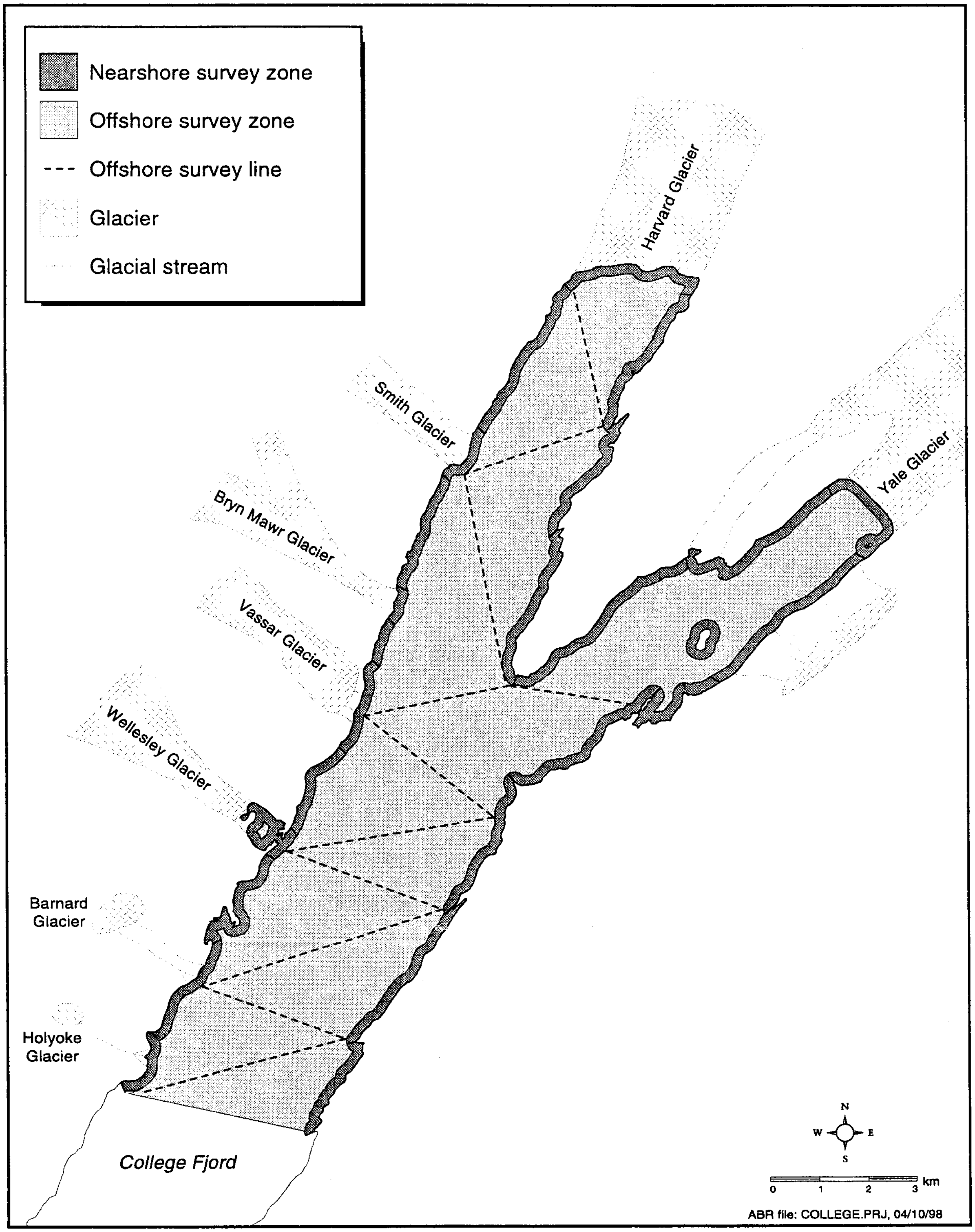

Fig. 3. Locations of nearshore and offshore survey segments and the extent of the offshore zone that was used to estimate the population size of Kittlitz's murrelets in College Fjord, Alaska, in 1996 and 1997.

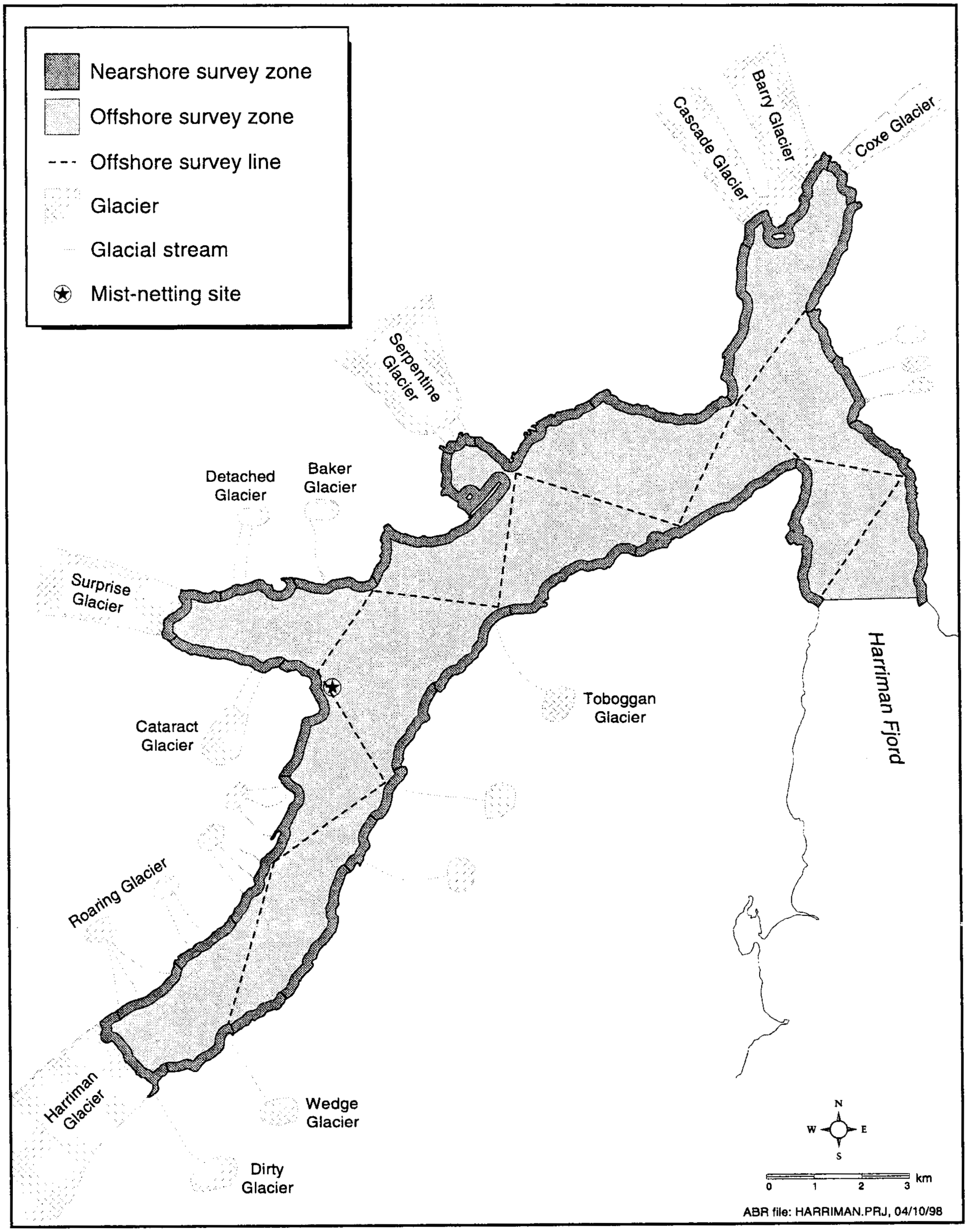

Fig. 4. Locations of nearshore and offshore survey segments and the extent of the offshore zone that was used to estimate the population size of Kittlitz's murrelets in Harriman Fjord, Alaska, in 1996 and 1997. The location of the mist-netting site in 1996 also is marked.

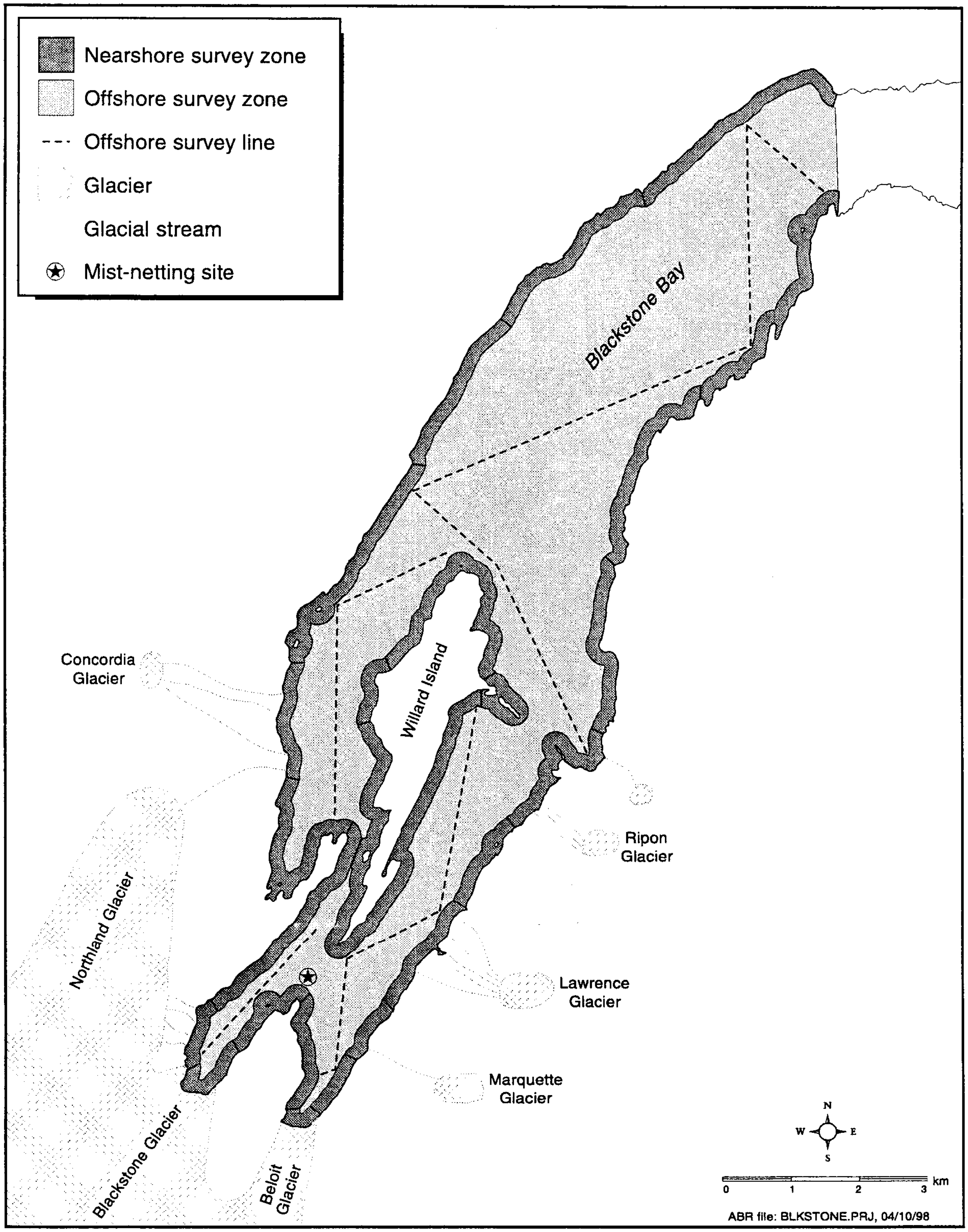

Fig. 5. Locations of nearshore and offshore survey segments and the extent of the offshore zone that was used to estimate the population size of Kittlitz's murrelets in Blackstone Bay, Alaska, in 1996 and 1997. The location of the mist-netting site in 1996 also is marked.

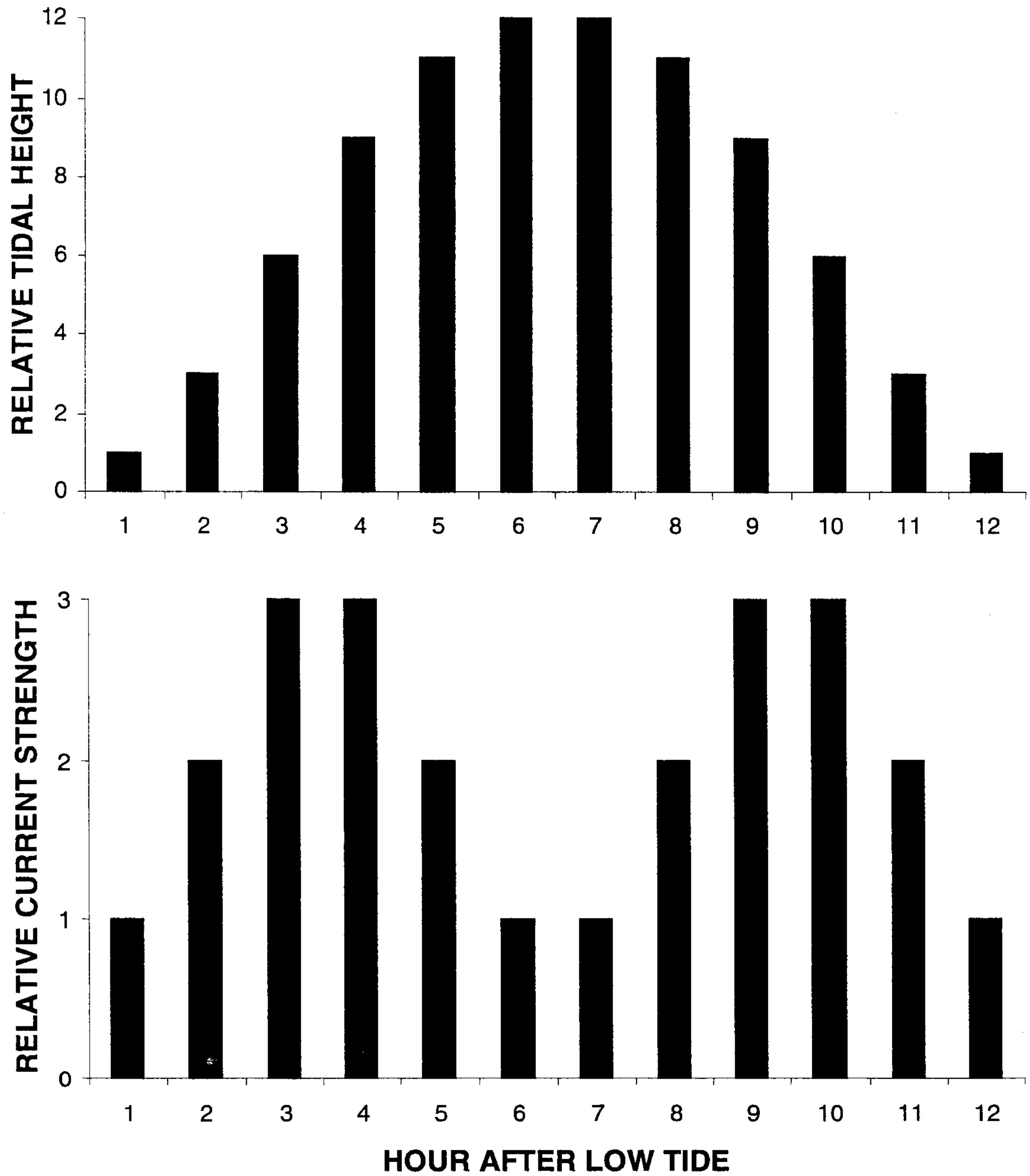

Fig. 6. Relative height of tide (top) and relative strength of tidal current (bottom) during one tidal cycle, by hour after low tide. Current strength is indicated by the hourly change in tidal height.

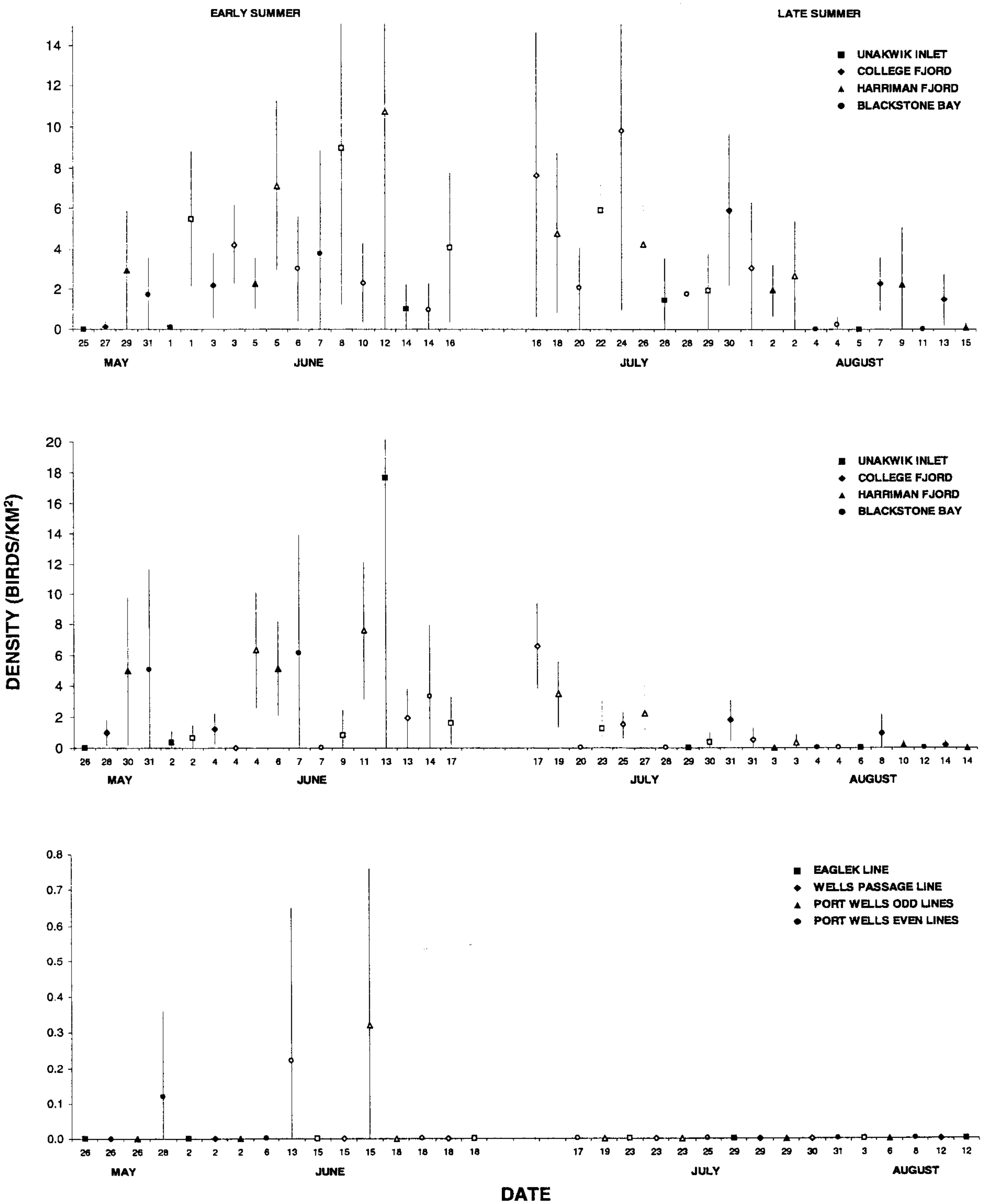

Fig. 7. Mean densities (birds/km^2) of Kittlitz's murrelets on nearshore (top), offshore (center), and pelagic (bottom) surveys in four study bays in Prince William Sound, Alaska, in early and late summer 1996 (solid objects) and 1997 (hollow objects). Vertical bars represent 95% CIs; to improve clarity of figures, the vertical scale has been adjusted, the tops of some CIs have been cut off, and vertical scales differ among plots.

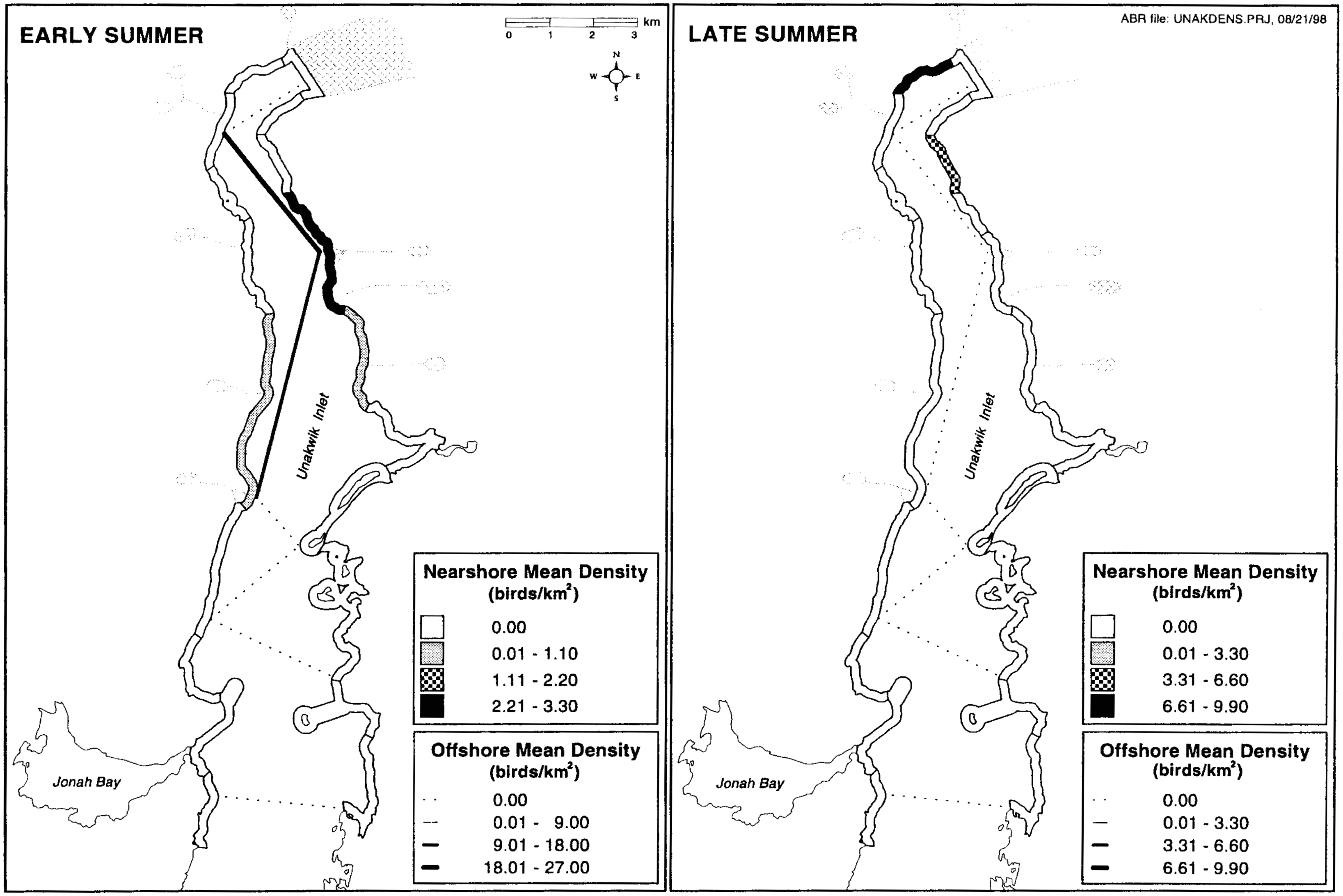

Fig. 8. Abundance and distribution of Kittlitz's murrelets on nearshore and offshore surveys in Unakwik Inlet in early (left) and late (right) summer 1996. Data are expressed as the mean density (birds/km^2) on all visits to each survey segment during a cruise. Note that density scale changes between early and late summer.

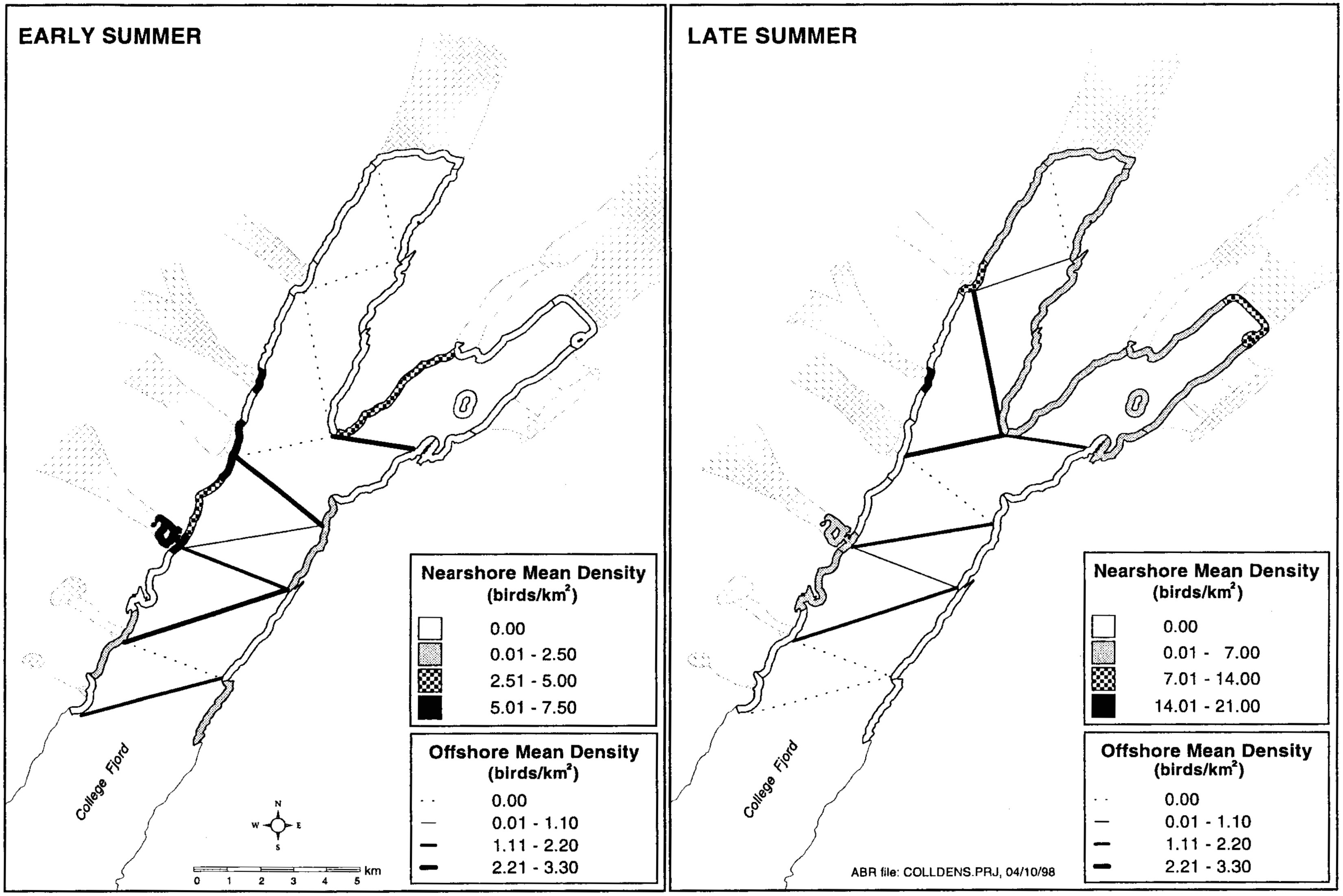

Fig. 9. Abundance and distribution of Kittlitz's murrelets on nearshore and offshore surveys in College Fjord in early (left) and late (right) summer 1996. Data are expressed as the mean density (birds/km^2) on all visits to each survey segment during a cruise. Note that density scale changes between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

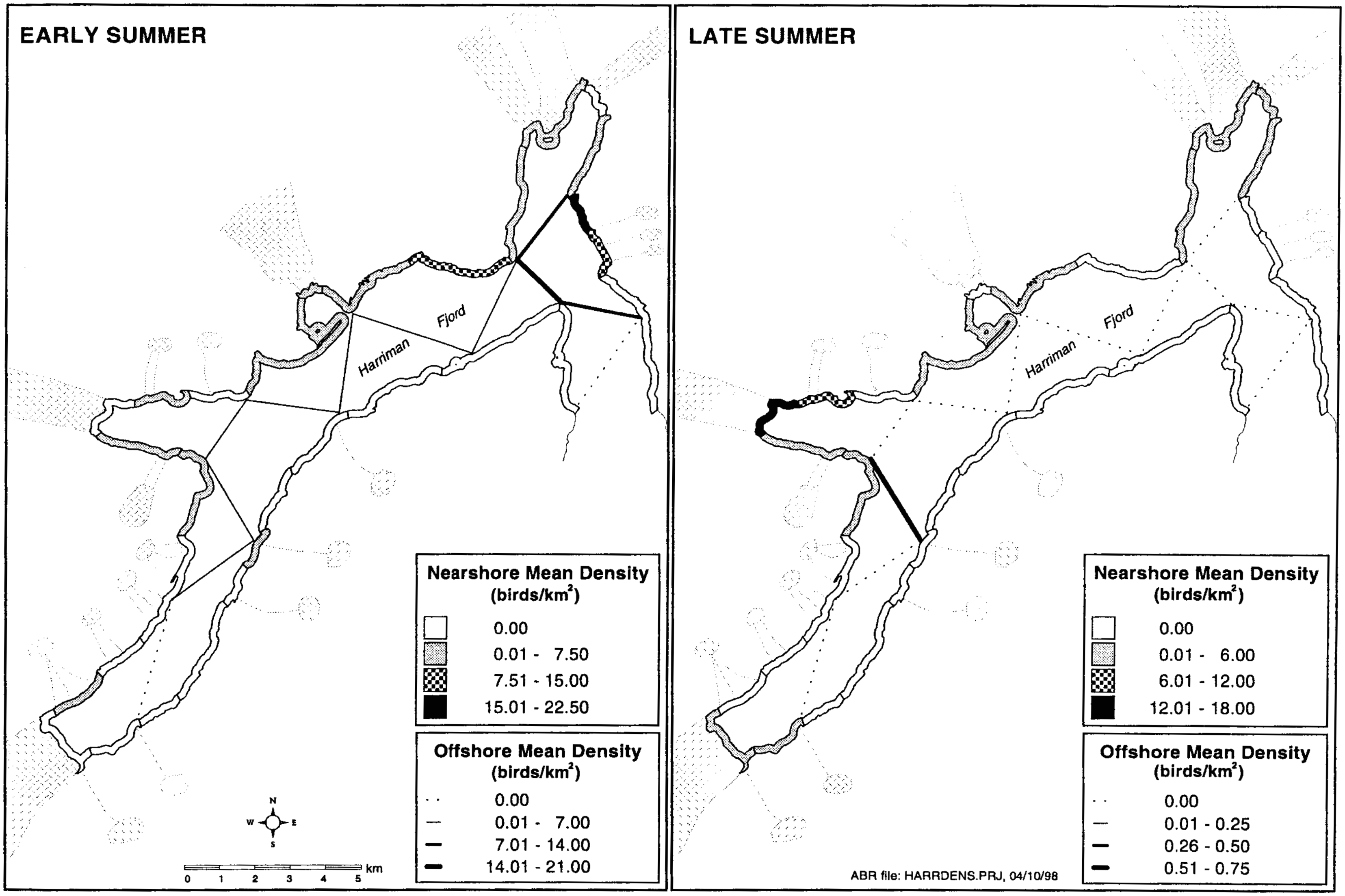

Fig. 10. Abundance and distribution of Kittlitz's murrelets on nearshore and offshore surveys in Harriman Fjord in early (left) and late (right) summer 1996. Data are expressed as the mean density (birds/km^2) on all visits to each survey segment during a cruise. Note that density scale changes between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

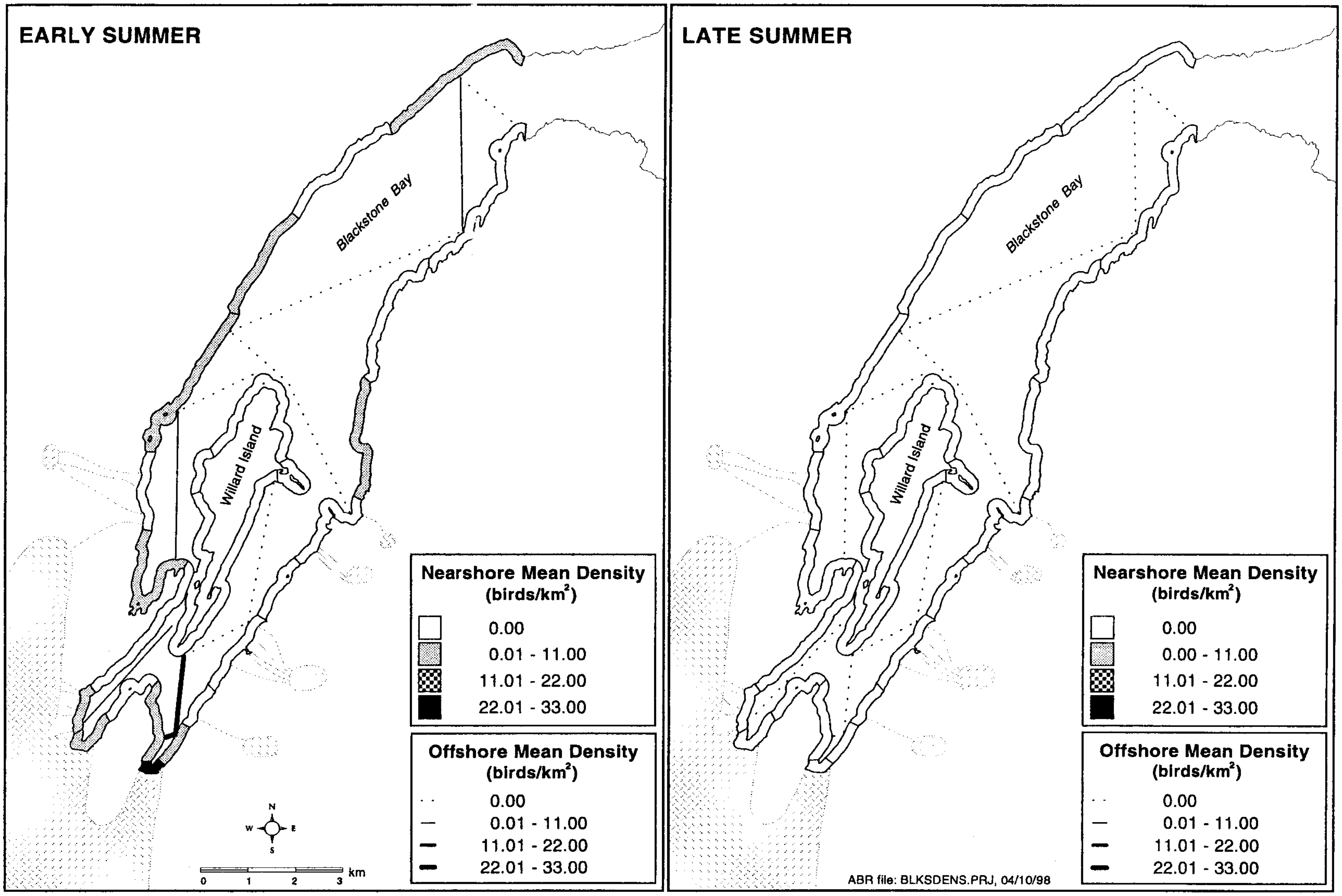

Fig. 11. Abundance and distribution of Kittlitz's murrelets on nearshore and offshore surveys in Blackstone Bay in early (left) and late (right) summer 1996. Data are expressed as the mean density (birds/km^2) on all visits to each survey segment during a cruise.

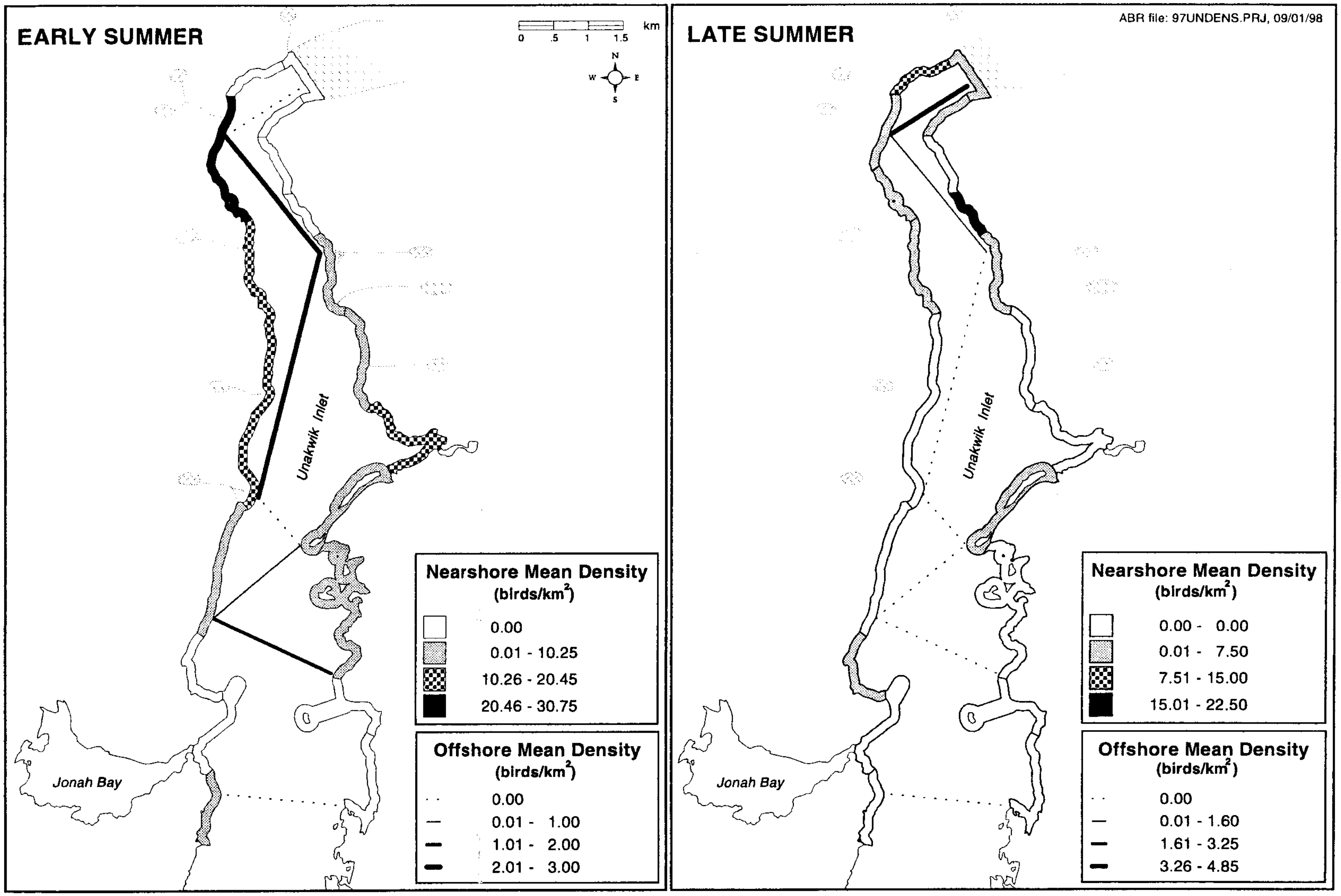

Fig. 12. Abundance and distribution of Kittlitz's murrelets on nearshore and offshore surveys in Unakwik Inlet in early (left) and late (right) summer 1997. Data are expressed as the mean density (birds/km^2) on all visits to each survey segment during a cruise. Note that density scale changes between early and late summer.

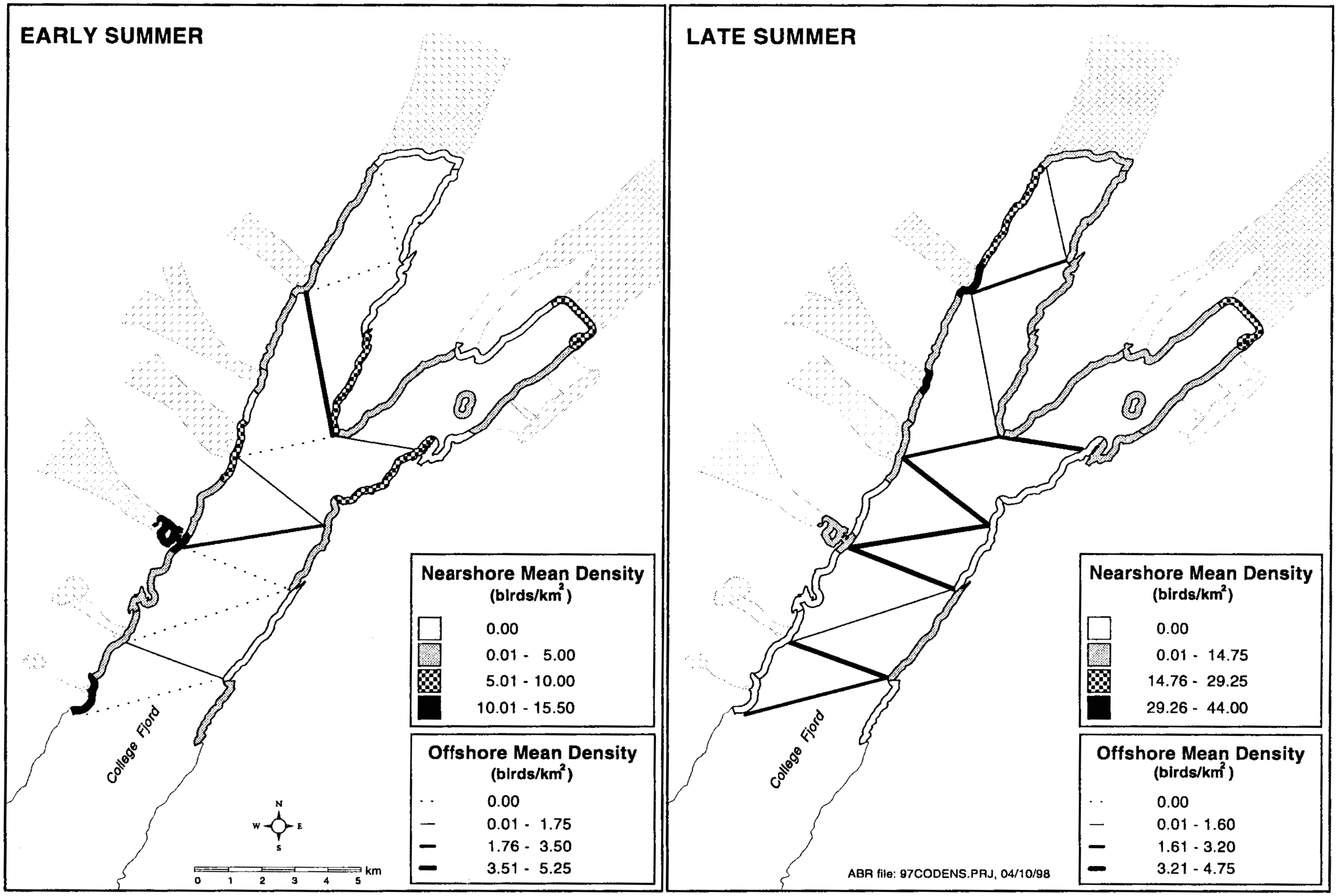

Fig. 13. Abundance and distribution of Kittlitz's murrelets on nearshore and offshore surveys in College Fjord in early (left) and late (right) summer 1997. Data are expressed as the mean density (birds/km^2) on all visits to each survey segment during a cruise. Note that density scale changes between early and late summer.

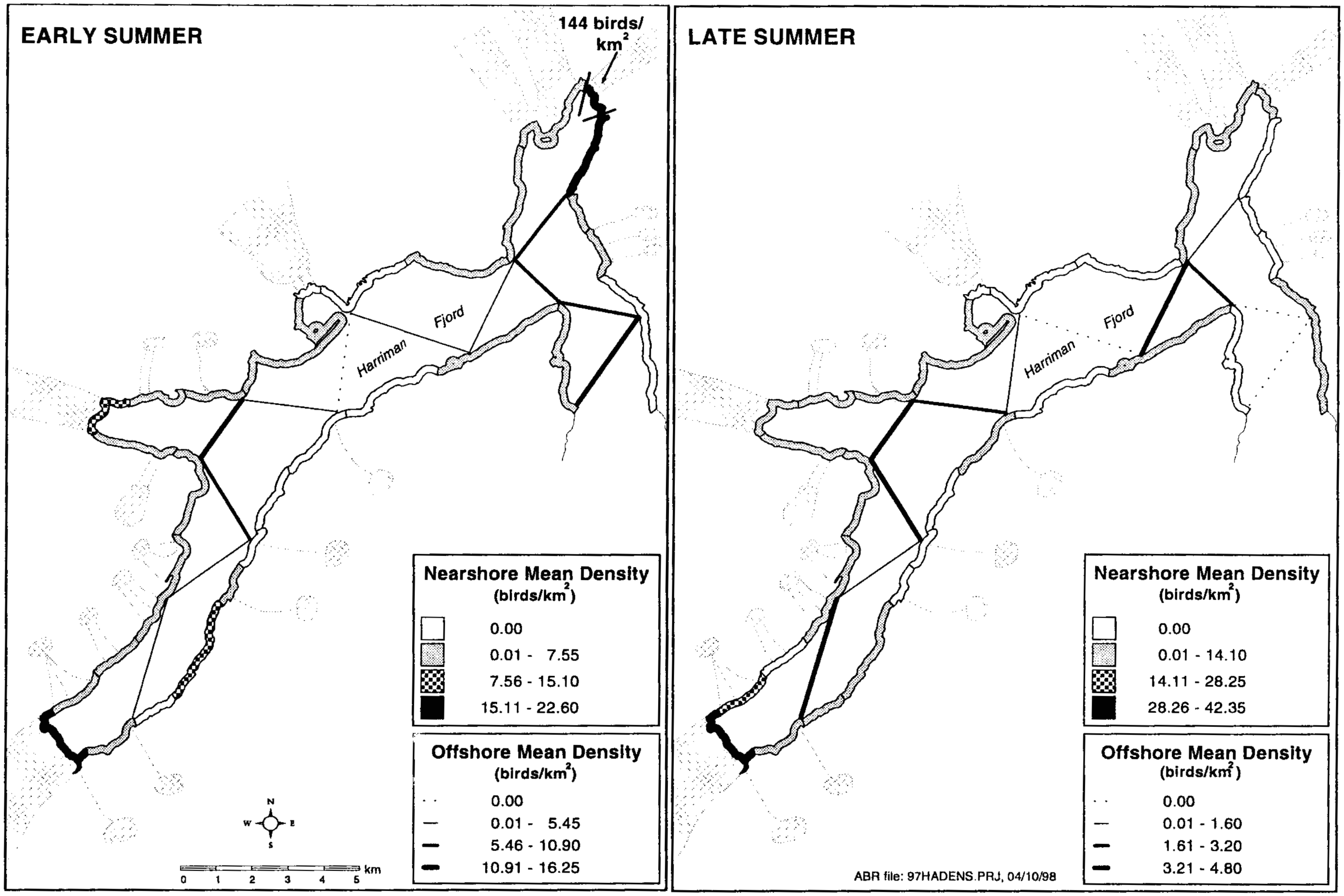

Fig. 14. Abundance and distribution of Kittlitz's murrelets on nearshore and offshore surveys in Harriman Fjord in early (left) and late (right) summer 1997. Data are expressed as the mean density (birds/km^2) on all visits to each survey segment during a cruise. One nearshore segment having an unusually high density in early summer is labeled directly, but the shading is the same as that for the highest density range. Note that density scale changes between early and late summer.

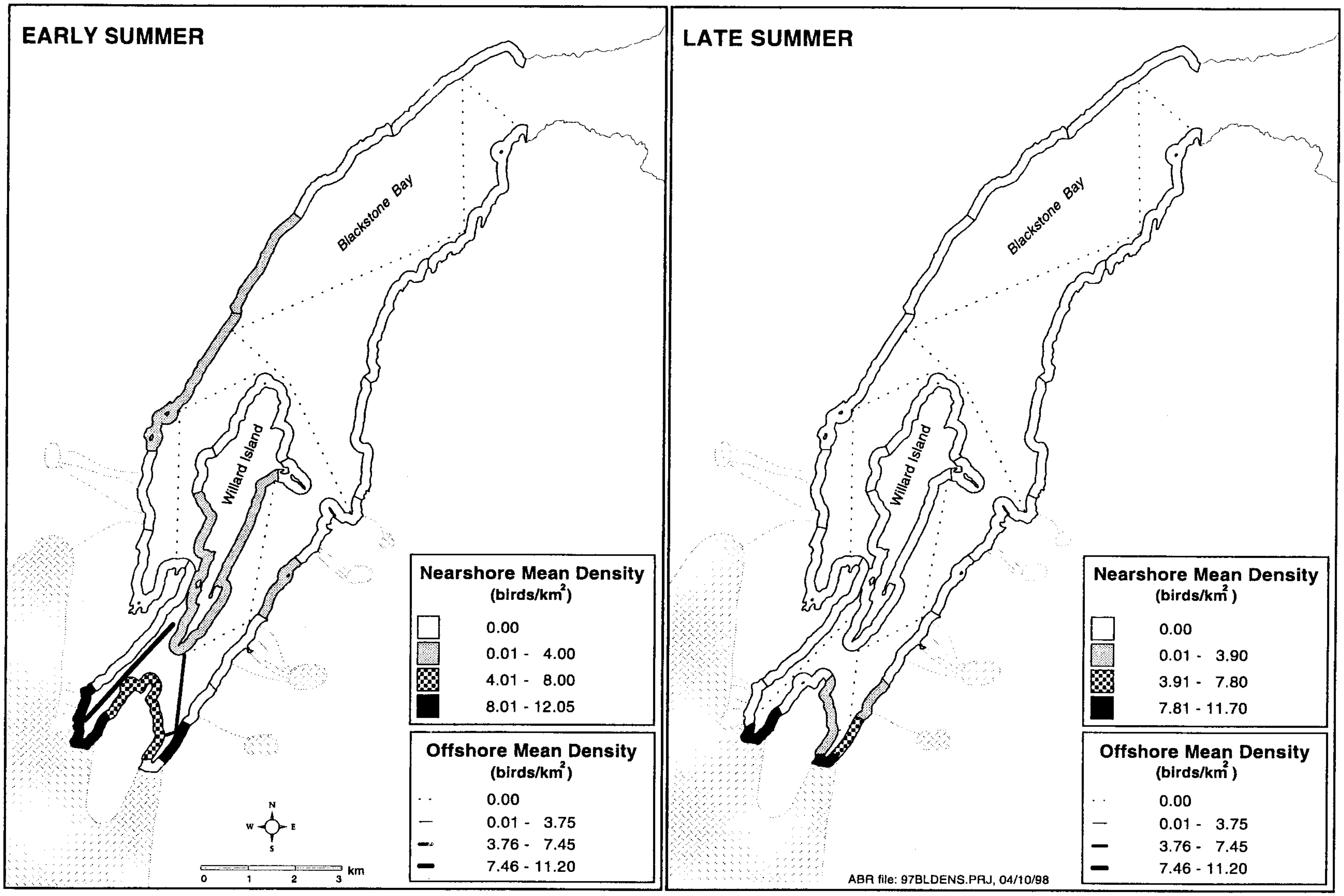

Fig. 15. Abundance and distribution of Kittlitz's murrelets on nearshore and offshore surveys in Blackstone Bay in early (left) and late (right) summer 1997. Data are expressed as the mean density (birds/km^2) on all visits to each survey segment during a cruise. Note that density scale changes between early and late summer.

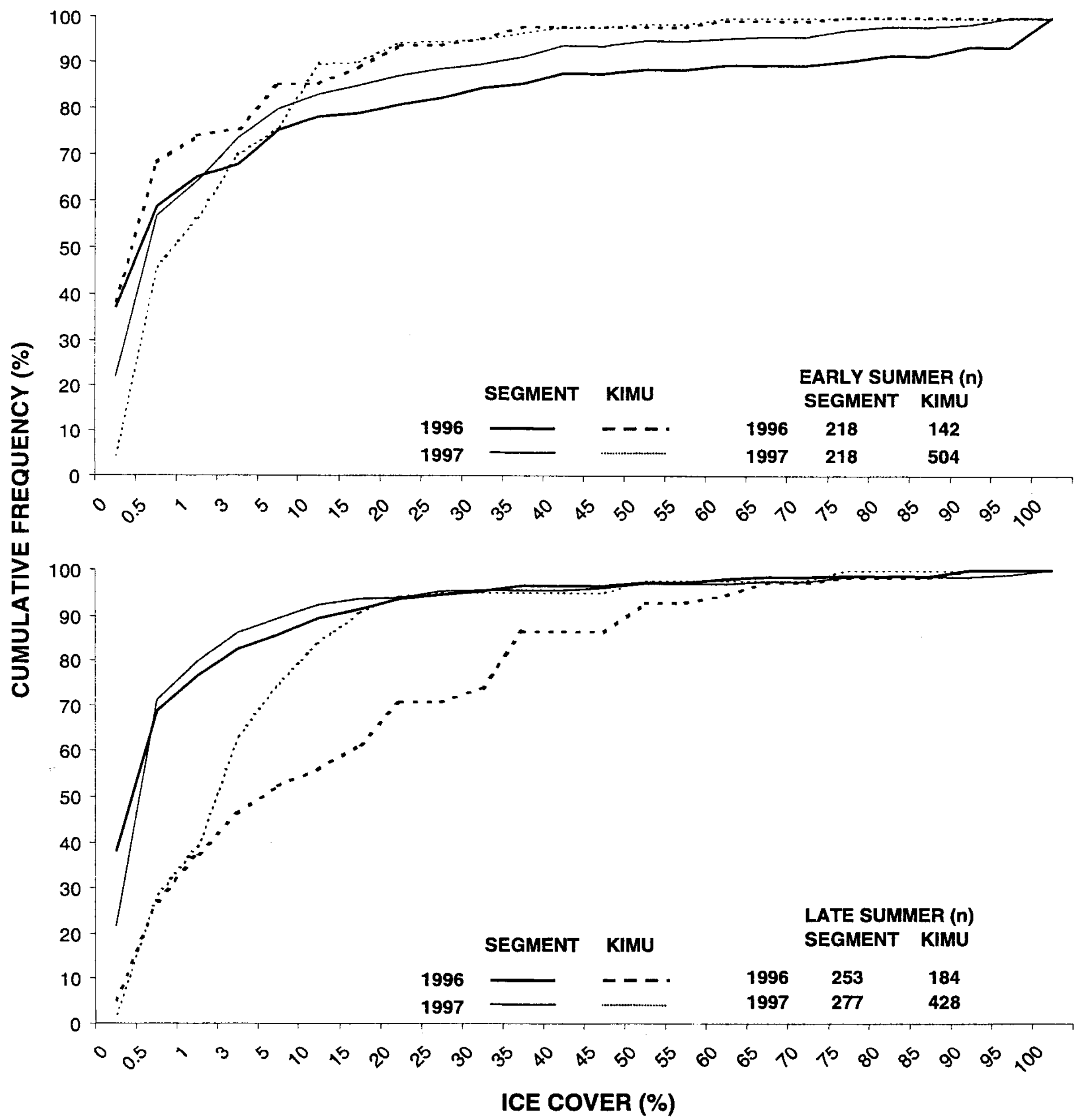

Fig. 16. Large-scale availability (SEGMENT) and use of ice by Kittlitz's murrelets (KIMU) on nearshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1996 and 1997. Scale is expanded at lower end of x-axis.

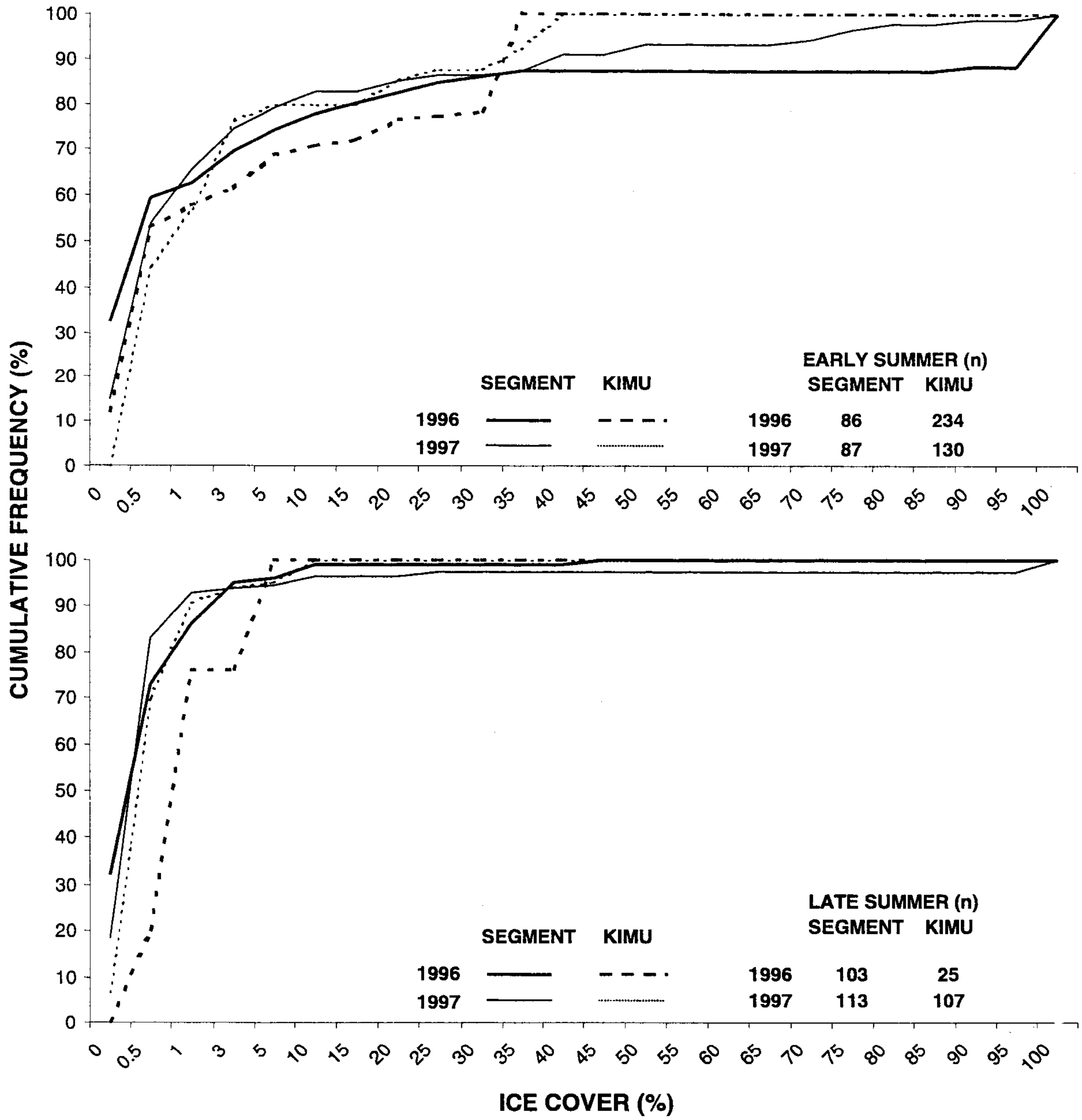

Fig. 17. Large-scale availability (SEGMENT) and use of ice by Kittlitz's murrelets (KIMU) on offshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1996 and 1997. Scale is expanded at lower end of x-axis.

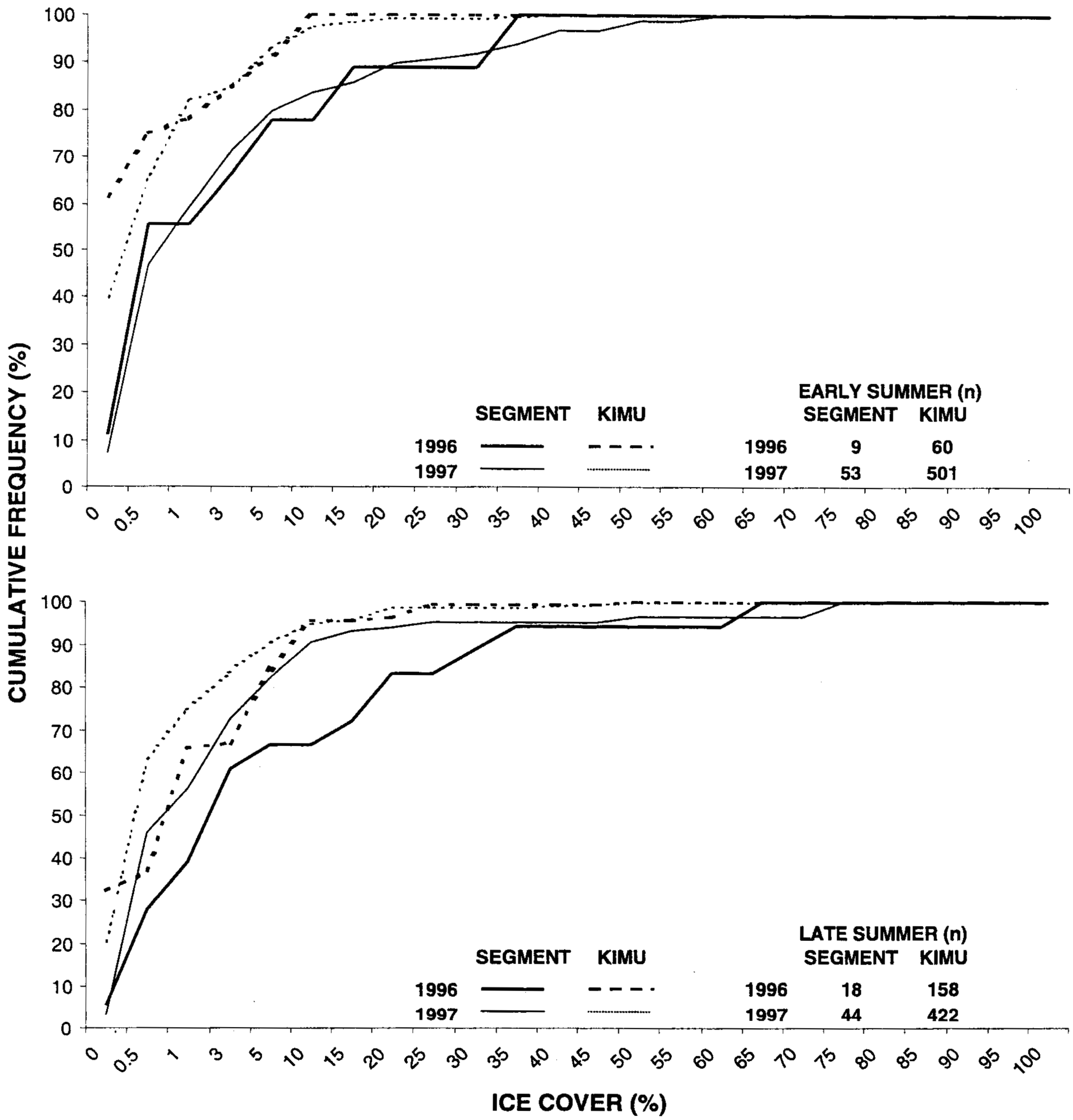

Fig. 18. Large-scale availability (SEGMENT) and fine-scale use of ice by Kittlitz's murrelets (KIMU) on nearshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1996 and 1997. Scale is expanded at lower end of x-axis.

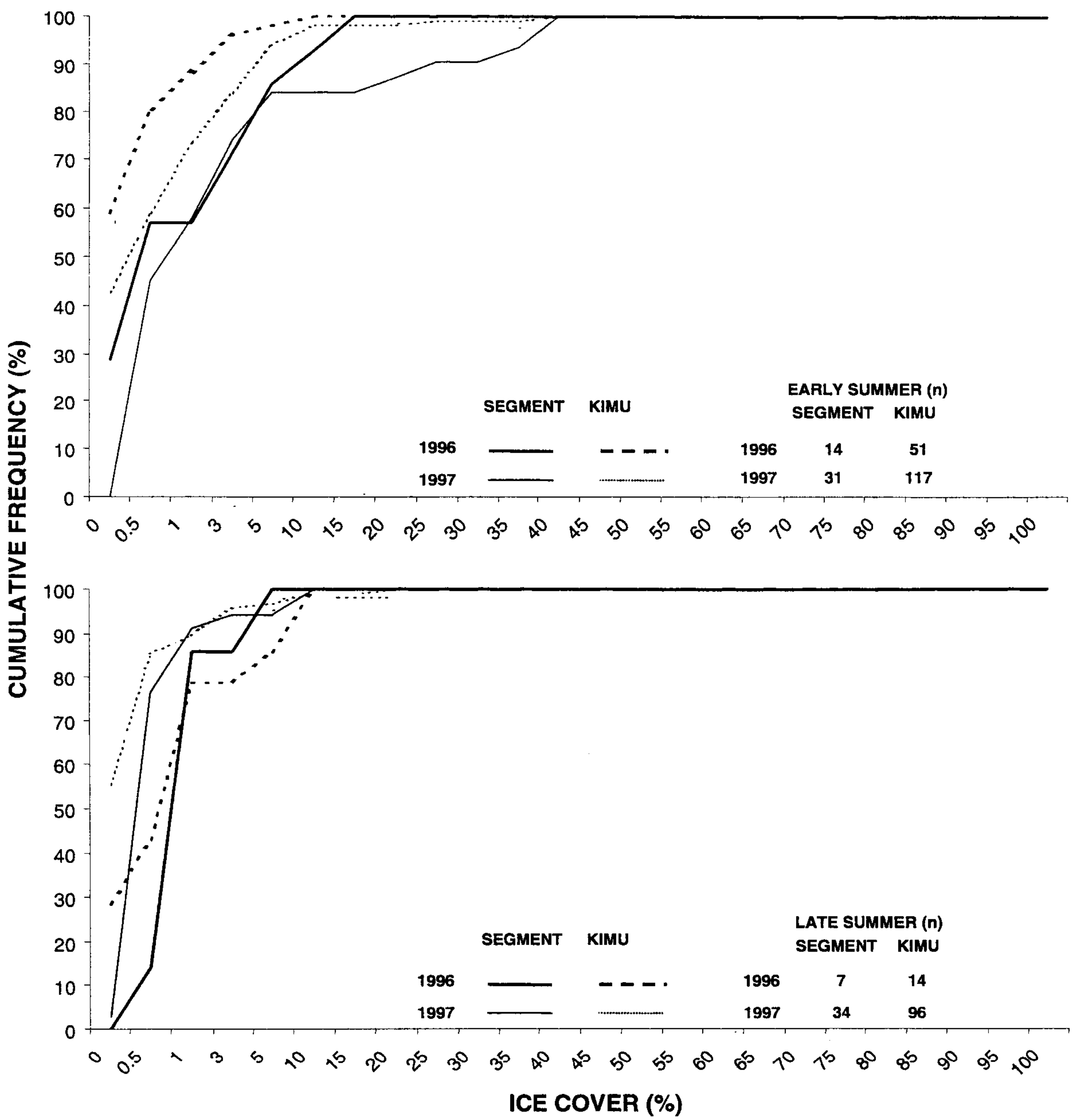

Fig. 19. Large-scale availability (SEGMENT) and fine-scale use of ice by Kittlitz's murrelets (KIMU) on offshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1996 and 1997. Scale is expanded at lower end of x-axis.

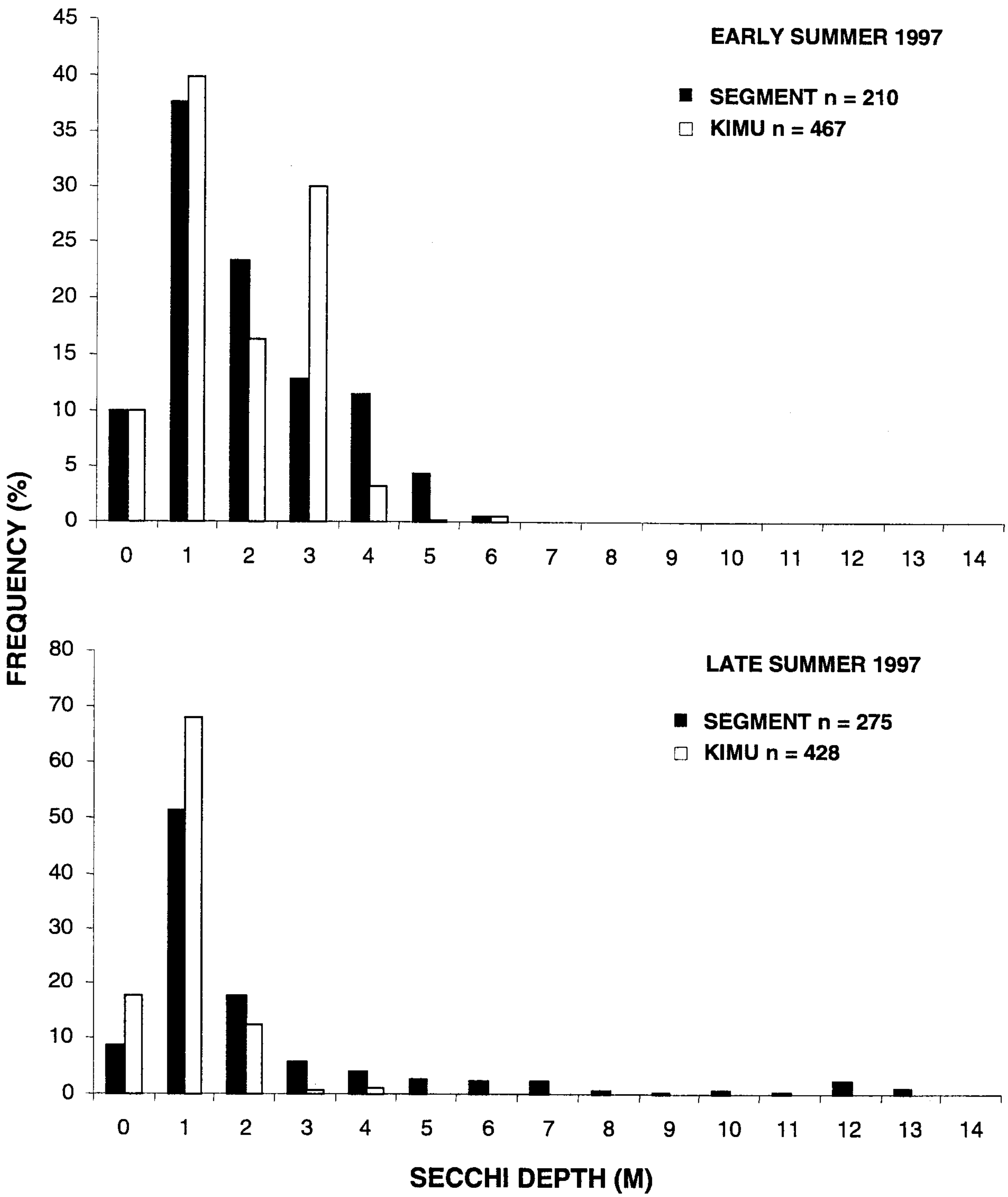

Fig. 20. Large-scale availability (SEGMENT) and use of secchi depths by Kittlitz's murrelets (KIMU) on nearshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1997.

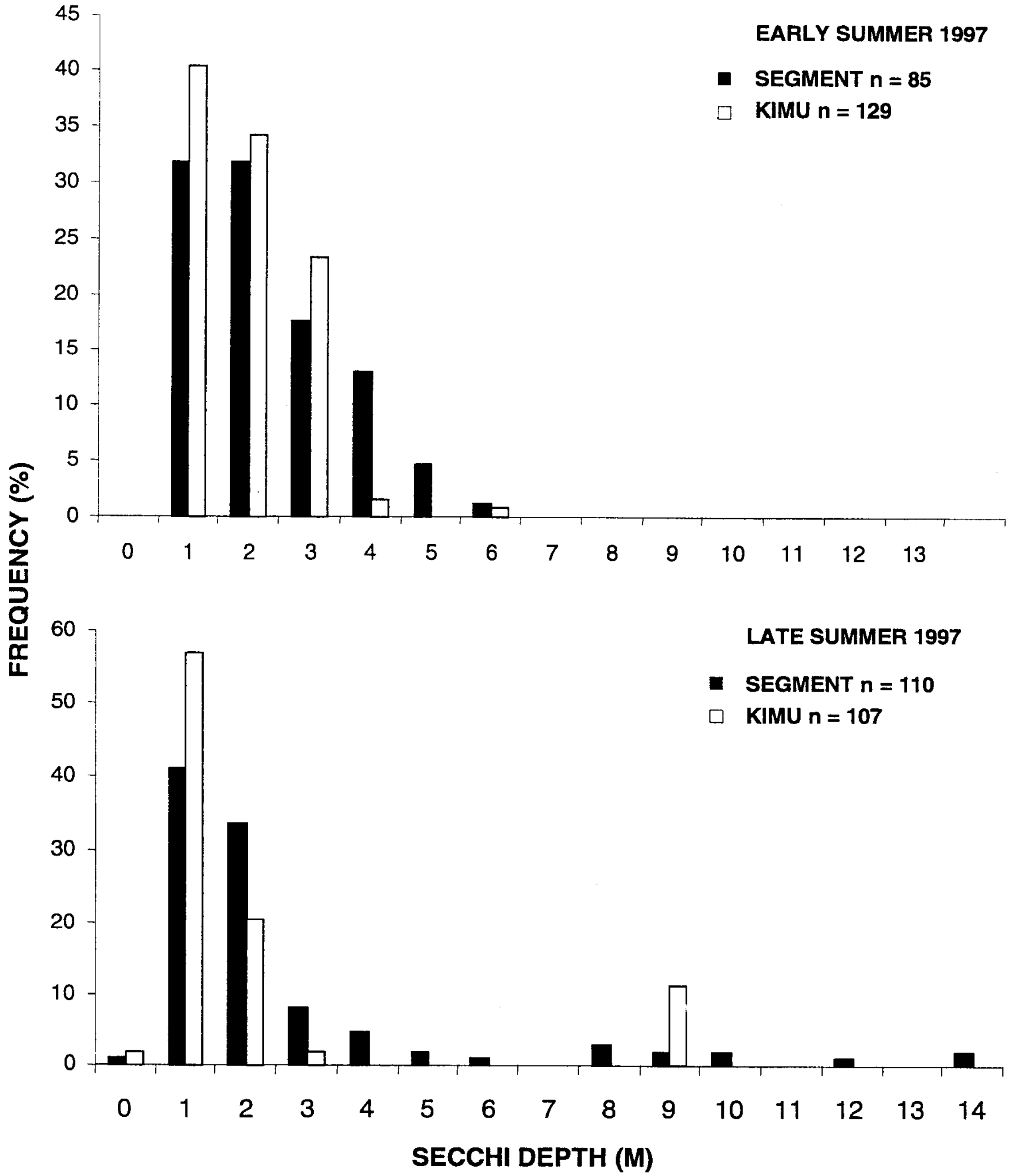

Fig. 21. Large-scale availability (SEGMENT) and use of secchi depths by Kittlitz's murrelets (KIMU) on offshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1997.

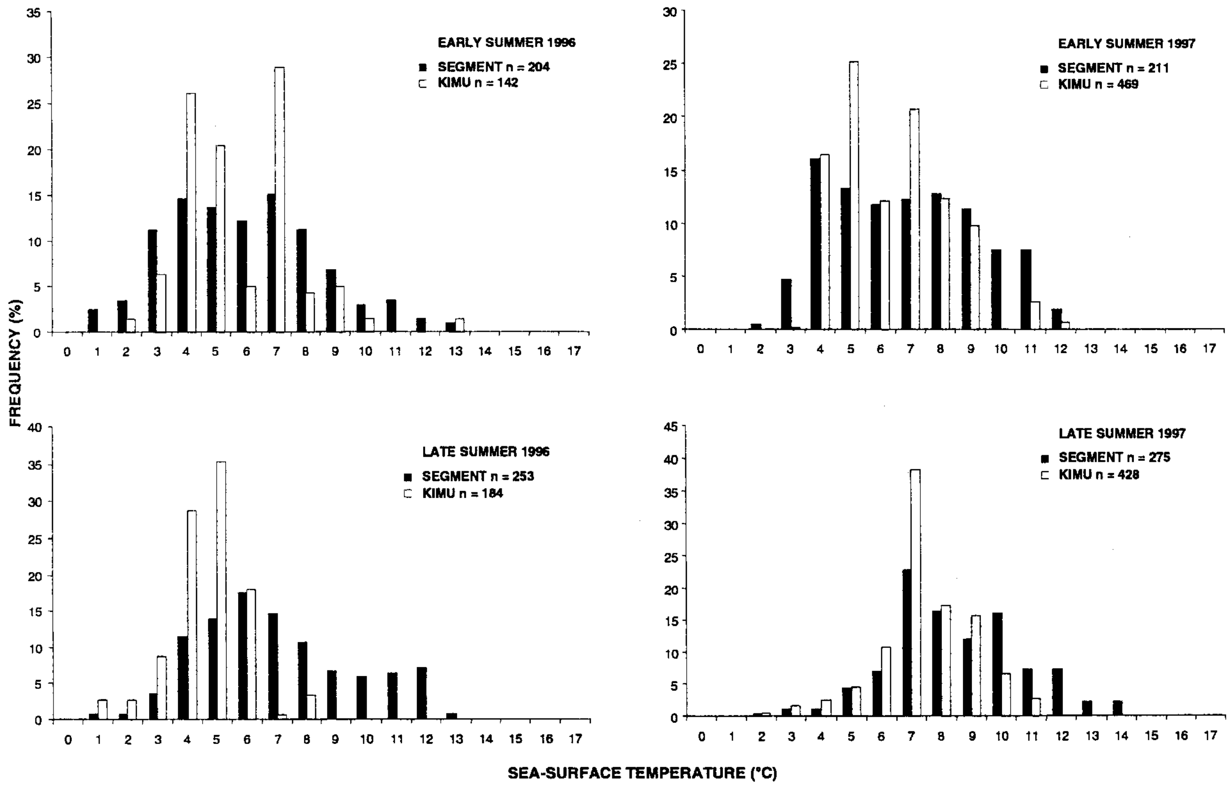

Fig. 22. Large-scale availability (SEGMENT) and use of sea-surface temperatures by Kittlitz's murrelets (KIMU) on nearshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1996 (left) and 1997 (right).

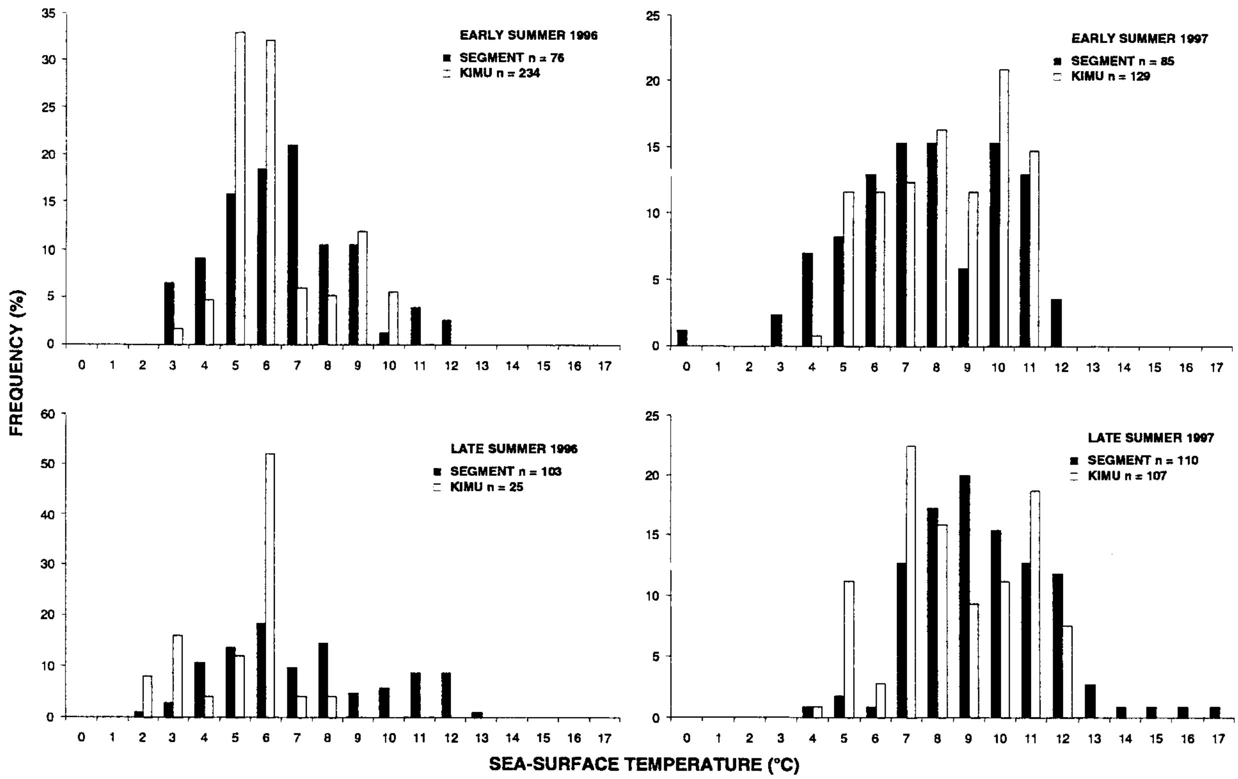

Fig. 23. Large-scale availability (SEGMENT) and use of sea-surface temperatures by Kittlitz's murrelets (KIMU) on offshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1996 (left) and 1997 (right).

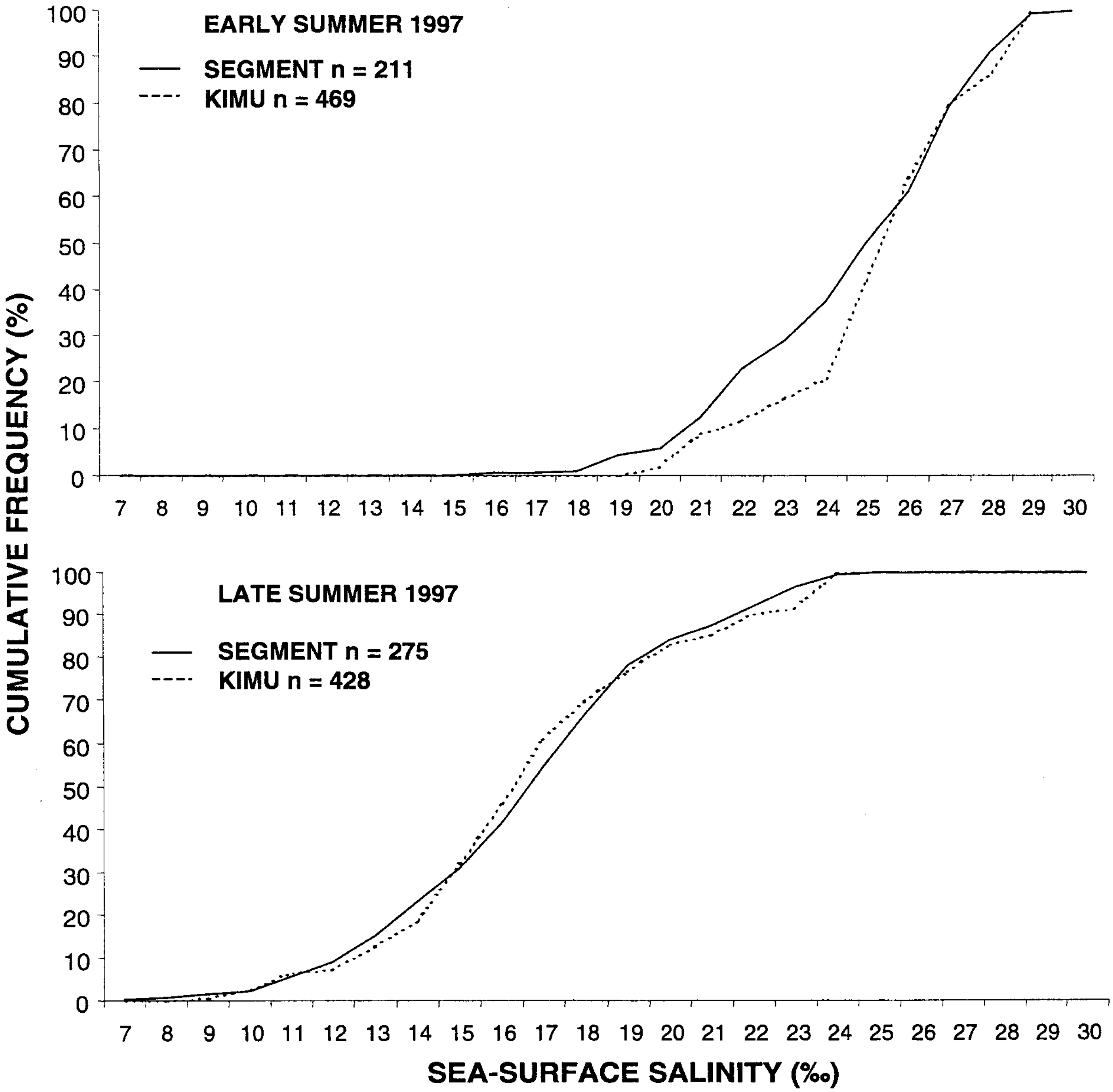

Fig. 24. Large-scale availability (SEGMENT) and use of sea-surface salinities by Kittlitz's murrelets (KIMU) on nearshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1997.

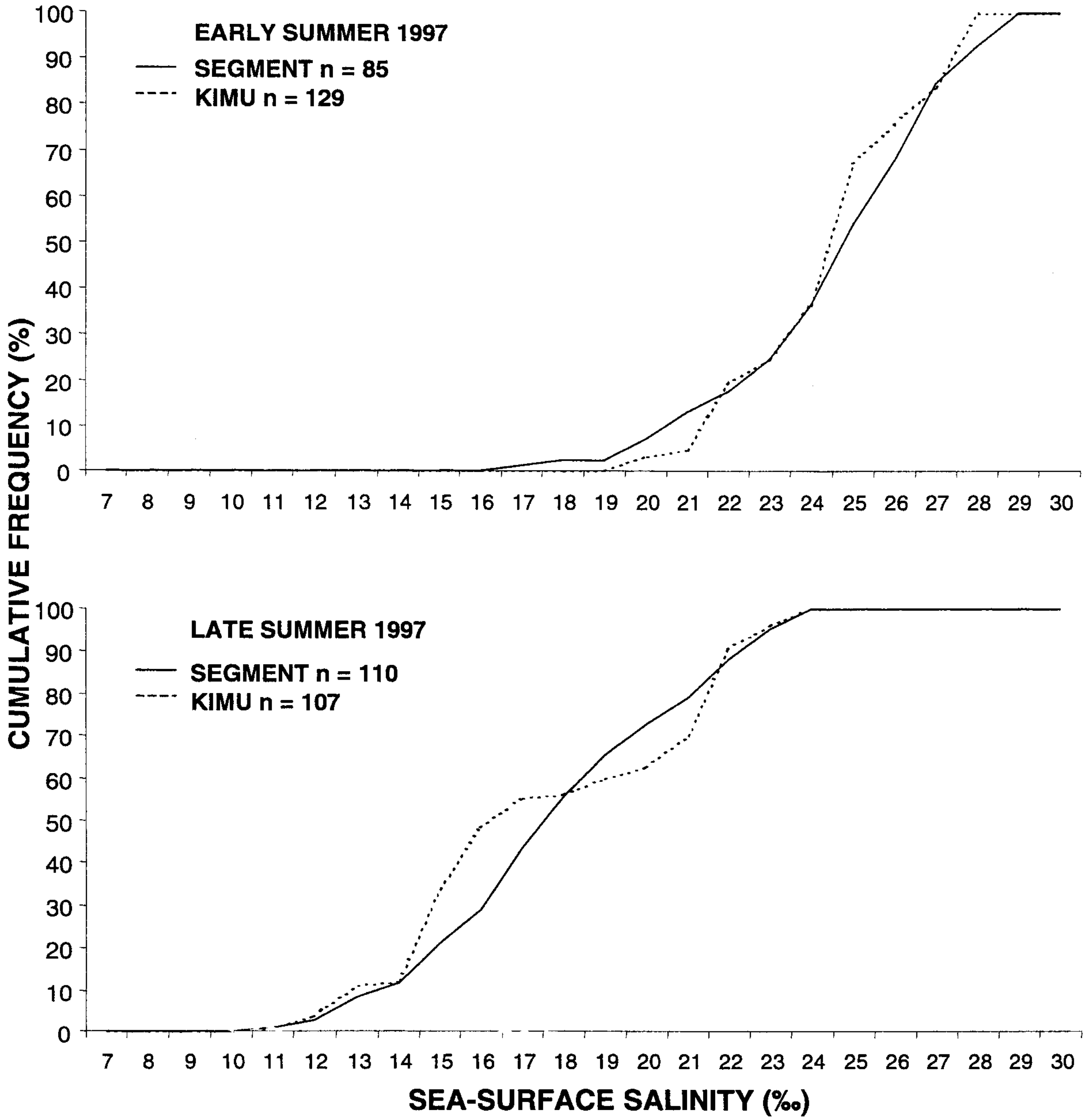

Fig. 25. Large-scale availability (SEGMENT) and use of sea-surface salinities by Kittlitz's murrelets (KIMU) on offshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1997.

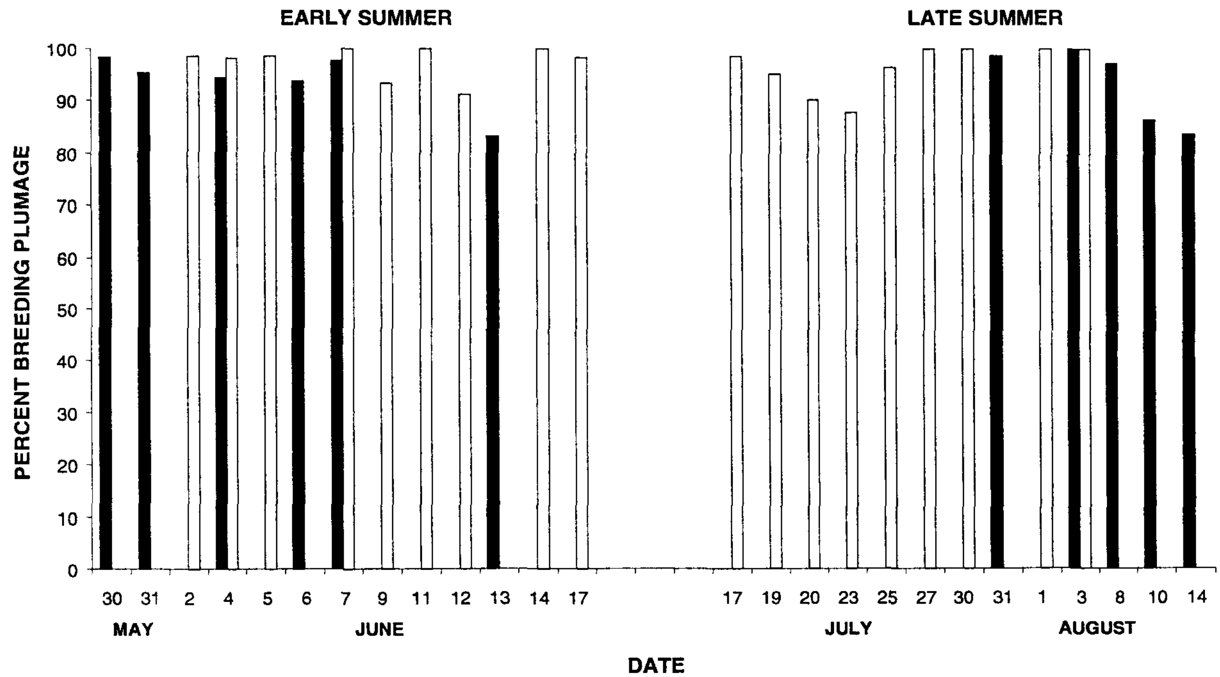

Fig. 26. Percentage of after-hatching-year (AHY) Kittlitz's murrelets that were in breeding plumage in four bays in Prince William Sound, Alaska, early and late summer 1996 (black bars) and 1997 (white bars). Data are for nearshore and offshore surveys combined during each bay-visit; only samples of ≥10 birds are presented. For a particular date, the lack of a second bar indicates a lack of data on that day during the other year.

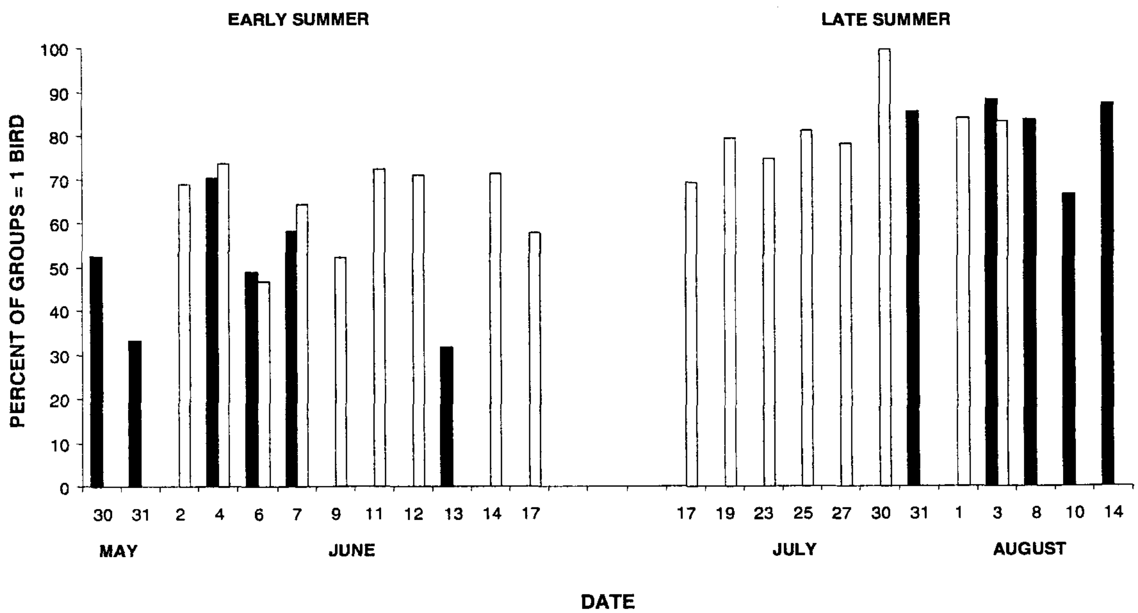

Fig. 27. Percentage of groups of Kittlitz's murrelets that consisted of single birds in four bays in Prince William Sound, Alaska, in early and late summer 1996 (black bars) and 1997 (white bars). Data are for nearshore and offshore surveys combined during each bay-visit; only samples of ≥10 birds are presented. For a particular date, the lack of a second bar indicates a lack of data on that day during the other year.

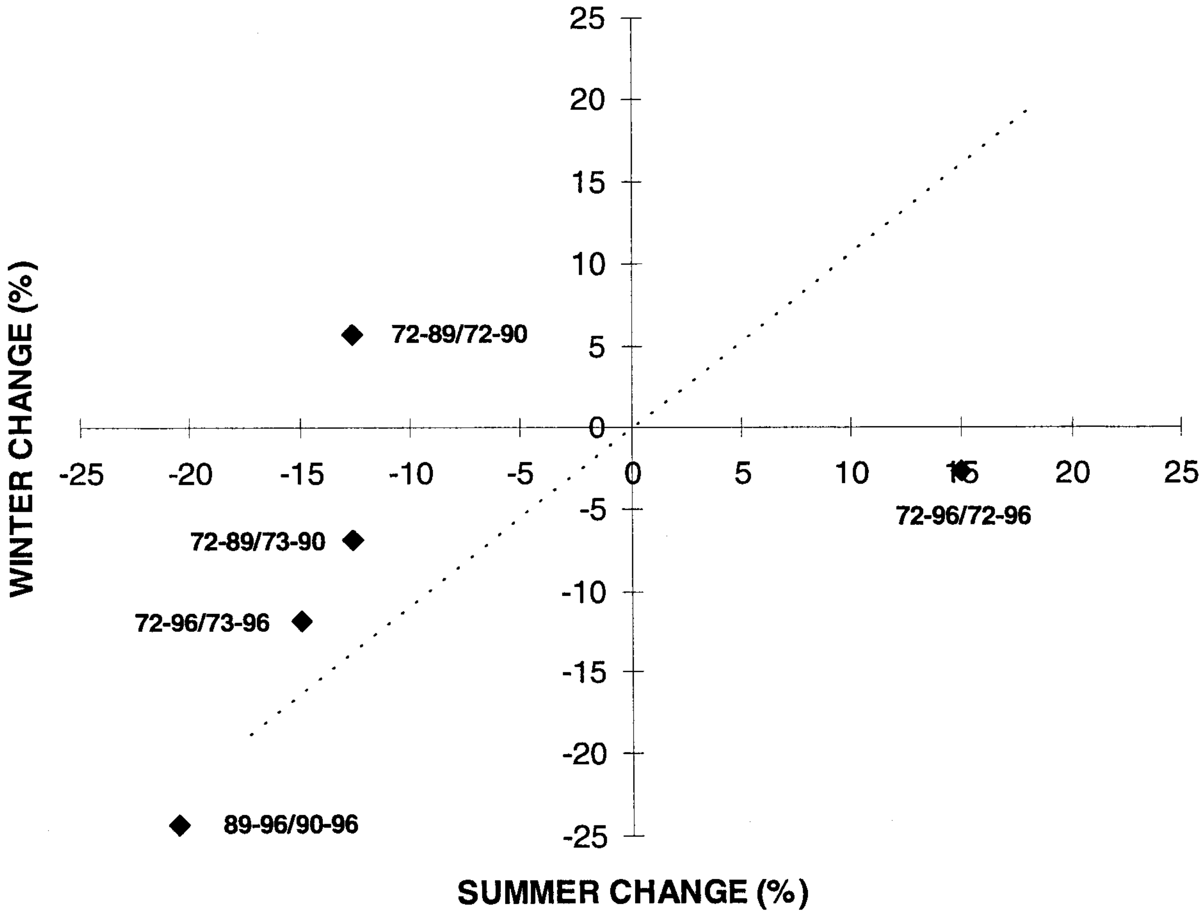

Fig. 28. Relationship between the percentage change of estimated Kittlitz's murrelet populations in Prince William Sound, Alaska, in summer and winter 1972–1996. Data are calculated from numbers presented in Agler and Kendall (1997) and represent comparisons of changes between two summer periods (first set of years) and changes between two similar winter periods (second set of years). Dashed line is that predicted for a linear positive relationship.

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[a]	Other
25 May	Unakwik Inlet			
26 May		Unakwik Inlet	EL, WPL, PWOL	
27 May	College Fjord			
28 May		College Fjord	PWEL	
29 May	Harriman Fjord			
30 May		Harriman Fjord		
31 May	Blackstone Bay	Blackstone Bay		
1 June	Unakwik Inlet			
2 June		Unakwik Inlet	EL, WPL, PWOL	
3 June	College Fjord			
4 June		College Fjord		
5 June	Harriman Fjord			
6 June		Harriman Fjord	PWEL	
7 June	Blackstone Bay	Blackstone Bay[b]		
8 June				activity surveys (Blackstone Bay)
9 June		Blackstone Bay[b]		mist-netting (Blackstone Bay)
10 June				mist-netting (Blackstone Bay)[c]
11 June				mist-netting (Harriman Fjord)
12 June				mist-netting (Harriman Fjord)
13 June		Unakwik Inlet		
14 June	Unakwik Inlet			

[a] EL = Eaglek Line; WPL = Wells Passage Line; PWOL = Port Wells Odd Lines; PWEL = Port Wells Even Lines.

[b] Partial survey conducted each day.

[c] 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[a]	Other
28 July	Unakwik Inlet			
29 July		Unakwik Inlet	EL, WPL, PWOL	
30 July	College Fjord			
31 July		College Fjord	PWEL	
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	PWOL	
7 August	College Fjord			
8 August		College Fjord	PWEL	
9 August	Harriman Fjord			
10 August		Harriman Fjord		
11 August	Blackstone Bay			
12 August		Blackstone Bay	EL, WPL	
13 August	College Fjord			
14 August		College Fjord, Harriman Fjord		
15 August	Harriman Fjord			

[a] EL = Eaglek Line; WPL = Wells Passage Line; PWOL = Port Wells Odd Lines; PWEL = Port Wells Even Lines.

Table 3. Sampling activities conducted in Prince William Sound, Alaska, in early summer (1–21 June) 1997.

	Activity			
Date	Nearshore surveys	Offshore surveys	Pelagic survey lines[a]	Other
1 June	Unakwik Inlet			
2 June		Unakwik Inlet		
3 June	College Fjord			
4 June		College Fjord, Harriman Fjord		
5 June	Harriman Fjord			
6 June	Blackstone Bay			
7 June		Blackstone Bay		
8 June	Unakwik Inlet			
9 June		Unakwik Inlet		
10 June	College Fjord			
11 June		Harriman Fjord		
12 June	Harriman Fjord			
13 June		College Fjord	PWEL	
14 June	Blackstone Bay	Blackstone Bay		
15 June			EL, WPL, PWOL	
16 June	Unakwik Inlet			counting cross-check (Unakwik Inlet)
17 June		Unakwik Inlet		
18 June			EL, WPL, PWOL, PWEL	
19 June				feeding behavior (dive times)
20 June				feeding behavior (dive times); bathymetry (Harriman Fjord)
21 June				feeding behavior (dive times); bathymetry (Harriman Fjord)

[a] EL = Eaglek Line; WPL = Wells Passage Line; PWOL = Port Wells Odd Lines; PWEL = Port Wells Even Lines.

Table 4. Sampling activities conducted in Prince William Sound, Alaska, in late summer (16 July–4 August) 1997.

	Activity			
Date	Nearshore surveys	Offshore surveys	Pelagic survey lines	Other
16 July	College Fjord			
17 July		College Fjord	PWEL	
18 July	Harriman Fjord			
19 July		Harriman Fjord	PWOL	
20 July	Blackstone Bay	Blackstone Bay		
21 July	weather day (no work)	weather day (no work)	weather day (no work)	
22 July	Unakwik Inlet			
23 July		Unakwik Inlet	EL, WPL, PWOL	
24 July	College Fjord			
25 July		College Fjord	PWEL	
26 July	Harriman Fjord			
27 July		Harriman Fjord		
28 July	Blackstone Bay	Blackstone Bay		
29 July	Unakwik Inlet[b]			
30 July	Unakwik Inlet[b]	Unakwik Inlet	EL	
31 July		College Fjord		
1 August	College Fjord			
2 August	Harriman Fjord			
3 August		Harriman Fjord	WPL	
4 August	Blackstone Bay	Blackstone Bay		

[a] EL = Eaglek Line; WPL = Wells Passage Line; PWOL = Port Wells Odd Lines; PWEL = Port Wells Even Lines.

[b] Partial survey conducted each day.

Table 5. Areas (km^2) sampled, total areas of sampling zones, and total areas by habitat types in the four study bays in Prince William Sound, Alaska, in 1996 and 1997.

	Total area		Area 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	4.24	37.92	0	0	0	4.24
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	24.09	192.49	0	0	0	24.09

Table 6. Characteristics affecting observation abilities during nearshore, offshore, and pelagic surveys in Prince William Sound, Alaska, during cruises in summer 1996 and 1997, by season, survey type, and year. Values were calculated from measurements taken or estimates made at the beginning of each sampling segment (nearshore and offshore surveys) and transect (pelagic surveys).

		Characteristic														
		Observation conditions[a]			Sea height[b]			Swell height[b]			Wind speed[b]			Precipitation[c]		
Season/survey type	Year	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n	No.	%	n
EARLY SUMMER																
Nearshore	1996	4.6	0.7	205	0.3	0.5	204	0.1	0.4	205	0.3	0.5	204	26	12.7	204
	1997	4.3	0.6	218	0.5	0.6	218	0.1	0.3	218	0.5	0.6	218	46	21.1	218
Offshore	1996	4.3	0.6	76	0.4	0.6	76	0.2	0.6	76	0.4	0.6	76	7	9.2	76
	1997	4.4	0.5	86	0.7	0.8	86	0.1	0.4	86	0.6	0.7	86	22	25.6	86
Pelagic	1996	4.0	0.7	64	0.6	0.6	64	0.9	0.7	64	0.9	0.7	64	0	0	64
	1997	4.4	0.7	64	0.7	0.7	64	1.1	1.0	64	0.8	0.8	64	8	12.5	64
LATE SUMMER																
Nearshore	1996	4.8	0.5	253	0.4	0.6	253	<0.1	0.2	253	0.4	0.6	253	25	9.9	253
	1997	4.4	0.5	275	0.7	0.6	275	0.1	0.3	275	0.7	0.6	275	12	4.4	275
Offshore	1996	4.4	0.7	103	0.5	0.6	103	0.1	0.3	103	0.4	0.6	103	22	21.4	103
	1997	4.2	0.4	110	0.9	0.6	110	0.4	0.6	110	0.9	0.6	110	16	14.6	110
Pelagic	1996	3.9	0.6	64	1.5	0.6	64	1.2	0.8	64	1.5	0.5	64	14	21.9	64
	1997	4.0	0.4	66	1.0	0.5	66	1.4	0.7	66	0.8	0.5	66	19	14.6	66

[a] Ranged from 1 to 5, with 1 being poor and 5 being excellent.
[b] Based on the Beaufort scale.
[c] Number of segment samples on which any type of precipitation was recorded.

Table 7. Environmental characteristics during nearshore, offshore, and pelagic surveys in Prince William Sound, Alaska, during cruises in summer 1996 and 1997, by season, survey type, and year. Values were calculated from measurements taken or estimates made at the beginning of each sampling segment (nearshore and offshore surveys) and transect (pelagic surveys).

		Characteristic											
		Ice cover (%)			Secchi depth (m)			Sea-surface temperature (°C)			Sea-surface salinity (‰)		
Season/survey type	Year	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n
EARLY SUMMER													
Nearshore	1996	14.5	29.5	218	–	–	0	6.0	2.5	204	–	–	0
	1997	8.8	19.7	218	1.7	1.3	210	6.9	2.4	211	24.9	2.8	211
Offshore	1996	15.8	32.9	86	–	–	0	6.6	2.1	76	–	–	0
	1997	10.5	22.6	87	2.0	1.2	85	7.7	2.4	85	24.9	2.6	85
Pelagic	1996	0	0	64	–	–	0	11.0	1.7	64	–	–	0
	1997	0	0	64	–	–	0	12.3	1.3	64	25.6	1.6	64
LATE SUMMER													
Nearshore	1996	5.0	14.3	253	–	–	0	7.1	2.6	253	–	–	0
	1997	4.9	15.8	277	2.0	2.6	275	8.5	2.2	275	17.1	3.4	275
Offshore	1996	1.4	5.2	103	–	–	0	7.3	2.7	103	–	–	0
	1997	3.5	16.2	113	2.3	2.7	110	9.5	2.2	110	18.2	3.2	110
Pelagic	1996	0	0	64	–	–	0	12.7	1.2	64	–	–	0
	1997	0	0	66	–	–	0	13.6	1.4	66	21.4	1.7	66

Table 8. Results of 5- (nearshore surveys) and 4- (offshore surveys) factor ANOVAs on ranked densities (birds/km^2) of Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1996 and 1997. For nearshore surveys, analysis was by year, season, site (bay), visit, and standardized habitat type; for offshore surveys, analysis was by year, season, site, and visit.

Survey type/source	MS	df	F	*P*-value[a]	Observed power[b]	Multiple comparisons
NEARSHORE						
Overall model	112,616.0	128	3.425	<0.001***	1.000	
Year	1,196,837.0	1	36.401	<0.001***	1.000	1997 > 1996
Season	53,390.3	1	1.624	0.203	0.247	
Site	137,754.0	3	4.190	0.006**	0.856	CF = HF, CF > UI, HF = UI, UI > BB[c]
Visit	70,354.2	2	2.140	0.118	0.439	
Habitat type	333,792.0	3	10.152	<0.001***	0.998	GA > GS = GU > MS[d]
Season × year	153,537.0	1	4.670	0.031*	0.579	
Site × year	48,523.4	3	1.476	0.220	0.392	
Habitat type × year	217,903.0	3	6.627	<0.001***	0.974	
Site × season	76,788.5	3	2.335	0.073	0.588	
Habitat type × season	76,221.0	3	2.318	0.074	0.584	
Habitat type × site	55,071.7	7	1.675	0.112	0.693	
OFFSHORE						
Overall model	31,121.0	38	5.527	<0.001***	1.000	
Year	18,375.5	1	3.264	0.072	0.437	
Season	31,142.5	1	5.531	0.019*	0.650	early summer > late summer
Site	103,948.0	3	18.462	<0.001***	1.000	HF = CF > UI = BB[c]
Visit	1,339.0	2	0.238	0.788	0.087	
Season × year	56,462.1	1	10.028	0.002**	0.885	
Site × year	29,496.5	3	5.239	0.002**	0.927	
Site × season	76,314.8	3	13.554	<0.001***	1.000	

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

[d] GA = glacial-affected; GS = glacial-stream-affected; GU = glacial-unaffected; MS = marine-sill-affected habitat.

Table 9. Results of Before-After tests of changes in densities of Kittlitz's Murrelets in Prince William Sound, Alaska, between 1996 and 1997, by survey type and comparison. Because the data on change were calculated as density (1997) – density (1996), a positive mean difference indicates an increase in 1997 over densities in 1996 and a negative mean difference indicates a decrease in 1997 over densities in 1996.

		Difference				
Survey type/comparison	Season	$\bar{x}$	SD	t	df	*P*-value[a]
NEARSHORE						
Both seasons combined		1.26	9.24	1.915	197	0.057
Early summer vs. late summer[b]	early summer	2.88	10.96	2.503	164	0.013*
	late summer	–0.36	6.79			
OFFSHORE						
Both seasons combined		–0.83	6.08	–1.209	78	0.230
Early summer vs. late summer[b]	early summer	–1.50	8.53	–0.954	40	0.346
	late summer	–0.17	1.43			

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

[b] Test statistics are for comparison of mean differences by season.

Table 10. Results of 5-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 and 1997, by year, season, site (bay), visit, and survey type.

Source	MS	df	F	*P*-value[a]	Observed power[b]	Multiple comparisons[c]
Overall model	383,676.0	77	4.737	<0.001***	1.000	
Year	1,712,529.0	1	21.142	<0.001***	0.996	1997 > 1996
Season	528,749.0	1	6.528	0.011*	0.723	early summer > late summer
Site	2,133,537.0	3	26.340	<0.001***	1.000	CF = HF > UI > BB[c]
Visit	189,806.0	2	2.343	0.096	0.476	
Survey type	110.2	1	0.001	0.971	0.050	
Year × survey type	333,302.0	1	4.115	0.043*	0.527	
Season × survey type	98,150.4	1	1.212	0.271	0.196	
Site × survey type	313,475.0	3	3.870	0.009**	0.826	

[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 11. Mean ice cover (%) and sea-surface temperature (°C) in four study bays in Prince William Sound, Alaska, in 1996 and 1997, by habitat variable, bay, year, season, and survey type.

		Season											
		Early summer						Late summer					
		Nearshore			Offshore			Nearshore			Offshore		
Habitat variable/bay	Year	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n
ICE COVER													
Unakwik Inlet	1996	10.0	23.5	60	21.9	38.7	21	1.3	3.4	40	1.0	2.6	14
	1997	6.9	18.8	60	17.1	27.6	21	2.0	8.0	40	0.5	0.2	14
College Fjord	1996	33.6	40.9	50	36.8	44.6	22	7.1	16.5	75	3.4	8.7	33
	1997	16.2	26.2	49	21.6	31.3	22	7.3	20.7	75	7.1	24.1	33
Harriman Fjord	1996	11.1	26.3	60	3.2	8.0	24	6.7	17.7	90	0.5	0.7	36
	1997	7.0	15.6	60	2.3	7.0	24	4.1	11.7	89	0.8	0.9	36
Blackstone Bay	1996	4.7	13.5	48	0.7	1.5	19	1.8	5.1	48	0.2	0.3	20
	1997	6.4	16.4	47	1.1	2.4	20	4.9	17.5	72	4.5	18.9	29
SEA-SURFACE TEMPERATURE													
Unakwik Inlet	1996	5.8	2.1	57	5.8	1.4	18	9.3	2.2	40	9.4	1.7	14
	1997	6.3	2.4	54	7.2	2.2	21	9.2	1.8	40	9.2	1.3	14
College Fjord	1996	4.5	1.9	41	5.2	1.7	15	5.7	1.9	75	5.2	1.5	33
	1997	4.9	1.3	50	5.1	1.7	21	8.5	2.0	75	9.6	1.5	31
Harriman Fjord	1996	6.1	2.2	58	6.0	1.3	24	5.9	1.7	90	6.6	1.7	36
	1997	7.2	1.6	60	8.7	1.4	23	7.0	1.5	90	7.9	1.5	36
Blackstone Bay	1996	7.5	3.1	48	9.2	1.7	19	9.5	2.3	48	10.7	1.9	20
	1997	9.3	2.0	47	9.8	1.3	20	10.1	2.3	70	11.5	2.3	29

Table 12. Estimated population sizes of Kittlitz's Murrelets in four study bays, Prince William Sound, Alaska, in 1996, by season, bay, and visit.

			Total nearshore	Offshore density ($birds/km^2$)		Offshore area	Total offshore		Overall total	
Season/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	0.72	37.92	14	27	15	27
	3	13 JN	9	17.66	22.83	37.92	670	866	679	866
College Fjord	1	27 MY	2	0.97	0.81	64.28	62	52	64	52
	2	3 JN	24	1.21	0.99	64.28	78	64	102	64
Harriman Fjord	1	29 MY	35	4.98	4.81	56.54	282	272	317	272
	2	5 JN	35	5.13	3.05	56.54	290	172	325	172
Blackstone Bay	1	31 MY	20	5.05	6.58	33.75	170	222	190	222
	2	7 JN	16	6.10	7.87	33.75	206	266	222	266
LATE SUMMER										
Unakwik Inlet	1	29 JL	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	1.32	64.28	114	85	184	85
	2	8 AU	29	0.93	1.21	64.28	60	78	89	78
	3	14 AU	16	0.20	0.26	64.28	13	17	29	17
Harriman Fjord	1	3 AU	30	0	0	56.54	0	0	30	0
	2	10 AU	28	0.16	0.31	56.54	9	18	37	18
	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 13. Maximal estimates of Kittlitz's murrelet population sizes in four bays in Prince William Sound, Alaska, in 1996 and 1997, by bay and year.

	Year					
	1996			1997		
Bay	Estimate	±	95% CI	Estimate	±	95% CI
Unakwik Inlet	679	±	866	133	±	61
College Fjord	184	±	85	504	±	177
Harriman Fjord	325	±	172	524	±	253
Blackstone Bay	222	±	266	119	±	157
Total	1,410	±	1,389	1,280	±	648

Table 14. Estimated population sizes of Kittlitz's Murrelets in four study bays, Prince William Sound, Alaska, in 1997, by season, bay, and visit.

			Total nearshore	Offshore density (birds/km^2)		Offshore area	Total offshore		Overall total	
Season/bay	Visit	Date[a]	count	$\bar{x}$	95% CI	(km^2)	Population	95% CI	Population	95% CI
EARLY SUMMER										
Unakwik Inlet	1	2 JN	58	0.64	0.82	37.92	24	31	82	31
	2	9 JN	102	0.82	1.60	37.92	31	61	133	61
	3	17 JN	47	1.57	1.76	37.92	60	67	107	67
College Fjord	1	4 JN	53	0	0	64.28	0	0	53	0
	2	11 JN	31	1.89	1.87	64.28	121	120	152	120
Harriman Fjord	1	5 JN	93	6.31	3.78	56.54	357	214	450	214
	2	12 JN	94	7.60	4.48	56.54	430	253	524	253
Blackstone Bay	1	7 JN	19	0	0	33.75	0	0	19	0
	2	14 JN	7	3.32	4.65	33.75	112	157	119	157
LATE SUMMER										
Unakwik Inlet	1	23 JL	37	1.24	2.00	37.92	47	76	84	76
	2	30 JL	12	0.34	0.67	37.92	13	25	25	25
College Fjord	1	17 JL	81	6.58	2.76	64.28	423	177	504	177
	2	25 JL	99	1.50	0.84	64.28	96	54	195	54
	3	1 AU	26	0.53	0.77	64.28	34	49	60	49
Harriman Fjord	1	19 JL	59	3.48	2.12	56.54	197	120	256	120
	2	27 JL	59	2.21	1.91	56.54	125	108	184	108
	3	3 AU	36	0.37	0.49	56.54	21	28	57	28
Blackstone Bay	1	20 JL	10	0	0	33.75	0	0	10	0
	2	28 JL	8	0	0	33.75	0	0	8	0
	3	4 AU	1	0	0	33.75	0	0	1	0

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

Table 15. Numbers of Kittlitz's murrelets counted during diel activity surveys in Blackstone Bay, Prince William Sound, Alaska, on 8 June 1996, by time of day and survey type.

	Survey type		
Time of day	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 16. Mean densities (birds/km^2) of Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1996 and 1997, by survey type, season, bay, year, and standardized habitat type. For nearshore surveys, highest densities within a bay during each season and year are in boldface.

			Habitat type											
			Glacial-affected			Glacial-stream-affected			Marine-sill-affected			Glacial-unaffected		
Survey type/ season	Bay	Year	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n
NEARSHORE														
Early summer	Unakwik Inlet	1996	0	0	3	**0.68**	2.09	21	0	0	6	0.28	1.52	30
		1997	0	0	3	**9.68**	12.44	21	0	0	6	5.54	12.98	30
	College Fjord	1996	**2.38**	5.06	10	1.22	3.21	10	–	–	0	0.73	2.20	30
		1997	4.41	7.54	10	**5.48**	6.35	10	–	–	0	2.16	3.15	30
	Harriman Fjord	1996	0.31	0.88	8	2.29	4.06	24	–	–	0	**3.54**	8.16	28
		1997	**44.49**	84.72	8	2.94	4.10	24	–	–	0	3.91	8.28	28
	Blackstone Bay	1996	**16.32**	30.11	4	0.96	3.04	10	0	0	4	1.88	4.79	30
		1997	**5.81**	7.42	4	2.40	7.60	10	0	0	4	1.62	4.16	30
Late summer	Unakwik Inlet	1996	0	0	2	**1.40**	5.22	14	0	0	4	0.49	2.18	20
		1997	2.92	4.12	2	3.80	5.40	14	0	0	4	**4.88**	11.16	20
	College Fjord	1996	**9.62**	10.77	15	1.77	4.15	15	–	–	0	1.57	2.83	45
		1997	**21.24**	33.66	15	2.77	5.57	15	–	–	0	3.40	6.67	45
	Harriman Fjord	1996	**5.61**	11.20	12	1.21	4.08	36	–	–	0	0.44	1.37	42
		1997	**15.40**	19.02	12	3.70	9.19	36	–	–	0	0.79	2.49	42
	Blackstone Bay	1996	0	0	4	0	0	10	0	0	4	0	0	30
		1997	**11.66**	9.12	6	0.34	1.32	15	0	0	6	0.48	1.93	45
OFFSHORE														
Early summer	Unakwik Inlet	1996	–	–	0	–	–	0	–	–	0	6.01	18.88	21
		1997	–	–	0	–	–	0	–	–	0	1.01	1.90	21
	College Fjord	1996	–	–	0	–	–	0	–	–	0	1.09	1.49	22
		1997	–	–	0	–	–	0	–	–	0	0.95	2.38	22
	Harriman Fjord	1996	–	–	0	–	–	0	–	–	0	5.06	6.96	24
		1997	–	–	0	–	–	0	–	–	0	6.95	7.19	24
	Blackstone Bay	1996	–	–	0	–	–	0	–	–	0	5.61	11.22	19
		1997	–	–	0	–	–	0	–	–	0	1.66	5.43	20

Table 16. Continued.

Survey type/ season	Bay	Year	Habitat type: Glacial affected $\bar{x}$	SD	n	Glacial stream affected $\bar{x}$	SD	n	Marine sill affected $\bar{x}$	SD	n	Glacial unaffected $\bar{x}$	SD	n
OFFSHORE (CONTINUED)														
Late summer	Unakwik Inlet	1996	–	–	0	–	–	0	–	–	0	0	0	14
		1997	–	–	0	–	–	0	–	–	0	0.79	1.99	14
	College Fjord	1996	–	–	0	–	–	0	–	–	0	0.97	1.84	33
		1997	–	–	0	–	–	0	–	–	0	2.87	3.91	33
	Harriman Fjord	1996	–	–	0	–	–	0	–	–	0	0.05	0.32	36
		1997	–	–	0	–	–	0	–	–	0	2.02	3.15	36
	Blackstone Bay	1996	–	–	0	–	–	0	–	–	0	0	0	20
		1997	–	–	0	–	–	0	–	–	0	0	0	30

Table 17. Mean large-scale ice cover (%), secchi depth (m), sea-surface temperature (°C), and sea-surface salinity (‰) in four study bays in Prince William Sound, Alaska, in 1996 and 1997, by comparison, survey type, and cruise.

Comparison/ survey type	Cruise[a]	Ice cover $\bar{x}$	Ice cover SD	Ice cover n	Secchi depth $\bar{x}$	Secchi depth SD	Secchi depth n	Sea-surface temperature $\bar{x}$	Sea-surface temperature SD	Sea-surface temperature n	Sea-surface salinity $\bar{x}$	Sea-surface salinity SD	Sea-surface salinity n
SEGMENT (AVAILABILITY)													
Nearshore	ES96	14.5	29.5	218	–	–	0	6.0	2.5	204	–	–	0
	LS96	5.0	14.3	253	–	–	0	7.1	2.6	253	–	–	0
	ES97	8.8	19.7	218	1.7	1.3	210	6.9	2.4	211	24.9	2.8	211
	LS97	4.9	15.8	277	2.0	2.6	275	8.5	2.2	275	17.1	3.4	275
Offshore	ES96	15.8	32.9	86	–	–	0	6.6	2.1	76	–	–	0
	LS96	1.4	5.2	103	–	–	0	7.3	2.7	103	–	–	0
	ES97	10.5	22.6	87	2.0	1.2	85	7.7	2.4	85	24.9	2.6	85
	LS97	3.5	16.2	113	2.3	2.7	110	9.5	2.2	110	18.2	3.2	110
KITTLITZ'S MURRELET (USE)													
Nearshore	ES96	5.0	12.0	142	–	–	0	5.7	1.9	142	–	–	0
	LS96	17.5	21.6	184	–	–	0	4.6	1.3	184	–	–	0
	ES97	5.8	10.7	504	1.5	1.1	467	6.3	1.7	469	25.7	2.3	469
	LS97	7.5	13.8	428	0.7	0.6	428	7.4	1.6	428	17.0	3.4	428
Offshore	ES96	10.1	14.3	234	–	–	0	6.4	2.0	234	–	–	0
	LS96	1.9	1.8	25	–	–	0	5.1	1.6	25	–	–	0
	ES97	7.5	12.8	130	1.6	0.8	129	8.2	2.0	129	24.8	2.2	129
	LS97	1.1	2.1	107	2.8	3.9	107	8.5	2.1	107	17.9	3.7	107

[a] ES96 = early summer 1996; LS96 = late summer 1996; ES97 = early summer 1997; LS97 = late summer 1997.

Table 18. Results of 2-factor MANOVA on large-scale availability of ice cover, secchi depth, sea-surface temperature, and sea-surface salinity by Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1997, by survey type and season.

Habitat variable[a]	Source	MS	df	F	*P*-value[b]	Observed power[c]	Results of multiple comparisons
Ice	Overall model	949,667.0	3	8.579	<0.001***	0.994	
	Survey type	43,313.3	1	0.391	0.532	0.096	
	Season	2,723,345.0	1	24.601	<0.001***	0.999	early summer > late summer
	Survey type × season	241,754.0	1	2.184	0.140	0.314	
Secchi	Overall model	287,685.0	3	7.881	<0.001***	0.990	
	Survey type	721,680.0	1	19.770	<0.001***	0.993	offshore > nearshore
	Season	118,425.0	1	3.244	0.072	0.436	
	Survey type × season	1,187.9	1	0.033	0.857	0.054	
SST	Overall model	4,033,542.0	3	36.769	<0.001***	1.000	
	Survey type	2,278,769.0	1	20.773	<0.001***	0.995	offshore > nearshore
	Season	8,052,535.0	1	73.407	<0.001***	1.000	late summer > early summer
	Survey type × season	6.7	1	0.000	0.994	0.050	
SSS	Overall model	5,320,620.0	3	349.195	<0.001***	1.000	
	Survey type	58,133.6	1	3.815	0.051	0.496	
	Season	12,000,000.0	1	801.782	<0.001***	1.000	early summer > late summer
	Survey type × season	59,747.1	1	3.921	0.048*	0.507	

[a] Ice = ice cover; secchi = secchi depth; SST = sea-surface temperature; SSS = sea-surface salinity.

[b] * = significant at α = 0.05; ** = significant at α = 0.01; *** = significant at α = 0.001.

[c] Power to detect a real difference at α = 0.05.

Table 19. Results of 3-factor MANOVA on large-scale availability of ice cover and sea-surface temperature by Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1996 and 1997, by year, survey type, and season.

Habitat variable[a]	Source	MS	df	F	*P*-value[b]	Observed power[c]	Results of multiple comparisons
Ice	Overall model	700,461.0	7	5.321	<0.001***	0.998	
	Year	1,742,991.0	1	13.104	<0.001***	0.951	1997 > 1996
	Survey type	74,605.3	1	0.567	0.452	0.117	
	Season	2,053,937.0	1	15.603	<0.001***	0.977	early summer > late summer
	Year × survey type	47.3	1	0.000	0.985	0.050	
	Year × season	691,705.0	1	5.250	0.022*	0.629	
	Survey type × season	113,285.0	1	0.861	0.354	0.153	
SST	Overall model	4,187,546.0	7	34.122	<0.001***	1.000	
	Year	12,000,000.0	1	98.277	<0.001***	1.000	1997 > 1996
	Survey type	2,238,156.0	1	18.237	<0.001***	0.989	offshore > nearshore
	Season	8,646,298.0	1	70.453	<0.001***	1.000	late summer > early summer
	Year × survey type	347,970.0	1	2.835	0.092	0.391	
	Year × season	971,661.0	1	7.917	0.005**	0.803	
	Survey type × season	24,718.9	1	0.201	0.654	0.073	

[a] Ice = ice cover; SST = sea-surface temperature.

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

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

Table 20. Results of 2-factor MANOVA on large-scale use of ice cover, secchi depth, sea-surface temperature, and sea-surface salinity by Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1997, by survey type and season.

Habitat variable[a]	Source	MS	df	F	*P*-value[b]	Observed power[c]	Results of multiple comparisons
Ice	Overall model	4,586,527.0	3	25.736	<0.001***	1.000	
	Survey type	6,349,347.0	1	35.627	<0.001***	1.000	nearshore > offshore
	Season	1,786,706.0	1	10.026	0.002**	0.886	late summer > early summer
	Survey type × season	8,241,948.0	1	46.247	<0.001***	1.000	
Secchi	Overall model	5,491,341.0	3	66.312	<0.001***	1.000	
	Survey type	4,693,644.0	1	56.679	<0.001***	1.000	offshore > nearshore
	Season	3,518,820.0	1	42.492	<0.001***	1.000	early summer > late summer
	Survey type × season	1,289,209.0	1	15.068	<0.001***	0.972	
SST	Overall model	12,000,000.0	3	67.987	<0.001***	1.000	
	Survey type	15,000,000.0	1	85.691	<0.001***	1.000	offshore > nearshore
	Season	3,934,505.0	1	22.458	<0.001***	0.997	late summer > early summer
	Survey type × season	3,745,603.0	1	21.380	<0.001***	0.996	
SSS	Overall model	25,000,000.0	3	737.674	<0.001***	1.000	
	Survey type	138,509.0	1	4.069	0.044*	0.522	offshore > nearshore
	Season	41,00,000.0	1	1,213.570	<0.001***	1.000	early summer > late summer
	Survey type × season	433,649.0	1	12.740	0.001***	0.946	

[a] Ice = ice cover; secchi = secchi depth; SST = sea-surface temperature; SSS = sea-surface salinity.

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

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

Table 21. Results of 3-factor MANOVA on large-scale use of ice cover and sea-surface temperature by Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1996 and 1997, by year, survey type, and season.

Habitat variable[a]	Source	MS	df	F	*P*-value[b]	Observed power[c]	Results of multiple comparisons
Ice	Overall model	5,129,476.0	7	23.979	<0.001***	1.000	
	Year	116,951.0	1	0.547	0.460	0.115	
	Survey type	1,609,697.0	1	7.525	0.006**	0.783	nearshore > offshore
	Season	1,130,791.0	1	5.286	0.022*	0.632	late summer > early summer
	Year × survey type	1,777,490.0	1	8.309	0.004**	0.821	
	Year × season	5,919,557.0	1	27.672	<0.001***	1.000	
	Survey type × season	11,000,000.0	1	52.026	<0.001***	1.000	
SST	Overall model	16,000,000.0	7	94.858	<0.001***	1.000	
	Year	49,000,000.0	1	292.325	<0.001***	1.000	1997 > 1996
	Survey type	9,335,906.0	1	55.852	<0.001***	1.000	offshore > nearshore
	Season	182,896.0	1	1.094	0.296	0.182	
	Year × survey type	951,242.0	1	5.691	0.017*	0.664	
	Year × season	6,193,901.0	1	37.055	<0.001***	1.000	
	Survey type × season	568,273.0	1	3.400	0.065	0.453	

[a] Ice = ice cover; SST = sea-surface temperature.

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

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

Table 22. Results of 2-factor MANOVA on large-scale availability versus use of ice cover, secchi depth, sea-surface temperature, and sea-surface salinity by Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1997, by survey type and season.

Habitat variable[a]	Source	MS	df	F	*P*-value[b]	Observed power[c]	Results of multiple comparisons
Ice	Overall model	23,000,000.0	5	43.574	<0.001***	1.000	
	Survey type	7,072,620.0	2	13.250	<0.001***	0.998	relationship differs by survey type
	Season	9,769,893.0	2	18.304	<0.001***	1.000	relationship differs by season
Secchi	Overall model	12,000,000.0	5	54.395	<0.001***	1.000	
	Survey type	8,086,858.0	2	36.154	<0.001***	1.000	relationship differs by survey type
	Season	14,000,000.0	2	64.516	<0.001***	1.000	relationship differs by season
SST	Overall model	40,000,000.0	5	74.718	<0.001***	1.000	
	Survey type	32,000,000.0	2	59.012	<0.001***	1.000	relationship differs by survey type
	Season	50,000,000.0	2	93.312	<0.001***	1.000	relationship differs by season
SSS	Overall model	62,000,000.0	5	665.552	<0.001***	1.000	
	Survey type	348,307.0	2	3.742	0.024*	0.686	relationship differs by survey type
	Season	150,000,000.0	2	1,640.994	<0.001***	1.000	relationship differs by season

[a] Ice = ice cover; secchi = secchi depth; SST = sea-surface temperature; SSS = sea-surface salinity.

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

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

Table 23. Results of 3-factor MANOVA on large-scale availability versus use of ice cover and sea-surface temperature by Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1996 and 1997, by year, survey type, and season.

Habitat variable[a]	Source	MS	df	F	*P*-value[b]	Observed power[c]	Results of multiple comparisons
Ice	Overall model	32,000,000.0	7	48.985	<0.001***	1.000	
	Year	3,140,719.0	2	4.784	0.008**	0.797	relationship differs by year
	Survey type	2,774,709.0	2	4.227	0.015*	0.742	relationship differs by survey type
	Season	17,000,000.0	2	26.216	<0.001***	1.000	relationship differs by season
SST	Overall model	67,000,000.0	7	113.466	<0.001***	1.000	
	Year	140,000,000.0	2	241.994	<0.001***	1.000	relationship differs by year
	Survey type	45,000,000.0	2	76.766	<0.001***	1.000	relationship differs by survey type
	Season	40,000,000.0	2	68.222	<0.001***	1.000	relationship differs by season

[a] Ice = ice cover; SST = sea-surface temperature.

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

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

Table 24. Mean large-scale availability and small-scale use of ice cover (%), secchi depth (m), sea-surface temperature (°C), and sea-surface salinity (‰) in four study bays in Prince William Sound, Alaska, in 1996 and 1997, by survey type, cruise, and habitat variable.

Comparison/ survey type	Cruise[a]	Ice cover $\bar{x}$	Ice cover SD	Ice cover n	Secchi depth $\bar{x}$	Secchi depth SD	Secchi depth n	Sea-surface temperature $\bar{x}$	Sea-surface temperature SD	Sea-surface temperature n	Sea-surface salinity $\bar{x}$	Sea-surface salinity SD	Sea-surface salinity n
SEGMENT (AVAILABILITY)													
Nearshore	ES96	6.7	11.6	9	–	–	0	4.2	0.7	9	–	–	0
	LS96	11.4	17.3	18	–	–	0	5.1	1.9	18	–	–	0
	ES97	8.0	14.8	53	1.5	1.2	52	6.4	1.8	52	25.4	2.3	52
	LS97	6.8	13.6	44	0.8	0.8	45	7.3	1.4	45	16.8	3.2	45
Offshore	ES96	3.1	4.5	14	–	–	0	5.4	1.8	14	–	–	0
	LS96	1.5	1.6	7	–	–	0	5.4	1.6	7	–	–	0
	ES97	6.5	11.9	31	1.6	1.0	30	7.9	2.0	30	24.6	2.1	30
	LS97	1.2	2.3	34	2.1	3.2	34	8.6	1.8	34	18.4	3.5	34
KITTLITZ'S MURRELET (USE)													
Nearshore	ES96	1.5	2.9	60	–	–	0	–	–	0	–	–	0
	LS96	3.6	6.5	158	–	–	0	–	–	0	–	–	0
	ES97	1.8	4.3	501	1.2	1.1	120	6.7	1.6	125	24.6	2.4	125
	LS97	2.6	6.3	422	0.9	1.2	88	7.6	1.5	87	17.0	2.8	87
Offshore	ES96	0.7	1.7	51	–	–	0	–	–	0	–	–	0
	LS96	2.2	3.5	14	–	–	0	–	–	0	–	–	0
	ES97	2.0	4.8	117	–	–	0	–	–	0	–	–	0
	LS97	0.8	2.6	96	–	–	0	–	–	0	–	–	0

[a] ES96 = early summer 1996; LS96 = late summer 1996; ES97 = early summer 1997; LS97 = late summer 1997.

Table 25. Results of 3-factor ANOVAs on large-scale availability, fine-scale use, and availability versus use of ice cover by Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1996 and 1997, by year, survey type, and season.

Comparison/source	MS	df	F	*P*-value[a]	Observed power[b]	Results of multiple comparisons[c]
AVAILABILITY						
Overall model	11,096.0	7	3.506	0.001***	0.966	
Year	258.9	1	0.082	0.775	0.059	
Survey type	18,101.7	1	5.720	0.018*	0.663	nearshore > offshore
Season	1,197.3	1	0.378	0.539	0.094	
Year × survey type	1,196.2	1	0.378	0.539	0.094	
Year × season	13,107.6	1	4.142	0.043*	0.526	
Survey type × season	6,439.4	1	2.035	0.155	0.295	
USE						
Overall model	1,817,748.0	7	12.306	<0.001***	1.000	
Year	24,199.2	1	0.164	0.686	0.069	
Survey type	706,806.0	1	4.785	0.029*	0.589	nearshore > offshore
Season	1,956,952.0	1	13.248	<0.001***	0.953	late summer > early summer
Year × survey type	215,476.0	1	1.459	0.227	0.226	
Year × season	3,026,796.0	1	20.491	<0.001***	0.995	
Survey type × season	586,396.0	1	3.970	0.047*	0.512	
AVAILABILITY VS. USE						
Overall model	3,690,472.0	7	19.146	<0.001***	1.000	
Year	30,157.1	2	0.156	0.855	0.074	
Survey type	2,629,045.0	2	13.640	<0.001***	0.998	relationship differs by survey type
Season	2,058,902.0	2	10.682	<0.001***	0.990	relationship differs by season

[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 26. Plumage characteristics of after-hatching-year (AHY) Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1996 and 1997, by survey type and cruise.

	Plumage								
	Breeding		Molting		Winter		Unknown		
Survey type/cruise	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Total
NEARSHORE									
Early summer 1996	130	91.5	8	5.6	2	1.4	2	1.4	142
Late summer 1996	175	95.6	8	4.4	0	0	0	0	183
Early summer 1997	484	96.0	18	3.6	2	0.4	0	0	504
Late summer 1997	413	96.5	15	3.5	0	0	0	0	428
OFFSHORE									
Early summer 1996	215	91.9	18	7.7	1	0.4	0	0	234
Late summer 1996	24	96.0	1	4.0	0	0	0	0	25
Early summer 1997	126	96.9	4	3.1	0	0	0	0	130
Late summer 1997	104	97.2	3	2.8	0	0	0	0	107
NEARSHORE + OFFSHORE									
Early summer 1996	345	91.8	26	6.9	3	0.8	2	0.5	376
Late summer 1996	199	95.7	9	4.3	0	0	0	0	208
Early summer 1997	610	96.2	22	3.5	2	0.3	0	0	634
Late summer 1997	517	96.6	18	3.4	0	0	0	0	535

Table 27. Results of statistical tests on proportions of after-hatching-year (AHY) Kittlitz's murrelets that were in breeding plumage in four bays in Prince William Sound, Alaska, in 1996 and 1997.

Comparison	χ^2	df	*P*-value[a]	Conclusion
NEARSHORE VS. OFFSHORE				
Early summer 1996	0.014	1	0.908	
Late summer 1996	0.010	1	0.925	
Early summer 1997	0.215	1	0.670	
Late summer 1997	0.129	1	0.731	
EARLY VS. LATE SUMMER (NEARSHORE + OFFSHORE)				
1996	3.169	1	0.080	
1997	0.143	1	0.721	
1996 VS. 1997 (NEARSHORE + OFFSHORE)				
Early summer	9.068	1	0.003**	1997 > 1996
Late summer	0.373	1	0.558	

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

Table 28. Results of statistical tests on proportions of Kittlitz's murrelet groups that consisted of single birds in four bays in Prince William Sound, Alaska, in 1996 and 1997.

Comparison	χ^2	df	*P*-value[a]	Conclusion
NEARSHORE VS. OFFSHORE				
Early summer 1996	1.019	1	0.338	
Late summer 1996	0.088	1	0.794	
Early summer 1997	3.008	1	0.087	
Late summer 1997	0.021	1	0.891	
EARLY VS. LATE SUMMER (NEARSHORE + OFFSHORE)				
1996	57.600	1	<0.001***	late summer > early summer
1997	22.143	1	<0.001***	late summer > early summer
1996 VS. 1997 (NEARSHORE + OFFSHORE)				
Early summer	14.673	1	<0.001***	1997 > 1996
Late summer	3.172	1	0.079	

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

Table 29. Density (birds/km^2) of hatching-year (HY; July–August) and after-hatching-year (AHY; May–June) Kittlitz's murrelets and HY:AHY ratios in four bays in Prince William Sound, Alaska, in 1996 and 1997, by survey type, year, and bay.

Survey type/year	Bay	HY density $\bar{x}$	HY density n	HY density Maximal	AHY density $\bar{x}$	AHY density n	AHY density Maximal	HY:AHY ratio $\bar{x}$	HY:AHY ratio Maximal
NEARSHORE									
1996	Unakwik Inlet	0	2	0	0.38	3	1.03	0:1	0:1
	College Fjord	0.02	3	0.07	1.16	2	2.19	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	2.74	2	3.76	0:1	0:1
	Total	0.01	10	0.07	1.42	9	3.76	0.01:1	0.02:1
1997	Unakwik Inlet	0	2	0	6.16	3	8.95	0:1	0:1
	College Fjord	0	3	0	3.28	2	4.22	0:1	0:1
	Harriman Fjord	0	3	0	8.93	2	10.76	0:1	0:1
	Blackstone Bay	0	3	0	1.98	2	3.02	0:1	0:1
	Total	0	11	0	5.21	9	10.76	0:1	0:1
OFFSHORE									
1996	Unakwik Inlet	0	2	0	6.01	3	17.66	0:1	0:1
	College Fjord	0	3	0	1.09	2	1.21	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	6.10	0:1	0:1
	Total	0	10	0	4.61	9	17.66	0:1	0:1
1997	Unakwik Inlet	0	2	0	1.01	3	1.57	0:1	0:1
	College Fjord	0	3	0	0.95	2	1.89	0:1	0:1
	Harriman Fjord	0	3	0	6.95	2	7.60	0:1	0:1
	Blackstone Bay	0	3	0	1.66	2	3.32	0:1	0:1
	Total	0	11	0	2.46	9	7.60	0:1	0:1

Table 30. Records of mixed-species Kittlitz's/marbled murrelet "pairs" in Prince William Sound, Alaska, in 1996 and 1997, by cruise, bay, and date.

Cruise	Bay	Date	Number of "pairs"
Late summer 1996	College Fjord	30 July	1
	College Fjord	7/8 August	1
Early summer 1997	Unakwik Inlet	1 June	2
	Unakwik Inlet	8 June	1
	Harriman Fjord	5 June	1
	Harriman Fjord	12 June	1–2
Late summer 1997	Unakwik Inlet	22 July	2
	Unakwik Inlet	29 July	1
	College Fjord	25 July	1
	Harriman Fjord	18 July	3
	Harriman Fjord	19 July	1
	Harriman Fjord	27 July	1–2
	Harriman Fjord	2 August	2

Table 31. Sampling effort and catch rates of Kittlitz's murrelets with floating mist nets in Prince William Sound, Alaska, in early summer 1996.

Date	Site	Time of sampling	Number of nets deployed	Number of Net-hours of sampling	Number of 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 32. Number (percentage) of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996 and 1997, by season, survey type, year, and time of day. Analyses were conducted only for birds on the water.

		Time of day								
		Morning[a]			Afternoon[a]			Total		
Season/ survey type	Year	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total
EARLY SUMMER										
Nearshore	1996	19	71	90	15	36	51	34	107	141
(Percent)		(21.1)	(78.9)		(29.4)	(70.6)		(24.1)	(75.9)	
	1997	164	108	272	109	123	232	273	231	504
(Percent)		(60.3)	(39.7)		(47.0)	(53.0)		(54.2)	(45.8)	
	1996+1997	183	179	362	124	159	283	307	338	645
(Percent)		(50.6)	(49.4)		(43.8)	(56.2)		(47.6)	(52.4)	
Offshore	1996	6	60	66	9	143	152	15	203	218
(Percent)		(9.1)	(90.1)		(5.9)	(94.1)		(6.9)	(93.1)	
	1997	4	24	28	22	69	91	26	93	119
(Percent)		(14.3)	(85.7)		(24.2)	(75.8)		(21.8)	(78.2)	
	1996+1997	10	84	94	31	212	243	41	296	337
(Percent)		(10.6)	(89.4)		(12.8)	(87.2)		(12.2)	(87.8)	
LATE SUMMER										
Nearshore	1996	70	60	130	29	25	54	99	85	184
(Percent)		(53.8)	(46.2)		(53.7)	(46.3)		(53.8)	(46.2)	
	1997	91	91	182	138	104	242	229	195	424
(Percent)		(50.0)	(50.0)		(57.0)	(43.0)		(54.0)	(46.0)	
	1996+1997	161	151	312	167	129	296	328	280	608
(Percent)		(51.6)	(48.4)		(56.4)	(43.6)		(53.9)	(46.1)	
Offshore	1996	1	21	22	0	0	0	1	21	22
(Percent)		(4.5)	(95.5)		(0)	(0)		(4.5)	(95.5)	
	1997	21	74	95	0	2	2	21	76	97
(Percent)		(22.1)	(77.9)		(0)	(100.0)		(21.6)	(78.4)	
	1996+1997	22	95	117	0	2	2	22	97	119
(Percent)		(18.8)	(81.2)		(0)	(100.0)		(18.5)	(81.5)	

[a] Morning = 0600–1159; afternoon = 1200–1930.

Table 33. Number (percentage) of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996 and 1997, by season, survey type, year, and tidal stage. Analyses were conducted only for birds on the water.

Season/ survey type	Year	Tidal stage: Rising tide[a] Feeding	Not feeding	Total	Falling tide[a] Feeding	Not feeding	Total
EARLY SUMMER							
Nearshore	1996	13	53	66	21	54	75
(Percent)		(19.7)	(80.3)		(28.0)	(72.0)	
	1997	132	132	264	141	99	240
(Percent)		(50.0)	(50.0)		(58.8)	(41.2)	
	1996+1997	145	185	330	162	153	315
(Percent)		(43.9)	(56.1)		(51.4)	(48.6)	
Offshore	1996	10	49	59	5	154	159
(Percent)		(16.9)	(83.1)		(3.1)	(96.9)	
	1997	9	50	59	17	43	60
(Percent)		(15.3)	(84.7)		(28.3)	(71.7)	
	1996+1997	19	99	118	22	197	219
(Percent)		(16.1)	(83.9)		(10.0)	(90.0)	
LATE SUMMER							
Nearshore	1996	50	46	96	49	39	88
(Percent)		(52.1)	(47.8)		(55.6)	(44.3)	
	1997	159	116	275	70	79	149
(Percent)		(57.8)	(42.2)		(47.0)	(53.0)	
	1996+1997	209	162	371	119	118	237
(Percent)		(56.3)	(43.7)		(50.2)	(49.8)	
Offshore	1996	1	17	18	0	4	4
(Percent)		(5.5)	(94.4)		(0)	(100.0)	
	1997	15	59	74	6	17	23
(Percent)		(20.3)	(79.7)		(26.1)	(73.9)	
	1996+1997	16	76	92	6	21	27
(Percent)		(17.4)	(82.6)		(22.2)	(77.8)	

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

Table 34. Number (percentage) of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996 and 1997, by season, survey type, year, and strength of tidal current. Analyses were conducted only for birds on the water.

		Current strength								
		Weak[a]			Moderate[a]			Strong[a]		
Season/ survey type	Year	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total
EARLY SUMMER										
Nearshore	1996	19	30	49	5	27	32	10	50	60
(Percent)		(38.8)	(61.2)		(15.6)	(84.4)		(16.7)	(83.3)	
	1997	114	133	247	66	40	106	93	58	151
(Percent)		(46.2)	(53.8)		(62.3)	(37.7)		(61.6)	(38.4)	
	1996+1997	133	163	296	71	67	138	103	108	211
(Percent)		(44.9)	(55.1)		(51.4)	(48.6)		(48.8)	(51.2)	
Offshore	1996	6	28	34	1	33	34	8	142	150
(Percent)		(17.6)	(82.4)		(2.9)	(97.1)		(5.3)	(94.7)	
	1997	1	11	12	15	37	52	10	45	55
(Percent)		(8.3)	(91.7)		(28.8)	(71.2)		(18.2)	(81.8)	
	1996+1997	7	39	46	16	70	86	18	187	205
(Percent)		(15.2)	(84.8)		(18.6)	(81.4)		(8.8)	(91.2)	
LATE SUMMER										
Nearshore	1996	23	27	50	53	38	91	23	20	43
(Percent)		(46.0)	(54.0)		(58.2)	(41.8)		(53.5)	(46.5)	
	1997	103	83	186	63	77	140	63	35	98
(Percent)		(55.4)	(44.6)		(45.0)	(55.0)		(64.3)	(35.7)	
	1996+1997	126	110	236	116	115	231	86	55	141
(Percent)		(53.4)	(46.6)		(50.4)	(49.6)		(61.0)	(39.0)	
Offshore	1996	0	11	11	0	4	4	1	6	7
(Percent)		(0)	(100.0)		(0)	(100.0)		(14.3)	(85.7)	
	1997	6	16	22	7	30	37	8	30	38
(Percent)		(27.3)	(72.7)		(18.9)	(81.1)		(21.1)	(78.9)	
	1996+1997	6	27	33	7	34	41	9	36	45
(Percent)		(18.2)	(81.8)		(17.1)	(82.9)		(20.0)	(80.0)	

[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 35. Number (percentage) of Kittlitz's murrelets that were feeding in nearshore waters of four bays in Prince William Sound, Alaska, in 1996 and 1997, by season, year, and standardized habitat type. Analyses were conducted only for birds on the water. No data are presented for marine-sill-affected habitats, because no Kittlitz's murrelets were recorded there, and for offshore surveys, because all sampling there occurred in only one habitat type.

		Habitat type								
		Glacial-affected			Glacial-stream-affected			Glacial-unaffected		
Season	Year	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total
Early summer	1996	9	9	18	4	27	31	21	71	92
(Percent)		(50.0)	(50.0)		(12.9)	(87.1)		(22.8)	(77.2)	
	1997	47	75	122	99	62	161	127	94	221
(Percent)		(38.5)	(61.5)		(61.4)	(38.5)		(57.5)	(42.5)	
	1996+1997	56	84	140	103	89	192	148	165	313
(Percent)		(40.0)	(60.0)		(53.6)	(46.4)		(47.3)	(52.7)	
Late summer	1996	45	32	77	17	28	45	37	25	62
(Percent)		(65.2)	(34.8)		(42.5)	(57.5)		(49.3)	(50.7)	
	1997	107	76	183	45	58	103	77	61	138
(Percent)		(58.5)	(41.5)		(43.7)	(56.3)		(55.8)	(44.2)	
	1996+1997	152	108	260	62	86	148	114	86	200
(Percent)		(58.5)	(41.5)		(41.9)	(58.1)		(57.0)	(43.0)	

Table 36. Results of multiway contingency table analyses of the effects of time of day, season, year, survey type, tidal stage, current strength, and standardized habitat type on proportions of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996 and 1997. Analyses were conducted only for birds on the water.

Source	χ^2	df	*P*-value[a]	Conclusion[b]
Overall model	254.628	9	<0.001***	
Time of day	1.465	1	0.226	
Season	7.348	1	0.007**	late summer > early summer
Year	36.006	1	<0.001***	1997 > 1996
Survey type	111.281	1	<0.001***	nearshore > offshore
Tidal stage	0.102	1	0.750	
Current strength	2.948	2	0.229	
Habitat type	1.268	2	0.530	

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

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

Table 37. Results of goodness-of-fit contingency table analyses of the effects of current strength on proportions of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996 and 1997. Analyses were conducted only for birds on the water and assumed that 16.7% of birds should be feeding in a weak current, 33.3% should be feeding in a moderate current, and 50.0% should be feeding in a strong current.

Comparison	χ^2	df	*P*-value[a]	Conclusion[b]
Early summer nearshore	266.412	5	<0.001***	W, M > expected; S < expected
Early summer offshore	158.669	5	<0.001***	W = expected; M > expected; S < expected
Late summer nearshore	273.811	5	<0.001***	W, M > expected; S = expected
Late summer offshore	25.411	5	<0.001***	W, M = expected; S < expected

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

[b] W = weak current; M = moderate current; S = strong current.

Table 38. Records of Kittlitz's murrelets holding prey items in four bays in Prince William Sound, Alaska, in 1996 and 1997, by season, bay, date, and prey type.

			Prey type			
Season/bay	Date	Number of birds (n)	Pacific sand lance	Unidentified fish	Approximate size of prey (cm)	Comments
EARLY SUMMER						
College Fjord	2 JN 1996	1		X	8–10	
Blackstone Bay	7 JN 1996	1		X		
LATE SUMMER						
Unakwik Inlet	29 JL 1997	2		X	~3	mixed-species feeding flock with marbled murrelets and black-legged kittiwakes; eating larval fishes
College Fjord	16 JL 1997	1		X		
	16 JL 1997	1	X		~10	
	16 JL 1997	1		X		ate fish at surface
	24 JL 1997	1	X			ate fish
	24 JL 1997	1		X		
	24 JL 1997	1		X		
	24 JL 1997	1		X		carrying fish
	1 AU 1997	1	X			ate fish
Harriman Fjord	31 JL 1996	1		X	8–10	
	8 AU 1996	1	X		6–8	
	19 JL 1997	1	X		~10	
	26 JL 1997	1	X		~8	
	27 JL 1997	1		X		
Total			6	11		

Table 39. Prey items and mean approximate prey sizes of prey items being held by Kittlitz's and marbled murrelets in four bays in Prince William Sound, Alaska, in 1996 and 1997, by bird species. Data are pooled across all season and cruises.

	Number of prey items			Prey size (cm)		
Species	Pacific sand lance	Pacific herring	Unidentified fish	$\bar{x}$	SD	n
Kittlitz's murrelet	6	0	11	7.4	2.9	8
Marbled murrelet	17	2	38	8.9	3.3	28

Table 40. Numbers of birds in mixed-species feeding flocks containing Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1996 and 1997, by season, bay, and species.

Season/bay	Date[a]	Time	Species: Kittlitz's murrelet	Marbled murrelet	Mew gull	Black-legged kittiwake	Arctic tern	Comments
EARLY SUMMER								
Harriman Fjord	5 JN 1997	1810	4	6	–	–	–	loose flock feeding near Point Doran, near another loose flock of ~10 feeding marbled murrelets
LATE SUMMER								
Unakwik Inlet	29 JL 1997	1540	2	4	–	~5	–	feeding on small fishes ~3 cm long
College Fjord	30 JL 1996	2020	25–40	100–110	–	20–30	–	feeding in large, loose flock ~100 × 100 m in area near mouth of Yale Arm
	16 JL 1997	1240	1	–	P[b]	P[b]	P[b]	murrelet flew into turbid glacial outflow where other birds were feeding off Harvard Glacier; not actually seen feeding, however.
Harriman Fjord	27 JL 1997	1005	~6	~85	–	–	–	large, loose flock feeding in center of bay
	2 AU 1997	1440	2	19	–	–	–	loose flock feeding in turbid glacial outflow at Surprise Glacier

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

[b] Present but numbers not recorded.

Table 41. Estimated population sizes and estimated annual rates of change of Kittlitz's murrelet populations required to cause those changes over time in Prince William Sound, Alaska, in 1972–1996, by season and years compared. Data are presented in Agler and Kendall (1997).

Season/years compared	Estimated population		Estimated annual rate of change (%/year)
	First year's estimate	Second year's estimate	
SUMMER			
1972–1989	63,229	6,436	–12.58
1972–1996	63,229	1,280	–15.00
1989–1996	6,436	1,280	–20.60
WINTER			
1972–1990	346	958	+5.82
1972–1996	346	181	–2.67
1973–1990	3,219	958	–6.88
1973–1996	3,219	181	–11.77
1990–1996	958	181	–24.28

Appendix 1. 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		

Appendix 2. 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		

Appendix 3. Plumage characteristics of after-hatching-year Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in early summer 1997, by survey type, bay, and visit.

			Plumage					Percent
Survey type/bay	Visit	Date	Breeding	Molting	Winter	Unknown	Total	breeding plumage
NEARSHORE								
Unakwik Inlet	1	1 June	57	0	1	0	58	98.3
College Fjord	1	3 June	52	1	0	0	53	98.1
Harriman Fjord	1	5 June	91	1	1	0	93	97.8
Blackstone Bay	1	6 June	19	0	0	0	19	100.0
Unakwik Inlet	2	8 June	95	7	0	0	102	93.1
College Fjord	2	10 June	31	0	0	0	31	100.0
Harriman Fjord	2	12 June	85	9	0	0	94	90.4
Blackstone Bay	2	14 June	7	0	0	0	7	100.0
Unakwik Inlet	3	16 June	47	0	0	0	47	100.0
Total			484	18	2	0	504	
Percent			96.0	3.6	0.4	0		
OFFSHORE								
Unakwik Inlet	1	2 June	4	0	0	0	4	100.0
College Fjord	1	4 June	0	0	0	0	0	–
Harriman Fjord	1	4 June	39	0	0	0	39	100.0
Blackstone Bay	1	7 June	0	0	0	0	0	–
Unakwik Inlet	2	9 June	4	0	0	0	4	100.0
Harriman Fjord	2	11 June	39	3	0	0	42	92.9
College Fjord	2	13 June	16	0	0	0	16	100.0
Blackstone Bay	2	14 June	15	0	0	0	15	100.0
Unakwik Inlet	3	17 June	9	1	0	0	10	90.0
Total			126	4	0	0	130	
Percent			96.9	3.1	0	0		

Appendix 4. Plumage characteristics of after-hatching-year Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in late summer 1997, by survey type, bay, and visit.

			Plumage					Percent
Survey type/bay	Visit	Date	Breeding	Molting	Winter	Unknown	Total	breeding plumage
NEARSHORE								
College Fjord	1	16 July	80	1	0	0	81	98.8
Harriman Fjord	1	18 July	56	3	0	0	59	94.9
Blackstone Bay	1	20 July	9	1	0	0	10	90.0
Unakwik Inlet	1	22 July	33	4	0	0	37	89.2
College Fjord	2	24 July	95	4	0	0	99	96.0
Harriman Fjord	2	26 July	59	0	0	0	59	100.0
Blackstone Bay	2	28 July	6	2	0	0	8	75.0
Unakwik Inlet	2	29 July	12	0	0	0	12	100.0
College Fjord	3	1 August	26	0	0	0	26	100.0
Harriman Fjord	3	2 August	36	0	0	0	36	100.0
Blackstone Bay	3	4 August	1	0	0	0	1	100.0
Total			413	15	0	0	428	
Percent			96.5	3.5	0	0		
OFFSHORE								
College Fjord	1	17 July	48	1	0	0	49	98.0
Harriman Fjord	1	19 July	22	1	0	0	23	95.7
Blackstone Bay	1	20 July	0	0	0	0	0	–
Unakwik Inlet	1	23 July	3	1	0	0	4	75.0
College Fjord	2	25 July	11	0	0	0	11	100.0
Harriman Fjord	2	27 July	14	0	0	0	14	100.0
Blackstone Bay	2	28 July	0	0	0	0	0	–
Unakwik Inlet	2	30 July	1	0	0	0	1	100.0
College Fjord	3	31 July	3	0	0	0	3	100.0
Harriman Fjord	3	3 August	2	0	0	0	2	100.0
Blackstone Bay	3	4 August	0	0	0	0	0	–
Total			104	3	0	0	107	
Percent			97.2	2.8	0	0		

Appendix 5. Records of marbled murrelets holding prey items in four bays in Prince William Sound, Alaska, in 1996 and 1997, by season, bay, date, and prey type.

			Prey type				
Season/bay	Date	Number of birds (n)	Pacific sand lance	Pacific herring	Unidentified fish	Approximate size prey (cm)	Comments
EARLY SUMMER							
Unakwik Inlet	15 JN 1997	1	X			~10	ate at surface
College Fjord	2 JN 1996	1	X			10–12	
Harriman Fjord	29 MY 1996	1			X	10–12	
	4 JN 1996	1			X		
	19 JN 1997	1	X			10–12	ate at surface
Pelagic survey	15 JN 1997	1	X			~10	
	18 JN 1997	1			X		
LATE SUMMER							
Unakwik Inlet	27 JL 1996	1			X	~10	ate fish
	27 JL 1996	1			X		ate fish under water
	28 JL 1996	1			X	8–10	
	28 JL 1996	1			X	10–12	
	22 JL 1997	1	X			10–12	
	23 JL 1997	1		X		~9	
	29 JL 1997	5			X	~3	mixed-species feeding flock with marbled murrelets and black-legged kittiwakes; eating larval fishes

Appendix 5. Continued.

Season/bay	Date	Number of birds (n)	Prey type: Pacific sand lance	Pacific herring	Unidentified fish	Approximate size prey (cm)	Comments
LATE SUMMER (CONTINUED)							
College Fjord	29 JL 1996	1	X			10–12	
	30 JL 1996	1			X		carrying fish
	30 JL 1996	1			X	10–12	
	7 AU 1996	1			X		
	12 AU 1996	2			X		
	15 JL 1997	2	X				carrying fish
	17 JL 1997	1	X			10–12	carrying fish
	24 JL 1997	1	X			~10	
	24 JL 1997	1			X		
	24 JL 1997	1	X				
Harriman Fjord	2 AU 1996	1		X		12–14	
	2 AU 1996	1			X	~8	
	13 AU 1996	1			X		
	18 JL 1997	1			X		carrying fish
	18 JL 1997	1	X			~10	ate under water
	18 JL 1997	1			X		ate fish
	19 JL 1997	1			X		carrying fish
	2 AU 1997	1			X		eats fish

Appendix 5. Continued.

			Prey type				
Season/bay	Date	Number of birds (n)	Pacific sand lance	Pacific herring	Unidentified fish	Approximate size prey (cm)	Comments
LATE SUMMER (CONTINUED)							
Blackstone Bay	3 AU 1996	9			X		feeding with black-legged kittiwakes on schools of fish near shore
	20 JL 1997	1	X			~10	
	20 JL 1997	1			X		
	20 JL 1997	1			X		carrying fish into bay from outside it
	26 JL 1997	1			X	~3	juvenile; ate fish
	4 AU 1997	2	X			10–12	
	4 AU 1997	1	X			12–14	ate fish
Pelagic surveys	28 JL 1996	1			X	10–12	
	23 JL 1997	1	X				
	25 JL 1997	1			X		
Total			17	2	38		

Appendix 6. Information from the manuscript on ecological and morphological adaptations for foraging in Kittlitz's and marbled murrelets. Data are preliminary and should not be cited.

FORAGING AND MORPHOLOGICAL DIFFERENCES BETWEEN KITTLITZ'S AND MARBLED MURRELETS

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RRH: MURRELET FORAGING AND MORPHOLOGY

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Abstract. We studied foraging ecology and its relationship to morphology in two closely related species, Kittlitz's (*Brachyramphus brevirostris*) and Marbled (*B. marmoratus*) murrelets. The two species differed significantly in preferred habitat type and mean secchi depth (an indicator of water clarity). Mean secchi depth was lowest in glacial affected and glacial stream affected waters, which were preferred for foraging by Kittlitz's Murrelets, and was highest in marine sill affected and glacial unaffected waters, which were preferred by Marbled Murrelets. Although feeding frequency in glacial affected habitats did not differ between species, very few Marbled Murrelets occurred in this habitat, whereas most Kittlitz's Murrelets occurred there. Field observations suggested that the two species foraged in different habitats and that these differences were accompanied by morphological differences in eye size. We examined eye morphomertics from a sample of museum specimens in an attempt to explain this ecological differentiation. Mean orbit diameters of Kittlitz's Murrelets were not significantlylarger than those of Marbled Murrelets. However, the proportion of total skull length and of total post-bill skull length occupied by orbit diameter was significantly greater in Kittlitz's Murrelets. These results suggest ecological differentiation in use of foraging habitat by the two species, with Kittlitz's Murrelets adapted to foraging in highly turbid water near glaciers and Marbled Murrelets adapted to foraging in clearer water away from glaciers. The actual adaptation which facilitates this differentiation still remains unclear. *Key words:* Brachyramphus brevirostris, B. marmoratus, *foraging ecology, habitat use, Kittlitz's Murrelet, Marbled Murrelet, morphological adaptation*.

Table 1. Results of 5-factor ANOVAs on ranked densities (birds/km^2) of Kittlitz's and Marbled murrelets on nearshore surveys in four bays in Prince William Sound, Alaska, in 1996 and 1997. The analyses were conducted by year, season, site (bay), visit, and standardized habitat type.

Species/source	SS	df	F	*P*[a]	Observed power[b]	Multiple comparisons
KITTLITZ'S MURRELET						
Overall model	14,000,000.0	128	3.425	<0.001***	1.000	
Year	1,196,837.0	1	36.401	<0.001***	1.000	1997 > 1996
Season	53,390.3	1	1.624	0.20	0.247	
Site	413,261.0	3	4.190	0.01**	0.856	CF = HF, CF > UI, HF = UI, UI > BB[c]
Visit	140,708.0	2	2.140	0.12	0.439	
Habitat type	1,001,376.0	3	10.152	<0.001***	0.998	GA > GS = GU > MS[d]
Habitat type × year	653,708.0	3	6.627	<0.001***	0.974	
Habitat type × season	228,663.0	3	2.318	0.07	0.584	
Habitat type × site	385,502.0	7	1.675	0.11	0.693	
MARBLED MURRELET						
Overall model	22,000,000.0	128	3.753	<0.001***	1.000	
Year	834,410.0	1	18.530	<0.001***	0.990	1997 > 1996
Season	1,502,405.0	1	33.365	<0.001***	1.000	late summer > early summer
Site	1,043,165.0	3	7.722	<0.001***	0.989	UI = BB > HF = CF[c]
Visit	414,111.0	2	4.598	0.01**	0.778	
Habitat type	1,470,528.0	3	10.886	<0.001***	0.999	GS = GU = MS > GA[d]
Habitat type × year	204,522.0	3	1.514	0.21	0.401	
Habitat type × season	319,140.0	3	2.362	0.07	0.593	
Habitat type × site	861,367.0	7	2.733	0.01**	0.912	

[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.

[d] GA = glacial affected; GS = glacial stream affected; GU = glacial stream affected; MS = marine sill affected

Table 2. Numbers and percentages of feeding by Kittlitz's and Marbled murrelets in four bays in Prince William Sound, Alaska, in 1996 and 1997, by survey type. Flying birds were excluded from analyses.

	Survey type								
	Nearshore			Offshore					
Species	Feeding	Not feeding	Total	Feeding	Not feeding	Total	χ^2	df	P[a]
Kittlitz's Murrelet	635	618	1,253	141	533	674	161.309	1	<0.001***
(Percent)	(50.7)	(49.3)		(20.9)	(79.1)				
Marbled Murrelet	4,111	3,216	7,327	804	1,706	2,510	433.452	1	<0.001***
(Percent)	(56.1)	(43.9)		(32.0)	(68.0)				

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

Table 3. Number and percentages of feeding Kittlitz's and Marbled murrelets on nearshore surveys in four bays in Prince William Sound, Alaska, in 1996 and 1997, by habitat type. Flying birds were excluded from analyses.

	Habitat type											
	Glacial affected			Glacial stream affected			Marine sill affected			Glacial unaffected		
Species	Feeding	Not Feeding	Total	Feeding	Not Feeding	Total	Feeding	Not Feeding	Total	Feeding	Not Feeding	Total
Kittlitz's Murrelet	208	192	400	165	175	340	0	0	0	262	251	513
(Percent)	(52.0)	(48.0)		(48.5)	(51.5)		(0)	(0)		(51.1)	(48.9)	
Marbled Murrelet	81	72	153	961	978	1,939	107	72	179	2,962	2,094	5,056
(Percent)	(52.9)	(47.1)		(49.6)	(50.4)		(59.8)	(40.2)		(58.6)	(41.4)	

Table 4. Mean secchi depths (m) of waters in which Kittlitz's and Marbled murrelets occurred in four bays in Prince William Sound, Alaska, in 1997, by survey type.

		Secchi depth					
Survey type	Species	$\bar{x}$	SD	n	t	df	P[a]
Nearshore	Kittlitz's Murrelet	1.14	1.01	895	31.132	1,487	<0.001***
	Marbled Murrelet	2.55	1.82	4,406			
Offshore	Kittlitz's Murrelet	2.23	3.12	290	6.309	411	<0.001***
	Marbled Murrelet	2.33	2.53	1,167			

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

Table 5. Mean secchi depths (m) of nearshore waters in which Kittlitz's and Marbled murrelets occurred in four bays in Prince William Sound, Alaska, in 1997, by habitat type.

		Secchi depth					
Habitat type	Species	$\bar{x}$	SD	n	t	df	P[a]
Glacial affected	Kittlitz's Murrelet	0.67	0.38	305	0.127	200	0.90
	Marbled Murrelet	0.68	0.30	97			
Glacial stream affected	Kittlitz's Murrelet	1.41	1.11	241	3.353	335	0.001***
	Marbled Murrelet	1.67	1.25	1,261			
Marine sill affected	Kittlitz's Murrelet	–	–	0	–	–	–
	Marbled Murrelet	4.36	0.99	113			
Glacial unaffected	Kittlitz's Murrelet	1.37	1.16	349	19.580	3,282	<0.001***
	Marbled Murrelet	2.93	1.88	2,935			

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

Table 6. Mean orbit diameters (mm) of Kittlitz's and Marbled Murrelets in Alaska. Comparisons are for actual measurements, for percentage of total head length, and for percentage of total post-bill (skull) head length.

	Orbit diameter					
Attribute/species	$\bar{x}$	SD	*n*	*t*	df	*P*[a]
MEASUREMENTS						
Kittlitz's Murrelet	18.37	0.54	16	0.785	27	0.44
Marbled Murrelet	18.17	0.82	13			
PERCENT OF TOTAL HEAD LENGTH						
Kittlitz's Murrelet	32.22	0.70	16	4.814	24	<0.001***
Marbled Murrelet	30.09	1.55	10			
PERCENT OF POST-BILL HEAD LENGTH						
Kittlitz's Murrelet	61.95	1.58	16	2.357	27	0.03*
Marbled Murrelet	60.45	1.84	13			

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