Exxon Valdez Oil Spill
Restoration Project Final Report

Status and Ecology of Kittlitz's Murrelet in Prince William Sound, 1996–1998

Restoration Project 98142
Final Report

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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), mid-(late June-early July; 1998 only), and late summer (July–August). This was the third 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 1996–1998. 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, birds penetrated throughout bays, with numbers decreasing rapidly as birds abandoned bays. Populations collectively totaled ~1,300 birds in all 3 yr. Glacial-affected and glacial-stream-affected habitats were most preferred, and marine-sill-affected habitats were least preferred, by Kittlitz's murrelets. Murrelet abundance was strongly related to ice cover, water clarity, and sea-surface temperatures. The low reproductive output in all years and the occurrence of mixed-species "pairs" are sources of conservation concern. The percentage of breeding-plumaged birds and the percentage of single-birds groups exhibited seasonal patterns, although neither helped to understand reproductive performance. Feeding frequency varied significantly by survey type, season, year, habitat type, ice cover, distance from shore, depth, and shoreline substrate. Kittlitz's murrelets ate fishes, primarily sandlance and unidentified fishes, and Kittlitz's and marbled murrelets overlapped extensively in prey type, prey size, dive times, and many other aspects of feeding ecology.

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

Project Data: The data from this study are archived at ABR, Inc., in Fairbanks, AK, under project 846. The data files consist of (1) a data file for all nearshore surveys; (2) a data file for all offshore surveys; (3) a data file for all pelagic surveys; (4) a data file for the limited feeding data; and (5) digitized locations of birds. All of these data files except (5) are keypunched in the software Microsoft Excel. The file of digitized locations of birds in the nearshore zone is in the software ARCVIEW. Robert H. Day (ABR, Inc., P.O. Box 80410; Fairbanks, AK 99708-0410; bday@abrinc.com; PH 907-455-6777) of ABR is the custodian of these data, and all questions and requests for use should be directed to him. After publication of these results, these data will be available for external use.

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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 1996–1998. 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 are affected by glaciers to various degrees. We conducted multiple systematic surveys in these bays during 3-week cruises in early (May–June) and late summer (July–August) 1996–1998 and in a 1.5-week mid-summer (late June–early July) cruise in 1998.

We studied Kittlitz's murrelets on nearshore (≤200 m from shore within bays) surveys, offshore (>200 m from shore within bays) 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 each survey segments in terms of the level of influence 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), secchi depths (1997–1998 only), sea-surface temperatures, sea-surface salinities (1997–1998 only), and depth. We also digitized location records of birds on nearshore surveys, determined the nearest shoreline substrate, and calculated the distance from the nearest freshwater input for each bird. To study feeding ecology, we compared proportions of birds that were feeding by survey type, time of day, season, year, tidal stage, current strength, percent ice cover, secchi depth, sea-surface temperature, sea-surface salinity, distance from nearest freshwater input, distance from nearest shore, mean water depth, habitat type, and shoreline substrate. We also attempted to catch hatching-year (juvenile) Kittlitz's murrelets to study trophics. Finally, we observed feeding birds and examined prey type and size and measured dive times.

Results

In all years, Kittlitz's murrelets were common on nearshore and offshore surveys and rare on pelagic surveys. Kittlitz's murrelets occurred in highest densities in College and Harriman fjords and in lowest densities in Unakwik Inlet and Blackstone Bay. They also occurred in highest densities in 1997, regardless of how the data were examined. Arrival times and early-summer distribution varied among bays, primarily because of variations in ice cover and/or sea-surface temperatures. In contrast, birds were widely distributed throughout these bays in late summer, as ice cover decreased and temperatures increased. Numbers increased rapidly in early summer, peaked around 1 July in most bays, and decreased rapidly in late summer, as these birds abandoned the bays. Population estimates in all 4 bays varied dramatically among years but collectively totaled ~1,300 birds in all 3 yr.

Glacial-affected habitats were most preferred, glacial-stream-affected habitats were second in preference, and glacial-unaffected and marine-sill-affected habitats were least preferred by Kittlitz's murrelets. At a large scale, most Kittlitz's murrelets occurred in waters with ≤20% ice cover. They occurred in greater ice cover than was available to them as a whole, although this pattern varied by season: on nearshore surveys, use was less than availability in early summer but greater than availability in late summer. In contrast, at a fine scale, use always was less than availability. At both large and small scales, Kittlitz's murrelets occurred in water that was more turbid than what was available to them on average; most birds occurred in waters with secchi depths ≤3 m. Most Kittlitz's murrelets occurred in waters 4–10°C; they used colder sea-surface temperatures than were available on average at a large scale but warmer temperatures at a small scale. Kittlitz's murrelets occurred primarily in waters with salinities 21–29‰ in early summer and 12–25‰ in late summer; at both scales, they used salinities that were greater than available on average.

Ratios of hatching-year (HY) to after-hatching-year (AHY) birds indicated that reproductive output in all bays was extremely low or absent in all years: only one HY bird was recorded in 1996, none were seen in 1997, and we saw evidence of breeding (but no fledged young) in 1998. Other evidence suggested that birds spent such short periods in two of the bays that they could not have reproduced. Consequently, we were unable to catch newly fledged HY birds to study their residence times and turnover rates. For nearshore and offshore surveys combined, >90% of birds were in breeding plumage in early summer; in contrast, in late summer, the proportion of breeding-plumaged birds was high and declined only at the end of that season, as birds began to enter the post-breeding (pre-basic) molt. The proportions of breeding-plumaged birds in early summer 1996 and 1998 were the lowest of all cruises. Seasonal patterns in the proportions of single-bird groups were pronounced; however, these seasonal patterns did not match the predicted pattern and had little utility in our understanding of reproduction. We observed what appeared to be mixed-species "pairs" of Kittlitz's and marbled murrelets during early summer 1997 and all late-summer cruises.

Because we were unable to live-capture Kittlitz's murrelets, we were unable to collect samples for trophic studies. We were, however, able to examine other aspects of feeding ecology. The proportion of birds seen feeding was significantly higher in nearshore waters, in late summer, in 1997, in glacial-affected and glacial-stream-affected habitats, in both very low and very high percent ice cover, near the shoreline, in shallow water, and off of all shoreline substrates except bedrock. Kittlitz's murrelets ate fishes, primarily sandlance (but also Pacific herring and probably capelin), and primarily from 0- or 1-yr age classes. Prey type (forage fishes), mean prey sizes (~8–10 cm), and mean dive times (~29 sec) overlapped extensively between Kittlitz's and marbled murrelets. Kittlitz's murrelets also occasionally occurred in mixed-species feeding flocks, primarily with marbled murrelets. Kittlitz's murrelets, however, seem to be more adapted to foraging in highly turbid water than marbled murrelets do.

Discussion

Kittlitz's murrelets exhibit a clumped distribution at several scales, from a regional scale to a within-bay scale. Such a clumped distribution makes sampling design important in monitoring the abundance and distribution of this species.

Densities of Kittlitz's murrelets exhibited significant seasonal, interannual, and geographic variation during the 3 yr of the study. Kittlitz's murrelets arrive in these bays from spring (probably April in some bays but May in most bays) to mid-June; they begin leaving the bays in mid-July, most are gone by early August, and some linger in the breeding bays until mid-August. The timing of movements of populations of Kittlitz's murrelets differed markedly among bays and years. 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 also 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 population in the four bays combined varied little overall among years, although it did vary within bays. Determination of whether populations have changed, however, is hampered by a lack of good baseline data on population sizes in these study bays. The large-scale, random-sampling surveys used by the USFWS are not appropriate for estimating population size of this highly clumped species.

Kittlitz's murrelets exhibited an overall preference for glacial-affected and glacial-stream-affected habitats; hence, such areas are important and should be protected from disturbance during the summer. In early summer, Kittlitz's murrelets were limited in distribution by heavy ice cover and cold sea-surface temperatures; when conditions ameliorated by late summer, however, these birds ranged throughout all bays. Kittlitz's murrelets exhibited a shift to areas with slightly higher ice cover later in the summer as they moved into parts of the bays where high ice cover previously had excluded them. This shift was corroborated by 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 only variable that showed no interannual variation in use was ice cover, indicating its overriding importance in determining the within-bay distribution and abundance of this species.

All evidence indicated that reproductive output was extremely low in all years. An earlier reference to a widespread lack of reproductive output in Glacier Bay suggests that breeding failures may not be uncommon in this species, and a later data set from the same location suggests that productivity may be high in some years. Consistently low reproductive performance, however, would result in population declines if adult survival was non-compensatory. It is unclear what the great range in plumage variation of Kittlitz's murrelets that we have seen in this study actually means. Closely related marbled murrelets exhibit similar variation in plumages, however, and some of them breed in "non-standard" breeding plumages. Although it is possible that a substantial number of these "non-standard" birds were subadults, the similarly late molt in birds during the two "late springs" instead suggests that the timing of the prenuptial molt may be delayed by environmental conditions for a few weeks. 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. The occurrence of mixed-species "pairs" of Kittlitz's and marbled murrelets is cause for concern, because it suggests that reproductive isolating mechanisms between the two species may be breaking down in some cases, perhaps because the populations of Kittlitz's murrelets are being swamped by populations of marbled murrelets.

Kittlitz's murrelets exhibited variation in feeding frequency by survey type, season, year, habitat type, ice cover, distance from shore, depth, and shoreline substrate. Interestingly, all three of the variables that reflected a preference for shallow-water foraging (nearshore surveys, narrowest distance from shore, shallowest depths) were significant. Similar results for marbled murrelets suggest that both species prefer to forage in as shallow water as possible. Both the characteristics of their feeding apparatus 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. Further, studies that have examined food habits of other birds feeding near tidewater glaciers have found that they feed primarily on macrozooplankton, suggesting that Kittlitz's murrelets do, too. Kittlitz's and marbled murrelets overlapped extensively in prey type, prey size, and dive times and often occurred together in mixed-species feeding flocks, 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.

Conclusions and Recommendations

We recommend (1) that another survey of Kittlitz's murrelets in these study bays be conducted in 2003, to determine whether the overall population size has changed; (2) that a survey of all of the Prince William Sound bays where Kittlitz's murrelets are concentrated be conducted around the same time or earlier, to permit a more accurate population estimate for the bulk of the Sound population to be estimated; (3) that a survey of the Kittlitz's murrelet population on the Kenai Peninsula be conducted; (4) that a study of the effects of disturbance on habitat use, feeding, and behavior be conducted; (5) that we analyze our existing data set to describe and compare habitat use between Kittlitz's and marbled murrelets; (6) that 2–3 consecutive years of extensive (30–45 day) surveys of productivity be conducted during mid-late summer, to see whether these birds ever produce large numbers of young; (7) that a study of the distribution, abundance, and availability of prey in the various habitats within these bays be conducted; and (8) that an intensive study of ecological overlap in feeding ecology between Kittlitz's and marbled murrelets be conducted. 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 that commonly nests 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 meant that Kittlitz's murrelets might qualify for protection under the Act but that additional information on vulnerability and threats was needed before a determination about listing is possible. (This category no longer exists under revised guidelines.) 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 the overall population size is so low that 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, (2) uncertainty about impacts from the *Exxon Valdez* oil spill, and (3) 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); this estimate almost certainly is low (Gaston and Jones 1998; Day et al., in press). 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, Kendall and Agler 1998). The magnitude of mortality of this species as a result of the oil spill is unknown, but van Vliet and McAllister's (1994) estimate of 1,000–2,000 birds suggested that 5–10% of the total world population may have been killed. Subsequent evaluation of carcasses suggested that ~370 Kittlitz's murrelets were killed in Prince William Sound, although several other estimates are possible from the numbers presented (see Table 8 and text in Kuletz 1996: 781). Although the accuracy of these estimates is unclear, the species' small total world population makes any substantial mortality of concern to wildlife managers and conservation biologists. Further, trends of these populations are not known with certainty, although the information for Prince William Sound is examined in the Discussion of this report. Because of both the spill-caused mortality and a general lack of information on the status and ecology of this species, the *Exxon Valdez* Oil Spill Trustee Council (1996) listed Kittlitz's murrelet as "injured with recovery unknown" and funded this 3-yr study on its ecology.

This study investigates the population status and distribution, habitat use, reproductive performance, and feeding characteristics of Kittlitz's murrelet in four bays in northwestern Prince William Sound. During this study, we evaluated the distribution and abundance (including population size), at-sea habitat use, productivity, and feeding ecology of this little-known seabird.

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 1998; Day et al. 1983, in press; 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 25 known or probable nests of this species have been located (Day et al. 1983, in press; Piatt et al. 1994, Andreev and Golubova 1995, 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, in press; Piatt et al. 1994, Day 1995).

Except for work conducted in 1996 and 1997 (Day and Nigro 1998), information on at-sea habitat use by Kittlitz's murrelet essentially is 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 press). 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 1998, Kendall and Agler 1998), 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 and 1997 found that the species preferred glacial-affected habitats, avoided areas of heavy ice cover, and 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 1998).

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-central 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. Further, essentially nothing is known about the productivity of this rare species.

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, Russia, contained 10–20 crustaceans, and a bird collected at Wrangel Island, Russia, 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 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 and 1997 found that feeding frequencies were highest in 1997, in nearshore areas, in late summer, and during periods when tidal currents were weak-moderate; that frequencies did not differ by time of day, overall tidal stage, and habitat type; and that those birds seen feeding ate fishes, primarily sandlance, herring, and/or capelin (Day and Nigro 1998).

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 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 the shallow, neritic community that otherwise would be expected from its location (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 northwestern quarter 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 lies 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 heavily vegetated with conifers (primarily Sitka spruce *Picea sitchensis* and western hemlock *Tsuga heterophylla*) in the lower halves of the bays and sparsely-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. 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 at 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). Although two small pink salmon (*O. gorbuscha*) runs have been recorded at small outflow streams near Holyoke and Barnard glaciers (Roy 1987), we saw no evidence of spawning anywhere within this bay during the 3 yr of this study.

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, although there are four small runs of coho (*O. kisutch*) and pink salmon at the mouth of the bay, beyond the area where we sampled (Roy 1987).

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; however, there are two small chum (*O. keta*) and pink salmon runs at the mouth of the bay (Roy 1987), beyond the area where we sampled. We also saw schools of small fishes feeding in the bay in late summer of 1997, some of which probably were young salmon.

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). In 1998, we sampled during three research cruises that were conducted from 1 to 19 June (early-summer 1998 cruise), from 28 June to 5 July (mid-summer 1998 cruise), and from 15 July to 4 August (late-summer 1998 cruise). Unless indicated otherwise, we sampled the 4 bays 2 times each during each early- and late-summer cruise and sampled each bay once during the mid-summer 1998 cruise: Unakwik Inlet (3 samples in early summer all 3 yr), College Fjord (3 samples in late summer 1996 and 1997), Harriman Fjord (3 samples in late summer all 3 yr), and Blackstone Bay (3 samples in late summer 1997; Tables 1–7). 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 of Kittlitz's murrelets. While traveling between bays, we also sampled the distribution and abundance of these murrelets in 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's segment or 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, from none to various types of rain and snow and to mixed precipitation);
- 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 and 1998);
- 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 and 1998).

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

- time of observation;
- total number of birds seen;
- plumage (see "Reproduction," below);
- location (in the air, on the water);
- activity (flying, sitting/resting, feeding [birds holding prey in their bills or birds diving, except for escape dives and other dives that did not appear to represent feeding behavior], courting, preening/comfort, sleeping); and
- ice cover around that observation (see "Habitat Use," below).

On nearshore surveys, we also assigned observation numbers to all sightings and plotted all sightings with their numbers 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 zones within bays vs. more open pelagic waters outside of bays). Based on our findings on the timing of occupation of the bays in 1996, we revised the sampling schedule in 1997 and 1998 to arrive later in early summer and to depart earlier in late summer. 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 early- and late-summer cruise during 1996 and 1997 and during early summer 1998. Poor weather prevented us from getting a complete set of temporally overlapping samples in late summer 1998, although we were able to get an overlapping set of samples in two of the bays.

We used nearshore surveys to sample 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, 1998), and Murphy et al. (1997). In each bay, we drove a small boat slowly ($\bar{x}$ = 9.7 km/h; n = 61 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 or flying over this zone, including searching the area ≤300 m ahead of the boat to detect and count birds flushing ahead of us. Hence, each survey resulted in a count of the number of Kittlitz's murrelets for each segment-visit (i.e., a sample of each nearshore segment during a visit to that bay), which was of a known area (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. The area of nearshore waters in each segment was measured from digitized maps with GIS software (Table 8).

We used offshore surveys to sample 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, 1998), 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 ($\bar{x}$ = 10.1 km/h; n = 61 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.) Each survey resulted in a count of the number of Kittlitz's murrelets for each segment-visit (which was of a known area), with offshore segments consisting of individual sections of the survey trackline (see 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 8).

We used pelagic surveys to sample Kittlitz's murrelets that occurred in more open waters of Prince William Sound, outside of the bays (Fig. 1). Following Day and Nigro (1997, 1998), these surveys were sampled as lines that were fixed in space and were sampled as we were running between bays in a larger ship. 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 (following Gould and Forsell 1989; Day and Nigro 1997, 1998). We discarded transects <7 min in length at the end of a pelagic survey line. Each survey resulted in a count of the number of Kittlitz's murrelets for each transect-visit, which was of a known area.

On nearshore and offshore surveys, we checked for numbers of Kittlitz's murrelets possibly missed while sampling by operating the boat slowly and by watching for birds diving or flushing far 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 both 1997 and 1998 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 that we sampled.

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. While using a 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 a hand-held counter in a coat pocket, to keep the other observer from knowing when birds were being counted. After surveying each 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. We classified each survey segment examined on nearshore and offshore surveys (and, hence, individual records of Kittlitz's murrelets seen on those surveys) into one of four standardized (i.e., classified with categories that had been determined *a priori*) habitat-type categories that reflected the general level of influence of glaciers on the nearby marine habitat (Table 8):

- glacial-affected (≤200 m from a tidewater glacier);
- glacial-stream-affected (>200 m from a tidewater glacier but having ≥1 glacial meltwater stream entering the segment);
- marine-sill-affected (>200 m from a tidewater glacier but ≤200 m from a marine sill); and
- glacial-unaffected (>200 m from a tidewater glacier and not in an area affected by a glacial stream or a sill—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, a segment with glacial streams entering the bay under a tidewater glacier 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 would not significantly affect the results of statistical tests.

The amount of ice cover from calved ice determined whether a segment's classification changed among visits from these standardized categories, so, in addition to the standardized habitat category for each segment, we also recorded the actual habitat type encountered during each segment-visit. A nearshore segment having a tidewater glacier always was classified as glacial-affected. On the other hand, a nearshore segment of any of the other three types could be classified as glacial-stream-affected, marine-sill-affected, or glacial-unaffected on one visit but glacial-affected on the next visit if it was covered with ≥75% ice on the latter 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, we were unable to sample all or significant portions of 49 (7.5%) of 654 total nearshore segment-visits in early summer, of 5 (5.1%) of 99 segment-visits in mid-summer, and of 13 (1.7%) of 758 segments in late summer, or 67 (4.4%) of 1,511 nearshore segment-visits for all seasons and years combined. Because of heavy ice cover, we were unable to sample all or significant portions of 24 (9.2%) of 261 offshore survey segment-visits in early summer, of 5 (12.5%) of 40 segment-visits in mid-summer, and of 4 (1.3%) of 308 segment-visits in late summer, or 33 (5.4%) of 609 offshore segment-visits for all seasons and years combined. We did, however, survey as much of these segments as we could from the edges with binoculars, to see whether Kittlitz's murrelets inhabited these areas of heavy ice cover. Because we saw no evidence on any cruise that these murrelets used areas of such heavy ice cover in numbers (only 3 [0.1%] of 2,606 birds were seen in ice cover 90%, none were seen in ice cover >90%, and these birds were seen only in patches of open water between areas of 100% ice cover), we assumed for calculations and testing of mean densities that the portions of those unsampled segments that we were unable to examine from their edges also had no Kittlitz's murrelets.

In all 3 yr, 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 (which was affected by temperatures and the amount of rainfall), the hardness of the ice and the sea-surface temperature (both of 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 within a segment (i.e., at a fine scale). For the large-scale data, we estimated ice cover for each nearshore, offshore, or pelagic survey segment as a whole (0%, <1%, 1%, 3%, and 5–100% in 5% units). For the fine-scale data, we estimated for individual birds the percent of ice cover within a circle 50 m in radius around each bird, with the categories being the same as those for segments. We began categorizing ice cover for individual bird records partially through the early-summer 1996 cruise, however, and we occasionally forgot ice-cover estimates for individual birds after that time. Consequently, sample sizes for examining fine-scale ice relationships were not as large as those for examining large-scale relationships.

In 1997 and 1998, we examined habitat use by Kittlitz's murrelets with respect to water clarity, with secchi depth representing water clarity. We assigned the secchi depth recorded for the beginning of each nearshore or offshore survey segment (but not 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. We also measured individual secchi depths for a subset of birds on each cruise.

In all 3 yr, 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 each nearshore or offshore survey segment or pelagic transect as the temperature of the water in which the birds were found. We also measured individual sea-surface temperatures for the subset of birds on each cruise for which we also had measured individual secchi depths.

In 1997 and 1998, we also 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. We also measured individual sea-surface temperatures for the subset of birds on each cruise for which we also had measured individual secchi depths and sea-surface temperatures.

We also examined habitat use of Kittlitz's murrelets with respect to distance from shore. Because we were unable to determine our locations on offshore surveys, we mapped locations of birds only on nearshore surveys. We digitized the 3 yr of mapped nearshore-survey data on each bird observation in the software Atlas GIS (v. 4.0), then used that software to calculate the distance from the nearest shore for each observation of ≥1 bird.

In early summer 1997, we mapped the locations of all "significant" inputs of fresh water in all four bays; again, the offshore data were excluded from this component of the habitat analyses. Because multiple sources of freshwater occurred on, under, and along the sides of tidewater glaciers, their entire faces were classified as significant inputs. We used the 3 yr of digitized nearshore data on each bird observation in the software Atlas GIS to calculate the distance from the nearest freshwater input for each bird.

We also examined habitat use of Kittlitz's murrelets with respect to mean water depth. The centers of the bays were too deep for us to use the hand-held depth-sampling gear, so we collected all depth data only for nearshore surveys. In mid- and late summer 1998, we measured depths at 100 m from shore and at regular intervals along the shorelines of Unakwik Inlet, College Fjord, and Blackstone Bay with a hand-held fathometer that was accurate to ±1 m (Depthmate model; Speedtech Instruments, Great Falls, VA; range 0–80 m). In early summer 1997, we used a side-scanning sonar on the M/V *Miss Kaylee* to measure the depth of most 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 every 250-400 m along the shoreline at a distance of 100 m from shore. Because some parts of this bay were too shallow to take the ship into, we filled in missing measurements later with a weighted hand line (in 1997) or used the hand-held fathometer (in 1998). For all depth data combined, we took measurements at an average of 1 sample every 430 m ($n = 138$ samples) of shoreline in Unakwik Inlet, 1 every 481 m ($n = 152$) in College Fjord, 1 every 336 m ($n = 246$) in Harriman Fjord, and 1 every 389 m ($n = 171$) in Blackstone Bay; every segment had ≥5 measurements. We calculated the mean depth of each nearshore segment by averaging all depth measurements for that segment, then assigned the mean depth for that segment as the large-scale depth of the water in which the birds were found.

We examined habitat use of Kittlitz's murrelets with respect to shoreline substrate, with the assumption that the substrate recorded on the shoreline extended offshore, into the nearshore zone. The offshore surveys were too far away for shorelines to have any effect, so all substrate data were considered to apply only to nearshore surveys. In early summer 1997, we mapped the shoreline substrate for all shorelines in all four bays. Shoreline substrates were, with one exception (ice), broad categories representing particle size. The four broad categories for substrate type were ice (i.e., along the faces of tidewater glaciers), fine alluvium (mud, sand, gravel), large alluvium (cobble, boulder), and bedrock. We used the 3 yr of digitized nearshore data on each bird observation in the software Atlas GIS to assign the shoreline substrate category for each bird.

Reproduction.—During nearshore, offshore, and pelagic surveys, we classified each Kittlitz's murrelet into 1 of 5 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 (bird is undergoing extensive molt, so that its exact plumage cannot be determined with certainty; is speckled brown-and-white and looks more white than brown underneath at a distance);
- winter [= Basic] plumage (bird is black-and-white, may have wear on the flight feathers, and does not avoid flying);
- hatching-year [HY; = Juvenal] plumage (bird has new black-and-white plumage, including flight feathers; 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 the bird escaped without our being able to see the plumage well).

After-hatching-year (AHY) birds were considered to include all plumage categories except HY.

Because a few HY/winter-plumaged AHY 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 [i.e., egg tooth and breast band], 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 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 search the bays for these brightly-colored birds and map their locations on a regular basis.

Trophics and Feeding.—We attempted to capture Kittlitz's murrelets alive with floating mist nets (following Burns et al. 1994, 1995; and 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) ≥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 in early summer 1996, 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.

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. Before analysis, we converted the time of each record to hours after the previous low tide (to the nearest 0.01 hr) with uncorrected tide-tables for Valdez, Alaska.

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).

When possible, we classified prey that were being held or being eaten by Kittlitz's murrelets as invertebrate or fish and identified them to the lowest possible taxon (e.g., Pacific sand lance, Pacific herring, unidentified fish). When possible, we also estimated the size maximal length of prey items to the nearest 1 cm or to a 2-cm range of estimated length (e.g., 8–10 cm). We recorded these data both for prey items seen during our regular sampling and for prey items seen during off-sampling periods.

We opportunistically timed lengths of feeding dives of Kittlitz's murrelets to the nearest 1 sec. In addition, we recorded on- or 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. 97 SR-2) and SPSS (v. 7.0). The multiway contingency tables with maximum-likelihood estimators were analyzed with the software JMP (v. 2.01 for Macintosh). All statistical tests were 2-tailed, and the level of significance (α) for all tests was 0.05. When possible, the statistical power to detect a real difference at $\alpha = 0.05$ is presented. In all tests involving densities, we used ln-transformed densities because the data required this transformation to meet the assumptions of a parametric test (normality, homoscedasticity). Before transformation, we added 0.167 as a constant to all densities (following Mosteller and Tukey 1977), to avoid computing the natural logarithm of zero. We used a Tukey's HSD test for all multiple comparisons involving ANOVAs or MANOVAs.

Additional information presented with any ANOVAs involved calculations of observed power, which is presented in the tables that summarize the analytical results. The observed power gives the probability that the *F*-test would detect a population difference between groups equal to that implied by the sample difference. It differs from more usual power calculations, in that, in these calculations, the power is calculated for each individual comparison (e.g., Site 1 vs. Site 2, Site 1 vs. Site 3) and data set. In contrast, in more usual power calculations, you specify a minimal detectable difference against which all comparisons are made.

We summarized those 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 for each sampling segment (nearshore and offshore surveys) and transect (pelagic surveys).

Abundance and Distribution.—We spatially mapped all points from the 3 yr of nearshore surveys in the software ARCVIEW (v. 3.1). We then linked those digitized GIS points to a database containing all attributes (e.g., site, season, year) and ran a series of nearest-neighbor analyses based on those attributes in ARCVIEW. This analysis uses distances between points and their nearest neighbors to calculate the overall statistical distribution of distances, then uses a

Z-test to test the null hypothesis the points are randomly distributed. If it rejects that hypothesis, the program then tests whether the points are either uniform or clumped by comparing relative sizes of the mean and the SD; a uniform distribution has a SD much smaller than the mean, and a clumped distribution has a SD much larger than the mean.

We used the summarized count data from nearshore, offshore, and pelagic surveys (as densities by segment-visit or pelagic transect-visit) to calculate and plot mean density by bay, bay-visit, and segment- or transect-visit on each cruise. We calculated densities of Kittlitz's murrelets on individual nearshore or offshore survey segments by dividing the total count of Kittlitz's murrelets on that segment by the area of water sampled on that segment; these calculations were made for each segment-visit. We calculated densities of Kittlitz's murrelets on each pelagic 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 normally were ~0.7–1.0 km^2 at speeds run in this study (13–20 km/h).

We used the ln-transformed segment-visit estimates of densities in 5- (nearshore data) and 4-factor (offshore data) ANOVAs that examined differences in mean densities among visits, seasons, years, sites (i.e., bays), and habitats. The null hypothesis for the nearshore test was that mean densities did not differ by visit, season, year, site, or standardized habitat type; the null hypothesis for the offshore test was similar, except that it had only one habitat type and, hence, excluded that factor.

Not all surveys were conducted at the same time in all 3 yr, so we also conducted a test of just those nearshore and offshore density data that were collected during the same time periods during all years. This analysis provided a cross-check of the above tests of differences in densities among seasons and years. We filtered the data set by those bay-visits that overlapped in time in early and late summer, then conducted 5- (nearshore data) and 4-factor (offshore data) ANOVAs that examined differences in mean densities among visits, seasons, years, sites (i.e., bays), and habitat types (excluding offshore), as above. In this test, we excluded data from mid-summer because we had collected data during that season only in 1998. The null hypothesis for the nearshore test was that mean densities did not differ by visit, season, year, site, or standardized habitat type; the null hypothesis for the offshore test was similar, except that it excluded habitat type.

We also used the ln-transformed density data for both nearshore and offshore surveys to test whether mean densities of Kittlitz's murrelets 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 standardized habitat type that occurred in both survey types (glacial-unaffected), then again tested for differences in mean densities between survey types with a 5-factor ANOVA. In each test, the null hypothesis was that mean densities did not differ between survey types.

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 correlated across bay-visits.

For each cruise, we calculated the mean density of Kittlitz's murrelets on each nearshore and offshore survey segment across all bay-visits during each cruise. We then plotted these density estimates onto maps of each bay, visually interpreted the patterns of distribution within each bay, and compared these patterns of distribution between seasons and among years. All comparisons of within-bay distribution were qualitative, in that they did not involve statistical tests of differences in distribution. To aid in the interpretation of these plots, we calculated mean percent ice cover and mean sea-surface temperature for each bay during each cruise.

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: 831). This latter value was calculated as the mean offshore density × total area of the offshore zone in that 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 maximal population size 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.

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 ANOVAs. For all analyses, data were pooled among all bays and visits during a cruise. The first analyses involved a set of 3-factor MANOVAs for the 1997 and 1998 data only. (Secchi and sea-surface salinity data were collected only in 1997 and 1998, whereas ice and sea-surface temperature data were collected in 1996–1998; hence, all four variables were measured contemporaneously only in 1997 and 1998.) 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 year, 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 season, year, and survey type and that use did not differ by season, year, and survey type. Then, 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 season, year, and survey type.

The second analyses involved a set of 3-factor MANOVAs only for the variables ice cover and sea-surface temperature for all 3 yr of the study. This second set of analyses was conducted for the entire 3-yr data set. One MANOVA with ranked data compared availability and another compared use of these two habitat variables by the factors season, year, and survey type. The null hypotheses for each habitat variable were that availability did not differ by season, year, and survey type and that use did not differ by season, year, and survey type. A nested MANOVA with ranked data compared availability versus use with the factors season, year, and survey type nested within availability and use. The null hypothesis for each habitat variable was that availability did not differ from use by season, year, and survey type.

In addition to the large-scale analyses of availability versus use, we conducted a fine-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 season, year, and survey type. The null hypotheses were that availability did not differ by season, year, and survey type and that use did not differ by season, year, and survey type. Then, a nested ANOVA with ranked data compared availability versus use with the factors season, year, and survey type nested within availability and use. The null hypothesis was that availability did not differ from use by season, year, and survey type.

In addition to the comparisons of large-scale availability versus small-scale use of ice, we conducted similar analyses for secchi depth, sea-surface temperature, and sea-surface salinity with a series of 3-factor ANOVAs. We collected these data only during 1997 and 1998, however. Analyses and null hypotheses are similar to those for ice cover, above.

Reproduction.— To estimate the reproductive performance of Kittlitz's murrelets, we followed the technique developed by Kuletz and Kendall (1998) for estimating the reproductive performance of marbled murrelets in Prince William Sound. We calculated mean densities of HY birds in each bay during each late-summer cruise by our level of certainty about whether they actually were HY birds (i.e., definite, probable, possible). Because densities of birds in most bays were changing through time, we also calculated the maximal density of HY birds in each bay during all visits to that bay on each late-summer cruise. We then calculated mean densities of AHY birds in each bay during each early-summer cruise. Again, because densities in most bays were changing through time, we also calculated the maximal density of AHY birds in each bay during all visits to that bay on each early-summer 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 multiway contingency table with maximum-likelihood estimators in the software JMP to test whether proportions of breeding-plumaged birds differed among seasons, years, and survey types. 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). The null hypothesis was that the proportion of birds in breeding plumage did not differ by season, year, or survey type.

We used the data from all 3 yr 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 breeding pairs to forage alone at sea. The conceptual model used for mid-summer (during the peak of hatching) was that the proportion of single-bird groups should be slightly lower overall than that seen in early summer, as additional birds from successful nests are able to spend more time foraging together. The conceptual model used for late summer was that the proportion of single-bird groups (1) should 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. All of these models assume (1) that non-incubating breeding birds have no behavioral tendency to flock with birds that are not members of the pair while at sea and (2) that non-breeding birds have no temporal pattern of flocking that would affect the hypothesized pattern for breeding birds.

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 data on total numbers of birds in each group 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 multiway contingency table with maximum-likelihood estimators in the software JMP to test whether proportions of breeding-plumaged birds differed among seasons, years, and survey types. The null hypothesis was that the proportions of single-bird groups did not differ by season, year, or survey type.

We occasionally recorded what appeared to be mixed-species "pairs" of Kittlitz's and marbled murrelets. We compiled all records of these mixed-species "pairs" during each bay-visit, cruise, and year, summarized the number of such records in each bay during each year and calculated the ratio of the maximal population size of Kittlitz's murrelets to marbled murrelets in each bay during each year, and calculated a Pearson's product-moment correlation between the number of records of such "pairs" and the marbled:Kittlitz's ratio in each bay during each year.

Trophics and Feeding.—We used the nearshore and offshore data on the activity of Kittlitz's murrelets to test for variation in the proportion of birds that were feeding by a total of 15 independent variables. 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).

We examined variations in the proportions of Kittlitz's murrelets that were feeding by classifying all data by survey type (nearshore, offshore), time of day (morning [0600–1159]; afternoon [1200–1930]), season (early summer, mid-summer, late summer), year (1996, 1997, 1998), tidal stage (rising, falling), current strength (weak, moderate, strong; see following two paragraphs), ice cover (0–1%, 3–10%, 15–35%, 40–100%), secchi depth (0–1 m, 2–3 m, 4–14 m), sea-surface temperature (0–3°C, 4–6°C, 7–9°C, 10–17°C), sea-surface salinity (4–10‰, 11–17‰, 18–24‰, 25–30‰), distance from nearest freshwater input (nearshore surveys only; 1–100 m, 101–250 m, 251–1,000 m, >1,000 m), distance from nearest shore (nearshore surveys only; 1–50 m, 51–100 m, 101–150 m, 151–200 m), mean segment depth (nearshore surveys only; 1–20 m, 21–40 m, 41–60 m, 61–80 m), standardized habitat type (nearshore surveys only; glacial-affected, glacial-stream-affected, marine-sill-affected, glacial-unaffected), and shoreline substrate (nearshore surveys only; ice, sand-gravel, cobble-boulder, bedrock). We then compiled all of the feeding/not feeding data by each of these variables and used a multiway contingency table with maximum-likelihood estimators in the software JMP to test whether any of these variables were significant in determining the proportion of birds that were feeding. The null hypothesis was that proportions feeding did not differ by any of the 15 variables.

To examine variation in the proportions of bird that were feeding by tidal stage and current strength, we first converted the time of each bird record to hours after the previous low tide and recoded those records to 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 ~6.5 hr later, the tide rises 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 2 hr 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).

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.

We summarized all data on prey that we observed Kittlitz's murrelets holding or eating during the 3 yr of the study; because data were limited, we pooled them for all years. These data included both identification to lowest possible taxon and mean estimated size (maximal length). We calculated the percentage of all prey items by season, to examine whether there was a seasonal trend in the frequency of ingestion of fishes. 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. We summarized and compared prey species eaten and prey sizes between Kittlitz's and marbled murrelets from the same bays over the 3 yr of the study and tested for differences in prey sizes with a 2-sample *t*-test that assumed unequal variances. The null hypothesis was that mean prey size did not differ between species.

We calculated mean dive times for all Kittlitz's murrelets that had been measured during the 3 yr of the study; to increase sample sizes, we pooled the data from all seasons and years. We summarized and compared mean dive times between Kittlitz's and marbled murrelets from the same bays over the 3 yr 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.

We summarized the data on mixed-species feeding flocks by season, species other than Kittlitz's murrelets, and number of birds involved. We also calculated the frequency of occurrence of each species across all feeding flocks combined.

We calculated the mean size of feeding flocks of Kittlitz's murrelets by season, year, and survey type. An observation of ≥1 bird was counted as a flock of birds, with only those flocks that contained feeding birds being analyzed here. We used a 3-factor MANOVA to test within each species for differences in flock size by season, year, and survey type. The null hypothesis for each species was that flock size did not differ by season, year, and survey type. We used a 3-factor nested ANOVA to test for differences in the mean size of feeding flocks by species, with season, year, and survey type as the nesting factors. The null hypothesis was that the size of feeding flocks did not differ between species. Too few birds were seen on pelagic surveys to include them in this analysis, so only nearshore and offshore data were included.

RESULTS

Characteristics that could affect our observation abilities were favorable for sampling in all 3 yr and differed little among years (Table 9). Mean observation conditions averaged 4+ on a scale of 1–5 (with 1 being poor and 5 being excellent) on all except pelagic surveys in early summer 1998 and late summer 1996 and 1998. Observation conditions were better within bays than on pelagic surveys outside of bays and, within bays, 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, rarely exceeding Beaufort 2 (≤15 cm). 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. Precipitation clearly was greatest in 1998, when it ranged between 26% and 63% of the time, depending on the cruise and the survey type. This increased frequency of precipitation was the primary reason why mean observation conditions were lowest overall in 1998.

Overall environmental conditions differed between seasons and among years, being generally icier and cooler in 1996 and 1998 than in 1997 (Table 10). Ice cover in early summer 1998 probably was underestimated for offshore surveys, however, because it was moving around so much in Harriman Fjord that we were unable to sample some segments of 100% ice at one time but were able to sample them later, after the ice had moved. The 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 recorded on pelagic surveys only in 1998. Secchi depths were higher in 1997 than in 1998, probably because of the increased amount of precipitation in 1998; no 1996 data were available for comparison. Secchi depths were greater in late summer than in early summer, as the water cleared after the 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; in addition, they always were higher outside of bays than in them. Sea-surface salinities were higher in 1997 than in 1998, probably because of the increased amount of precipitation in 1998; no 1996 data were available for comparison. Reflecting the input of substantial amounts of fresh water added to these bays by meltwater coming from the tidewater and hanging glaciers, sea-surface salinities decreased substantially from early to late summer, depending on the survey type.

Abundance and Distribution

Patterns of Abundance and Distribution.—Kittlitz's murrelets did not exhibit a random distribution on nearshore surveys in any of the four bays during any of the cruises. In 26 of the 28 tests that we conducted on the 4 bays (i.e., 4 bays × 2 cruises in 1996, 2 cruises in 1997, and 3 cruises in 1998), these birds exhibited nearest-neighbor distances that differed significantly from what would be expected for a random distribution. In all cases, comparisons of the relative sizes of the means and SDs indicated that these distributions were significantly clumped. In the 2 tests that did not differ significantly from random distributions, one had a sample size of 0 and the other had a sample size of 1; hence, these two tests were limited by small sample sizes. We thus conclude that this species always occurs in a clumped distribution. Although we were unable to test the offshore data in a similar fashion, our impression was that the birds in that area also exhibited a clumped distribution.

On nearshore surveys, densities of Kittlitz's murrelets in Unakwik Inlet showed little seasonal pattern, other than often late arrival and complete departure from the bay by 1 August; densities during much of the summer were in the range 2–7 birds/km^2 (Fig. 7) Densities in College Fjord exhibited a consistent seasonal pattern of arrival in late May, a buildup to a peak in mid-summer or the early part of late summer, and departure by ~15 August; peak densities were slightly higher here than in Unakwik Inlet. The seasonal pattern of abundance in Harriman Fjord was similar to that in College Fjord, except that, in most years, densities here already were substantial by our first visits in late May; hence, birds arrived here earlier than they did in Unakwik Inlet and College Fjord. The highest densities in Harriman Fjord were similar to those in College Fjord, although they peaked during the latter part of early summer, rather than later in the summer, as at College Fjord. Densities in Blackstone Bay were erratic in all years but suggested arrival before our surveys began in late May; overall densities were lower here than in the other bays and peaked at just over 3 birds/km^2.

On offshore surveys, densities of Kittlitz's murrelets showed a seasonal pattern of arrival in early to mid-June, peaked in mid-summer (except for one unusual data point), and declined to zero by 1 August; densities were low and mostly occurred in the range 0–2 birds/km^2 (Fig. 8). One unusual survey in 1996 resulted in a density several times that recorded in all other surveys; we do not know why densities on this survey were so unusual. Densities in College Fjord showed a consistent seasonal pattern of arrival in late May, buildup to a peak in mid-summer or the early part of late summer, and departure by ~15 August, as on nearshore surveys; again, peak densities were slightly higher here than in Unakwik Inlet. Densities in Harriman Fjord indicated that a large number of birds were present in offshore waters by our first visits in late May, although arrival in 1998 was delayed. Densities dropped to zero with abandonment of the bay by early or mid-August and were slightly higher than those in College Fjord, including a peak in mid- or the early part of late summer. Densities in Blackstone Bay showed a pattern of arrival before our first surveys in late May, late arrival in some years, and abandonment of the offshore zone before mid-summer; unlike the pattern seen in nearshore surveys, high densities were similar to those in College and Harriman fjords.

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 all early-summer data pooled ($r = 0.232$; n = 27; $P = 0.258$) but was for late-summer data ($r = 0.656$; n = 30; $P < 0.001$). When the data were pooled among all seasons and years, the relationship also was significant ($r = 0.324$; n = 61; $P = 0.012$).

On pelagic surveys, Kittlitz's murrelets were essentially absent from pelagic waters and never were recorded on the Eaglek Line or the Wells Passage Line (Fig. 9), which are the two survey lines that were located in the more open part of Prince William Sound (Fig. 1). The only records were of a single bird on one of the Port Wells even lines in early summer 1996 and a total of 5 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, 4 of the 5 main factors were significant in the ANOVA model: season, year, site, and habitat type (Table 11). Densities were higher in mid- and late summer, higher in 1997 than in 1998 and 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). Densities did not differ among visits, probably because of high variability and, hence, low power (Fig. 7, Table 11). Two significant interactions were found, indicating that the species changes preferred habitat types among seasons and among sites. The former change probably is caused by the way in which heavy ice cover may limit the distribution of birds in early summer, whereas the latter change probably was caused by the disappearance of birds in a bay in one season or another. The two non-significant interaction terms indicate that Kittlitz's murrelets do not vary significantly in density at a site among years and do not significantly change overall habitat preferences among years.

On offshore surveys, only the main factor "site" differed significantly in the ANOVA model (Table 11). Densities were higher in College and Harriman fjords than in Unakwik Inlet and Blackstone Bay; this pattern was similar to that in the nearshore. The one significant interaction reflected changes in densities in ≥1 bay among years, probably because of interannual differences in arrival and departure times, which would affect overall density estimates (Fig. 8). 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 all years, so new ANOVAs of only those data that were collected on the same narrower range of dates during all years provided a cross-check of the above tests of differences in densities by the factors season and year (Table 12). For nearshore surveys, densities differed significantly among years, like in the earlier test, indicating that there is significant interannual variation in nearshore densities of this species. Likewise, sites and habitat types were significantly different in both analyses; however, season became non-significant in this analysis, probably because the ends of the tails of the abundance curves were eliminated. For offshore surveys, densities differed significantly only by site (Table 12), a result identical to that seen in the above ANOVA. Although the relative position of College and Harriman fjords changed between the two analyses, these two still had the highest densities.

The plots of densities in Figs. 7 and 8 suggested a possible difference in overall densities between nearshore and offshore zones, so we tested for such a difference (Table 13). 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 (glacial-unaffected habitats). The results of this reanalysis indicate that offshore densities are significantly higher than are nearshore densities in this one habitat type (Table 13).

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. 10 and 11). 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, Kittlitz's murrelets were widely distributed throughout Harriman Fjord and Blackstone Bay in early summer 1996 (Figs. 12 and 13). They were distributed particularly widely throughout Harriman Fjord, although they avoided nearshore segments on the southern shore of the bay, whereas they were most common at the glaciated head of Blackstone Bay and occurred 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. 10–13). 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. 14–17). 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. 14–17). In all, they were seen off of all 12 tidewater glaciers in the 4 bays combined, suggesting a strong attraction to this habitat.

In early summer 1998, Kittlitz's murrelets were concentrated in the central and upper parts of Unakwik Inlet, although heavy ice in the uppermost inlet kept them from occupying the vicinity of Meares Glacier (Fig. 18). Ice in College Fjord was particularly heavy during this cruise, with several km^2 each of calved ice jamming most of Harvard and Yale arms; only small leads were found on the western and southern edges of those arms, respectively. Consequently, as in 1996, Kittlitz's murrelets were forced to occupy the central and lower parts of this bay, primarily off of the tidewater and hanging glaciers (Fig. 19). In Harriman Fjord, Kittlitz's murrelets arrived late and occurred sporadically (Fig. 20). In Blackstone Bay, Kittlitz's murrelets also arrived late and occurred toward, but not at, the upper end of the bay (Fig. 21).

In mid-summer 1998, Kittlitz's murrelets in Unakwik Inlet were able to penetrate closer to Meares Glacier than they could in early summer (Fig. 22). In College Fjord, a lead opened up in western Harvard Arm (although most of it remained choked with ice), and much of Yale Arm opened up, allowing these birds to penetrate closer to the heads of this bay (Fig. 22). In Harriman Fjord, Kittlitz's murrelets were concentrated near the tidewater glaciers, although heavy ice in Surprise and Barry arms forced them to the outer edges of these arms (Fig. 23). These birds were able to penetrate to the head of Blackstone Bay by this time, however (Fig. 23).

In late summer 1998, Kittlitz's murrelets Kittlitz's murrelets were able to penetrate throughout Unakwik Inlet, although a few birds also were recorded in the lower bay (Fig. 18). They also were able to penetrate throughout College Fjord, concentrating off of tidewater glaciers, although heavy ice off of Harvard Glacier excluded them from that segment (Fig. 19). In Harriman Fjord, birds were more widely distributed than they had been earlier in the summer and concentrated off of the tidewater glaciers as that habitat became available (Fig. 20). In Blackstone Bay, the few birds present concentrated near Blackstone Glacier (Fig. 21).

The factors that cause these interannual variations in distribution and abundance within bays appear to be ice cover and/or sea-surface temperature (Table 14). Heavy ice and/or low sea-surface temperatures prevent Kittlitz's murrelets from penetrating throughout these bays in early summer and certainly affect the distribution of these birds at that time. In contrast, ice cover decreases and sea-surface temperatures increase in mid- and late summer, allowing these birds to penetrate throughout the entire bays. For example, College Fjord always has the heaviest ice and lowest temperatures in early summer, and birds were able to penetrate into the upper ends of the arms only in the one year when overall ice cover was lowest (1997). In contrast, Blackstone Bay has little ice on average, and these birds are able to penetrate farther up this bay than they can in College Fjord; however, in the heaviest ice year (1998), they were unable to penetrate to the tidewater glaciers at the head of this bay. Harriman Fjord, which generally has much less ice than College Fjord does, still has enough to affect distribution in early summer; however, there apparently are enough areas of open water for birds to arrive here early. The distribution of ice in this bay is quite dynamic, with the estimates of overall ice cover in early summer 1998 probably underestimated by several percent. For example, ice occasionally filled Surprise Inlet and the offshore zone off its mouth, making it impossible for us to sample, yet all of the ice had moved out shortly thereafter, allowing us to sample those areas. Finally, the early-summer pattern of distribution in Unakwik Inlet is difficult to interpret with respect to ice and temperatures.

Population Size.—Populations of Kittlitz's murrelets exhibit seasonal patterns in overall numbers in all four bays (Fig. 24). These patterns vary from bay to bay, however.

Kittlitz's murrelets exhibit substantial interannual variation in arrival time in Unakwik Inlet (Fig. 24). Arrival was late in most years, not occurring until around mid-June in 1996 and 1998; arrival occurred in early June in 1997, which was the milder spring here (Table 14, Appendices 1–3). One unusual estimate of ~680 birds in early summer 1996 has not been matched since (usually peaking at ~200 birds) and suggests that the overall population size was biased upward in that year. Numbers in this bay probably peak around mid-summer at ~150–200 birds. Essentially the entire population has abandoned this bay by late July or early August.

In College Fjord, Kittlitz's murrelet populations arrive in late May, exhibit a steady increase throughout June, and probably peak at ~550–600 birds in mid-summer or early in late summer (Fig. 24, Appendices 1–3). Arrival is slightly delayed by heavy ice, as seen in the lower estimates in early June 1996 and 1998. The one mid-summer estimate probably was low because of the unusually heavy ice conditions in this bay in 1998 (Table 14). The population exhibits a steady decline in late summer, with essentially all birds gone by ~15 August.

In Harriman Fjord, Kittlitz's murrelets exhibit a pattern similar to that seen in Unakwik Inlet and College Fjord, although it is clear that a substantial percentage of the bay's population has arrived sometime in April or May (Fig. 24, Appendices 1–3). Arrival was delayed in early summer 1998, which, as indicated above, was a late spring (Table 14). Numbers increase rapidly and probably peak at around 600 birds late in the early-summer period or around mid-summer. They then decline rapidly, with essentially the entire population gone from the bay by ~15 August.

In Blackstone Bay, Kittlitz's murrelets also arrive before our first surveys in late May, as in Harriman Fjord (Fig. 24, Appendices 1–3). They exhibit a pattern different from that in all other bays, however, with most of the population disappearing by late June; a few birds are seen until late July, however. Numbers probably peak at ~200 birds.

Overall population estimates for Kittlitz's murrelets suggest that populations within some bays are changing interannually but that the overall population size is remarkably similar among years (Table 15). The differences in population size within individual bays differed most dramatically between 1996 and 1997–1998. This difference probably was caused by the fact that the timing of surveys in 1996 fell more toward the ends of the seasonal curves of abundance (Fig. 24) than it did in 1997–1998. As indicated above, the maximal population estimate for Unakwik Inlet in 1996 appeared to us to be abnormally high and has not been approached since. Hence, the overall population estimate for all bays combined probably was slightly inflated in that year. Populations in Unakwik Inlet and College and Harriman fjords remained constant in 1997 and 1998, as did the overall population estimate in 1997 and 1998. The peak population in Blackstone Bay, however, appeared to be decreasing consistently through time.

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 16). 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 and 1998 were so low in Blackstone Bay (counting birds repeatedly was feasible only in this small 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 total birds possibly seen by either observer, and the other observer missed 1.9–3.2% of all birds possibly seen by either observer. (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 ×

[0.019–0.032] = 0.00036–0.00061, or 0.04–0.06%) and the sum of these two percentages (i.e., *0.019 + [0.019–0.032] = 0.019–0.051, or 1.9–5.1%)*. We emphasize that these values only tell you the estimated percentage of birds that were missed by both observers, *out of those birds that were seen by at least one observer*. Some unknown bias may mean that additional birds were missed by both observers without their knowing it and without their knowing how often such birds are missed. Given the very good–excellent viewing conditions overall (Table 9), the slow rate of sampling that greatly decreased the probability of missing birds (see "Abundance and Distribution" in "Methods," above), and the high inter-observer consistency, however, we believe that the number of birds that we missed during sampling was so low that it approached zero.

Habitat Use

Relationships to Habitat Type.—On nearshore surveys, Kittlitz's murrelets used all four standardized habitats (Tables 11, 12, and 17). The highest overall mean densities occurred in glacial-affected habitats, with lower mean densities in glacial-stream-affected habitats, then glacial-unaffected habitats; lowest overall mean densities occurred in marine-sill-affected habitats (Tables 11 and 12). Highest mean densities occurred in glacial-affected habitats in 15 (56%) of the 27 bay/season/years in which Kittlitz's murrelets occurred on nearshore surveys; these murrelets were absent from Blackstone Bay in late summer 1996, so no preference was possible at that time (Table 17). Kittlitz's murrelets never occurred in highest densities in glacial-affected habitats in Unakwik during any season/year; they often did, however, in College and Harriman fjords and Blackstone Bay. There was a particularly strongly attraction to glacial-affected habitats in late summer, when the highest densities were recorded there in 8 (73%) of 11 bay/season/years; again, Unakwik Inlet was unusual, in that highest mean densities never occurred in glacial-affected habitats. Highest mean densities occurred in glacial-stream-affected habitats in 8 (30%) of the 27 bay/season/years; this was the most important habitat in this bay, having the highest densities in 5 (71%) of 7 season/years. Highest mean densities occurred in glacial-unaffected habitats in only 4 (15%) of the 27 bay/season/years; these highest mean densities occurred with no coherent pattern, however. Again, highest mean densities never occurred in marine-sill-affected habitats.

Between early- and late-summer seasons within a year, the highest mean densities consistently occurred in one habitat type for only 4 (36%) of 11 possible bay/season/years: 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 17). Again, Blackstone Bay could not be compared between seasons in 1996. The use of glacial-unaffected habitats was not consistent between seasons within a year. The lack of consistency in preferred habitats between early and late summer but the high degree of consistency between mid- and late summer (glacial-affected habitats) and among years within late summer (glacial-affected habitats) suggests either that these birds prefer different habitats in early summer or that they are excluded from their preferred habitats in early summer by other habitat-related limitations (e.g., ice cover, sea-surface temperature).

One other line of evidence suggests that Kittlitz's murrelets were attracted to glacial-affected habitats. In the ANOVAs for both nearshore and offshore data (Tables 11–13), the highest densities of Kittlitz's murrelets were found in those bays that had the highest number of tidewater glaciers (College and Harriman fjords), no matter how the data were examined. These results suggest that some sort of selection for glacial-affected habitats is occurring at a bay level of scale.

On offshore surveys, glacial-unaffected habitats were the only standardized habitat types that were available to Kittlitz's murrelets (Table 17). Within that one habitat, however, mean densities varied widely among bays and cruises, resulting in the non-significant "season" factor in the 4–factor ANOVAs discussed under "Abundance and Distribution," above (Tables 11 and 12).

Relationship to Ice Cover.—At a large scale, Kittlitz's murrelets showed pronounced relationships to ice cover (Figs. 25 and 26). 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.

Available ice cover varied between seasons and survey types and among years (Table 18). 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 18% of nearshore and 15% of offshore segments had >20% ice cover (Figs. 25 and 26). 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 5% of nearshore and 1% of offshore segments had >20% 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, whereas only 13% of nearshore and 15% of offshore segments had >20% 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 5% of nearshore and 3% of offshore segments had >20% ice cover. In early summer 1998, ice cover ranged from 0% to 100% on both nearshore and offshore surveys; 78% of all nearshore and 77% of all offshore segments had ≤5% ice cover, whereas only 14% of nearshore and 10% of offshore segments had >20% ice cover. In late summer 1998, ice cover ranged from 0% to 100% on nearshore but only 0% to 15% on offshore surveys; 88% of all nearshore and 97% of all offshore segments had ≤5% ice cover, whereas only 6% of all nearshore and 0% of all offshore segments had >20% ice cover. Across the 3 yr of nearshore and offshore surveys combined, 77% (early summer) to 90% (late summer) of all segments had ≤5% ice cover, whereas only 4% (late summer) to 14% (early summer) of all segments had >20% ice cover.

In the 2-yr comparison, available ice cover did not differ significantly between survey types or among years but did differ significantly among seasons (Table 19). Multiple comparisons indicated that availability was significantly higher in early and mid-summer than in late summer. In the 3-yr comparison, availability did not differ significantly between survey types but did differ significantly among both years and seasons (Table 20). Multiple comparisons indicated that availability was significantly higher in early and mid-summer than in late summer (as in the 2-yr model) and in higher 1997 and 1998 than in 1996. The significant year effect actually was opposite that seen for mean percent ice cover in Table 18. This seemingly greater mean ice cover in 1996 than 1997 and 1998 occurred because the data are non-normally distributed (Figs. 25 and 26); the medians, which are tested by ranked data, actually matched the pattern shown in Table 20. 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 amount of higher-percentage ice cover in early summer 1996 was biologically significant. Hence, we are ignoring the multiple comparisons in Table 20 and conclude that the amount of "biologically significant" ice cover was higher in 1996 than in 1997 and 1998.

Ice use by Kittlitz's murrelets varied among seasons and years and between survey types (Table 18). 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. 25 and 26). Eighty-five percent and 69% of all birds occurred in ≤5% ice cover, whereas only 6% and 23% occurred in >20% ice cover, on nearshore and offshore surveys, respectively. 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; 52% and 100% of all birds occurred in ≤5% ice cover, whereas only 29% and 0% occurred in >20% ice cover, on nearshore and offshore surveys, respectively. 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; 76% and 80% of all birds occurred in ≤5% ice cover, whereas only 5% and 12% occurred in >20% ice cover, on nearshore and offshore surveys, respectively. In late summer 1997, Kittlitz's murrelets occurred in 0–75% ice cover on nearshore surveys and 0–10% ice cover on offshore surveys; 75% and 95% of all birds occurred in ≤5% ice cover, whereas only 5% and 0% occurred in >20% ice cover, on nearshore and offshore surveys, respectively. The abrupt jumps on the use plot for the offshore surveys during both seasons were caused by flocks of Kittlitz's murrelets. In early summer 1998, Kittlitz's murrelets occurred in 0–10% ice cover on nearshore surveys and 0.5–20% ice cover on offshore surveys; 98% and 79% of all birds occurred in ≤5% ice cover, whereas 0% occurred in >20% ice cover on both nearshore and offshore surveys. In late summer 1998, Kittlitz's murrelets occurred in 0–75% ice cover on nearshore surveys and 0.5–15% ice cover on offshore surveys; 63% and 94% of all birds occurred in ≤5% ice cover, whereas only 8% and 0% occurred in >20% ice cover, on nearshore and offshore surveys, respectively. The 1 record of a Kittlitz's murrelet on pelagic surveys in 1996 and the 5 records in 1997 occurred in 0% ice cover. Across the 3 yr of nearshore and offshore surveys combined, 72% (late summer) to 77% (early summer) of all birds occurred in ≤5% ice cover, whereas only 8% (late summer) to 9% (early summer) of all birds occurred in >20% ice cover; 99% of all birds occurred in ≤40% ice cover in early summer and occurred in ≤75% ice cover in late summer.

Large-scale use of ice by Kittlitz's murrelets in the 2-yr comparison did not differ significantly between years or survey types, but it did among seasons (Table 21). Multiple comparisons indicated that they occurred in significantly greater ice cover in late summer than in mid- and early summer (Figs. 25 and 26, Table 18). The results of the 3-yr comparison were identical to those of the 2-yr comparison (Table 22) and again indicated a distributional shift into heavier ice in late summer.

Large-scale availability versus use of ice indicated that Kittlitz's murrelets occurred in ice cover that, on average, was greater than that available overall. This pattern was consistent between the 2-yr analysis (Table 23) and the 3-yr analysis (Table 24). It appeared that at least much of this pattern was caused by the fact that use was greater than availability in late-summer nearshore surveys and in both seasons of offshore surveys (Figs. 25 and 26). Use did not change (Tables 21 and 22), but availability did (Table 20), across years, indicating that this species has a specific amount of ice in which it prefers to occur, regardless of availability.

At a fine scale, Kittlitz's murrelets always showed pronounced avoidance of heavy ice cover (Figs. 27 and 28, Table 25). 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. Across the 3 yr of nearshore and offshore surveys combined, 93% of all birds occurred in ≤5% ice cover and >99% occurred in ≤20% ice cover, whereas <1% of all birds occurred in >20% ice cover; hence, it appears that these birds are excluded when the small-scale ice cover is surprisingly small. Large-scale ice availability on these segments did not differ among seasons, years, or survey types (Tables 25 and 26). Use of ice by Kittlitz's murrelets, however, differed by season, year, and survey type. Multiple comparisons indicated that Kittlitz's murrelets occurred in ice cover that was significantly greater in late and mid-summer than in early summer, in generally greater ice in 1998 and 1996 than in 1997, and on nearshore surveys than on offshore surveys. Again, this increased use in late summer probably reflected the move at that season toward glacier faces (see above). Finally, the analysis of use versus availability indicated that Kittlitz's murrelets occurred in ice that was significantly less at a small scale than that available at a large scale (Table 26). Hence, they are able to penetrate areas of high-percent ice cover only when there are areas of nearly open water within them.

Relationship to Water Clarity.—Large-scale availability of secchi depths varied among seasons and years and between survey types (Table 18). Secchi depths had narrow ranges in early summer but ranged widely in late summer, particularly in the nearshore zone (Figs. 29 and 30). 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 ≤3 m, whereas 0% of all nearshore and offshore segments had secchi depths >6 m. In late summer 1997, secchi depths 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 had secchi depths of ≤3 m, whereas only 6% of all nearshore and 9% of all offshore segments had secchi depths of >6 m. In early summer 1998, secchi depths ranged from 0 m to 5 m on both nearshore and offshore surveys; 93% of all nearshore and 92% of all offshore segments had secchi depths ≤3 m, whereas 0% of all nearshore and offshore segments had secchi depths >6 m. In late summer 1998, secchi depths ranged from 0 m to 10 m on nearshore surveys and from 0 m to 8 m on offshore surveys; 89% of all nearshore segments and 85% of all offshore segments had secchi depths of ≤3 m, whereas only 4% of all nearshore and 3% of all offshore segments had secchi depths of >6 m. On all 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 (Figs. 29 and 30, Table 18), probably because of the general clearing of the water column due to a decrease in phytoplankton concentrations.

At a large scale, available secchi depths differed significantly between survey types but did not differ among seasons or years (Table 19). Multiple comparisons indicated that depths were significantly higher on offshore surveys than on nearshore surveys (Figs. 29 and 30, Table 18), probably because most sediment that entered bays did so in the nearshore zone. Because we collected data on secchi depths only in 1997 and 1998, we could not conduct the 3-yr analysis.

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. 29 and 30). Eighty percent and 98% of all birds occurred in secchi depths ≤3 m, whereas 0% and 0% occurred in secchi depths >6 m, on nearshore and offshore surveys, respectively. In late summer 1997, Kittlitz's murrelets occurred in 0–5 m secchi depths on nearshore and 0–14 m depths on offshore surveys; 97% and 81% of all birds occurred in secchi depths ≤3 m, whereas 0% and 19% occurred in secchi depths >6 m, on nearshore and offshore surveys, respectively. In early summer 1998, Kittlitz's murrelets occurred in waters of 0–2 m secchi depths on nearshore and 1–3 m depths on offshore surveys; 100% and 100% of all birds occurred in secchi depths ≤3 m, whereas 0% and 0% occurred in secchi depths >6 m, on nearshore and offshore surveys, respectively. In late summer 1998, Kittlitz's murrelets occurred in 0–3 m secchi depths on nearshore and 0–6 m depths on offshore surveys; 100% and 96% of all birds occurred in secchi depths ≤3 m, whereas 0% and 0% occurred in secchi depths >6 m, on nearshore and offshore surveys, respectively. Across both years and survey types combined, 97% and 95% of all Kittlitz's murrelets occurred in secchi depths ≤3 m, whereas only 0% and 2% occurred in secchi depths >6 m, on early- and late-summer surveys, respectively.

Large-scale use of secchi depths differed significantly by season, year, and survey type (Table 21). Multiple comparisons indicated that Kittlitz's murrelets occurred in water that was significantly clearer in early summer than in mid-or late summer, in 1997 than in 1998, and on offshore surveys than on nearshore surveys (Figs. 29 and 30, Table 18). Kittlitz's murrelets used water that was clearer on average (1) in early summer because large amounts of sediment are dumped into these bays with large amounts of meltwater later in the summer (Day and Nigro, pers. obs.), (2) in 1997 because the frequency of rainfall (and, hence, the amount of meltwater) was smaller in that year (Table 9), and (3) on offshore surveys because the water actually was significantly clearer overall on offshore surveys (Table 19). Further, 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. Again, we were unable to conduct a 3-yr analysis.

Large-scale availability versus use of secchi depths indicated that Kittlitz's murrelets occurred in water that, on average, was more turbid than that available overall (Table 23). This result is easily seen in the plots of availability versus use (Figs. 29 and 30), in which the peak frequency of use is only 1 m, regardless of the season, year, or survey type. We were unable to conduct a 3-yr comparison.

At a fine scale, Kittlitz's murrelets always showed a preference for highly turbid water (Fig. 31, Table 25). Across the 2 yr of nearshore and offshore surveys combined, 98% of all birds occurred in secchi depths ≤3 m, whereas 0% occurred in secchi depths >6 m. Small-scale use (Table 27) followed the pattern seen for large-scale use (Table 23). Finally, small-scale use was significantly smaller than large-scale availability, also as was seen for large-scale use versus availability.

Relationship to Sea-surface Temperature.—Sea-surface temperatures ranged widely among seasons, years, and survey types (Figs. 32 and 33, Table 18). 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, available temperatures were 1–13°C and from 3–12°C on nearshore and offshore surveys, respectively. In late summer 1996, they were 1–13°C and 2–13°C on nearshore and offshore surveys, respectively. In early summer 1997, temperatures were 3–12°C and 0–12°C on nearshore and offshore surveys, respectively. In late summer 1997, they were 2–14°C and 4–17°C on nearshore and offshore surveys, respectively. In early summer 1998, temperatures were 1–12°C and 2–12°C on nearshore and offshore surveys, respectively. In late summer 1998, they were 3–13°C and 4–13°C on nearshore and offshore surveys, respectively. Hence, available sea-surface temperatures generally were warmer overall in late summer than in early summer and were warmer on offshore surveys than on nearshore surveys. For all 3 yr of nearshore and offshore surveys combined, 83% and 81% of all waters were 4–10°C in early and late summer, respectively.

In the 2-yr comparison, available sea-surface temperatures differed significantly among seasons and between years and survey types (Figs. 32 and 33, Table 19). Multiple comparisons indicated that temperatures were significantly higher in late summer than in mid- and early summer, higher in 1997 than in 1998, and higher on offshore surveys than on nearshore surveys. Temperatures were higher in late summer because of seasonal warming and higher on offshore surveys because tidewater glaciers and glacial-fed streams dumped cold water into the bays in the nearshore zone; the difference between years did not, however, match that for ice cover, although the *P*-value for that factor nearly was significant (Table 19). In the 3-yr comparison, available temperatures differed significantly by season, year, and survey type (Table 20), as for the 2-yr comparison. Multiple comparisons were similar to those for the 2-yr comparison, with the addition of 1996 as the coldest year of all.

Kittlitz's murrelets occurred in a wide range of sea-surface temperatures on both nearshore and offshore surveys (Figs. 32 and 33, Table 18). In early summer 1996, they occurred in waters 2–13°C and 3–10°C on nearshore and offshore surveys, respectively; 2 of the nearshore records were outliers at 13°C, however. In late summer 1996, they occurred in waters 1–8°C and 2–8°C on nearshore and offshore surveys, respectively. In early summer 1997, they occurred in waters 3–12°C and 4–11°C on nearshore and offshore surveys, respectively. In late summer 1997, they occurred in waters 2–12°C and 4–12°C on nearshore and offshore surveys, respectively. In early summer 1998, they occurred in waters 4–9°C and 3–11°C on nearshore and offshore surveys, respectively. In late summer 1998, they occurred in waters 3–10°C and 4–10°C on nearshore and offshore surveys, respectively. For all 3 yr of nearshore and offshore surveys combined, 94% and 93% of all Kittlitz's murrelets occurred in waters 4–10°C in both early and 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).

In the 2-yr comparison, large-scale use of sea-surface temperatures differed significantly among seasons and between years and survey types (Table 21). Multiple comparisons indicated that Kittlitz's murrelets occurred in water that was significantly warmer in early and mid-summer than in late summer, in 1997 than in 1998, and on offshore surveys than on nearshore surveys (Figs. 32 and 33, Table 21). In the 3-yr comparison, use differed significantly among seasons and between years and survey types (Table 22), as in the 2-yr comparison. Multiple comparisons were the same, with the addition of 1996 and the coldest year of use. The seasonal decline in temperatures at which this species occurred reflected the movement into glacial-affected waters later in the summer, as discussed above.

In the 2-yr comparison, large-scale availability versus use of sea-surface temperatures indicated that Kittlitz's murrelets occurred in water that, on average, was cooler than that available (Table 23). In the 3-yr comparison, temperatures used again were, on average, less than those available (Table 24). This difference in all data sets was driven largely by the movement of birds into cooler waters near glaciers in late summer.

At a fine scale, Kittlitz's murrelets preferred temperatures 5–8°C (Fig. 34, Table 25). For both years of nearshore and offshore surveys combined, 96% of all Kittlitz's murrelets occurred in waters 4–10°C. Availability differed between years and survey types, whereas use differed only between years, and in a pattern similar to that for availability (Table 28). In contrast to the pattern for large-scale use versus availability, however, small-scale temperatures used by Kittlitz's murrelets were, on average, warmer than those available to them (Table 23). This result, however, probably is biased by the fact that the sample size for late summer, when birds move into cooler waters, was considerably smaller than that for early summer, when birds tend to be in waters that are warmer than those available overall.

Relationship to Sea-surface Salinity.—Sea-surface salinity had a moderate range in early summer but ranged widely in late summer (Figs. 35 and 36, Table 18). On all cruises, salinities on both nearshore and offshore surveys were higher toward the outer edges of the bays. In early summer 1997, salinities were 16–30‰ and 17–29‰ on nearshore surveys and offshore surveys, respectively. In late summer 1997, they were 7–25‰ and 11–24‰ on nearshore and offshore surveys, respectively. In early summer 1998, salinities were 5–28‰ and 6–28‰ on nearshore surveys and offshore surveys, respectively. In late summer 1998, they were 7–26‰ and 11–24‰ on nearshore and offshore surveys, respectively. The generally lower salinities in 1998 reflected the greater amount of precipitation that resulted in greater freshwater input to these bays, plus additional amounts of calved ice that subsequently melted.

At a large scale, sea-surface salinities differed significantly among seasons and between years and survey types (Table 19). Multiple comparisons indicated that mean salinities were significantly greater in early summer than in mid- and late summer, greater in 1997 than in 1998, and greater in offshore waters than in nearshore waters (Figs. 35 and 36, Table 18). Salinities exhibited a seasonal difference because freshwater input into these bays later in the summer decreased their overall salinities, exhibited a yearly difference because of less precipitation in 1997, and exhibited a difference between survey types because the fresh water that entered these bays did so primarily in the nearshore zone. Because we collected data on sea-surface salinity only in 1997 and 1998, we were unable to conduct a 3-yr comparison.

In early summer 1997, Kittlitz's murrelets occurred in waters 20–30‰ on nearshore and 20–28‰ on offshore surveys; however, 98% and 97% of all birds occurred in waters 21–29‰ on nearshore and offshore surveys, respectively (Figs. 35 and 36, Table 18). In late summer 1997, Kittlitz's murrelets occurred in waters 9–24‰ on nearshore and 11–24‰ on offshore surveys; use was highly variable on both nearshore and offshore surveys. In early summer 1998, Kittlitz's murrelets occurred in waters 8–25‰ on nearshore and 6–28‰ on offshore surveys; however, use was concentrated in waters 20–22‰ and 19–23‰ on nearshore and offshore surveys, respectively. In late summer 1998, Kittlitz's murrelets occurred in waters 7–26‰ on nearshore and 12–24‰ on offshore surveys; as in late summer 1997, use was highly variable on both nearshore and offshore surveys. Hence, salinities used by Kittlitz's murrelets were higher in early summer than in late summer but had a greater range in late summer, although the heavy precipitation in 1998 modified the early-summer pattern.

Large-scale use of sea-surface salinities by Kittlitz's murrelets differed significantly among seasons and between years and survey types (Table 21). Multiple comparisons indicated that Kittlitz's murrelets occurred in water that was significantly more saline in early summer than in mid- and late summer, more saline in 1997 than in 1998, and more saline on offshore surveys than on nearshore surveys. Salinities used were higher early in the summer because many birds had not yet moved to the vicinity of glacier faces, higher in 1997 because of the lower precipitation that year, and higher on offshore surveys because most freshwater input occurred in the nearshore zone. Again, we were unable to conduct a 3-yr comparison.

The comparison of large-scale availability versus use of sea-surface salinities indicated that Kittlitz's murrelets occurred in water that, on average, was more saline than that available overall (Table 23). Again, we were unable to conduct a 3-yr comparison.

At a fine scale, Kittlitz's murrelets occurred in a wide range of salinities (Fig. 37, Table 25). Across the 2 yr of nearshore and offshore surveys combined, 94% of all Kittlitz's murrelets occurred in waters 14–28‰. These birds occurred in water that, on average, was more saline than that available to them (Table 29).

Reproduction

Patterns of Production.—During all 3 yr 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 1998 or on offshore surveys in any of the 3 yr. We did, however, see an adult carrying a fish up into the hills near the mouth of Harriman Fjord on 3 July 1998, although we did not see any HY birds there later in the summer; if that chick had hatched on the day that we saw the bird carrying the fish, it would have fledged on or shortly after 27 July. 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 (see below). In addition, we saw numerous marbled murrelets (particularly in 1996, when we sampled late into the fledging period of this species) 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 (Day et al., in press), 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 4 bays during all 3 yr (Table 30). 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 during 1996 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 at least some of the bays in all 3 yr. Kittlitz's murrelets need ≥54 d after the egg is laid to incubate the egg and raise a chick to fledging (Day 1996); further, 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 d or more after fledging (Kuletz and Marks 1997; also see Beissinger 1995). Hence these birds probably need ~60 d or more from arrival in the bay to fledging of the young, plus the young spend additional time in the bays before departing for the winter. By using the seasonal pattern of occurrence in each bay (Fig. 24), we estimate that this species was not present long enough to be able to breed in either Unakwik Inlet or Blackstone Bay. In both College and Harriman fjords, Kittlitz's murrelets usually are present ~75 days, or long enough for breeding to occur. Indeed, we saw one HY bird in College Fjord in 1996 and saw an adult carrying a fish up into the hills near the mouth of Harriman Fjord in 1998, indicating at least attempted reproduction there.

Plumage as an Indicator of Reproduction.—Four AHY plumage categories could be recorded during all cruises (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 AHY Kittlitz's murrelets that were classified as breeding-plumaged birds ranged between 91% and 100% (Table 31, Appendices 4–10). The one exception was early summer 1998, when only 84% of all birds were in breeding plumage. The two cruises with the lowest overall percentage of breeding-plumaged birds were early summer 1996 and 1998. As discussed earlier (see "Within-bay Distribution," above), these were the two early-summer cruises with the highest percent ice cover and the lowest sea-surface temperatures (Table 10). On both nearshore and offshore surveys, the proportions of all Kittlitz's murrelets that were classified as molting birds ranged between 0% and 16%, with most cruises having 3–6% molting birds. Again, the two cruises with the highest percentage of molting birds were early summer 1996 and 1998, indicating that the Prealternate (i.e., prebreeding) molt was substantially delayed during those two springs. Winter-plumaged birds rarely were recorded, and only in early summer. Birds had not completely molted back into winter plumage by the end of the late-summer cruises; that molt occurs in August and September, with the peak probably occurring from mid-August through late September (Day et al., in press). No birds were seen so poorly that we were unable to identify the plumage.

The proportion of birds in breeding plumage differed by season and year but did not differ by survey type (Table 32). The proportion was higher in mid- and late summer than in early summer and higher in 1997 than in 1998 or 1996.

The proportion of Kittlitz's murrelets that were in breeding plumage during each bay-visit generally ranged between 90% and 100% (Fig. 38). In early summer, the proportion of birds in breeding plumage declined through time, although the rate of decline varied among years. Again, the rate of decline appeared to be higher in 1996 and 1998, the two icy, cold springs. By mid-summer, the proportion of birds in breeding plumage approached 100%, suggesting that the incompletely molted birds from early summer either left the bays or (more probably) completed the molt. In late summer, the proportion of birds in breeding plumage varied substantially among years, although it is clear that the Prebasic (i.e., post-breeding) molt begins by ~1 August, as indicated by the rapidly declining percentage after that date. The reason for the unusual dip, then increase, in the proportion in breeding plumage around 20 July in 1997 is unexplained.

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 (Table. 33). Overall proportions were much higher in mid- and late summer than in early summer. The one exception was early summer 1998, when the proportion of single-bird groups was high.

The proportion of birds in single-bird groups differed by season and survey type but did not differ by year (Table 34). The proportion was highest in late summer and lowest in early summer and was higher in nearshore waters than in offshore waters.

There was a pronounced seasonal pattern in the proportion of single-bird groups (Fig. 39). The proportion of single-bird groups increased through time in early summer, with the possible exception of 1996 (percentages varied so much that we cannot discern a pattern). The proportion in mid-summer was about the same as that at the end of early summer in 1998. The proportion was generally highest in late summer, however, or opposite the pattern predicted by the model.

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. The one HY Kittlitz's murrelet seen on 30 July 1996 was gone a week later. Its fate was unknown, and it may have been lost to predation. In 1996, we spent numerous daylight hours attempting to catch HY marbled murrelets with a long-handled net from our skiff so that we could develop the expertise for catching HY Kittlitz's murrelets in 1997 and 1998; however, we were unable to catch even one HY marbled murrelet with this technique. Those birds generally dove when the boat was ≥5 m away, so we were unable to get within net-range of them. In addition, in both 1997 and 1998, few HY marbled murrelets were produced before the cruise ended, so we were unable to attempt to catch them at night with spotlights, following the technique developed by Whitworth et al. (1997) for capturing Xantus' murrelets (*Synthliboramphus hypoleucus*).

Mixed-species "Pairs" of Murrelets.—We observed what appeared to be mixed-species "pairs" of Kittlitz's and marbled murrelets during 4 of the 7 cruises across the 3 yr of the study (Table 35). 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 early or mid-summer 1998. We also saw none in Blackstone Bay during any cruise. For unknown reasons, most "pairs" were seen in College and Harriman fjords. These are the two bays in which Kittlitz's murrelets occur in highest numbers, so perhaps it is a simple relationship with population size. 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.

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 "long-groan" call of the Kittlitz's murrelet is a hoarse, raspy *ah-ah*, *ah-ah-ah*, or *aaaaahhh* that is of variable length (usually 1–3 sec) and that may be made once to several times in succession (Day et al., in press). 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 only one bird make other vocalizations of any type (Day et al. in press).

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.

There was no relationship between the number of mixed-species "pairs" that occurred in a bay and the relative abundance of Kittlitz's and marbled murrelets in that bay (Table 36). Ratios in bays with these mixed-species "pairs" ranged between ~2:1 and ~32:1. Ratios in bays with no mixed-species "pairs" ranged between ~2:1 and ~12:1, however. The correlation coefficient for this relationship was only 0.04 (df = 10; P = ~0.999).

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 37). 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-hr/night, for a total of 36 net-hr of sampling (Table 37). During that time, we caught no Kittlitz's murrelets, for a mean catch rate of 0 birds/net-hr. 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 or 1998 and reallocated that time to other activities.

Patterns of Feeding.—Of the 15 variables examined in the multiway contingency tables, Kittlitz's murrelets exhibited significant variation of feeding for 8 of them: survey type, season, year, habitat type, percent ice cover, distance from shore in nearshore zone, depth of nearshore zone, and shoreline substrate in nearshore zone (Tables 38–44). The percentage of birds that were feeding did not differ significantly by time of day, tidal stage, current strength, secchi depth, sea-surface temperature, sea-surface salinity, and distance from nearest fresh water (Tables 38 and 45–50).

Kittlitz's murrelets exhibited a much higher frequency of feeding in one survey type (Fig. 40, Table 39). The proportion of birds that were feeding was significantly higher in nearshore zones than in offshore zones in all three models in which the variable was included (Table 38). In fact, the proportion feeding in the nearshore zone was nearly four times that in the offshore zone.

Kittlitz's murrelets exhibited a different frequency of feeding by season (Fig. 41, Table 39). The proportion of birds that were feeding was significantly higher in late summer than it was in early or mid-summer. This variable was significant in 3 of the 4 models in which it was used (Table 38). Feeding frequency also varied among years, with the proportion highest in 1997, second-highest in 1998, and lowest in 1996 (Fig. 42). This variable was significant in all 4 models (Table 38).

Although Kittlitz's murrelets exhibited a different frequency of feeding by habitat type, no habitat types were significant, even though the overall model was (Fig. 43, Table 40). This variable was significant in 2 of the 4 models in which it was used and almost was in a third one (Table 38), but the program considered this variable to be "unstable" analytically. As a result, no conclusions could be drawn about which habitats were more important for feeding. Examination of Figure 43, however, suggests that feeding frequencies were higher in glacial-affected and glacial-stream-affected habitats and lower in glacial-unaffected habitats, with the sample size for marine-sill-affected habitats being too small to allow any conclusions. We suspect that the high feeding frequency but low sample size for marine-sill-affected habitats was the cause of instability in this variable.

The proportion of Kittlitz's murrelets that were feeding varied significantly by percent ice cover (Fig. 44, Table 41). Feeding frequency declined with increasing ice cover, then jumped abruptly at the highest cover category (Fig. 44). Hence, it appears that there is a decreasing frequency with increasing cover but that the few birds that are able to penetrate high-cover areas do so because they are good places to feed. Most birds are unable to penetrate such areas, however (only ~4% of all birds were in this cover—Fig. 44; also see "Habitat Use," above). This variable was significant in both models in which it was used (Table 38).

The proportion of Kittlitz's murrelets that were feeding in the nearshore zone varied by distance from shore (Fig. 45, Table 42). Feeding frequency declined steadily with increasing distance, suggesting that these birds prefer to feed as close to shore and, thus, in as shallow water as they can. Likewise, Kittlitz's murrelets fed in decreasing frequency with increasing depth of the nearshore segment, and only ~1% of all Kittlitz's murrelets occurred in the deepest segments, suggesting actual avoidance of such areas (Fig. 46, Table 43). Although it appears in Fig. 46 that the frequency for 61–80 m is significantly smaller than that for 21–40 and 41–60 m, the small sample size probably results in low power, and hence the lack of significant difference, for that category. These two variables were significant in the only model in which they were used (Table 38).

Kittlitz's murrelets also exhibited a significant difference in feeding frequency with respect to the shoreline substrate in the nearshore zone (Fig. 47, Table 44). Feeding frequencies were highest in shorelines bounded by large alluvium, small alluvium, or ice and lowest in shorelines bounded by bedrock. This variable was significant in the only model in which it was used (Table 38).

Food Habits.—Although the data on food habits are limited, Kittlitz's murrelets primarily appeared to forage on fishes in these bays in all 3 yr (Table 51). We were able to identify only about 25% of the fishes that Kittlitz's murrelets were seen holding. All but one of them were Pacific sand lance, primarily because that fish is distinctive at a distance. The other identified fish was a Pacific herring, a species that appeared to be abundant in the study bays in 1997 and 1998. Another Kittlitz's murrelet near the face of Yale Glacier, in College Fjord, was seen holding a long, slender fish that did not appear to be a sand lance. Although we believe that most of the unidentified fishes were Pacific sand lance, 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 1996–1998 (Table 52, Appendix 12). Of those prey items that were identified to species, 83% of those taken by Kittlitz's murrelets and 74% of those eaten by marbled murrelets were Pacific sand lance. The remaining identified items eaten by both species were Pacific herring.

Mean prey sizes of Kittlitz's murrelets were slightly smaller than those of marbled murrelets feeding in the same bays (Table 52). These mean sizes did not, however, differ significantly between the two species ($t = -0.684$; df = 33; $P = 0.499$), indicating that there was extensive overlap between the two species in the size of fish prey that they eat. Likewise, the range in prey sizes for Kittlitz's murrelets (3–12 cm; n = 16) was slightly smaller than that for marbled murrelets (3–14 cm; n = 40), although there was extensive overlap in sizes. These lengths suggest that these fishes all were from 0- or 1-yr age-classes.

There was a pronounced seasonal difference in the number of records of Kittlitz's murrelets that were holding fishes (Fig. 48). Less than 10% of all records occurred in early summer, and less than 20% occurred in mid-summer. Hence, ~75% of all records of these birds holding fishes occurred in late summer.

Mixed-species Feeding Flocks.—We saw Kittlitz's murrelets in mixed-species feeding flocks on only ten occasions during the 3 yr of research (Table 53). We saw one of these flocks in 1996, five in 1997, and four in 1998, matching our impression that fishes were more available overall to birds in 1997 and 1998 than in 1996: considerably more Kittlitz's murrelets were seen holding fishes in 1997 and 1998 than in 1996 (Table 51), as were marbled murrelets (Appendix 12), and feeding frequencies were significantly higher overall in 1997 and 1998 than in 1996 (Table 38). 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 53). The mid-summer sampling intensity was too small to make any inferences about the frequency of these flocks; however, it appeared to us that the number of fish schools in mid-summer 1998 was similar to that in late summer 1998.

The marbled murrelet is the species that Kittlitz's murrelets most often associated with in these mixed-species feeding flocks, being recorded in 80% of the flocks (Table 53). Black-legged kittiwakes (*Rissa tridactyla*) were next in frequency, being recorded in 50% of these flocks. Mew gulls (*Larus canus*), glaucous-winged gulls (*L. glaucescens*), and arctic terns (*Sterna paradisaea*) all appeared to occur uncommonly in these flocks.

Kittlitz's murrelets feeding off the faces of the glaciers did not forage in the same manner as mew and glaucous-winged gulls, black-legged kittiwakes, and arctic terns. These latter four species primarily appeared to forage on prey that were stunned and/or 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 the inability of these four species to dive deeply and their reliance on surface-seizing (the three species of gulls) and shallow diving (the terns) for catching prey. As a result, these species often moved from spot to spot where pieces of glacier ice were being calved. In contrast, Kittlitz's murrelets appeared to forage by pursuit diving and capturing prey underwater, and we never saw them moving to locations where ice was calving.

Dive Times.—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). These mean dive times did not differ between species ($t = -0.186$; df = 134; $P = 0.853$).

Other Aspects of Feeding.—Surprisingly, Kittlitz's murrelets did not forage extensively in tide rips, as marbled murrelets commonly 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 earlier feeding data, which showed no effect of current strength on feeding frequency (Table 38).

Kittlitz's murrelets tended to forage as either single birds or small groups. The mean flock size of feeding birds was 1.3 for all nearshore data combined, 1.3 for all offshore data combined, and 1.3 (SD = 0.8; n = 766) for all nearshore and offshore data combined (Table 54). Marbled murrelets tend to feed in larger groups, in that the mean flock size of feeding birds was 1.7 for all nearshore data combined, 1.8 for all offshore data combined, and 1.7 (SD = 0.8; n = 4,636) for all nearshore and offshore data combined (Table 54). Although these data suggest that the mean flock size for marbled murrelets is 31% to 38% larger than that of Kittlitz's murrelets in nearshore and offshore surveys, respectively, the difference is not significant: the overall model is significant (mean square = 15.270; df = 11; F = 2.638; $P = 0.002$; observed power = 0.976), but species is not (mean square = 19.721; df = 1; F = 3.407; $P = 0.065$; observed power = 0.454). We suspect that the great variability caused by sometimes-large flocks of feeding marbled murrelets in mid- and late summer resulted in this non-significant result.

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. 16). 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 did see a harbor seal (*Phoca vitulina*) eating a cod (Gadidae) of unknown species in this bay.

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. 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 among years. Hence, interannual differences in these aspects of the ecology of Kittlitz's murrelets that we studied here could not be caused by interannual differences in the sightability of birds. Characteristics affecting observation conditions were similar among years except for precipitation, which occurred more frequently in 1998 than in 1997 or 1996. Environmental characteristics exhibited substantial variation among seasons and years, with ice cover being greater in 1996 and 1998 than 1997 in most cases. Secchi depths generally were smaller in 1998 than in 1997, probably because of the higher precipitation in 1998. Sea-surface temperatures were considerably higher in 1997 than 1996 and 1998, a pattern that is complementary to the reduced ice cover in 1997. Sea-surface salinities were higher in 1997 than in 1998, probably because of the higher rainfall in 1998; late-summer salinities were similar between years, however.

Abundance and Distribution

Kittlitz's murrelets exhibit a clumped distribution at several scales. At the regional scale, they occur only in the glaciated fjords of northern and northwestern Prince William Sound, with very low numbers of birds scattered elsewhere throughout the Sound (Isleib and Kessel 1983, Kendall and Agler 1998; Day et al., in press). At the bay scale, densities were not identical among bays but instead were highest in the two bays that had the greatest number of tidewater glaciers and/or greatest number of glaciers overall (see below). Finally, within bays, they exhibited a clumped distribution in all analyses that could be conducted (i.e., excluding the two analyses that had sample sizes of 0 and 1). Further, it also appeared to us that they exhibited a similarly clumped distribution in the offshore zone, although we were unable to test for such a pattern.

Densities of Kittlitz's murrelets exhibited significant seasonal, interannual, and geographic variation within the 4 study bays during the 3 yr of the study. The seasonal pattern of larger densities in mid-and late summer reflected the sometimes-late arrival of this species in all of the bays in at least one year. The interannual variation indicated that overall densities were highest in 1997, which was the year that we would characterize as having an "early spring:" ice cover was low, and sea-surface temperatures were high. Conversely, densities were lowest in 1998 (and nearly that low in 1996), which was a "late spring" with heavy ice cover and low sea-surface temperatures. We are unsure of the exact mechanism by which these birds respond to these interannual variations in environmental conditions (i.e., do they leave again only after visiting the bays and seeing what conditions are like, or are such cold conditions evident at a regional scale, as the birds are leaving the wintering grounds?) that apparently result in such interannual variations in densities.

Kittlitz's murrelets differed substantially in abundance among the four study bays. 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 selects for those bays having the greatest numbers of tidewater glaciers and/or the greatest number of glaciers overall. Further, although not presented here, data on marbled murrelets in these same bays suggest that they occur in higher densities in Unakwik Inlet and Blackstone Bay, which are the two bays that are less preferred by Kittlitz's murrelets (Day and Nigro, unpubl. data). Hence, it appears that these two species exhibit different preferences at a bay scale.

Although densities of Kittlitz's murrelets differed significantly between nearshore and offshore waters within bays only when the nearshore data were filtered to have a habitat type identical to that in the offshore data set, densities in these two locations clearly were much higher than they were on pelagic surveys, in more open waters outside of bays. Hence, it is clear that Kittlitz's murrelets rarely, if ever, leave these bays during the breeding season to forage out in more open waters of Prince William Sound. Along these lines, 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 to feed. Alternatively, because these birds were seen only in early summer, it is possible that they were birds from the study bays that had not yet made it to those bays during spring arrival. This preference for bays by Kittlitz's murrelets is consistent both with that pattern 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).

We speculate that the later arrival of Kittlitz's murrelets in at least some bays during early summer 1996 and 1998 was related somehow to the considerably greater ice cover and/or colder sea-surface temperatures in those bays than occurred in the other bays, 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 varied dramatically among years, ice cover during that season was the highest of all bays and ranged between 16% and 37% overall. These percentages still are in the range at which ice cover has a strong negative effect on densities of Kittlitz's murrelets. Sea-surface temperatures in College Fjord in early summer showed a pattern similar to that for ice cover. Hence, overall environmental conditions in early summer were more stressful in College Fjord, and the consistently later arrival of birds there probably reflected that smaller amount of environmental amelioration.

This among-bay variation in the amount of ice cover also affected the distribution of Kittlitz's murrelets within bays during early summer but essentially did not during other cruises. In early summer, birds were restricted to ice-free areas that were restricted in distribution in some bays during some years. In contrast, these birds were distributed essentially throughout all bays during the mid- and late-summer cruises (with the exception of a complete absence of birds in Blackstone Bay in late summer 1996). A movement toward glacier faces from early to late summer 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 within bays. In early summer of all 3 yr, 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 preference for feeding in glacial-affected habitats, and there was a high (67% of all glacial-affected segments) frequency of association with glacial-affected habitats in early summer 1997 (the "early spring"), suggesting that food was not in short supply near glaciers at that time and that birds would enter those habitats in early summer when ice cover was low. In contrast, amelioration of environmental characteristics by late summer allowed Kittlitz's murrelets to spread throughout all parts of all of the 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 late summer 1997 and 1998 but not 1996. This glacier was inactive and did almost no calving in 1996, and the little calving that did occur in 1996 was seen primarily in late summer. In 1997 and 1998, however, this glacier was extremely active and calved nearly continuously. An embayment that appeared near the northern end of the glacier face in 1997 was a site of active calving and rapid retreat, and another embayment developed south of there in 1998. Further, the exposure of large amounts of sediments off the face of this glacier during low tides in 1998 suggested that it had retreated by ≥10 m from the maximal advance in 1997. It appears to us that this glacier is in the process of coming off of the rear edge of the moraine/sill in a substantial part of the glacier face, and possibly along its entire face; if so, further rapid retreat will occur in the near future (D. Trabant, U.S. Geological Survey, Fairbanks, AK, pers. comm.). We are unclear why Kittlitz's murrelets occurred in such high densities near this actively calving glacier in 1997 and 1998, but there clearly was a sudden attraction to it.

Population Size.—Population sizes of Kittlitz's murrelets in these 4 bays are fairly small, representing a total population of ~1,400 ± 1,700 birds in 1996, ~1,275 ± 750 birds in 1997, and ~1,275 ± 1,100 birds in 1998. We believe that the overall population size in 1996 was slightly inflated by the unusually high estimate for Unakwik Inlet. Maximal numbers of birds counted during paired nearshore and offshore surveys were 262 birds in 1996, 317 in 1997, and 348 in 1998 in the 4 bays combined, putting the lower limits on the 3 years' population estimates at those levels. Hence, possibly as many as 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 4 bays between 1996 and 1997 but were almost identical between 1997 and 1998; 95% CIs overlapped between years for all bays except College Fjord between 1996 and 1997. These variations in population estimates for at least some bays suggest that there is substantial among-bay movement of birds.

The patterns of population change seen here described "normal" seasonal patterns of seasonal increase, then decrease, in numbers during the breeding season for at least some of the bays. The patterns for College and Harriman fjords match this pattern well, although it is clear that birds arrive in Harriman Fjord much earlier than they do in College Fjord. Indeed, Irons (pers. comm.) found ~300 Kittlitz's murrelets in Harriman Fjord on 4 April 1984, suggesting that they may arrive there much earlier than they do in College Fjord. Populations in Unakwik Inlet follow a "normal" seasonal pattern in some years, but arrival was greatly delayed in most years. In contrast, populations in Blackstone Bay arrive early but are irregular in attendance; however, it appears that this species essentially abandons the bay by mid-late June. These among-bay differences suggest that this species use different bays differently, with College and Harriman fjords clearly representing possible breeding bays and Unakwik Inlet and Blackstone Bay representing summering, but not breeding, bays.

The primary previous estimate of population sizes of Kittlitz's murrelets in this region is from Isleib and Kessel (1973), who stated that July-August 1972 surveys estimated ~57,000 Kittlitz's murrelets in Prince William Sound as a whole. 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. Isleib and Kessel (1973) 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. These estimates involve some uncertainties, 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 occurring within bays are equivalent to our offshore surveys) sample from Unakwik Inlet on 30 July represented 76% of all Kittlitz's murrelets seen on all pelagic 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 pelagic 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 explicitly state that it was; conversely, if a flock this large was a regular occurrence, there would have been no reason to mention this flock in particular. Finally, we saw numerous large flocks of feeding marbled murrelets, some occasionally with Kittlitz's murrelets in them, in the centers of all of these bays at this time of year during all 3 yr of the study. Given the flocking behavior of feeding marbled murrelets at this time of the year, it also possible that these authors identified some Kittlitz's murrelets in this large flock and assumed that all were Kittlitz's murrelets, thereby inflating the size of the population estimate.

Data presented in 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. Data from Irons and B. K. Lance (USFWS, Anchorage, AK, unpubl. data) also are available for both winter and summer of 1998, to add to the time-line. These latter estimates are extremely low, but the general impression of the biologists collecting the data (Lance, pers. comm.) was that there were extremely few Kittlitz's murrelets anywhere in Prince William Sound in 1998. The Sound-wide estimates for July since the *Exxon Valdez* oil spill have varied from a high of 6,436 in 1989 to lows of 1,280 in 1996 and 279 in 1998, or by –78% to +129% among samples from subsequent years (Table 55). We question whether the total population of Kittlitz's murrelets in Prince William Sound actually did vary by this amount over these years; as indicated above, it is possible that birds simply moved around, into areas where these scientists were not sampling. In addition, our population estimates (1,410, 1,280, and 1,270 birds in 1996–1998, respectively), which are generated for only ~50% of the bays that contain most of the Sound's population of Kittlitz's murrelets, are greater than the population estimated by Agler and Kendall (1997) and Irons and Lance (unpubl. data) for all of Prince William Sound during the summers of both 1996 and 1998. Further, the highest number of birds counted by us on nearshore and offshore surveys combined during 1 visit to each of our 4 bays in 1998 (348 birds) was higher than the number that Irons and Lance estimated for the entire Sound that year (279 birds). 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—even though Irons and Lance's estimates for 1998 appear to us to be unusually low.

The extensive interannual variation in estimated population size seen in the studies of Agler and Kendall and of Irons and Lance (Table 55), coupled with the extreme variation in abundance and distribution among bay-visits and bays (depending on date, ice cover, and sea-surface temperatures) that we have seen in this study, suggests 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?), (2) the distribution of Kittlitz's murrelets within these bays has changed over time, so that fewer are being recorded on those locations (which are fixed in space) that are sampled, or (3) the broad-scale surveys used by the USFWS 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 either of the latter two explanations appears to be most likely. Interannual differences in the number and distribution of birds within a bay do occur (see above), and random sampling does not estimate population sizes of highly clumped species accurately (Thompson 1992).

For argument's sake, however, we assumed that the summer 1972, 1989, 1996, and 1998 population estimates and that the winter 1972, 1973, 1990, 1996, and 1998 population estimates for Kittlitz's murrelets in Prince William Sound (Table 55) were accurate and calculated what sort of average annual population changes would be required for the population to have undergone such changes among years (Table 56). In both sets of comparisons, we included data for both 1996 and 1998 as end-points because the 1998 estimates appeared to be unusually low. 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 between years. The estimates of changes in summer populations among time periods ranged from –12.58%/yr to –29.43%/yr, and those for changes in winter populations ranged from +5.82%/yr to –26.90%/yr. One might reasonably assume that, if the overall population is changing, a change in summer should be matched by a similar change in winter; the two data sets are highly correlated (Fig. 49; $r = 0.825$; df = 6; $P = 0.012$), indicating a seasonal consistency in estimated population trends within the Agler/Kendall and Irons/Lance data sets. A comparison of the summer 1972–1989 and 1989–1998 data suggests an increasing rate of decline that, if true, is approaching 30%/yr in this decade. If only the 1996 and 1998 data are compared, they suggest rates of change of –53.30%/yr for the summer data and –34.50%/yr for the winter data.

In contrast to these data for the Sound-wide surveys, our data for 1996–1998 suggest an interannual rate of change of –9.20% for 1996–1997, –0.60% for 1997–1998, and –5.08% for 1996–1998. We suspect, however, that our estimate for 1996 was slightly inflated because of the uniquely high estimate for Unakwik Inlet (see above)—an estimate that has not been approached since then. Hence, in our study bays, we suspect that the overall population change, if one has occurred at all, has been minor; in fact, the interannual variations that we have seen simply may be caused by sampling error.

For comparison with these estimates, 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 because 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 entire 25 yr since the first population-level data were collected.

At least six conclusions are apparent from evaluating all of these estimates. First, we believe that the summer 1972 estimate of the number of Kittlitz's murrelets in Prince William Sound is biased strongly upward. As stated above, the raw counts showed extreme clumping with a highly biased overall population estimate; such high interannual variation in estimates probably is the direct result from such a bias. Second, this clumped distribution, which is characteristic of Kittlitz's murrelets at scales from individual bays to the entire Sound, does not result in accurate estimates of population size when random sampling is used; whether these estimates can be used as population indices is doubtful. Third, if, for argument's sake, these estimates are used as population indices, the data suggest that a long-term population decline in the population of Kittlitz's murrelets has been occurring across Prince William Sound as a whole since at least the early 1970s. No matter how the Sound-wide data are examined, they generally suggest a rate of decline of somewhere between 10%/yr and 30%/yr. Further, if the summer data for 1972–1989 are examined separately from those for 1989–1998, they suggest that the rate of decline has increased from ~12–13%/yr to nearly 30%/yr. Fourth, when our data are examined for 1996–1998, they indicate numbers of birds in only part of Prince William Sound that are comparable to or higher than numbers that are estimated with stratified sampling for the entire Sound, again suggesting again that these Sound-wide surveys are of questionable accuracy in estimating the population size of this highly clumped species; in 1998, we actually counted more birds in the four study bays than the USFWS estimated for the entire Sound. Fifth, if a decline of the Kittlitz's murrelet population, as indicated by the Sound-wide surveys, actually is occurring, most of the estimated rates of decline can only be described as alarming. Finally, our estimates suggest that a decline is not occurring, although it is possible that a very slow decline may be occurring; determining whether such a slow rate of possible decline actually is occurring would require several more years of population monitoring.

Evaluation of Sampling Protocol.—Our evaluation of the sampling protocol suggests that the best time for sampling occurs between 0600 and either 1500 or 1700. On nearshore and offshore surveys combined, 85.6% of our sampling effort (by time) over all 3 yr combined was concentrated in the period 0600–1500. If the optimal sampling period for surveys actually is 0600–1700, we concentrated 96.8% of our overall sampling effort during that period. Hence, nearly all of our sampling effort occurred at the optimal time of the day for sampling this species.

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 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 inter-observer 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 miss a high percentage under any circumstances). It would, however, be impossible without a major sampling effort, one that is beyond the scope of this project, to determine the actual percentage of birds that we both miss. Thus, we believe that the sampling protocol was more than adequate for this study.

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 excessively heavy 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 and 1998). 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. Once ice cover declined and sea-surface temperatures increased in these glacial-affected habitats in mid-late 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 the within-bay 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). In addition, glacial-affected habitats are preferred by other seabird species elsewhere, for densities of northern fulmars (*Fulmarus glacialis*) and black-legged kittiwakes in the Canadian Arctic also are higher off the faces of tidewater glaciers than away from them (McLaren and Renaud 1982).

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 seasonal decreases in secchi depth (which is lowest off the faces of glaciers), temperature (which is lowest near 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; that effect would be greater in early summer, when ice cover was greatest. 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 among seasons; however, we have no data to prove that ice characteristics, other than percent cover, changed between cruises. We are unclear why ice was more limiting in early summer than later in the summer. Perhaps the greater frequency of high-percentage ice cover in early summer made these small birds hesitant to dive in areas where access to open water might disappear suddenly.

Kittlitz's murrelets occurred in ice cover 0–75% in early summer and 0–90% in late summer, with >90% of all birds across all years occurring in ≤20% ice cover during both seasons. Although these birds 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. Finally, the overriding importance of ice in affecting the distribution of Kittlitz's murrelets is indicated by the fact that this is the only variable that did not vary interannually in use.

Kittlitz's murrelets occurred in secchi depths of 0–6 m in early summer and 0–14 m in late summer, with 90% of all birds across all years occurring in depths ≤3 m in early summer and ≤2 m in late summer. In general, the water was clearer in the offshore zone than in the nearshore zone and clearer in early summer than in late summer. In nearshore waters, in particular, Kittlitz's murrelets experienced great spatial variation in available water clarity, with clarity consistently increasing 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 occurred in sea-surface temperatures of 2–13°C in early summer and 1–12°C in late summer, with >90% of all birds across all years occurring in waters 4–10°C in early summer and 4–9°C in late summer. 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 1998 and 1996. Kittlitz's murrelets showed similar patterns of use, although the one exception was the seasonal pattern, which indicated a movement into cooler waters near glaciers later in the summer. Overall, however, they tend to avoid waters greater than ~12°C.

Kittlitz's murrelets occurred in sea-surface salinities of 6–30‰ in early summer and 7–27‰ in late summer, with >90% of all birds across all years occurring in waters 21–29‰ in early summer and 12–25‰ in late summer. Available salinities were higher in the offshore zone than in the nearshore zone and higher in early summer than in late summer. Kittlitz's murrelets actually did not follow this pattern, in that they used salinities that were greater than were available to them on average.

Reproduction

Production.—All data suggest that Kittlitz's murrelets produced very few young during the 3 yr of this study. Measured reproductive output by Kittlitz's murrelets in the four study bays was essentially zero in 1996 and actually was zero in 1997 and 1998 (although we saw evidence of attempted reproduction in Harriman Fjord in 1998). In addition, it appears that only some of the bays (College and Harriman fjords) are used for breeding by this species, with birds in Unakwik Inlet and Blackstone Bay generally present for too short a time to breed successfully. Finally, if HY Kittlitz's murrelets (which appear to be similar in behavior to marbled murrelets) spend any time at sea in the vicinity of the nest after they had fledged, we should have seen them because the late-summer surveys occurred across a broad part of the estimated fledging period of Kittlitz's murrelets in this region (Day 1996). In 1996, we actually saw a fledgling after we had begun sampling, indicating that we were there at the appropriate time. In 1997 and 1998, 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. 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 and 1998. Either way, the limited data from this study (the fledgling on 30 July 1996, the chick being fed in 1998 possibly fledging on or after 27 July, and an egg in the oviduct of a bird at Hinchinbrook Island that suggested fledging on or after 21 July [Day 1996]) indicate that we were sampling at an appropriate time to locate any fledglings that were produced. Hence, we believe that we were in the field in the appropriate time in all 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/yr, are estimated to have an annual adult survivorship of ~85%. Further, Kittlitz's murrelets, like marbled murrelets, also exhibit geographic asynchrony in the timing of movements into and out of specific locations 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 in which the average age at first breeding was 3 yr would need to have an annual (female) fecundity of 0.39/pair to remain stable if the average annual survivorship was 85% and 0.23/pair if the annual survivorship was 90%. Such fecundity levels would require HY:AHY ratios of ~0.18–0.28:1 in late summer. After correcting for the higher numbers of AHY birds that occur 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 level of productivity will result in substantial annual declines in population size. Although we have not constructed such models, 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 reproductive failures in this species. Failures, however, have been recorded previously. During a collecting trip to Glacier Bay from late June to late July 1907, Grinnell (1909) and others found no evidence of breeding in a series of 38 Kittlitz's murrelets that were collected in the outer bay 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 that these collectors missed all evidence of reproduction is low. Hence, those data suggest that large-scale breeding failure also occurred in that year. Further, J. Bédard (in litt.) collected a series of Kittlitz's murrelets in outer Glacier Bay in July 1968; of the 17 birds collected, at least 16, and possibly all, were breeding. 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.

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 actually 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.) Perhaps a similar percentage of such birds occurred in early summer 1998. Indeed, based on our experience with other alcids, we would have considered most of the birds seen in early summer 1996 and 1998 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 and 1998 was delayed, that a large number of the birds seen in 1996 and 1998 were subadults and not adults, or that Kittlitz's murrelets have a molting strategy that is different from that of other alcids.

In mid-summer of 1998 and in late summer of all 3 yr, most breeding-plumaged birds were completely brown (i.e., in complete breeding plumages) early in the cruises. Late in the cruises, 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 among the late-summer cruises, the percentage of birds that had entered the molt was highest in the late summer 1996 cruise, which extended further into August than the 1997 and 1998 cruises 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 and 1998 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 seen in early summer 1997, when nearly all birds were in complete breeding plumage by early June. This latter pattern is the norm, in that the prealternate molt in this species is rapid and is ended by mid-late May (Day et al., in press).

It is possible that the large number of incompletely molted Kittlitz's murrelets that we saw in early summer 1996 and 1998, but not 1997, represented large numbers of subadult birds produced in previous years, rather than representing interannual variation in molt schedules of breeding adults. For example, 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). In addition, 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).

Although it is possible that the large number of incompletely molted Kittlitz's murrelets seen in the spring of some years represented large numbers of subadults produced in previous years, we believe that the difference in the frequency of completely molted birds among years was related to a delay in the timing of the prealternate molt, rather than to age of the birds. Because the timing of molt is believed to be controlled primarily by photoperiod, rather than by other extrinsic factors such as temperature (Payne 1972), the timing of the prealternate molt should be constant interannually. The fact that such late-molting birds were seen in the two years with the latest springs and not in the year with the earliest spring, however, indicates that some as-yet unknown environmental factor is a proximal modifier of the timing of molt in this species, such that it is delayed by perhaps a week or two during late springs. Indeed, molt is non-adaptive in cold weather because an excess loss of feathers may result in excess loss of body heat (Payne 1972). Hence, it appears that late springs result in a slight delay in the timing of molting (either the beginning of the molt or the rate of molting) in this species.

We also have seen great overall variation in plumage colors in the field and in museum specimens, suggesting that some plumage variation related to reproductive status possibly 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 have little explanatory power in the context of reproduction. The results often were opposite those that were predicted by the frequency models. 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, however, are consistent interannually in Kittlitz's murrelets, and an identical pattern is seen in marbled murrelets (Day and Nigro, unpubl. data), suggesting that these patterns reflect some previously unidentified aspect of the biology or behavior of this genus.

Mixed-species "Pairs."—We saw several of what appeared to be mixed-species "pairs" of Kittlitz's and marbled murrelets during four of the seven cruises. From their behavior, these birds appeared to be paired, but we could not determine whether they actually were 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 this interspecific pairing is related to the low number of Kittlitz's murrelets in these bays and that it may have a negative effect on the Kittlitz's murrelet population in Prince William Sound.

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 the production of reproductively fertile offspring (Mayr 1963, Welty 1982, Rhymer and Simberloff 1996, Simberloff 1996). 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 are similar phenotypically and have geographic overlap.

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; and Rhymer and Simberloff 1996, Simberloff 1996, Bérubé and Aguilar 1998). 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 ratios of ~7:1 on nearshore surveys, ~5:1 on offshore surveys, and ~200:1 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 overall reproductive output of the Kittlitz's murrelet population in these bays even further. Such a waste of reproductive effort can have serious consequences for the rare species, even if offspring are not produced (Rhymer and Simberloff 1996, Simberloff 1996).

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 net system, 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. Further, although marbled murrelets commonly are seen flying up and down these bays while flying to and from feeding areas, Kittlitz's murrelets do not leave the bays to feed, and no strong up- and down-fjord movements were seen. Headlands that large numbers of marbled murrelets are flying past are good locations for catching them with floating mist-nets (Kaiser et al. 1995). In addition, the distribution of Kittlitz's murrelets within bays 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, some in 1997 and one in 1998. 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 a preference for feeding in 8 of the 15 variables that were examined in the multiway contingency tables. They exhibited significantly higher rates of feeding in the nearshore zone, in late summer, in some years, in lower ice cover, in more glaciated habitat types, near the shoreline, in shallower depths, and off of certain shoreline substrates. Depth clearly is an important component of foraging in this species, for all three variables that independently suggest a preference for shallow foraging (nearshore surveys, near the shoreline, and shallow segment depths) were significant. Indeed, some areas that regularly were used for foraging by Kittlitz's murrelets (e.g., the shallow bank on the western edge of Barry Inlet in Harriman Fjord) were ≤3 m deep, suggesting that, at a mean dive time of ~30 sec, these birds were swimming horizontally over a large expanse of very turbid water while searching for prey. Exactly how they locate prey in such turbid water remains a mystery.

Proportions of Kittlitz's murrelets that were feeding did not differ significantly among current strengths. In contrast, an appreciable number of marbled murrelets foraging in the same bays seemed to have a strong preference for feeding when tidal currents were strong. For example, one would always see that species feeding in the tide rips and standing waves (i.e., tidal fronts) that formed 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 has not driven this species to have a preference for fast tidal speeds: if the birds had a steady supply of food being upwelled and/or concentrated near 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, some Kittlitz's murrelets did feed during periods of strong tidal currents—they simply did not feed in tidal fronts in this study. 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 species that we identified being primarily Pacific sand lance. We believe that most of the unidentified fishes were Pacific herring and/or capelin (especially the former), which also have been recorded in Kittlitz's murrelets elsewhere in Alaska (Sanger 1987). Certainly, numerous schools of Pacific herring were seen in the study bays in mid-late summer of all 3 yr, especially in 1997 and 1998. We do not know what the small schools of larval fishes that we saw in late summer 1997 were, although 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 usually occurs later and growth rates of young herring usually are much slower in these glaciated fjords than they are in the warmer, outer parts of Prince William Sound (E. D. Brown, University of Alaska, Fairbanks, AK), so it is likely that these small fishes were herring.

It appears that Kittlitz's murrelets, like marbled murrelets, primarily eat the common schooling fishes that form a major part of the diet of other nearshore bird species in Prince William Sound during much of the summer. A preference for fishes is to be expected from the morphology and proportions of the mouth and bill of this species (Kishchinskii 1968, Bédard 1969). That preference has been documented in the few birds that have been collected in Alaska for feeding studies (Sanger 1987, Vermeer et al. 1987, Piatt et al. 1994; Piatt, in litt.). At this time, 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 at 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 occurred between the two sampling periods (Piatt and Anderson 1996), however, so the later importance of pollock in Kachemak Bay may reflect this community shift more than it does simple geographic variation.

Our visual observations suggesting that Kittlitz's murrelets fed primarily on fishes are limited and probably are biased by the small size of macrozooplankton that would be difficult or impossible to see from a distance. Alternatively, the smaller zooplankton might be eaten underwater without our detecting them, whereas the large fishes were brought to the surface (presumably for manipulation) before they were eaten; a similar difference in handling efficiency may occur between small fishes and large fishes. Such a hypothesized difference in handling efficiency between small and large prey has not been documented for either Kittlitz's or marbled murrelets, however. Summer foods of Kittlitz's murrelets from a non-glaciated area off of 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 may be 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, it has been suggested that Kittlitz's murrelets avoid competition with marbled murrelets by foraging on a higher proportion of plankton than marbled murrelets do (Sanger 1987), although additional data on feeding suggest great overlap in prey (Day et al., in press).

Dramatic seasonal differences in the number of fishes that we saw Kittlitz's murrelets holding suggest that, in early summer, Kittlitz's murrelets feed primarily on small prey, probably macrozooplankton, that we were unable to see well from a distance or that were swallowed whole underwater. A lack of fishes seen as prey in early summer could be caused by (1) much lower foraging success in early summer than late summer, (2) a change in feeding behavior, such that prey are eaten only underwater in early summer but are brought to the surface in late summer, or (3) a dependence on small prey, probably macrozooplankton, in early summer. Four reasons suggest that Kittlitz's murrelets forage primarily on zooplankton in early summer, then switch to foraging primarily on fishes in mid- and late summer. First, there is no compelling reason to believe (and no data to suggest) that foraging success should be lower in early summer than late summer. Second, many species of fishes have thermal limits beyond which they do not like to cross (Lapkin et al. 1983), and these glaciated fjords are so cold, especially in early summer, that they probably form a substantial thermal barrier to fishes. In contrast, plankton, by definition, have no control over horizontal movements, so temperature should not affect their horizontal movements. Indeed, as mentioned above, Pacific herring move into and spawn in some of these glaciated fjords later than they do in the warmer, outer part of Prince William Sound; likewise, young herring and sandlance do not become common in Prince William Sound as a whole until July and August (E. D. Brown, University of Alaska, Fairbanks, AK, pers. comm.). Third, a wide range of species of seabirds in glaciated fjords have been recorded foraging primarily on macrozooplankton, rather than on fishes (see following paragraph), suggesting that plankton-feeding may be a general pattern in glaciated fjords. Finally, the presence of a large number of moribund zooplankton in glaciated fjords early in the summer (Weslawski and Legezynska 1998), especially large ones available near the water's surface (Stott 1936), would make an attractive and easily caught food source. On the other hand, although it is doubtful that there is a dramatic change in foraging behavior between seasons, it is possible that fishes are so small in early summer that they always are eaten underwater. Such a hypothesized size-related difference in handling efficiency of fishes has not been recorded in either Kittlitz's or marbled murrelets, however.

The preference of Kittlitz's murrelets for feeding in more strongly glaciated habitat types also suggests that macrozooplankton may form a significant part of their diet in Prince William Sound during summer. Elsewhere, zooplankton have been found to be important prey in such fjords. 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. Likewise, 300–500 black-legged kittiwakes, "a few" mew gulls, and probably some glaucous-winged gulls foraged extensively on the euphausiid *T. spinifera* off of the face of Chenega Glacier, in southwestern Prince William Sound, in both 1997 and 1998 (R. Suryan, USFWS, Anchorage, AK, pers. comm.). Similar feeding on macrozooplankton by seabirds also has been recorded at two tidewater glaciers in western Svalbard, where large numbers of black-legged kittiwakes and northern fulmars fed off the glacier faces on the euphausiid *T. inermis*, the mysid *Mysis oculata*, and the hyperiid amphipod *Parathemisto libellula* (Hartley and Fisher 1936)—all planktonic species that are common in the Gulf of Alaska (Cooney 1986; K. O. Coyle, University of Alaska, Fairbanks, AK, pers. comm.). Even seabird species that normally are fish-feeders (thick-billed murre *Uria lomvia* and Atlantic puffin *Fratercula arctica*) concentrated on these abundant and highly available plankton species (Hartley and Fisher 1936), suggesting that a preference for fish-feeding can be overriden if another prey type becomes both abundant and highly available. Further, an input of large amounts of fresh water at or near the surface of a fjord's glacier 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 copepods that occur at depth during the day; it appears that the euphausiids and mysids also are upwelled or that they rise in the water column to feed on the smaller copepods that are upwelled (see Stott 1936). The mixing process itself also 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, thus making zooplankton easily available to feeding birds.

Mixed-species Feeding Flocks.—We saw Kittlitz's murrelets in mixed-species feeding flocks on only a few occasions during the 3 yr of research. In these mixed-species flocks, Kittlitz's murrelets most often associated with marbled murrelets, reflecting the similarity in diets and foraging characteristics between the two species. The limited frequency of these mixed-species flocks suggests that they are unimportant to Kittlitz's murrelet populations as a whole for securing food.

Depth of Feeding.—Many Kittlitz's murrelets feed in shallow water, particularly over shallow banks left by the retreat of the glaciers. As indicated above, all three variables that reflected aspects of depth were significant, indicating a strong preference for shallow foraging depths: nearshore (rather than offshore) surveys, shallow segment depths in the nearshore zone, and that part of the nearshore zone nearest to the shoreline. Such a preference for shallow foraging areas suggest that Kittlitz's murrelets have limited depths to which they can dive and/or that they use the bottom in some way to help them catch prey. Indeed, juvenile marbled murrelets may herd schools of fishes against a shoreline, to make capturing them easier (Day and Nigro, pers. obs.), and some marbled murrelets apparently feed demersally (Krasnow and Sanger 1982).

No information on feeding depths of Kittlitz's murrelets elsewhere is available, although there is some information on feeding depths of marbled murrelets. At Langara Island, BC, marbled murrelets usually fed <500 m from shore and usually fed in water <30 m deep(Sealy 1975). At Barkley Sound, BC, marbled murrelets foraged in water 10–30 m deep (Carter and Sealy 1990). Similarly, at Kodiak Island, AK, marbled murrelets fed in water <50 m deep and foraged throughout the entire water column, including demersally (Krasnow and Sanger 1982). In addition, our data on marbled murrelets show that all three variables that are associated with shallow foraging also are significant in the multiway contingency tables. Hence, it appears that marbled murrelets have a similar preference for foraging in the shallowest water possible.

Dive Times.—Kittlitz's murrelets exhibited fairly long dive times while feeding. These ~30-sec dive times ranged primarily between ~20 sec and ~45 sec, in spite of the location of the foraging bird. For example, we saw some birds spend 30–40 sec foraging in highly turbid, but shallow (≤3 m deep), water in outer Barry Inlet of Harriman Fjord. Such long foraging times in such shallow water suggest that these birds are sweeping back-and-forth in the turbid water until they stumble across a fish or some zooplankton.

The mean dive time of Kittlitz's murrelets was almost identical to the mean dive time of marbled murrelets that were feeding in the same bays. Further, mean dive times of both species are similar to those of marbled murrelets in Barkley Sound, BC (Carter and Sealy 1990). These results again suggest extensive overlap in feeding characteristics between these two species.

Group Size and Foraging.—Kittlitz's murrelets primarily forage singly but occasionally forage in pairs; in contrast, marbled murrelets forage most often in pairs. Perhaps this preference for foraging singly explains why Kittlitz's murrelets occur so rarely in large, mixed-species foraging flocks, as marbled murrelets do. In British Columbia, the mean flock size of foraging marbled murrelets is ~2 birds, similar to the mean value we found (Carter and Sealy 1990). In California, marbled murrelets supposedly forage primarily in pairs (Strachan et al. 1995); however, the data that these authors present suggest that many of the birds are displaying, rather than foraging, while diving as has been hypothesized for Kittlitz's murrelets (Day et al., in press).

These results suggest that there is extensive overlap in the feeding ecology of Kittlitz's and marbled murrelets. In these glaciated fjords, both species feed more often in nearshore waters than in offshore waters, both feed most often in shallow water, both feed most often on the common forage fish species that occur here, both feed on prey that are of similar size, both forage together in mixed-species feeding flocks, and both dive for similar lengths of time. On the other hand, Kittlitz's murrelets forage less often in clear water, forage less often near sources of freshwater input, probably forage more often on zooplankton, and forage less often in mixed-species feeding flocks and less often in strong tidal currents than marbled murrelets do. We suggest that the larger relative eye size of Kittlitz's murrelets (Day and Nigro, unpubl. data) and the preference of this species for glacial-stream-affected and glacial-affected habitats reflect an adaptation for foraging in highly turbid water and is a mechanism for decreasing competition with marbled murrelets. Although these results suggest that the feeding ecology of the two species is so similar that some insights about the feeding ecology of Kittlitz's murrelets can be learned from the more common marbled murrelet, they also suggest that the overlap in the feeding ecology of these two species may be extensive enough to result in competition for food.

CONCLUSIONS AND RECOMMENDATIONS

The effects of the *Exxon Valdez* oil spill on Kittlitz's murrelets probably will never be known. At this point, all that is known is that some birds at sea died, representing an unknown percentage of an unknown population size of this species from somewhere in the northern Gulf of Alaska. No oil moved into the glaciated fjords, so there clearly are no effects within the bays where most of these birds spend the summer. Further, because the water-column is clean and because no oil made it into the glaciated fjords, the probability of persistent contamination affecting reproduction is so low as to approach zero. In fact, we have been unable to tie any perceived problems in this study to the spill itself. Hence, the primary effects on this species had to have occurred as a result of the initial at-sea mortality in late winter 1989. Such opinions have been seconded by the Trustee Council, which stated in 1999 that "the original extent of the injury and its [i.e., Kittlitz's murrelet's] recovery status are still unknown and probably will never be resolved" (*Exxon Valdez* Oil Spill Trustee Council 1999).

In spite of the lack of information on effects of the spill on this species, conducting this study has been beneficial to this species in several ways. First, it provided the first in-depth study of the most-poorly known seabird species that regularly nests in North America (Day et al. in press).

Second, learning about this species will, we hope, help improve its management and conservation. For example, management issues related to habitat use and human disturbance will, we hope, be resolved with the results of this study. Third, documenting low reproductive output in most years, although of no apparent relationship to the spill, is of great conservation concern. Although we do not believe that the overall population size in our four study bays is declining, the low overall population size is of great concern, as is the documentation of mixed-species "pairs" of Kittlitz's and marbled murrelets. Such topics will, we hope, help resource managers manage this species better and point them and the Trustee Council in the direction of further research that will aid in the conservation of this species.

We believe that we were able to learn much about the ecology of this rare seabird during this 3-yr study. Although some components of the study were not executed as originally envisioned because of environmental difficulties (e.g., using mist nests in the vicinity of floating ice) or unanticipated aspects of biology (e.g., essentially no young produced), we still were able to learn far more than ever was known previously about this species. We will make some recommendations here for further research.

Abundance and Distribution

The abundance and distribution surveys have yielded valuable and interesting information. Recommendations involving this topic relate to (1) overall population trends in our study bays, (2) overall population size and population trends in Prince William Sound as a whole, (3) overall population size and trends along the Kenai Peninsula, and (4) the opening of the road to Whittier.

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. We believe (and statistics books reinforce the point), however, that the USFWS random sample is not a good method for either estimating or tracking the size of the population of this highly clumped species. Although the size of the overall population of Kittlitz's murrelets in our four study bays does not appear to be changing, it is possible that the rate of change is so small that we have been unable to detect it in the 3 yr of this study. Accordingly, we recommend that the population be monitored again in 5 yr (i.e., during the summer of 2003). That way, one should be able to detect an overall population change, even if the annual rate of change is very small. We recommend 2–3 surveys in each bay, to get the best possible estimate of peak population size.

Another question involves the overall size and trends of the Prince William Sound population of Kittlitz's murrelets as a whole. As discussed earlier, random samples do not go a good job of estimating accurately the population size of a clumped species. It thus follows that such data are of limited use in monitoring the trend of such a population. Hence, a different sampling strategy is required—one that emphasizes intensively sampling the population in the limited habitat where essentially all of the Sound's population occurs. We recommend a cruise having additional, intensive nearshore and offshore surveys, similar to what we have done here, 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, if conducted in conjunction with the above surveys of our four study bays in the summer of 2003, would enable us to estimate with some confidence the overall size of the majority of Prince William Sound's population of Kittlitz's murrelets. Such surveys then could form the baseline data for a long-term monitoring scheme for this species in Prince William Sound as a whole. Given the probability that birds move among bays, a synoptic survey in one year would be better than partial surveys spread across two years.

The third issue involves estimating the overall population size and trends of that population along the Kenai Peninsula. It actually is possible that most of the birds that were killed as a result of direct mortality from the spill were from the Kenai Peninsula population, rather than the Prince William Sound population. Hence, we recommend one synoptic survey for estimating the overall population size that then could form the baseline for further population monitoring. As in Prince William Sound, the survey would be concentrated in the glaciated fjords.

One final issue that involves abundance and distribution needs to be discussed: disturbance. The ever-increasing amount of disturbance, coupled with the ever-decreasing population of Kittlitz's murrelets, in Blackstone Bay during the 3 yr of this study suggests that excessive disturbance is causing abandonment of this bay by Kittlitz's murrelets. Such disturbance is not going to go away. In fact, it is going to increase dramatically in the summer of 2000 with the opening of the Whittier road, which is going to flood the Sound (and particularly the glaciated fjords of the northwestern Sound) with tourists (including Alaskans). From what we have seen so far in these glaciated fjords, a great majority of this disturbance is concentrated in the nearshore zone, with a majority of that disturbance occurring in glacial-affected areas—habitats that are highly important to Kittlitz's murrelets for most aspects of their summer lives. Determining the effects of such disturbance on Kittlitz's murrelets will be mandatory for their adequate protection and management.

Habitat Use

The habitat studies also have yielded useful and interesting information, although we suggest no further emphasis on them in future surveys. The one exception would be for the involvement of standardized habitat analyses in those surveys involving other bays; such quantification would enable us to confirm that our classification system is useful across a broader area than just our study bays. We do, however, suggest the analysis of the existing data set for a comparative study of habitat use in Kittlitz's and marbled murrelets. Because the number of marbled murrelets in these four bays was so large that it swamped the number of Kittlitz's murrelets, we had to classify the plumage of and identify each *Brachyramphus* murrelet that we encountered. As a result, we have a large data set on marbled murrelets that has only been marginally examined. Analysis of this data set for comparing habitat use between these two species would result in the first quantitative description of comparative use and ecological overlap in these two species. Such information would provide information to wildlife managers for protecting these birds and possibly would provide insights for further research that would aid in the conservation of Kittlitz's murrelet.

Reproduction

The studies on reproduction performance have yielded sometimes confusing and contradictory information on most issues involving reproductive biology, primarily because of the poor reproductive performance seen in all years. It appears from the very limited data that this species may have only occasional years of good reproductive output. On the other hand, this species actually may be having trouble producing young in northern Prince William Sound as a whole, for some unknown reason. Consequently, we conclude that there simply is not enough information to determine what reproductive strategy is employed by this species and whether the lack of production is cause for alarm. Although long-term reproductive failure should result in overall population decline through simple attrition of old adults, our population data suggest that no dramatic population decline is occurring overall in our four study bays. On the other hand, the apparent pairing of some Kittlitz's murrelets with marbled murrelets suggests that overall 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.

Such incomplete conclusions about reproduction in this species suggest that additional research is necessary. This research would involve 2–3 consecutive years of extensive (45 day) surveys of productivity during the period 15 July–30 August to see whether any young are produced over this longer period than we were able to sample in this study. Although we believe that young would fledge primarily from mid-July through early–mid-August, it is possible that a few fledge later than we previously have been able to sample. The one problem with such a sampling strategy is that it gives one no information on reproductive effort (i.e., the number of AHY birds in early summer, as Kuletz and Kendall [1998] have suggested is important). However, determining whether and how often large numbers of young are produced is more important than measuring overall reproductive effort in discerning whether this species is in trouble reproductively.

Another approach to examining reproductive effort would be to use large-scale mist nets to capture large numbers of Kittlitz's murrelets alive, to examine them for evidence of reproduction. Given the great plumage variation in this species, however, a museum-based study of plumages should be conducted before such an attempt to catch birds alive (if it actually is possible, given the problems that we experienced) is made. If birds can be caught alive, they also could be fitted with radio transmitters and followed to nests—if they actually are nesting.

Feeding

The feeding studies indicated that feeding in this species is concentrated in shallow water, particularly that water near glaciers. They also indicated that there is extensive overlap in the feeding ecology of Kittlitz's and marbled murrelets in these study bays, suggesting the possibility of competition for food at some times. Unfortunately, because no other studies have been conducted in these glaciated fjords, we know nothing about the availability, distribution, and timing of availability of prey to Kittlitz's (and marbled) murrelets. Given the preference of Kittlitz's murrelets for foraging in glacial-affected and glacial-stream-affected habitats, and given the imminent increase in boat-related disturbance with the opening of the Whittier road, protecting such habitats from disturbance will be important in conserving this species. Further, studying the distribution, abundance, and availability of prey in the various habitats within these bays may provide insights into everything from habitat use to interannual variation in productivity. Such a study could be done with plankton nets and beach seines.

Investigating the possibility of competition for food between Kittlitz's and marbled murrelets will be a more difficult problem than simply measuring the availability of prey. It is one of those strange findings of ecology that it is difficult to detect competition—instead, one usually sees ecological isolation, which is designed to minimize competition. On the other hand, one usually is better off in determining how much overlap in resource use occurs, since those areas are the ones in which competition *could* occur. Given the substantial overlap in most aspects of feeding ecology that we saw in this study, it is probable that competition would occur if prey were limiting. Hence, we recommend additional research on the comparative feeding ecology of these two species in Prince William Sound, to measure ecological overlap more thoroughly than we did. This study should examine comparative food availability and distribution, prey taken and their sizes, relationships to habitat characteristics, and other aspects of feeding ecology.

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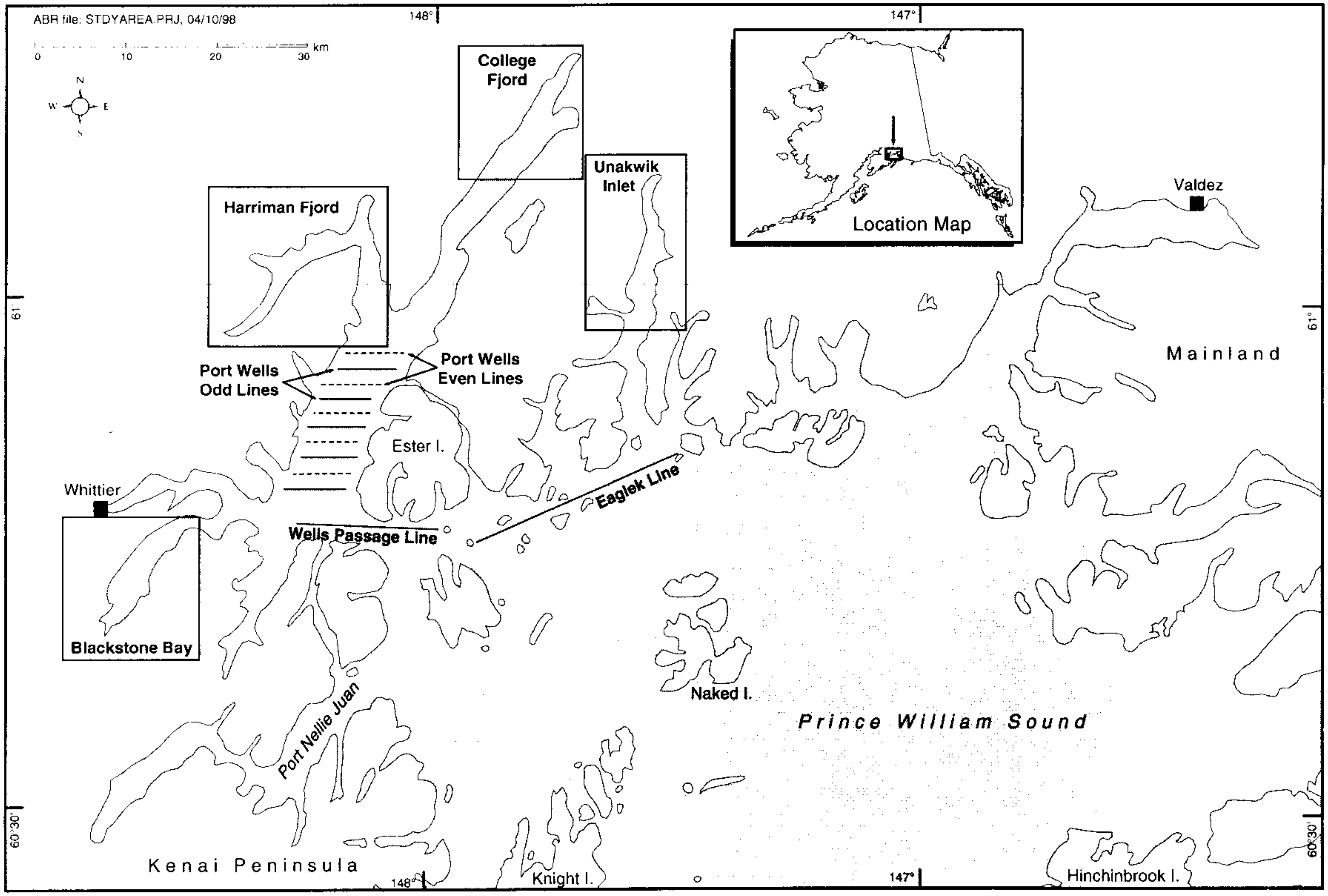

Fig. 1. Locations of study bays and pelagic survey lines sampled in Prince William Sound, Alaska, in 1996–1998.

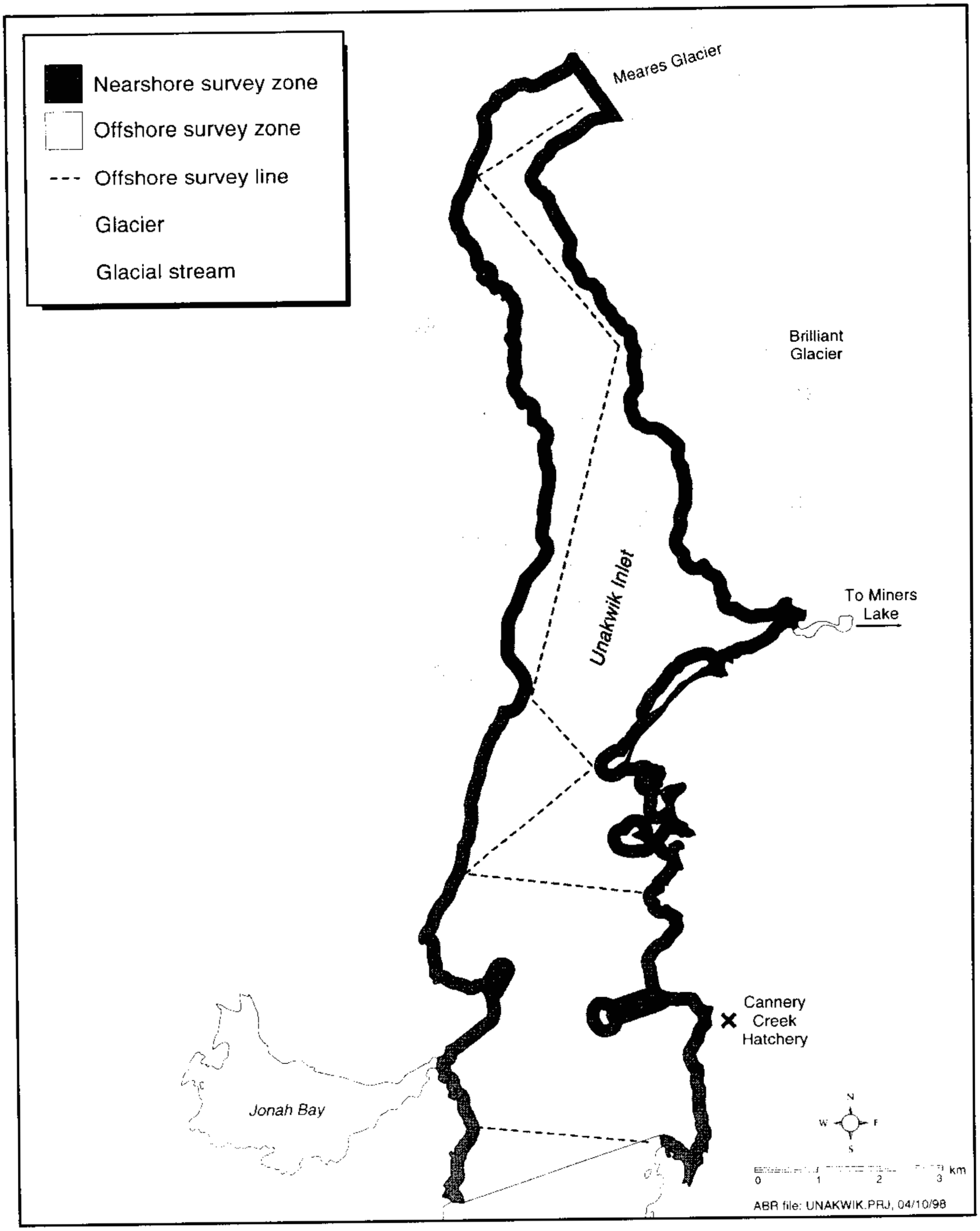

Fig. 2. Locations of nearshore and offshore survey segments and the extent of the offshore zone that was used to estimate the population size of Kittlitz's murrelets in Unakwik Inlet, Alaska, in 1996–1998.

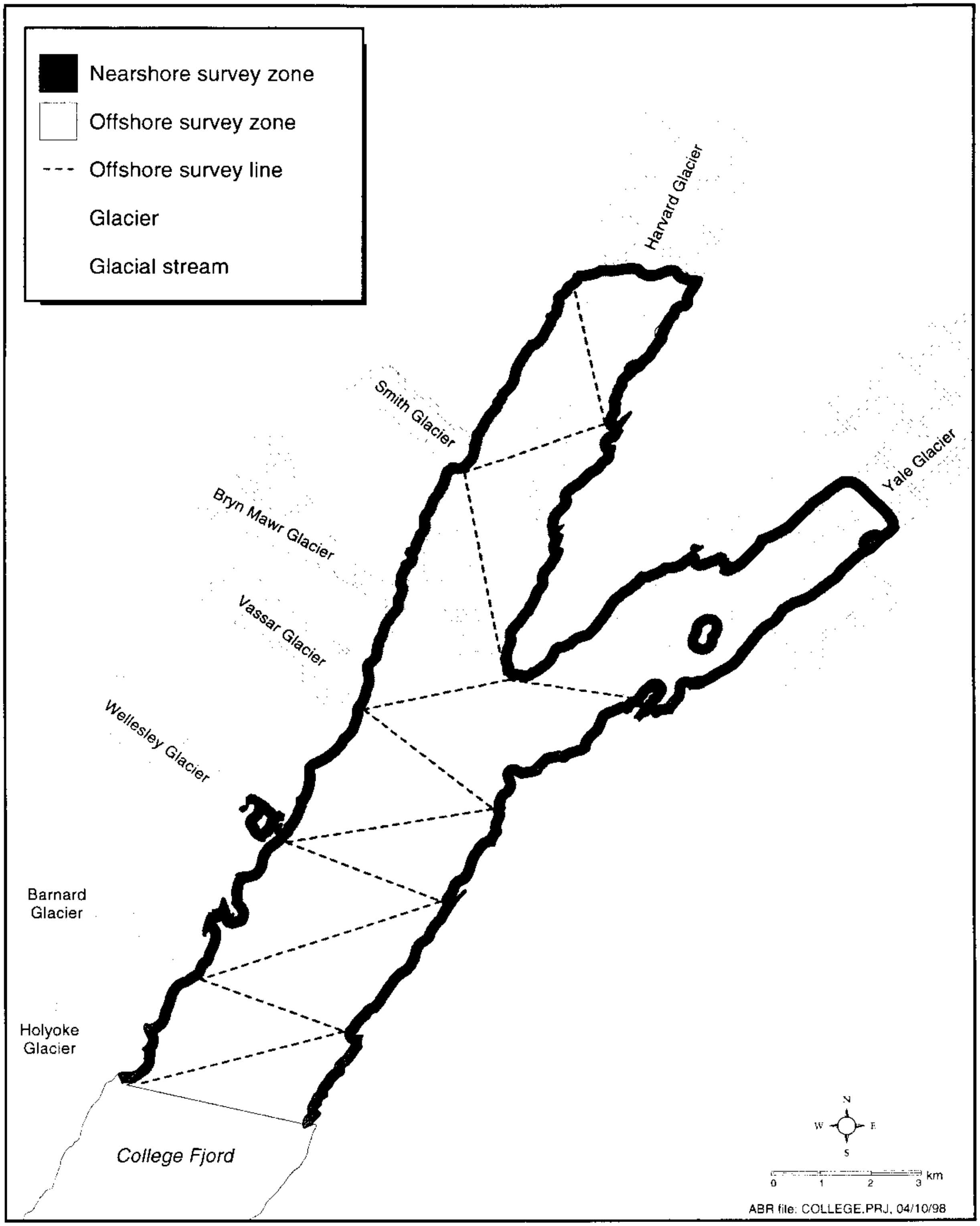

Fig. 3. Locations of nearshore and offshore survey segments and the extent of the offshore zone that was used to estimate the population size of Kittlitz's murrelets in College Fjord, Alaska, in 1996–1998.

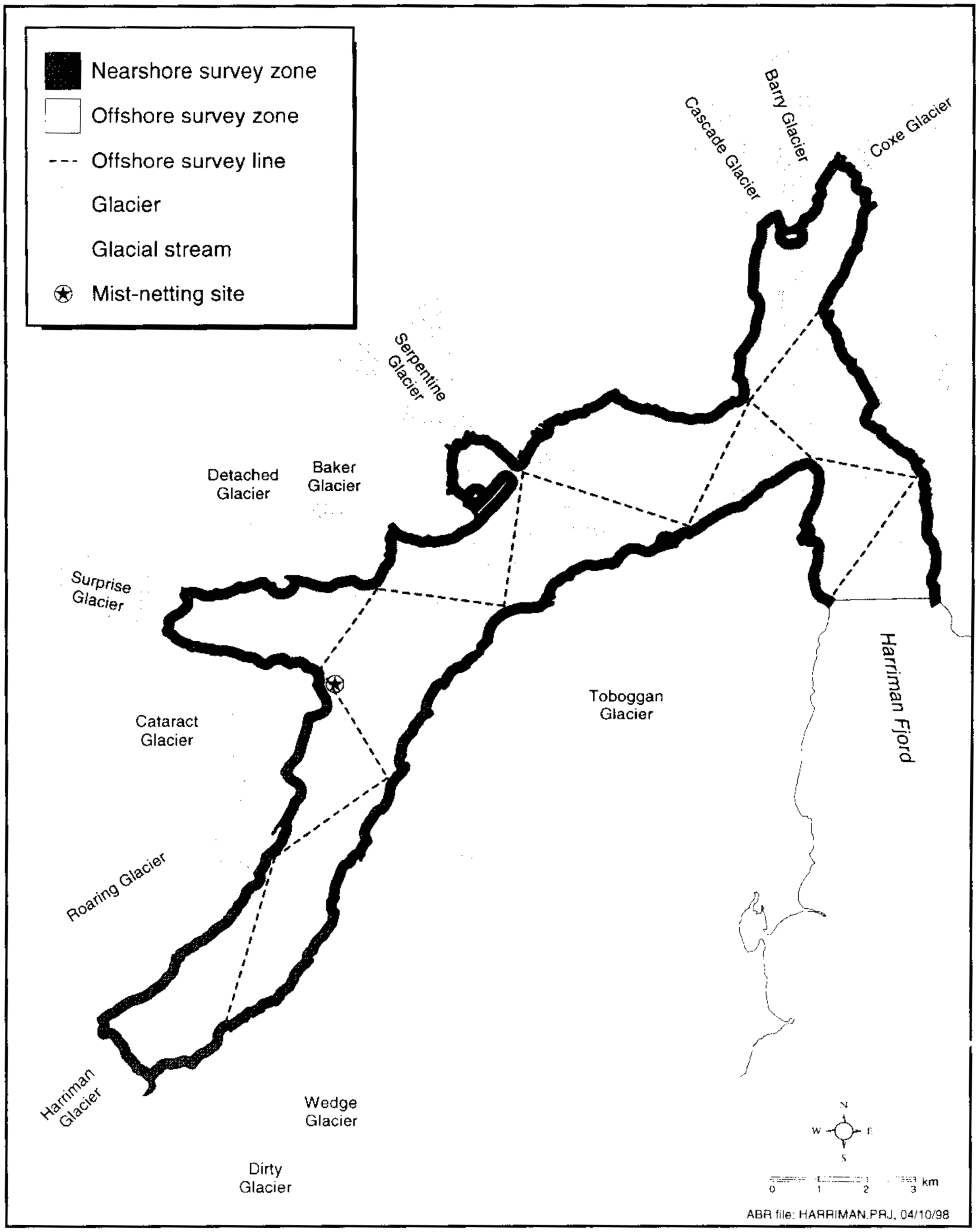

Fig. 4. Locations of nearshore and offshore survey segments and the extent of the offshore zone that was used to estimate the population size of Kittlitz's murrelets in Harriman Fjord, Alaska, in 1996–1998. The location of the mist-netting site in 1996 also is marked.

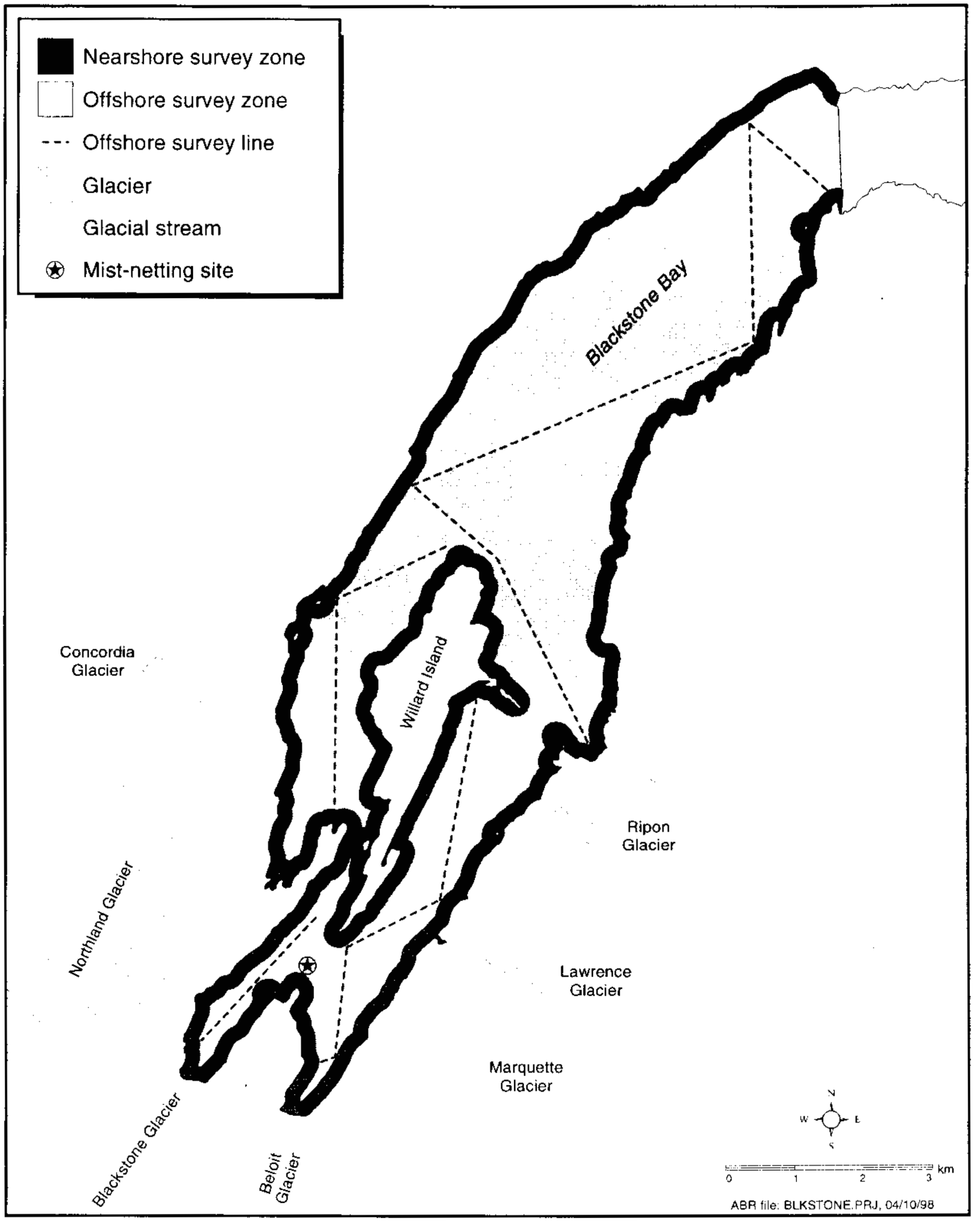

Fig. 5. Locations of nearshore and offshore survey segments and the extent of the offshore zone that was used to estimate the population size of Kittlitz's murrelets in Blackstone Bay, Alaska, in 1996–1998. The location of the mist-netting site in 1996 also is marked.

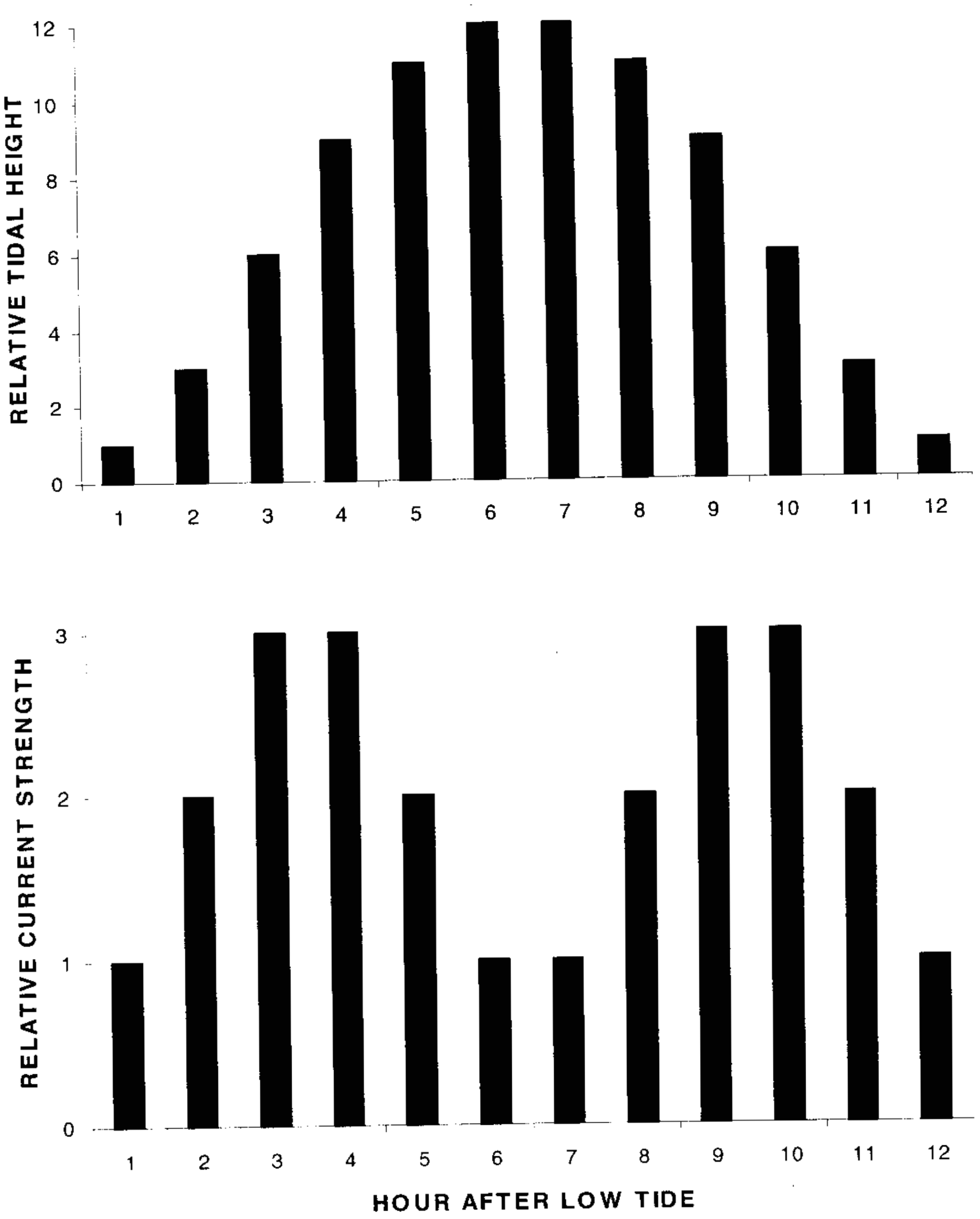

Fig. 6. Relative height of tide (top) and relative strength of tidal current (bottom) during one tidal cycle, by hour after low tide. Current strength is indicated by the hourly change in tidal height.

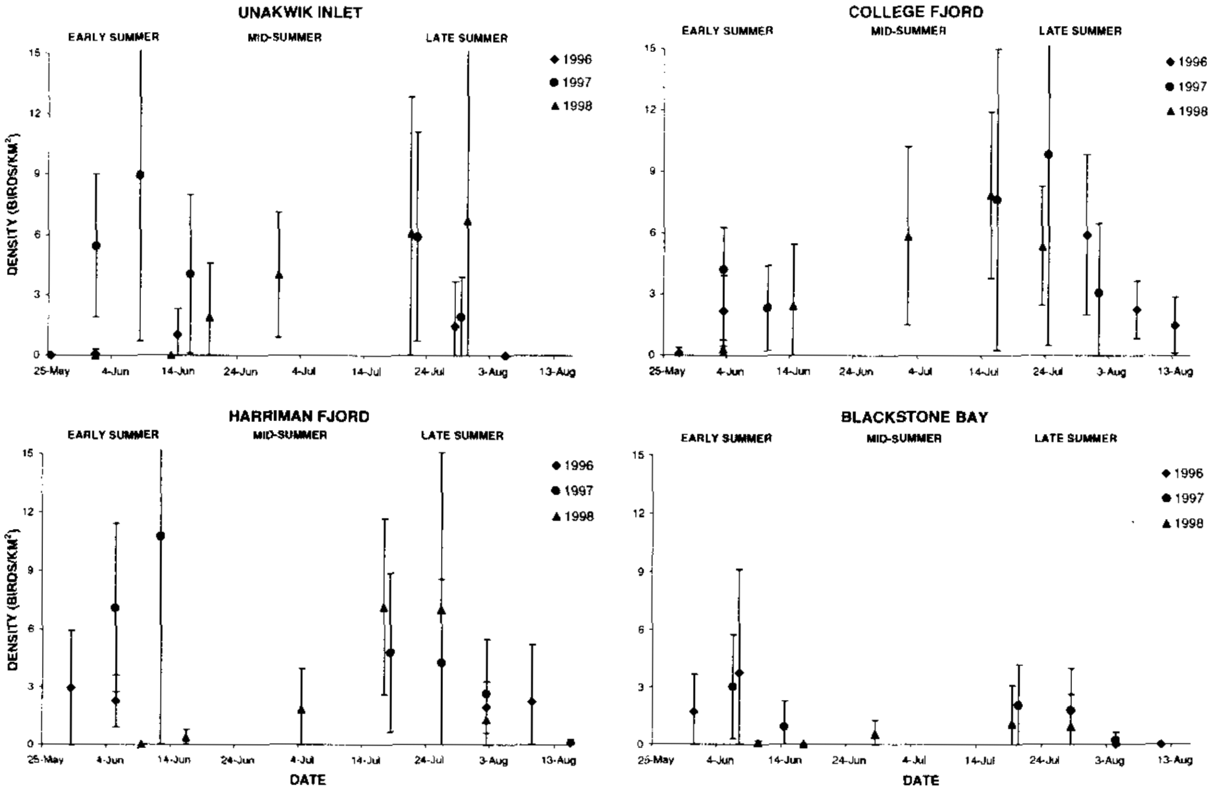

Fig. 7. Mean densities (birds/km^2) of Kittlitz's murrelets on nearshore surveys in four study bays in Prince William Sound, Alaska, in early, mid-, and late summer 1996–1998. Vertical bars represent 95% CIs; to improve ease of comparison of figures, the tops of some CIs have been cut off and vertical scales have been made identical among plots.

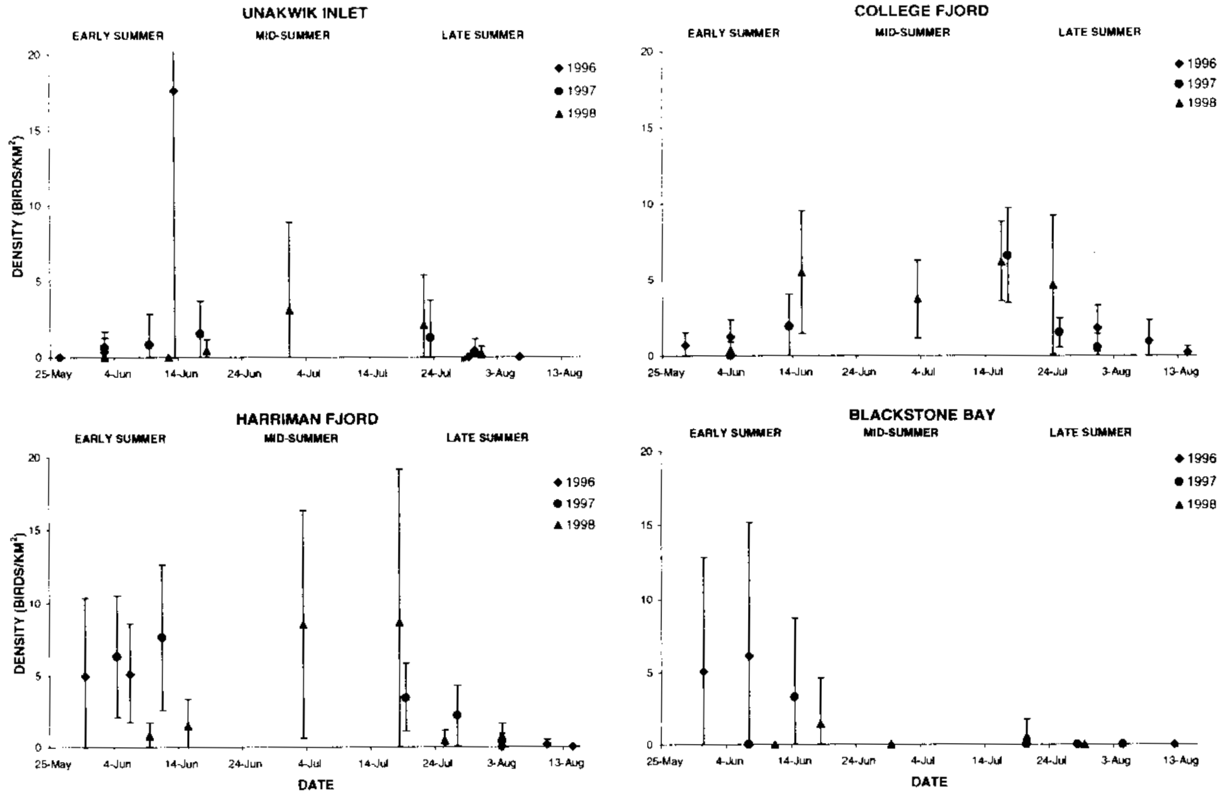

Fig. 8. Mean densities (birds/km^2) of Kittlitz's murrelets on offshore surveys in four study bays in Prince William Sound, Alaska, in early, mid-, and late summer 1996–1998. Vertical bars represent 95% CIs; to improve ease of comparison of figures, the tops of some CIs have been cut off and vertical scales have been made identical among plots.

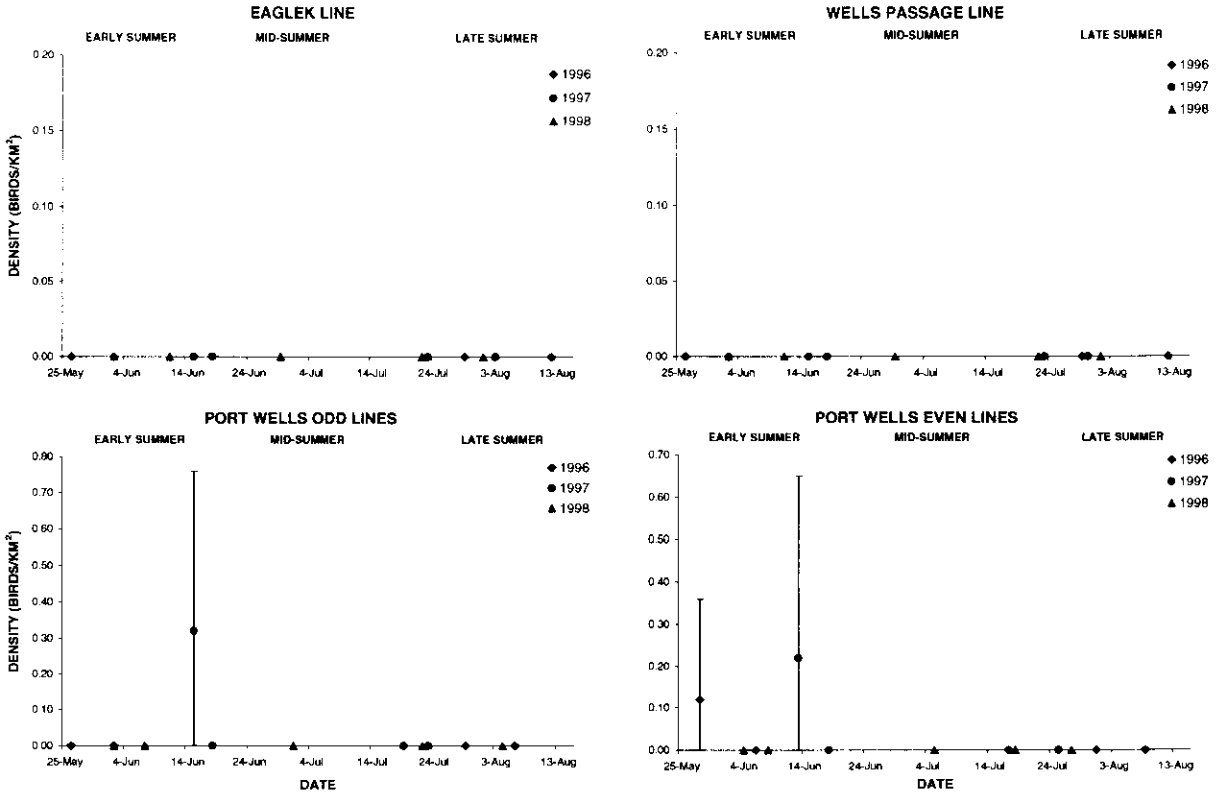

Fig. 9. Mean densities (birds/km^2) of Kittlitz's murrelets on pelagic surveys on four survey lines in Prince William Sound, Alaska, in early, mid-, and late summer 1996–1998. Vertical bars represent 95% CIs; vertical scales differ among plots.

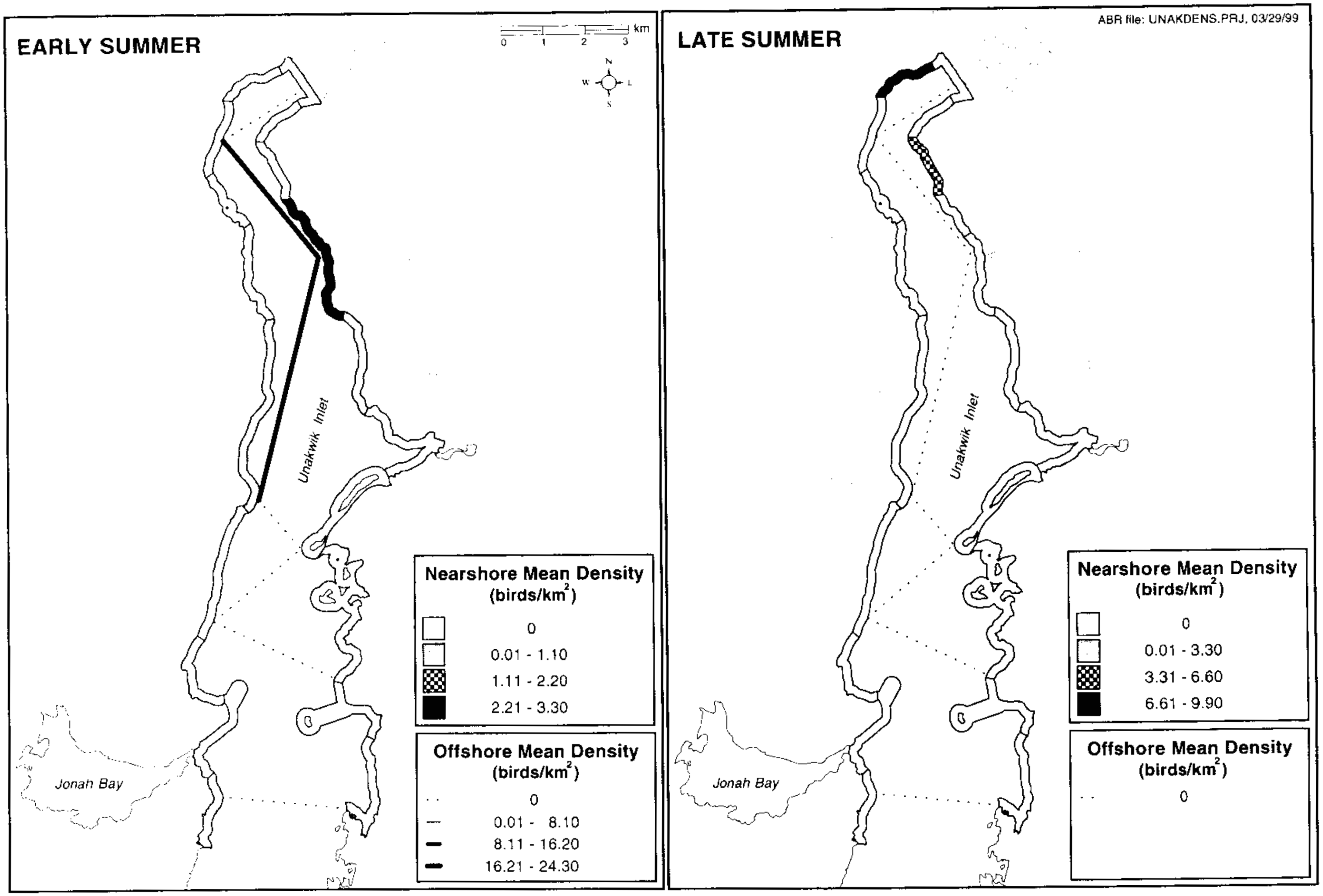

Fig. 10. Distribution and abundance of Kittlitz's murrelets on nearshore and offshore surveys in Unakwik Inlet in early (left) and late (right) summer 1996. Data are expressed as the mean density (birds/km^2) across all visits to each survey segment during a cruise. Density scales change between seasons and survey types.

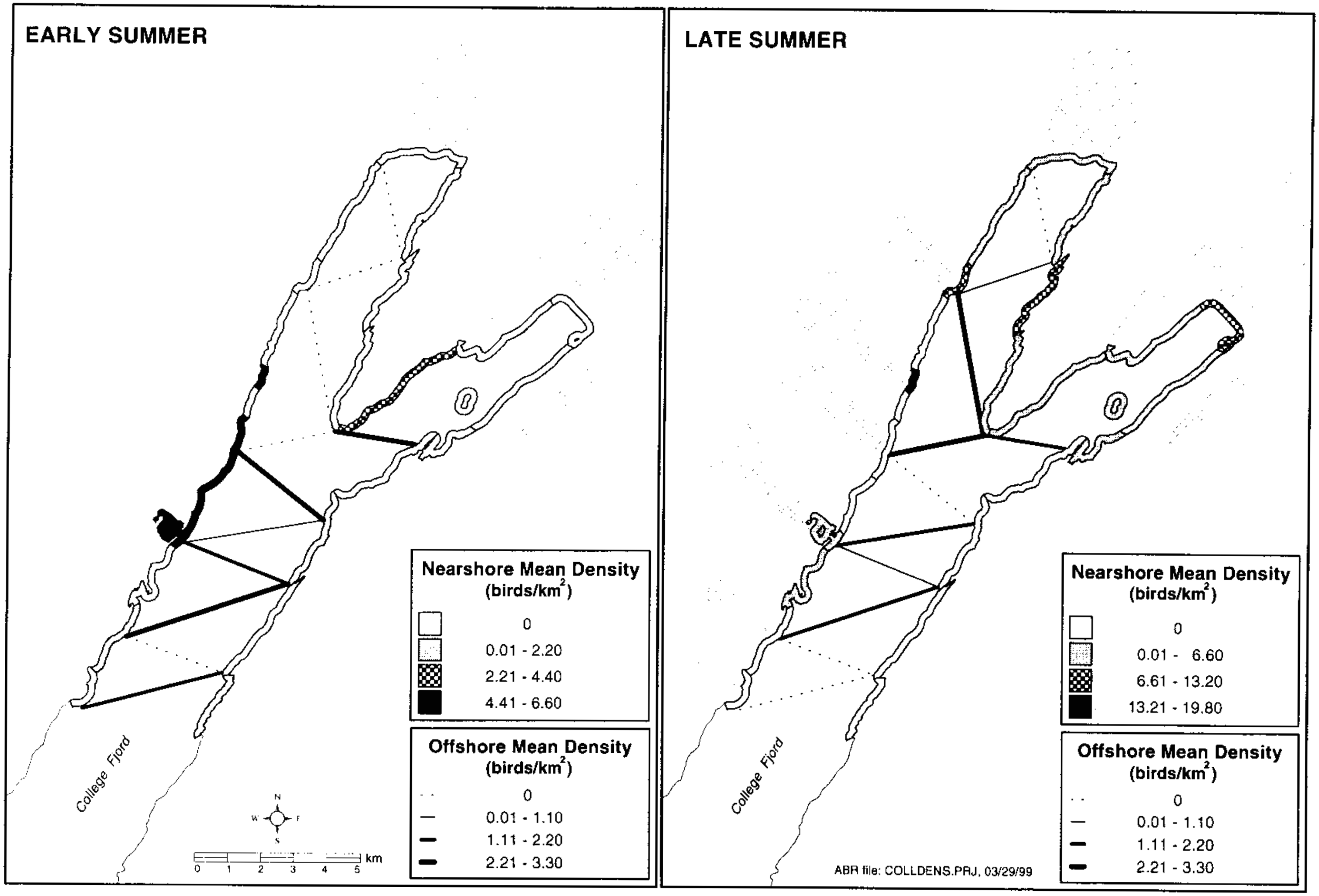

Fig. 11. Distribution and abundance of Kittlitz's murrelets on nearshore and offshore surveys in College Fjord in early (left) and late (right) summer 1996. Data are expressed as the mean density (birds/km^2) across all visits to each survey segment during a cruise. Density scales change between seasons and survey types.

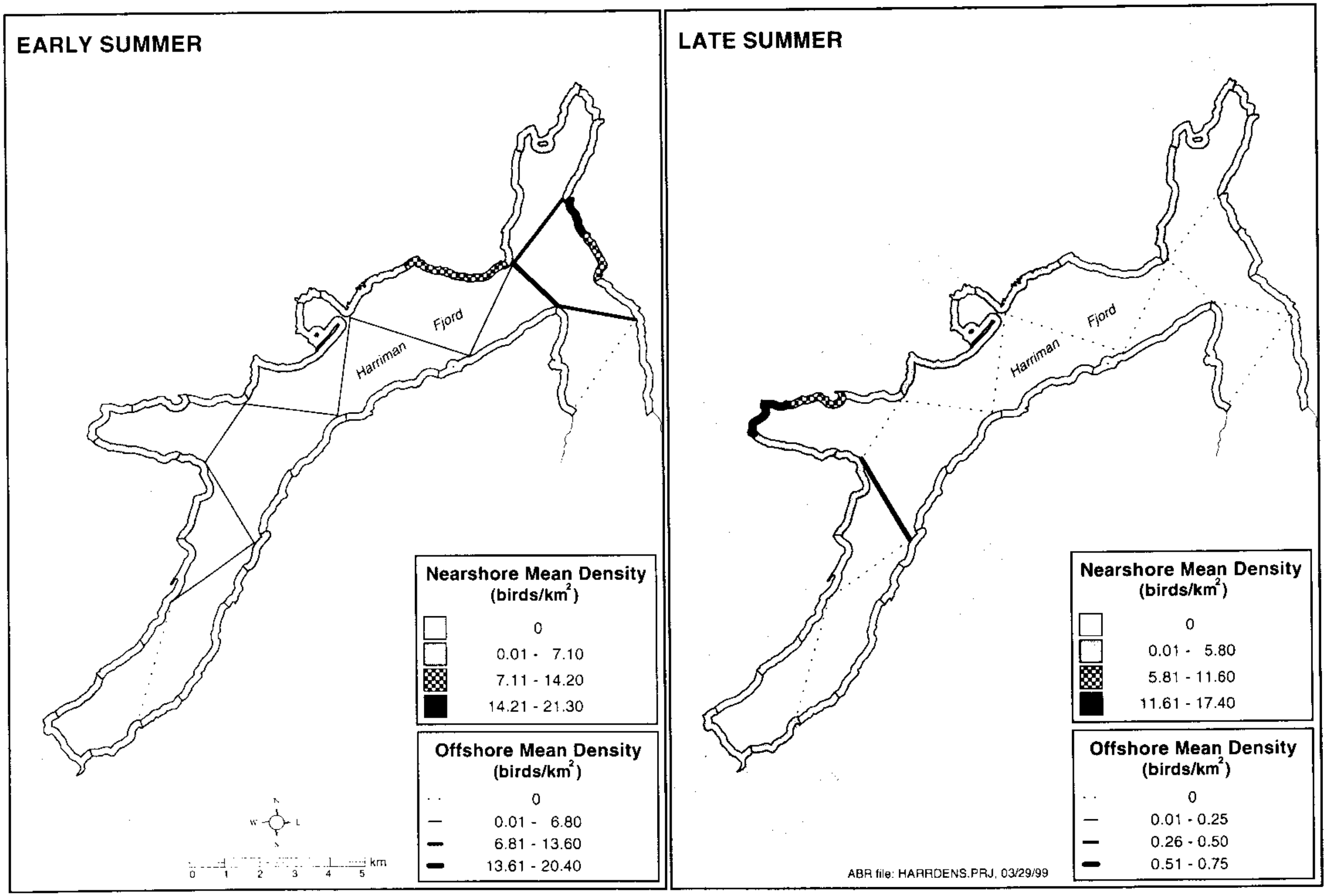

Fig. 12. Distribution and abundance of Kittlitz's murrelets on nearshore and offshore surveys in Harriman Fjord in early (left) and late (right) summer 1996. Data are expressed as the mean density (birds/km^2) across all visits to each survey segment during a cruise. Density scales change between seasons and survey types.

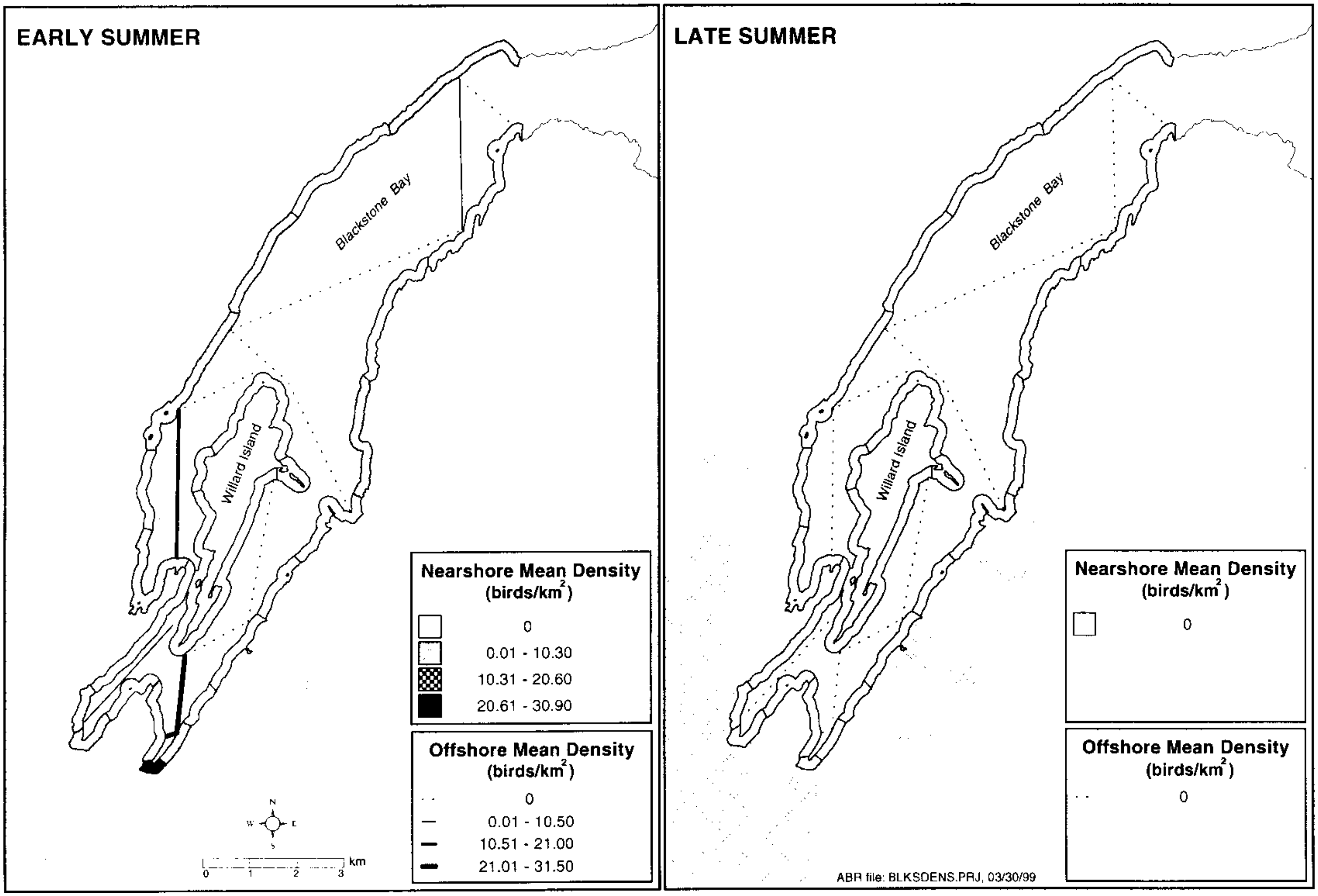

Fig. 13. Distribution and abundance of Kittlitz's murrelets on nearshore and offshore surveys in Blackstone Bay in early (left) and late (right) summer 1996. Data are expressed as the mean density (birds/km^2) across all visits to each survey segment during a cruise. Density scales change between seasons and survey types.

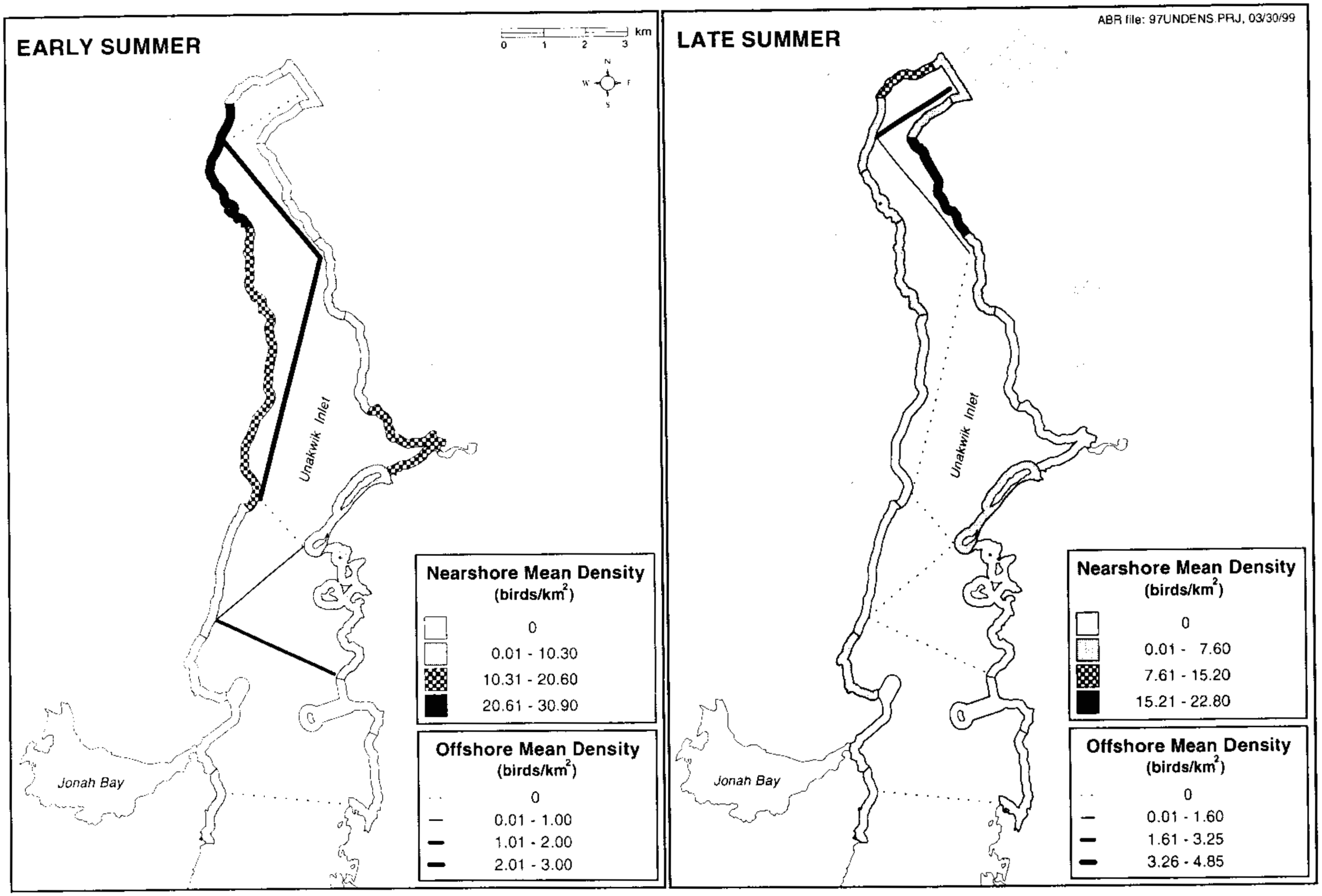

Fig. 14. Distribution and abundance of Kittlitz's murrelets on nearshore and offshore surveys in Unakwik Inlet in early (left) and late (right) summer 1997. Data are expressed as the mean density (birds/km^2) across all visits to each survey segment during a cruise. Density scales change between seasons and survey types.

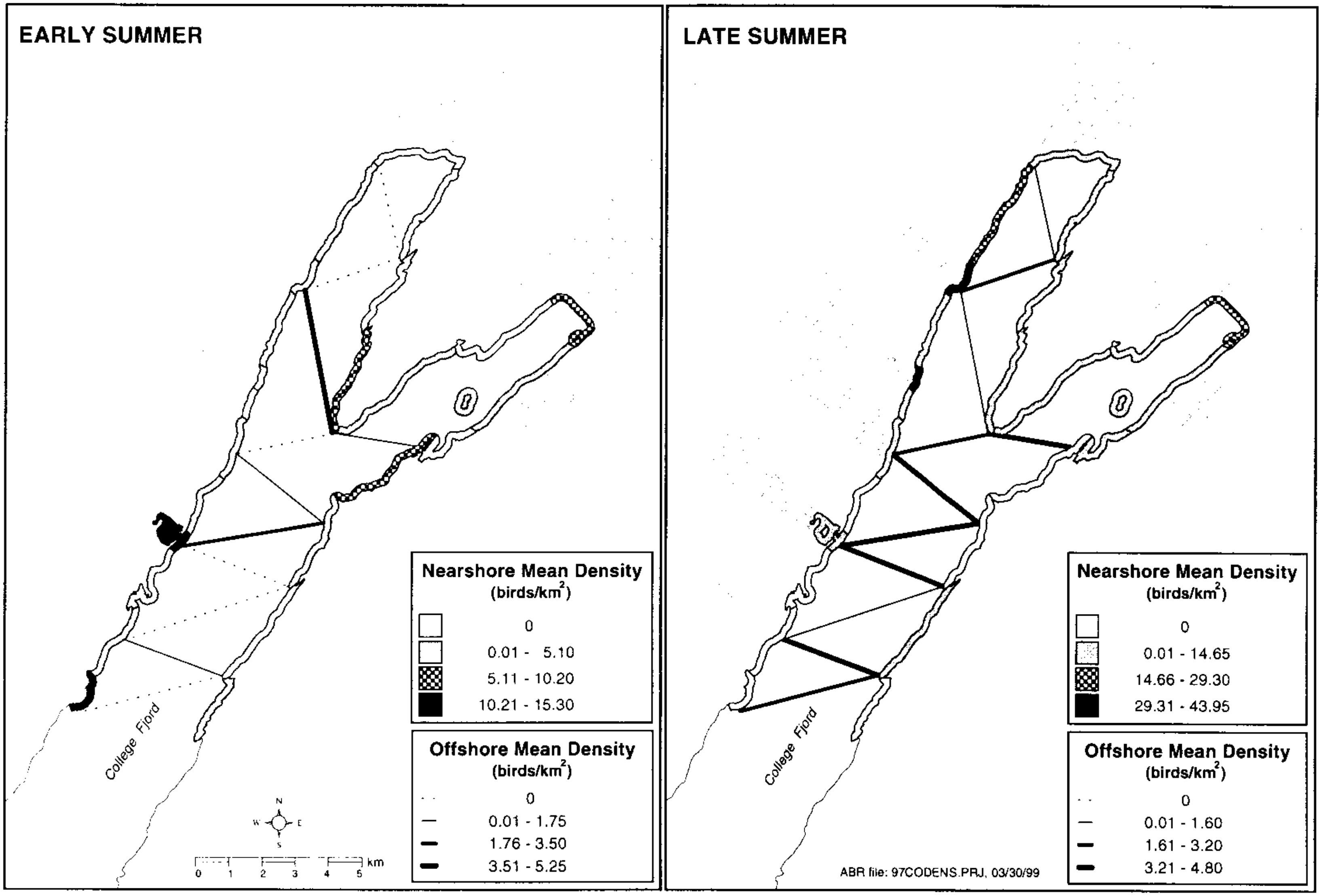

Fig. 15. Distribution and abundance of Kittlitz's murrelets on nearshore and offshore surveys in College Fjord in early (left) and late (right) summer 1997. Data are expressed as the mean density (birds/km^2) across all visits to each survey segment during a cruise. Density scales change between seasons and survey types.

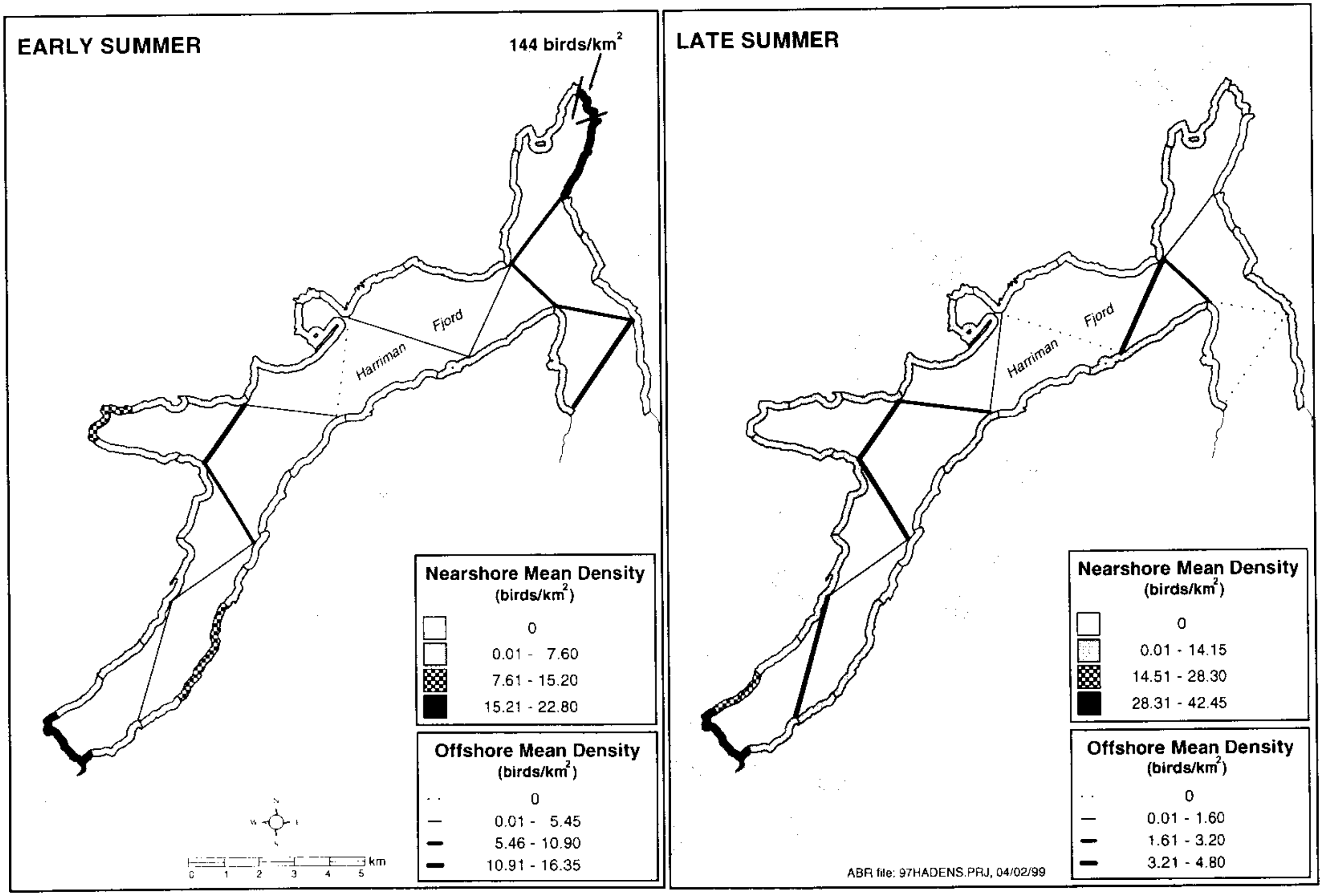

Fig. 16. Distribution and abundance of Kittlitz's murrelets on nearshore and offshore surveys in Harriman Fjord in early (left) and late (right) summer 1997. Data are expressed as the mean density (birds/km^2) across all visits to each survey segment during a cruise. One nearshore segment having an unusually high density in early summer is labeled directly, but the shading is the same as that for the largest density category. Density scales change between seasons and survey types.

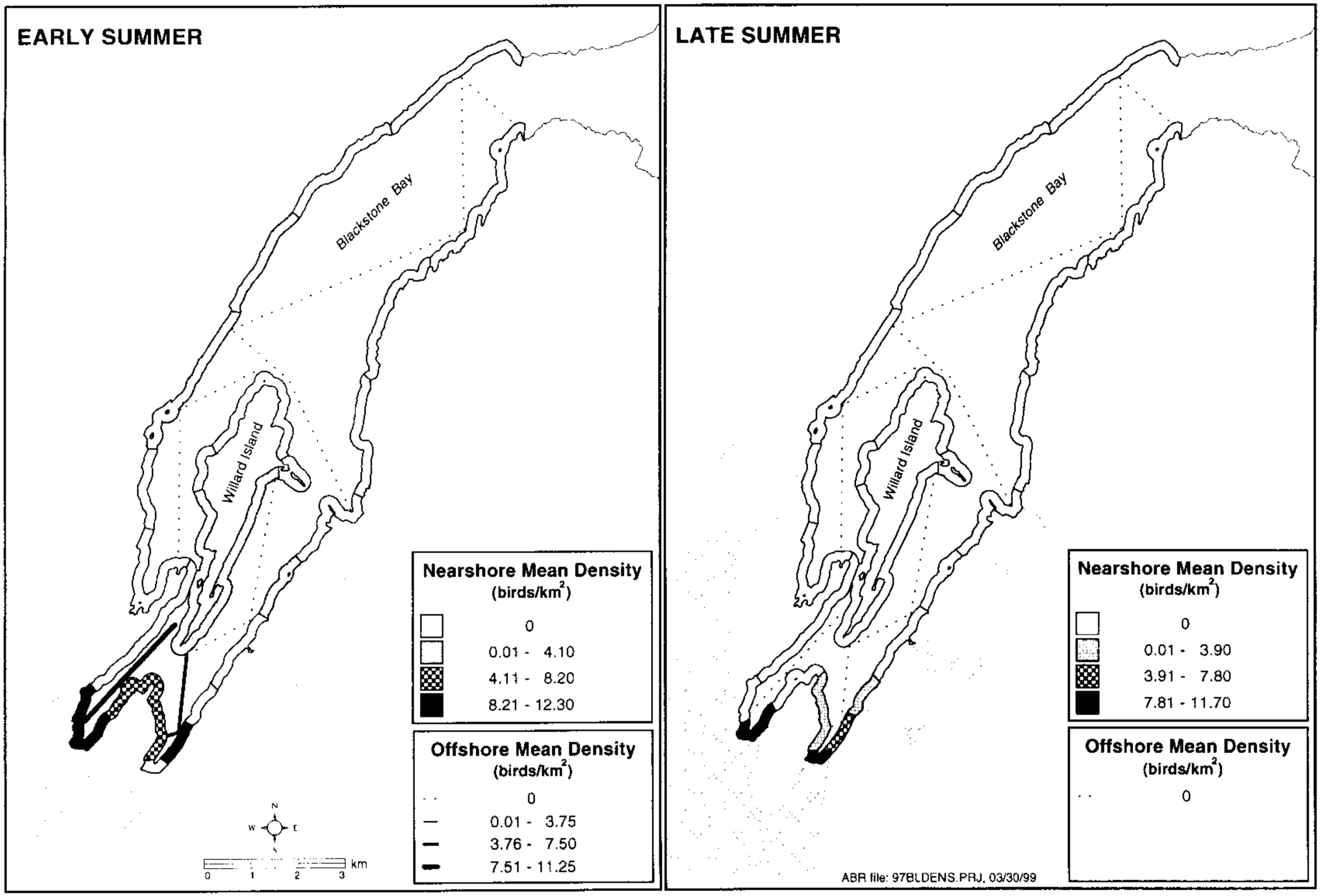

Fig. 17. Distribution and abundance of Kittlitz's murrelets on nearshore and offshore surveys in Blackstone Bay in early (left) and late (right) summer 1997. Data are expressed as the mean density (birds/km^2) across all visits to each survey segment during a cruise. Density scales change between seasons and survey types.

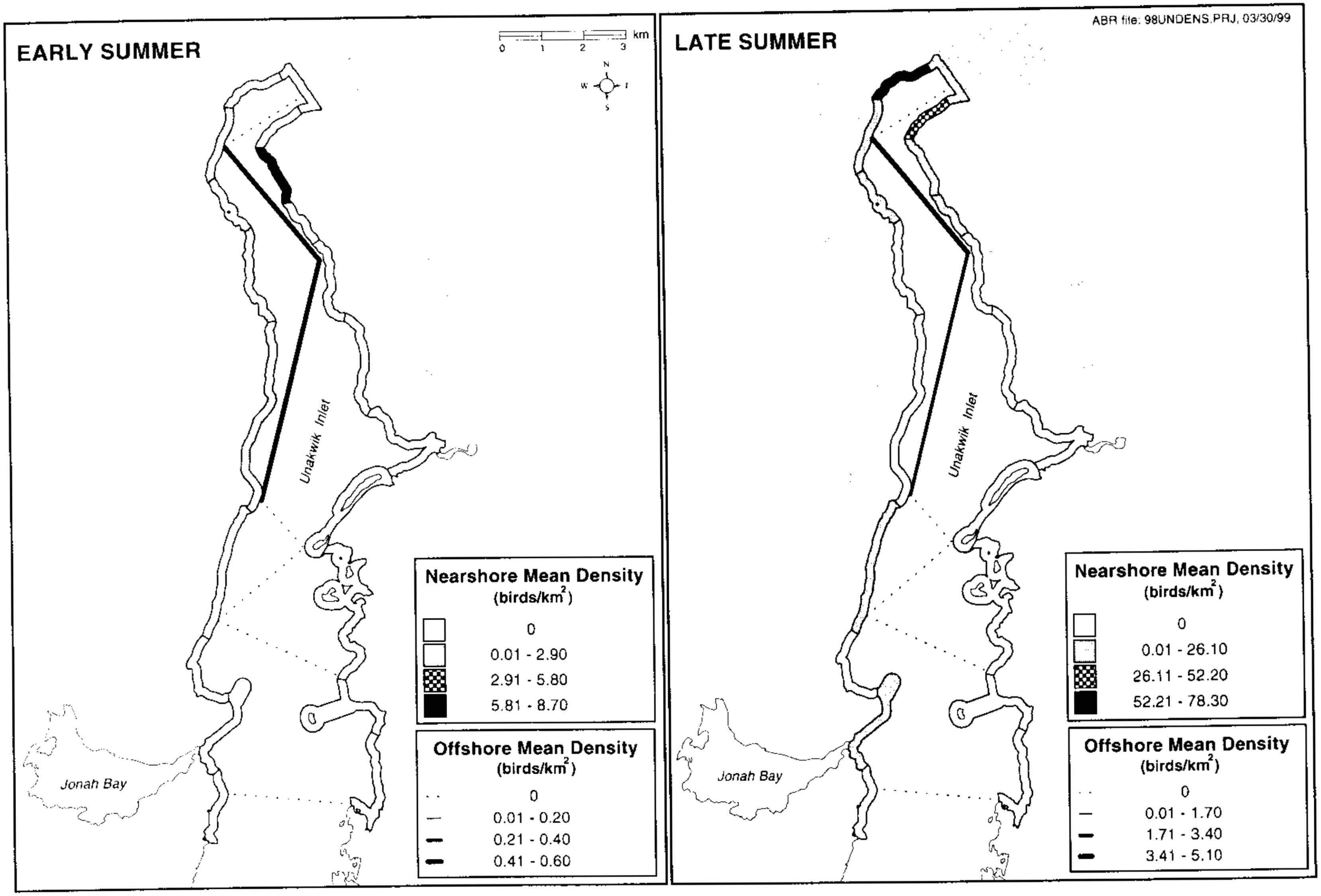

Fig. 18. Distribution and abundance of Kittlitz's murrelets on nearshore and offshore surveys in Unakwik Inlet in early (left) and late (right) summer 1998. Data are expressed as the mean density (birds/km^2) across all visits to each survey segment during a cruise. Density scales change between seasons and survey types.

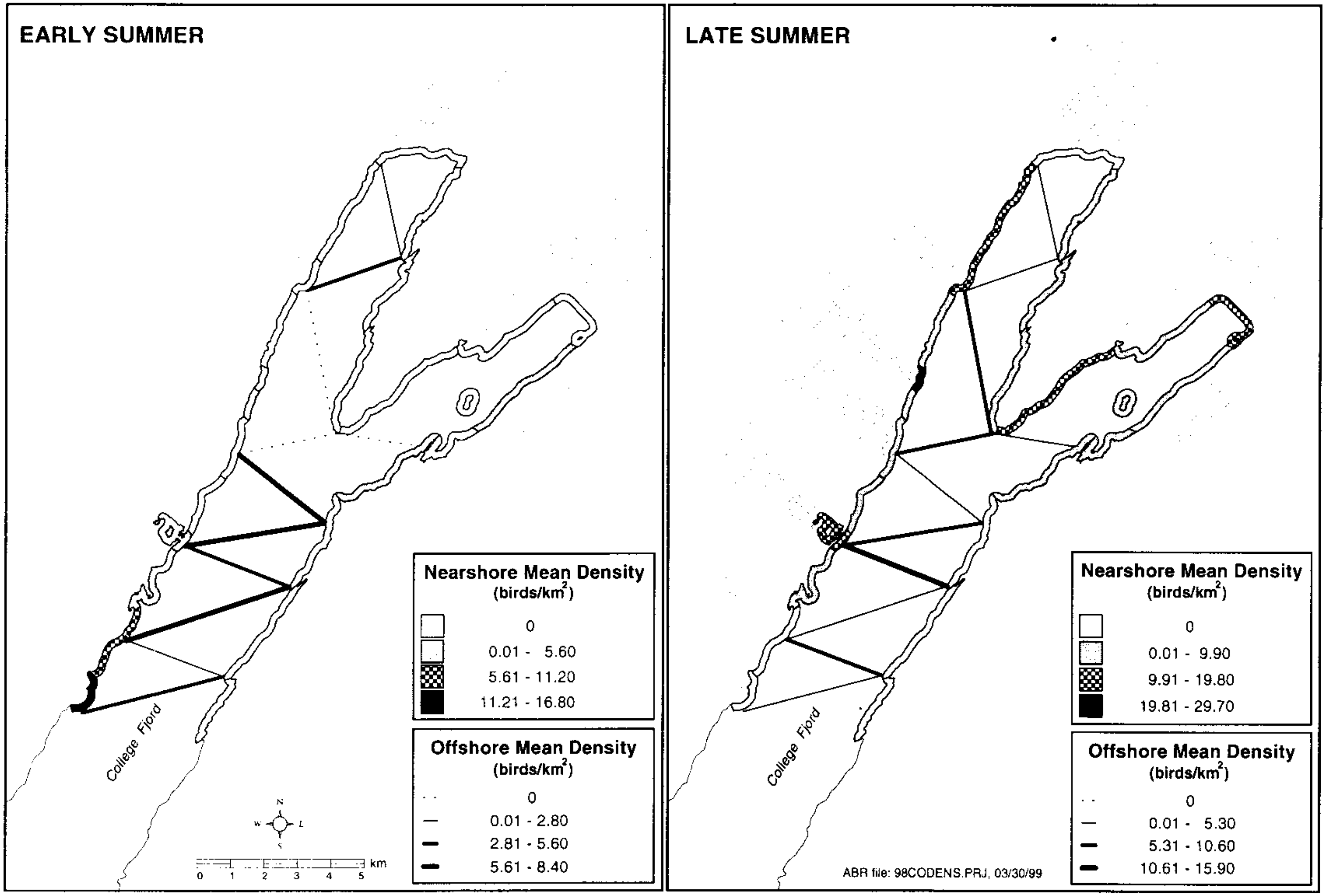

Fig. 19. Distribution and abundance of Kittlitz's murrelets on nearshore and offshore surveys in College Fjord in early (left) and late (right) summer 1998. Data are expressed as the mean density (birds/km^2) across all visits to each survey segment during a cruise. Density scales change between seasons and survey types.

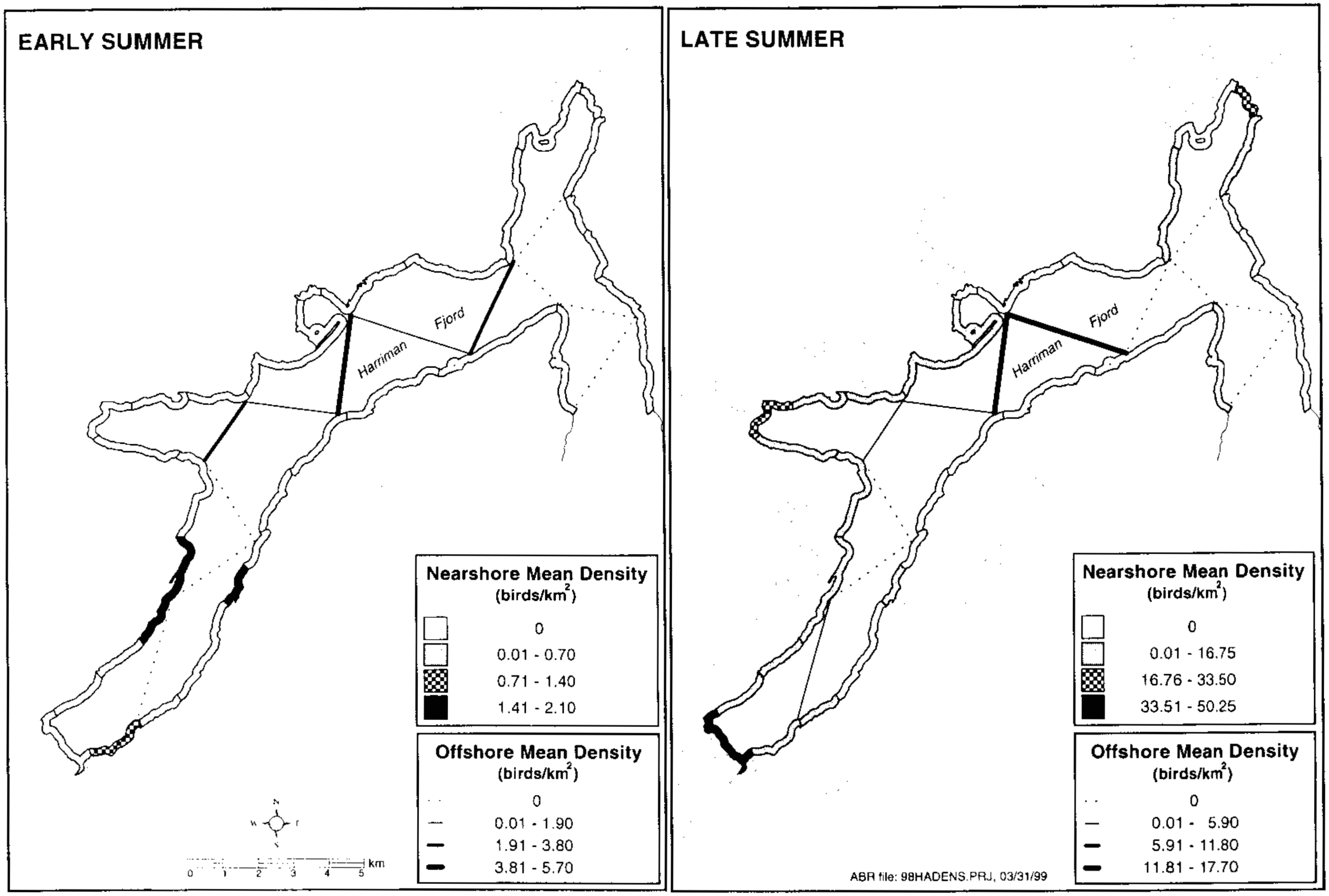

Fig. 20. Distribution and abundance of Kittlitz's murrelets on nearshore and offshore surveys in Harriman Fjord in early (left) and late (right) summer 1998. Data are expressed as the mean density (birds/km^2) across all visits to each survey segment during a cruise. Density scales change between seasons and survey types.

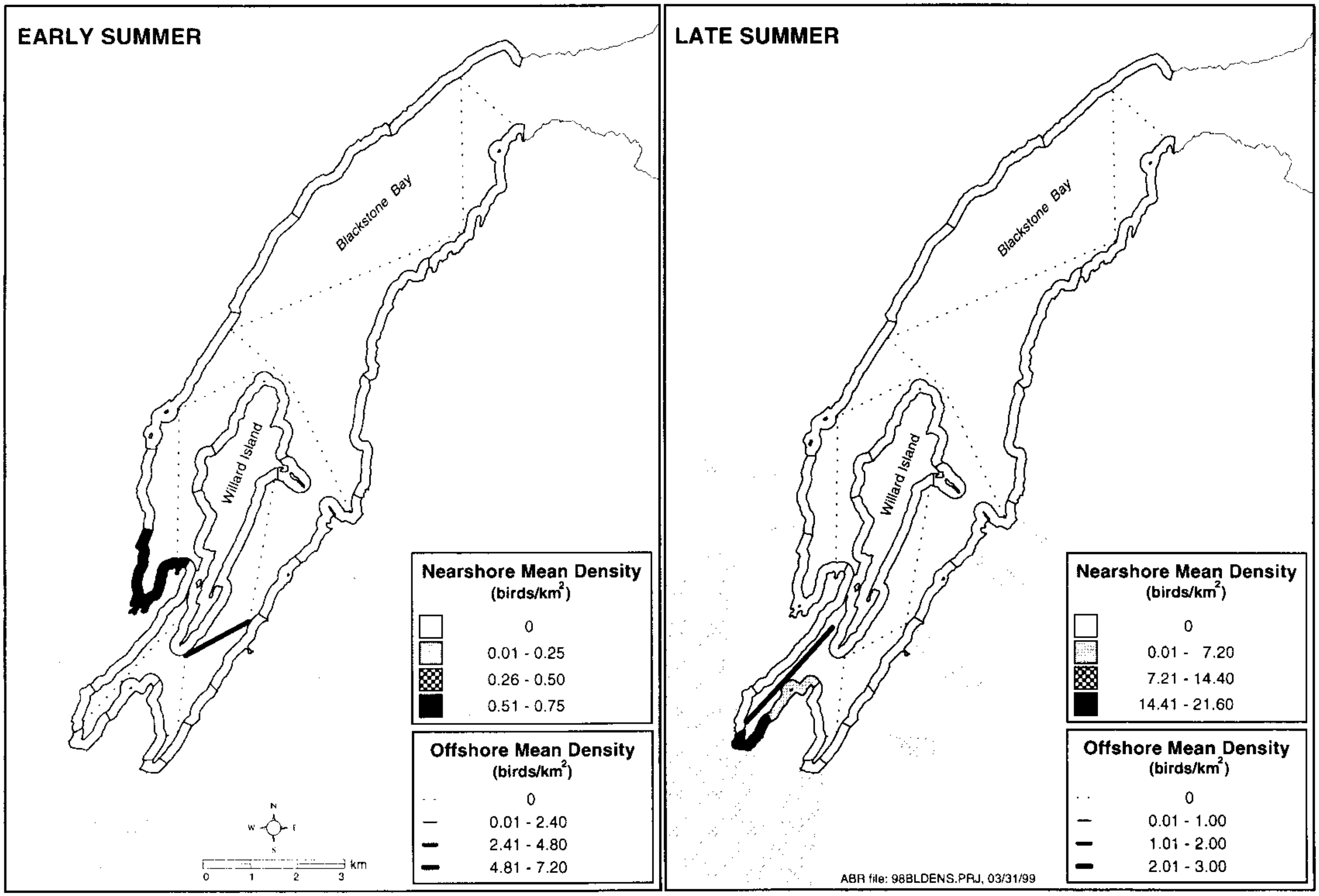

Fig. 21. Distribution and abundance of Kittlitz's murrelets on nearshore and offshore surveys in Blackstone Bay in early (left) and late (right) summer 1998. Data are expressed as the mean density (birds/km^2) across all visits to each survey segment during a cruise. Density scales change between seasons and survey types.

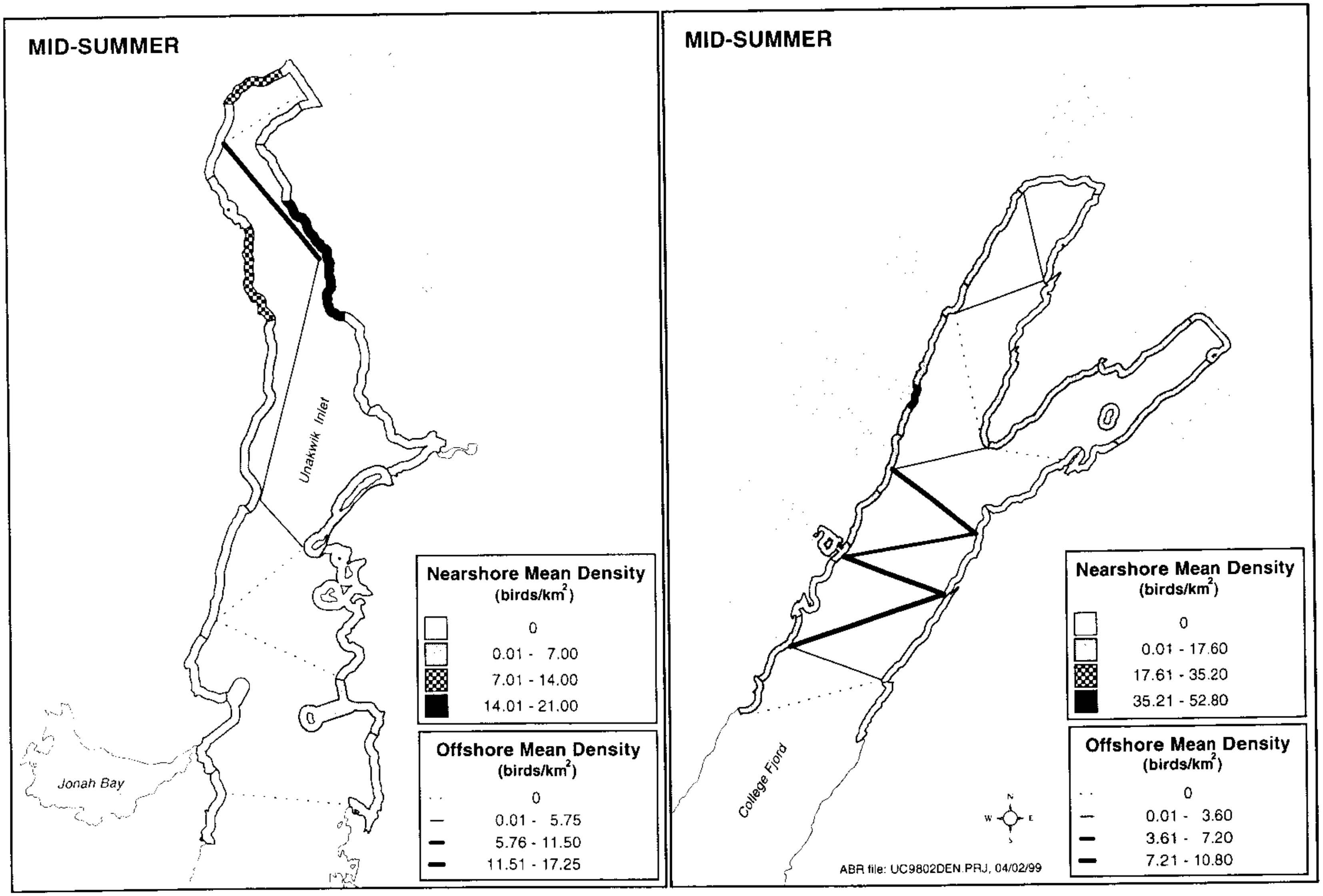

Fig. 22. Distribution and abundance of Kittlitz's murrelets on nearshore and offshore surveys in Unakwik Inlet (left) and College Fjord (right) in mid-summer 1998. Data are expressed as the mean density (birds/km^2) across all visits to each survey segment during a cruise. Density scales change between bays and survey types.

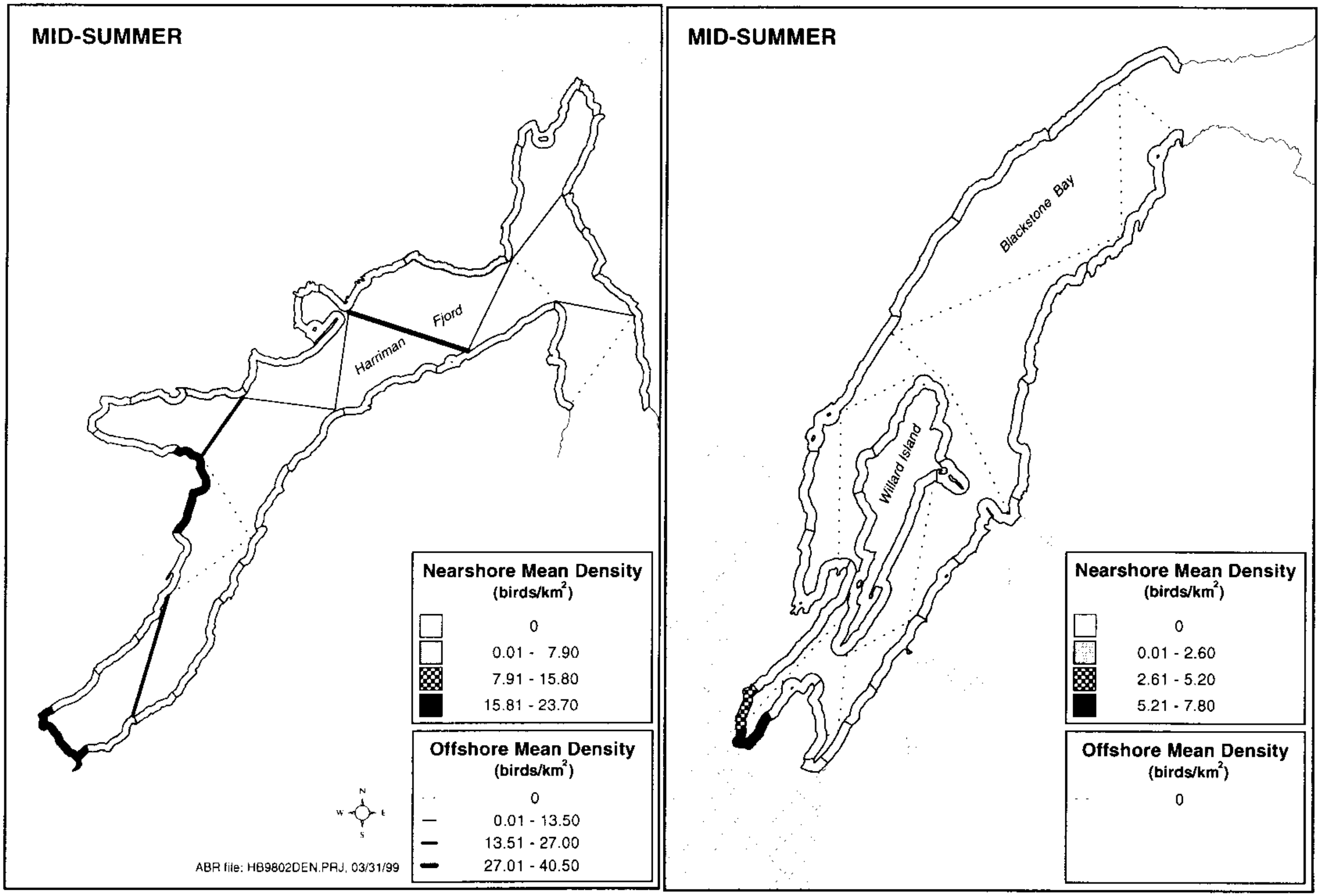

Fig. 23. Distribution and abundance of Kittlitz's murrelets on nearshore and offshore surveys in Harriman Fjord (left) and Blackstone Bay (right) in mid-summer 1998. Data are expressed as the mean density (birds/km^2) across all visits to each survey segment during a cruise. Density scales change between bays and survey types.

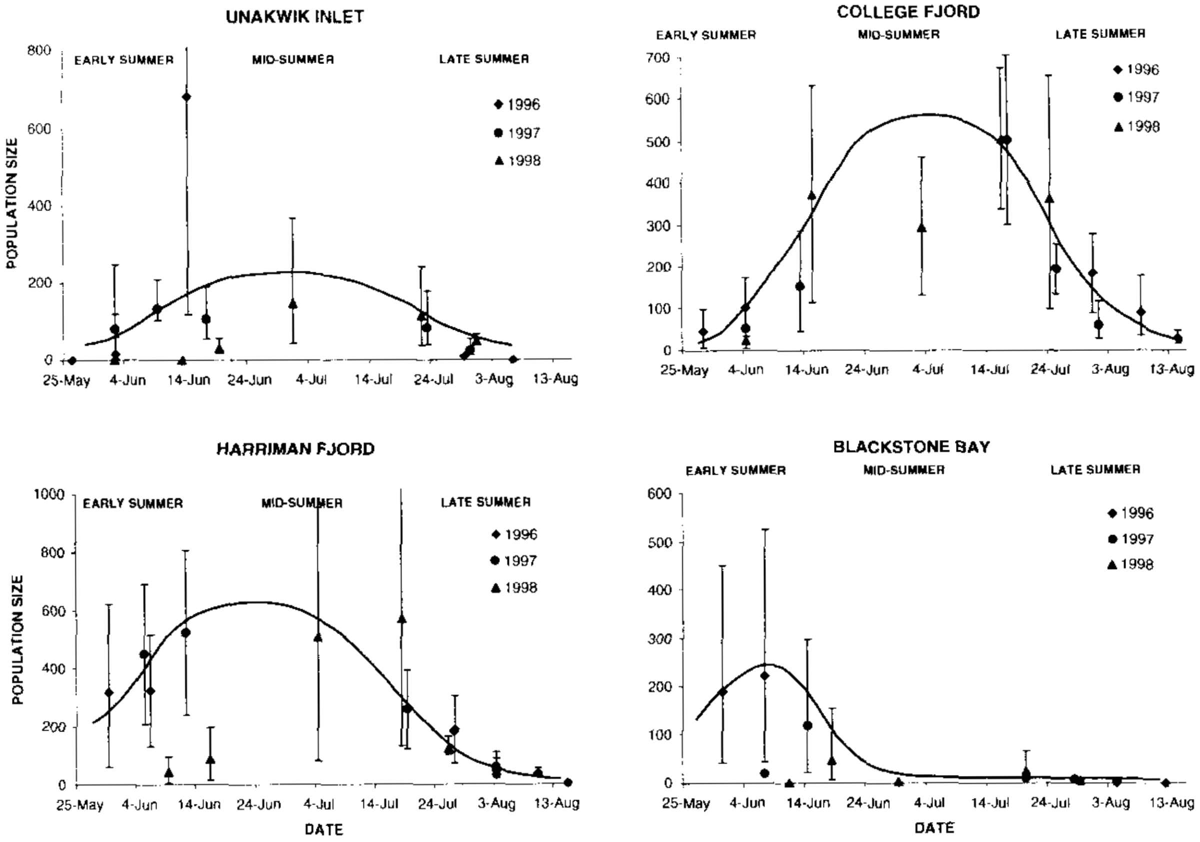

Fig. 24. Estimates of population size of Kittlitz's murrelets in four study bays in Prince William Sound, Alaska, in early, mid-, and late summer 1996–1998, by bay. Vertical bars represent 95% CIs; to improve clarity of figures, the tops of some CIs have been cut off and vertical scales differ among plots. Curves are fitted by hand.

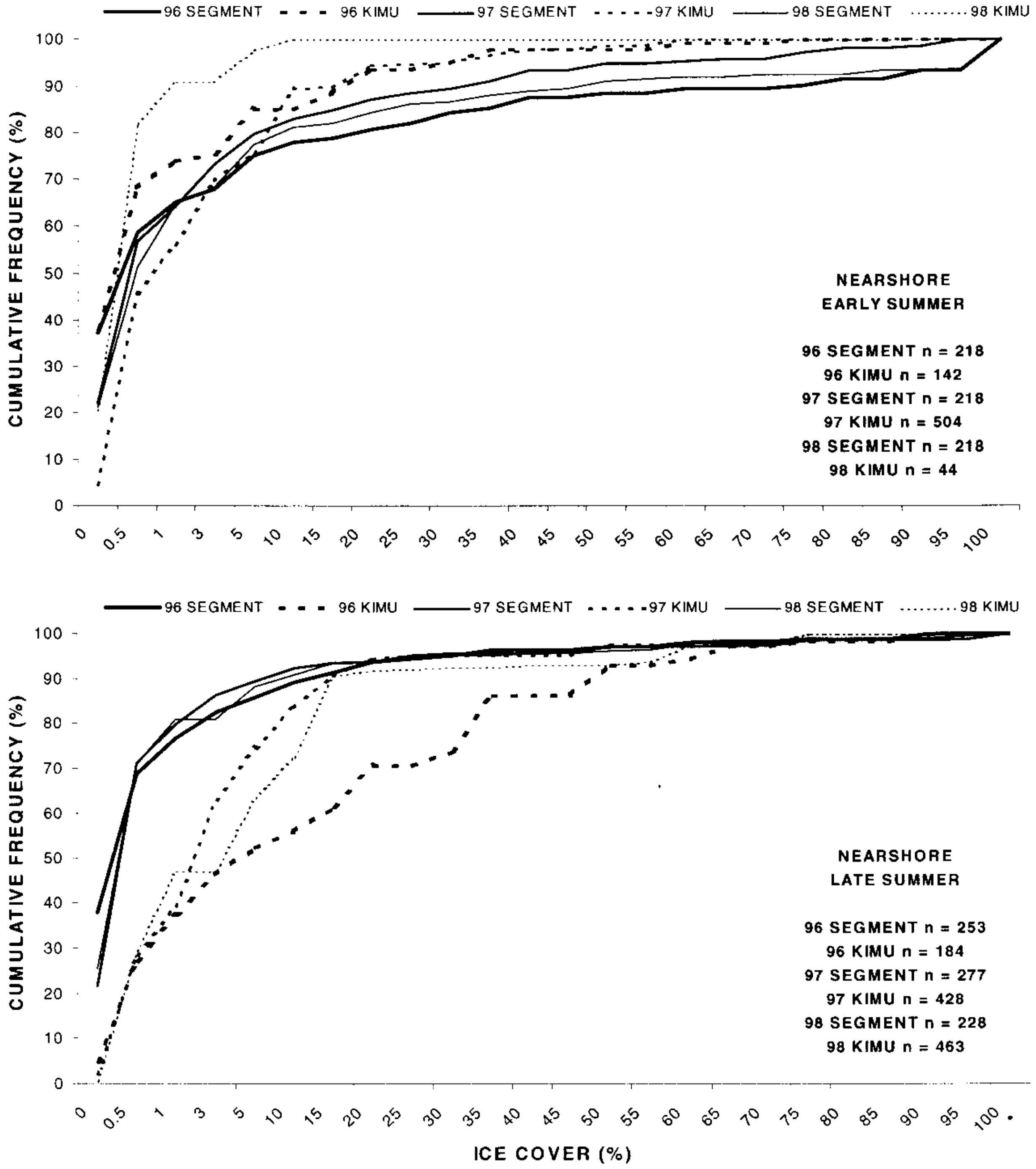

Fig. 25. Large-scale availability (SEGMENT) and use of ice by Kittlitz's murrelets (KIMU) on nearshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1996–1998. Scale is expanded at lower end of x-axis.

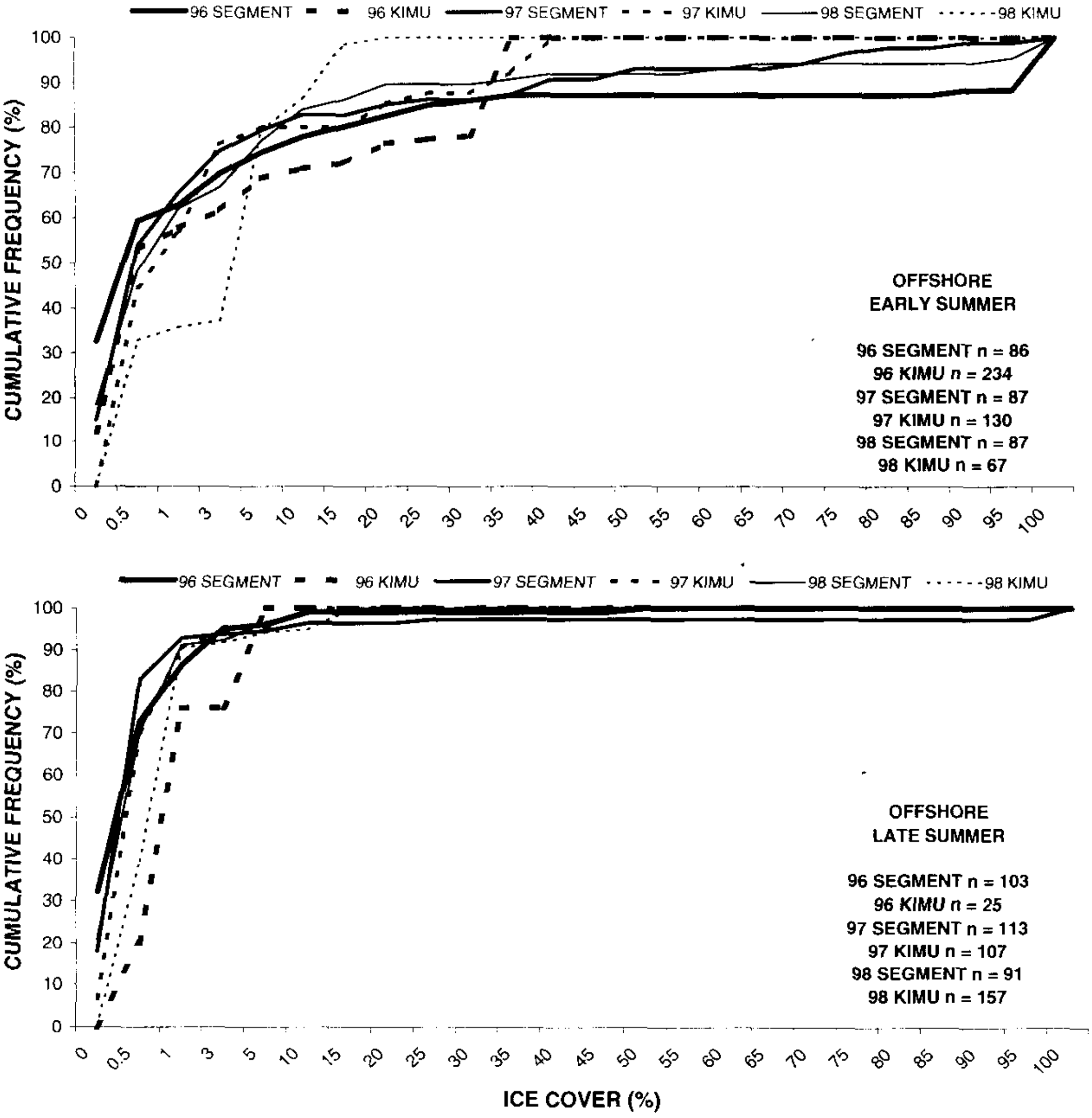

Fig. 26. Large-scale availability (SEGMENT) and use of ice by Kittlitz's murrelets (KIMU) on offshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1996–1998. Scale is expanded at lower end of x-axis.

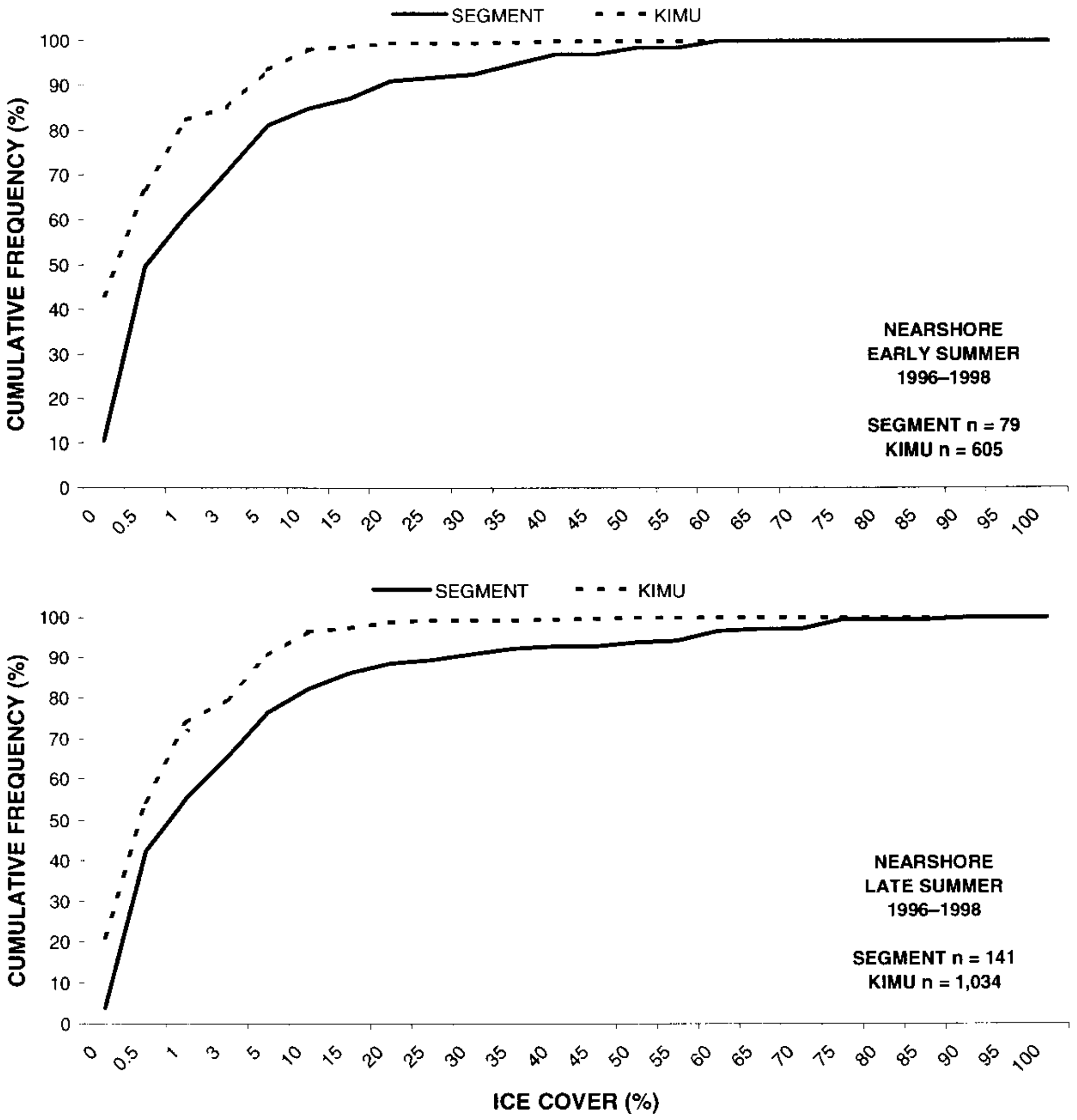

Fig. 27. Large-scale availability (SEGMENT) and fine-scale use of ice by Kittlitz's murrelets (KIMU) on nearshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1996–1998. Scale is expanded at lower end of x-axis.

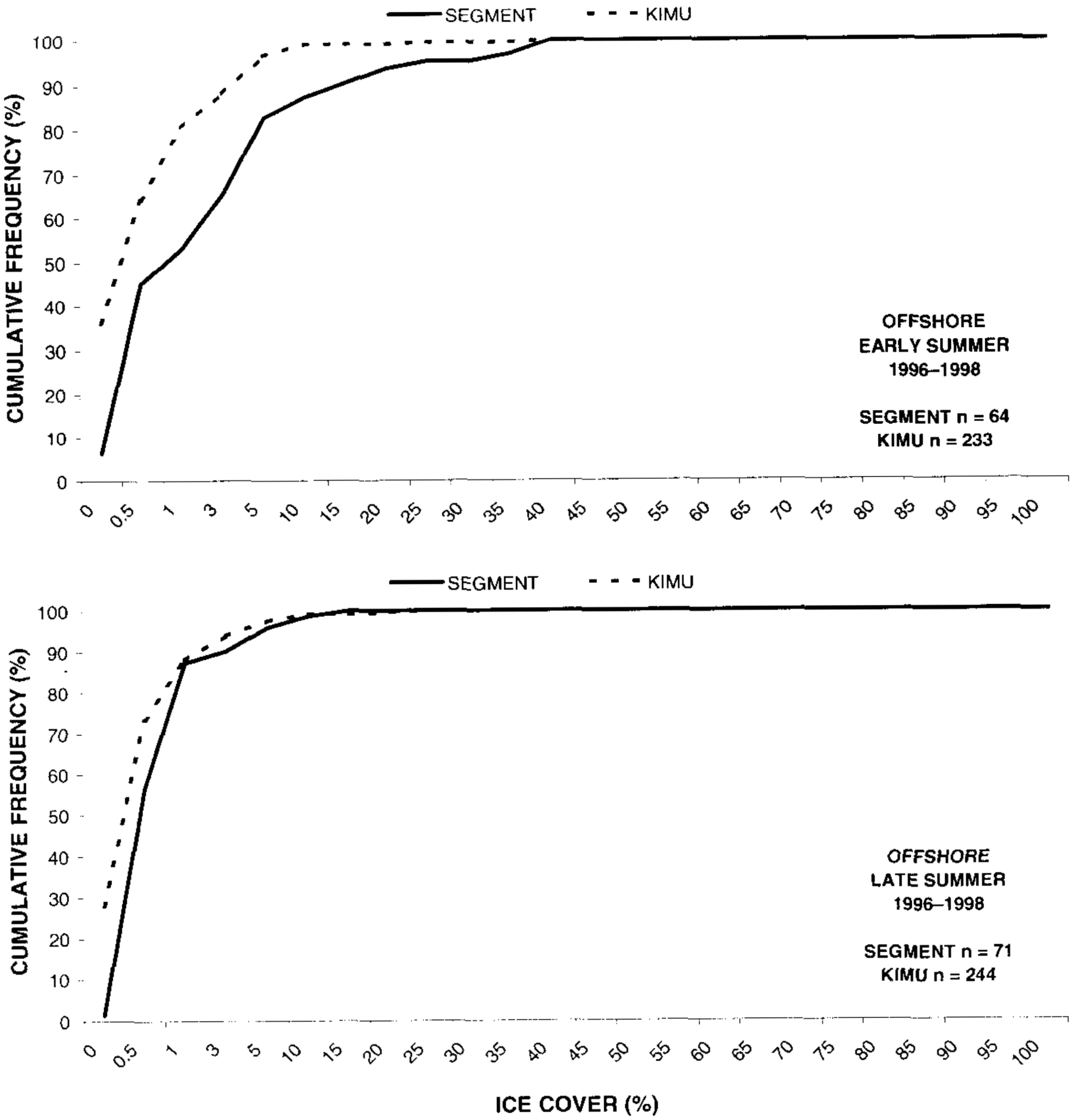

Fig. 28. Large-scale availability (SEGMENT) and fine-scale use of ice by Kittlitz's murrelets (KIMU) on offshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1996–1998. Scale is expanded at lower end of x-axis.

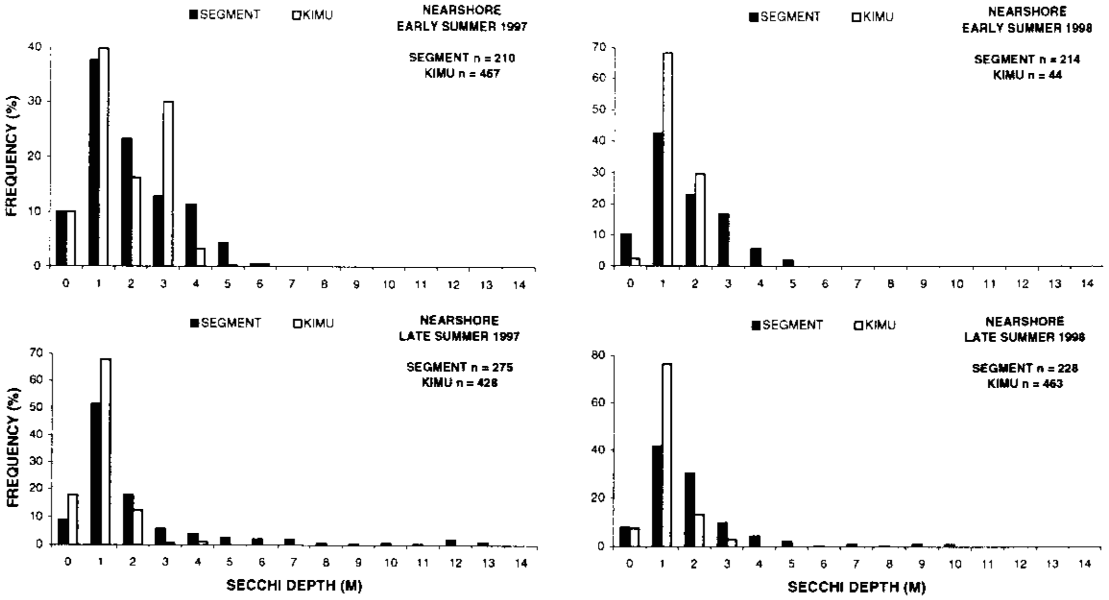

Fig. 29. Large-scale availability (SEGMENT) and use of secchi depths by Kittlitz's murrelets (KIMU) on nearshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1997–1998. Vertical scales differ among plots.

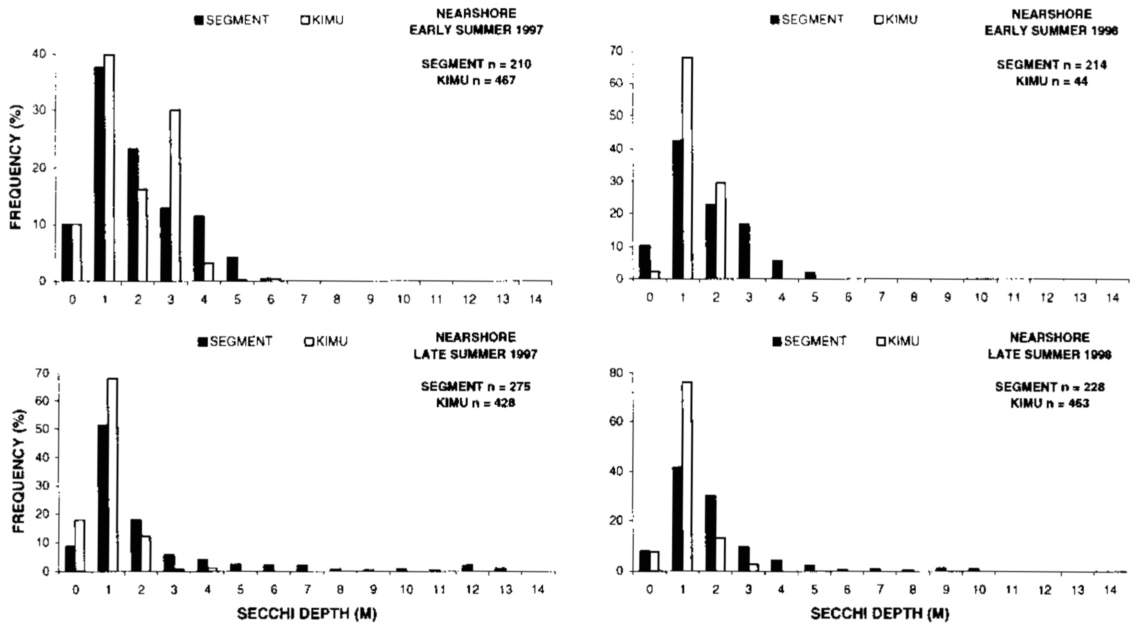

Fig. 30. Large-scale availability (SEGMENT) and use of secchi depths by Kittlitz's murrelets (KIMU) on offshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1997–1998. Vertical scales differ among plots.

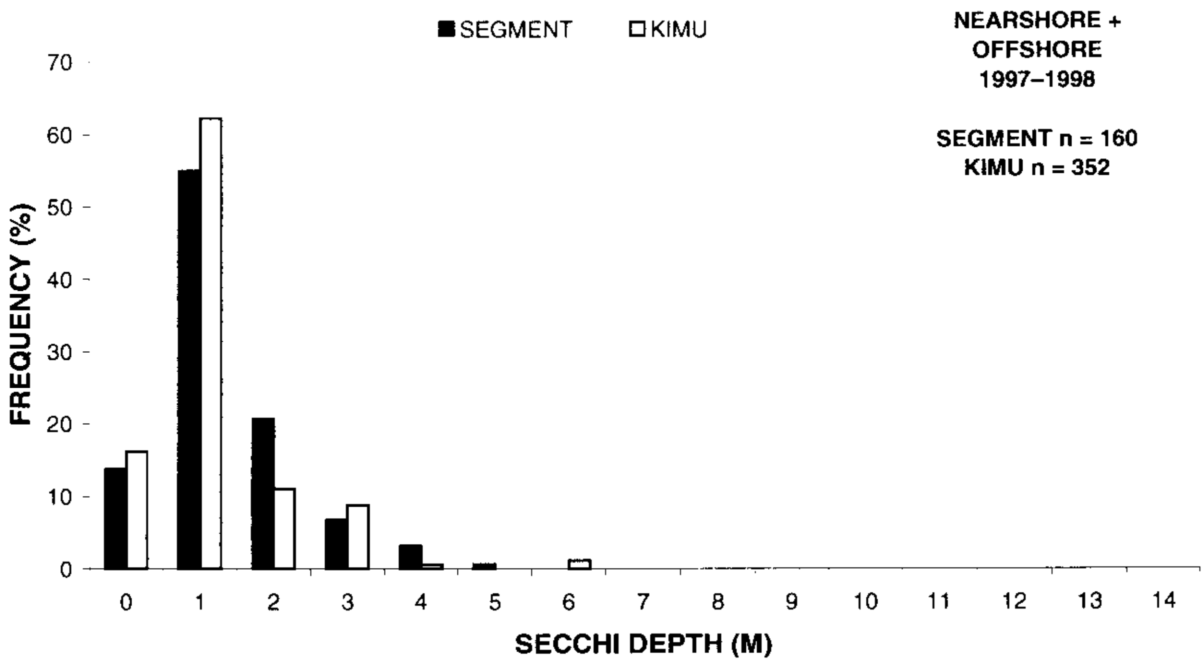

Fig. 31. Large-scale availability (SEGMENT) and fine-scale use of secchi depths by Kittlitz's murrelets (KIMU) on nearshore and offshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1997–1998. Data are pooled because of small sample sizes in some seasons, years, and survey types.

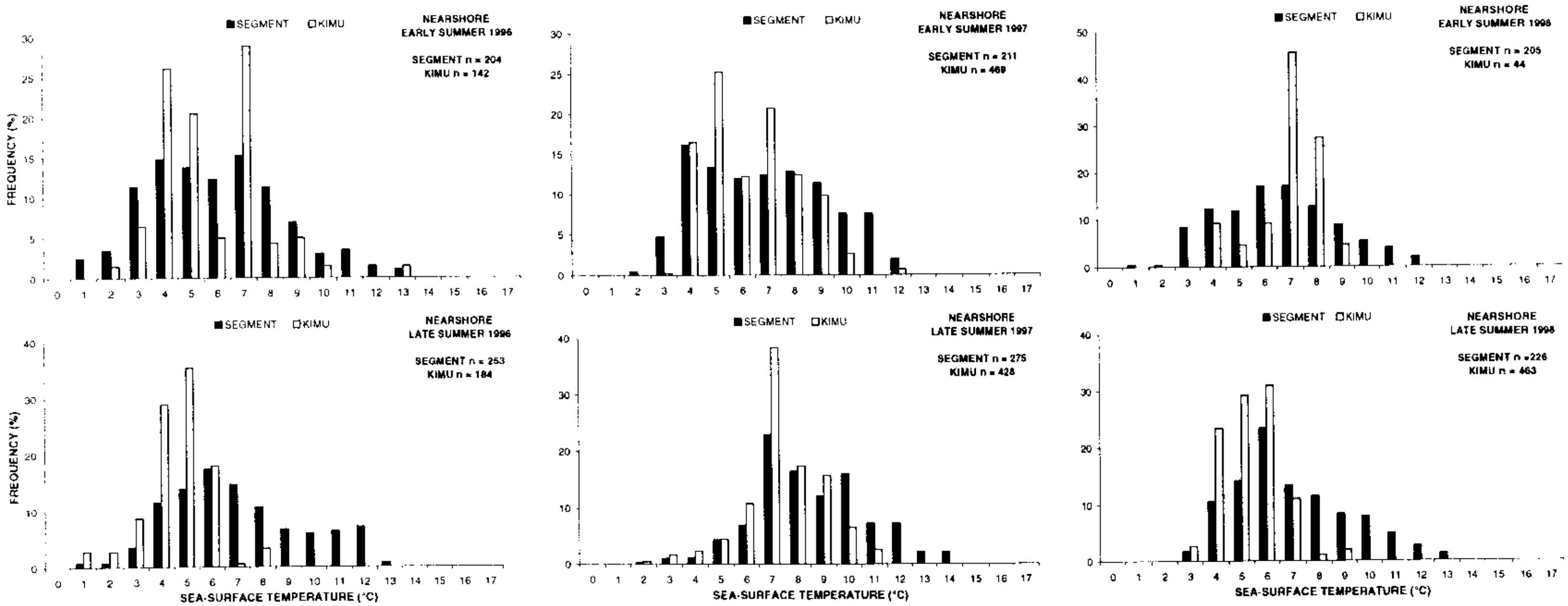

Fig. 32. Large-scale availability (SEGMENT) and use of sea-surface temperatures by Kittlitz's murrelets (KIMU) on nearshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1996–1998. Vertical scales differ among plots.

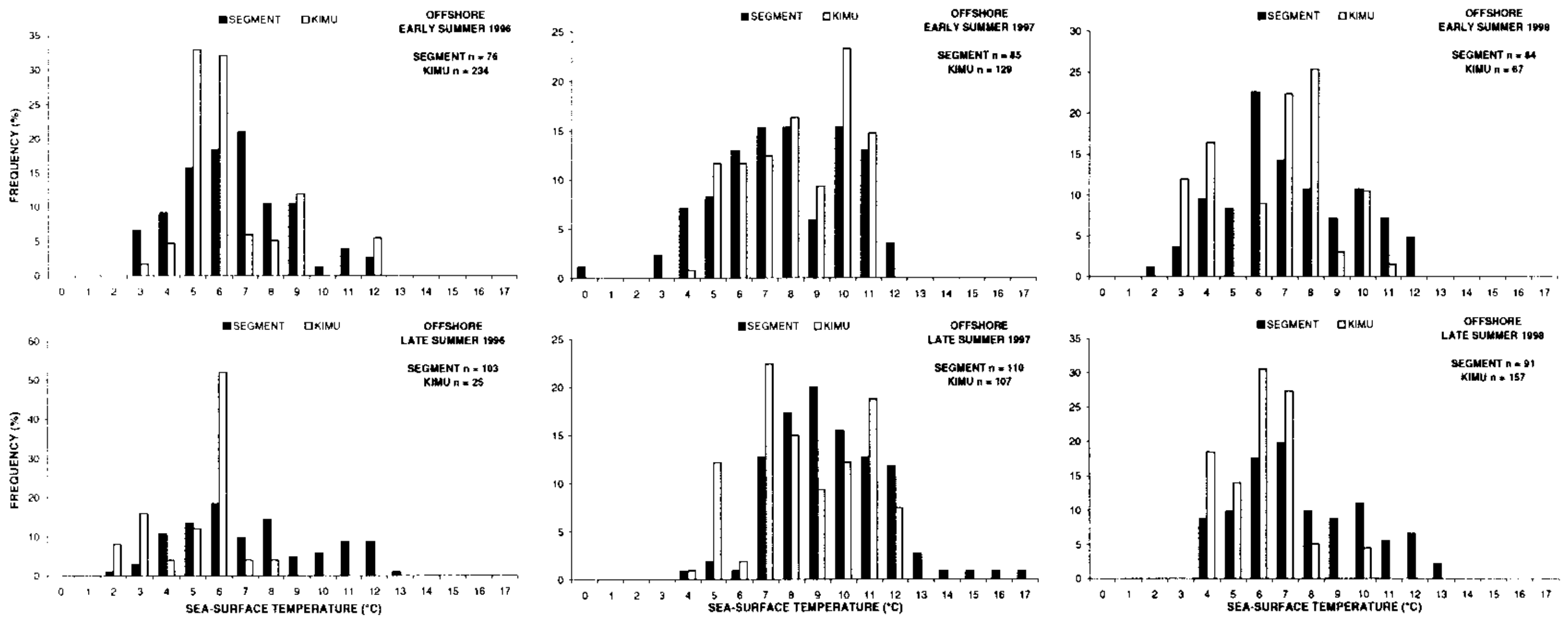

Fig. 33. Large-scale availability (SEGMENT) and use of sea-surface temperatures by Kittlitz's murrelets (KIMU) on offshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1996–1998. Vertical scales differ among plots.

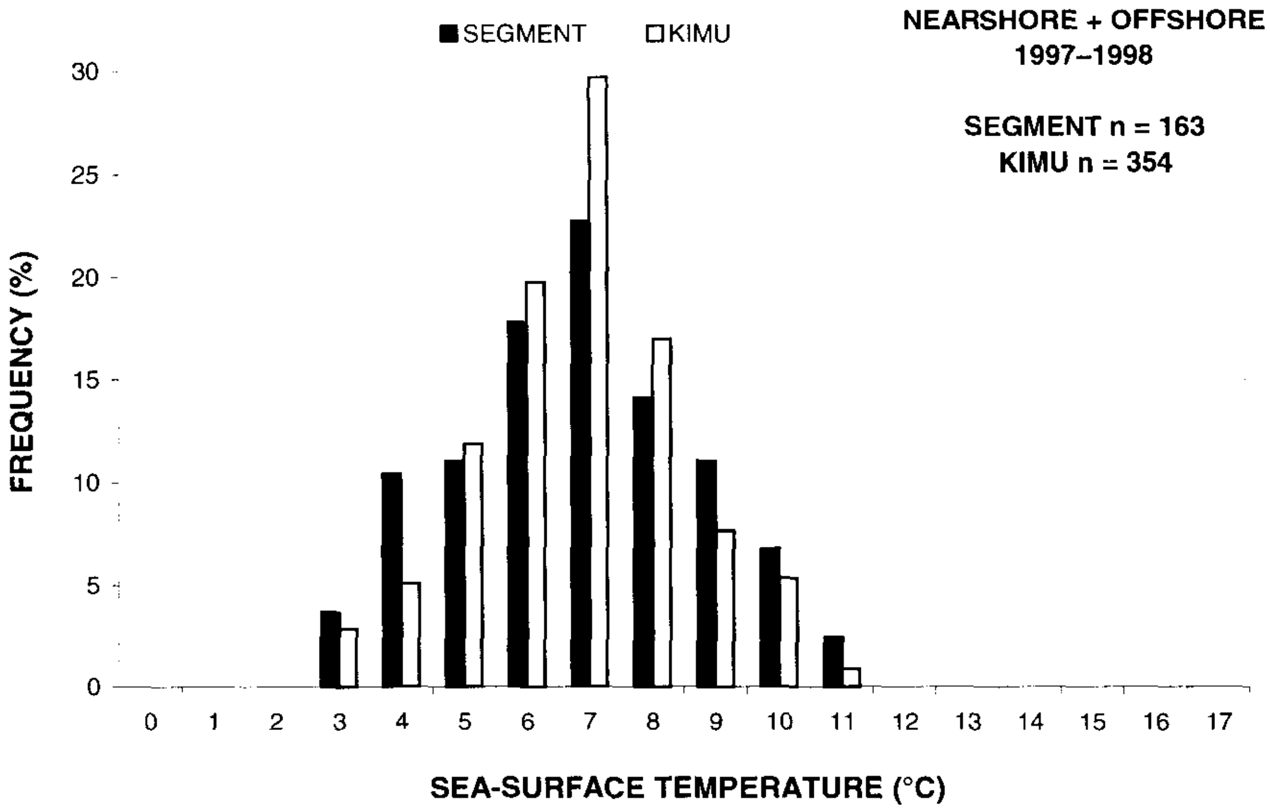

Fig. 34. Large-scale availability (SEGMENT) and fine-scale use of sea-surface temperatures by Kittlitz's murrelets (KIMU) on nearshore and offshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1997–1998. Data are pooled because of small sample sizes in some seasons, years, and survey types.

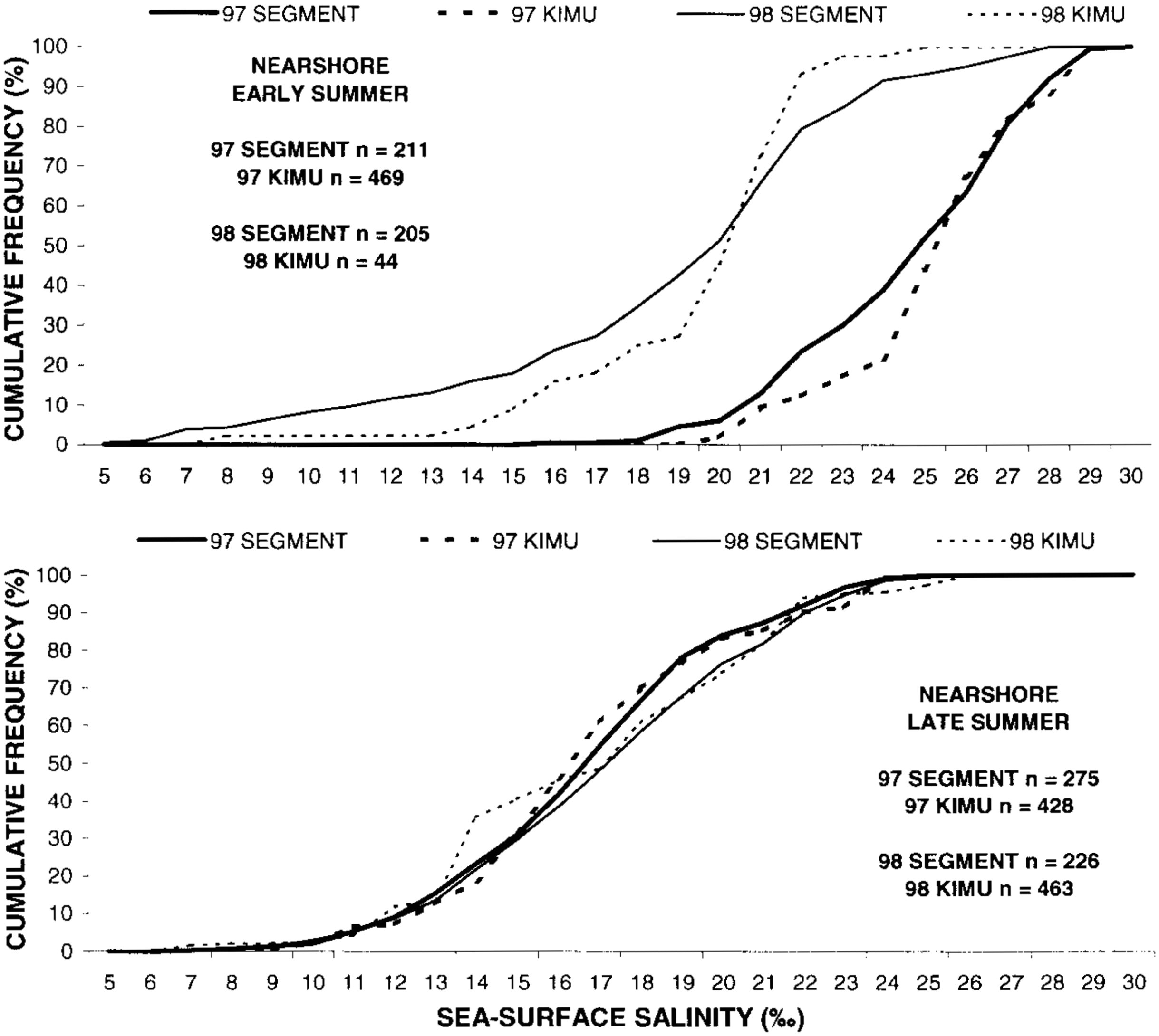

Fig. 35. Large-scale availability (SEGMENT) and use of sea-surface salinities by Kittlitz's murrelets (KIMU) on nearshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1997–1998.

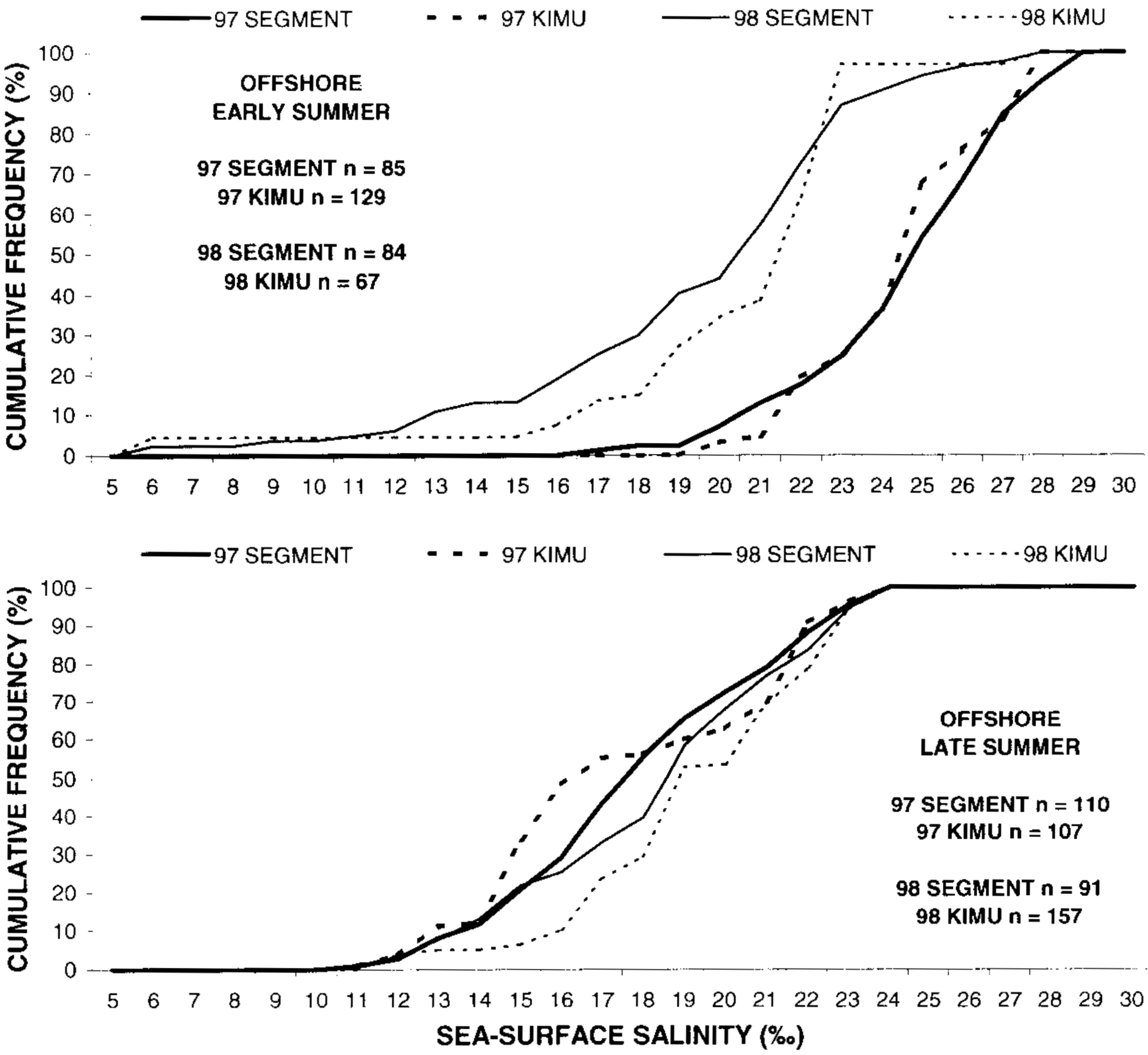

Fig. 36. Large-scale availability (SEGMENT) and use of sea-surface salinities by Kittlitz's murrelets (KIMU) on offshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1997–1998.

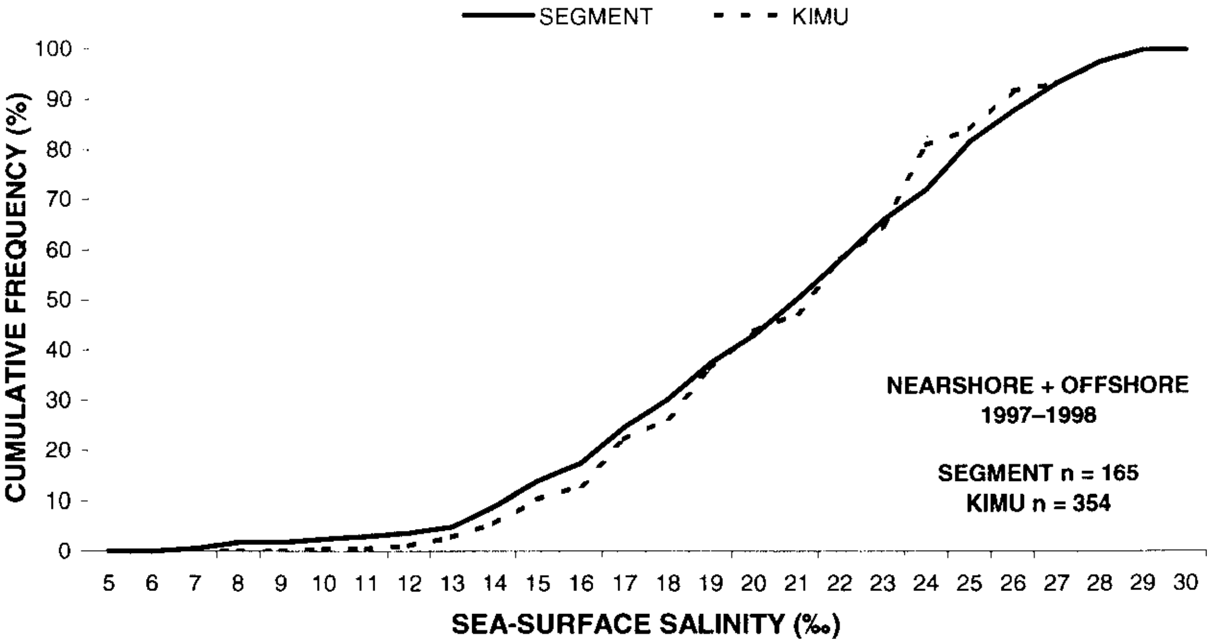

Fig. 37. Large-scale availability (SEGMENT) and fine-scale use of sea-surface salinities by Kittlitz's murrelets (KIMU) on nearshore and offshore surveys in four bays in Prince William Sound, Alaska, in early (top) and late (bottom) summer 1997–1998. Data are pooled because of small sample sizes in some seasons, years, and survey types.

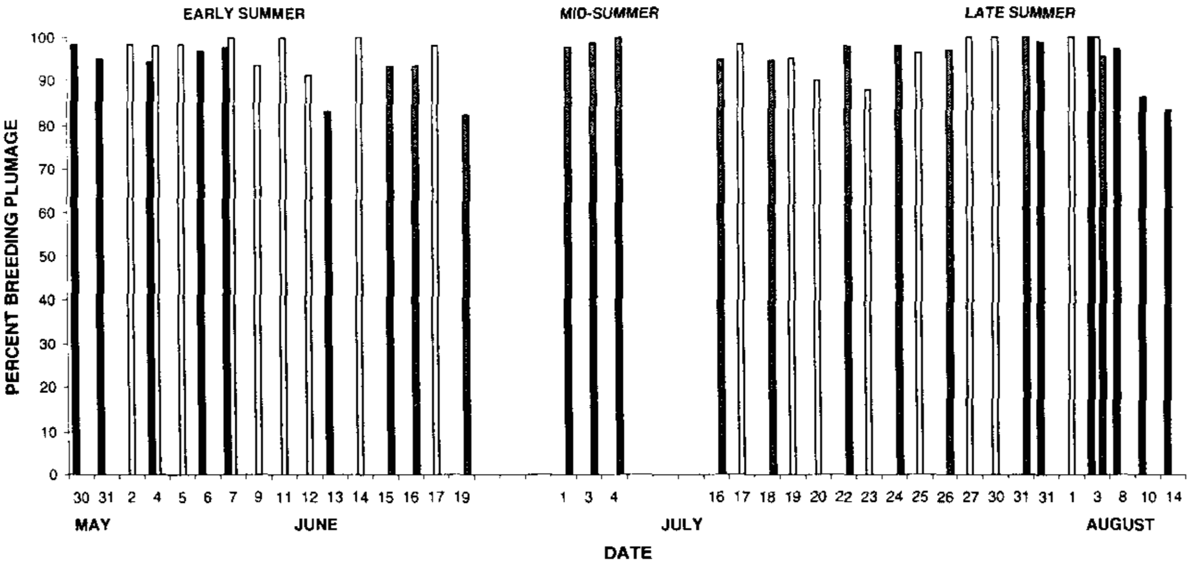

Fig. 38. Percentage of after-hatching-year (AHY) Kittlitz's murrelets that were in breeding plumage in four bays in Prince William Sound, Alaska, early, mid-, and late summer 1996 (black bars), 1997 (white bars), and 1998 (gray bars). Data are for nearshore and offshore surveys combined during each bay-visit; only samples of ≥10 birds are presented. For a particular date, the lack of a second or third bar indicates a lack of data on that day during the other year(s).

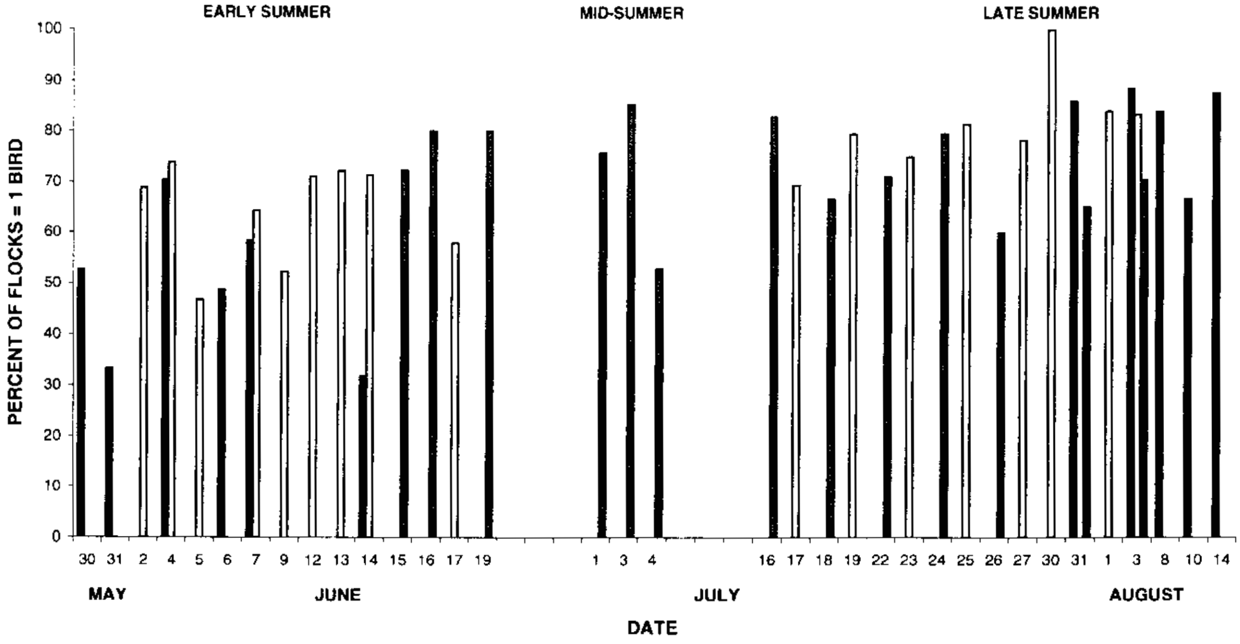

Fig. 39. Percentage of groups of Kittlitz's murrelets that consisted of single birds in four bays in Prince William Sound, Alaska, in early, mid-, and late summer 1996 (black bars), 1997 (white bars), and 1998 (gray bars). Data are for nearshore and offshore surveys combined during each bay-visit; only samples of ≥10 birds are presented. For a particular date, the lack of a second or third bar indicates a lack of data on that day during the other year(s).

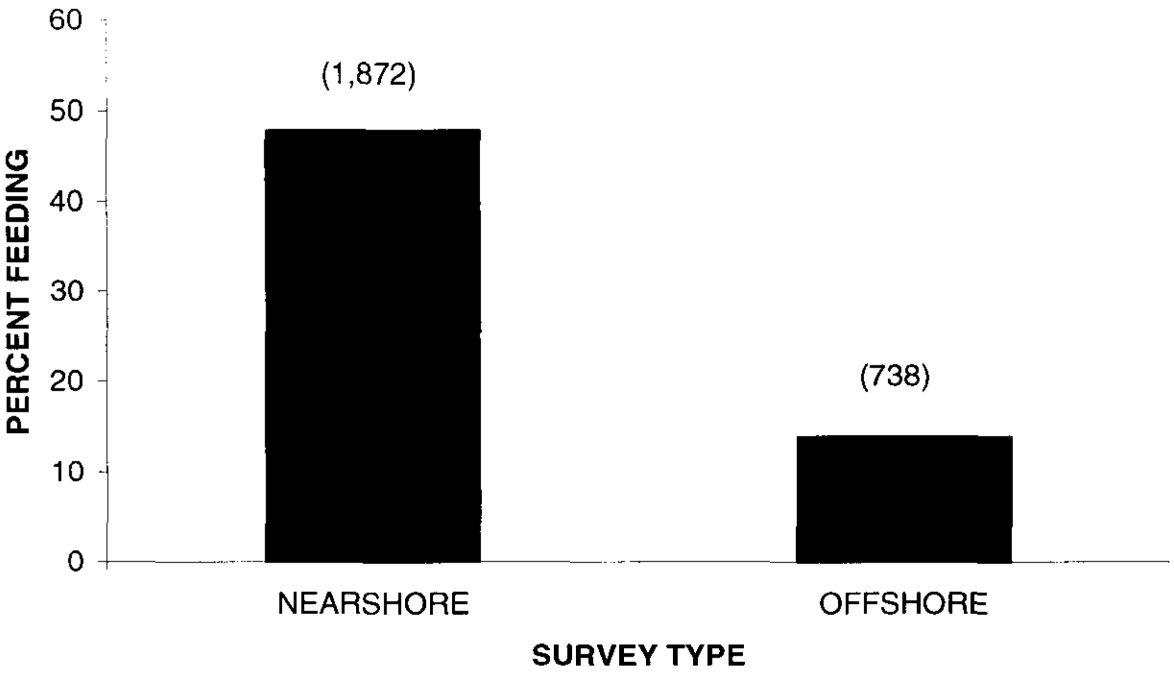

Fig. 40. Percentage of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996–1998, by survey type. Data are pooled across all cruises and years; sample sizes are in parentheses.

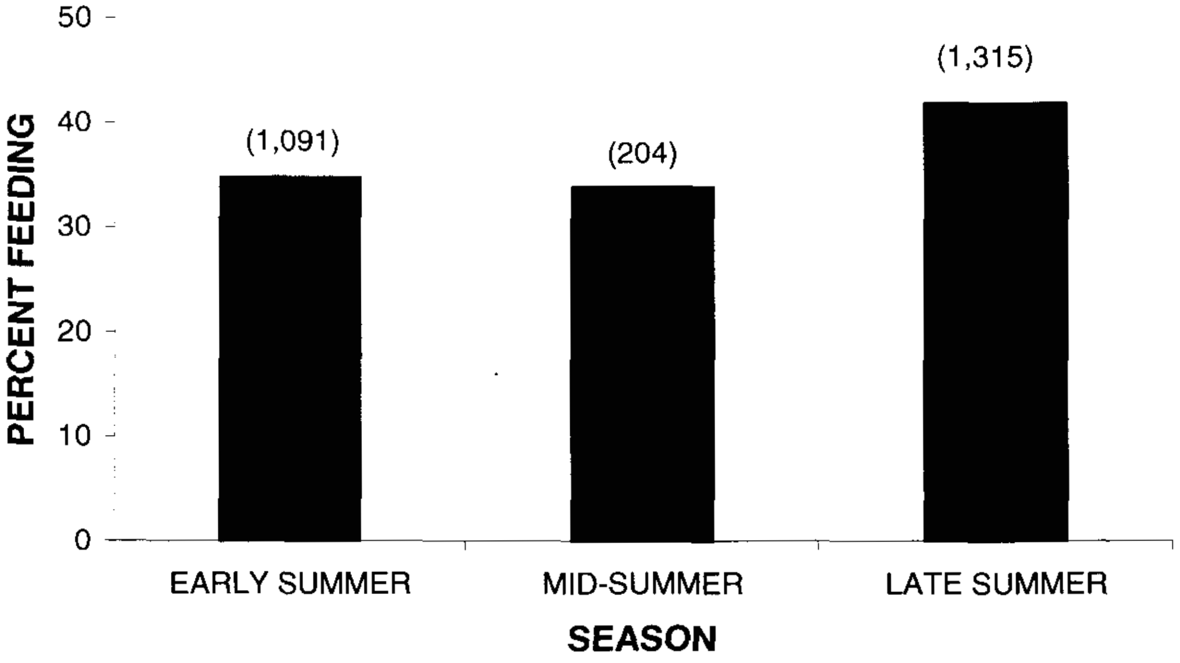

Fig. 41. Percentage of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996–1998, by season. Data are pooled across all cruises and years and both survey types; sample sizes are in parentheses.

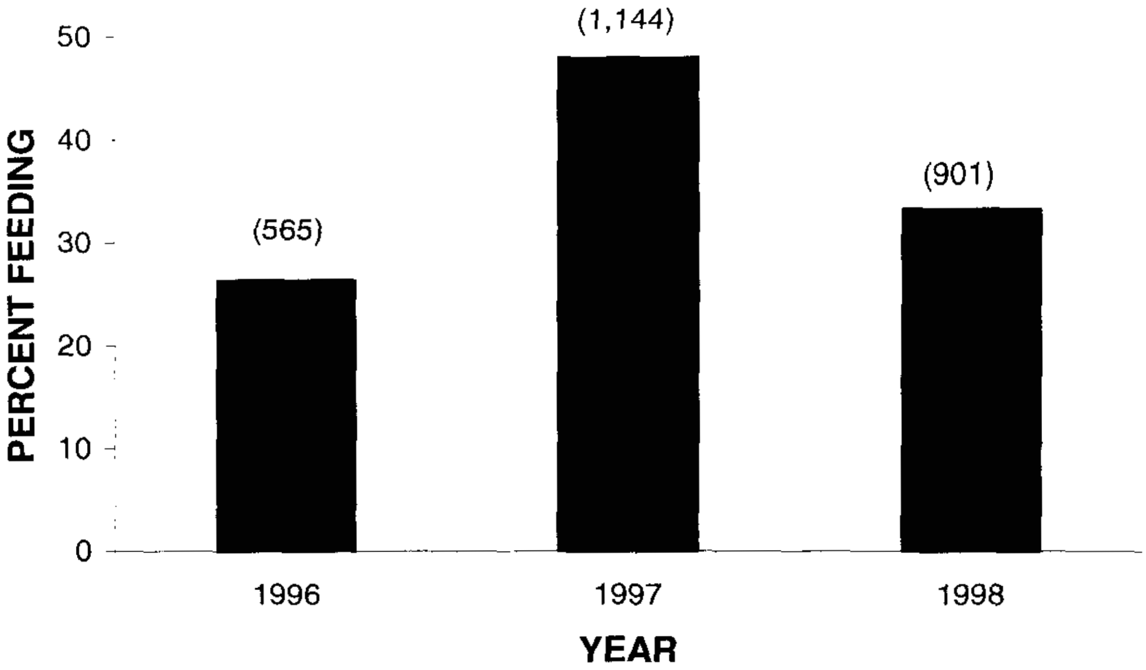

Fig. 42. Percentage of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996–1998, by year. Data are pooled across all cruises and both survey types; sample sizes are in parentheses.

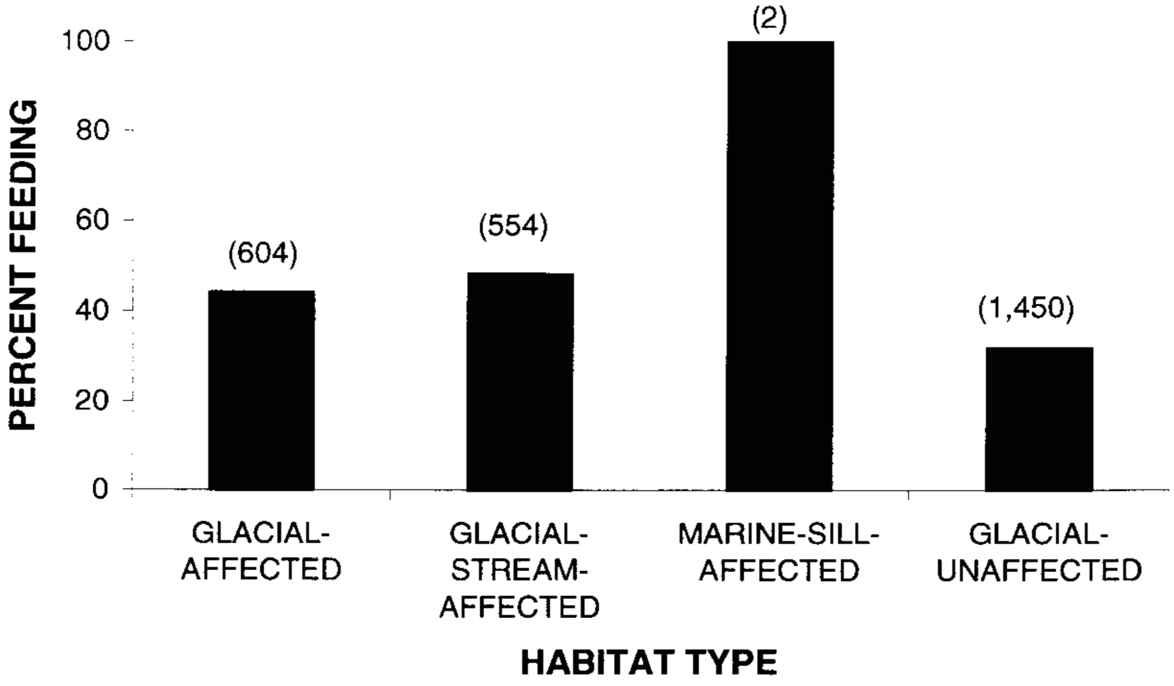

Fig. 43. Percentage of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996–1998, by standardized habitat type. Data are pooled across all cruises and years and both survey types; sample sizes are in parentheses.

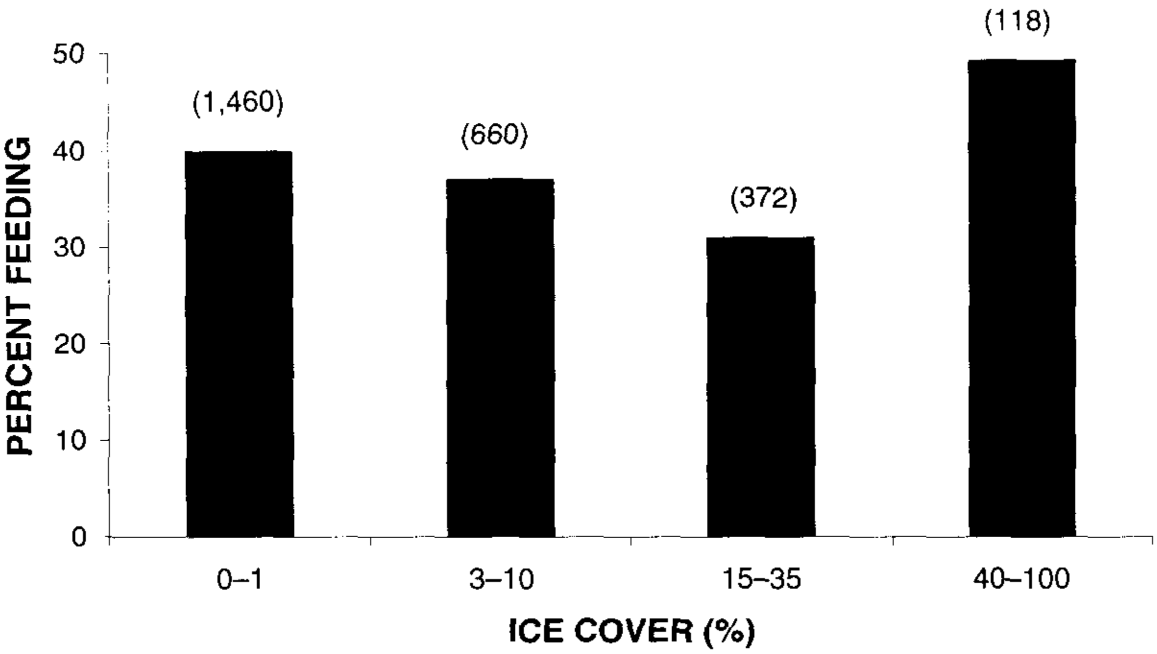

Fig. 44. Percentage of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996–1998, by percent ice cover. Data are pooled across all cruises and years and both survey types; sample sizes are in parentheses.

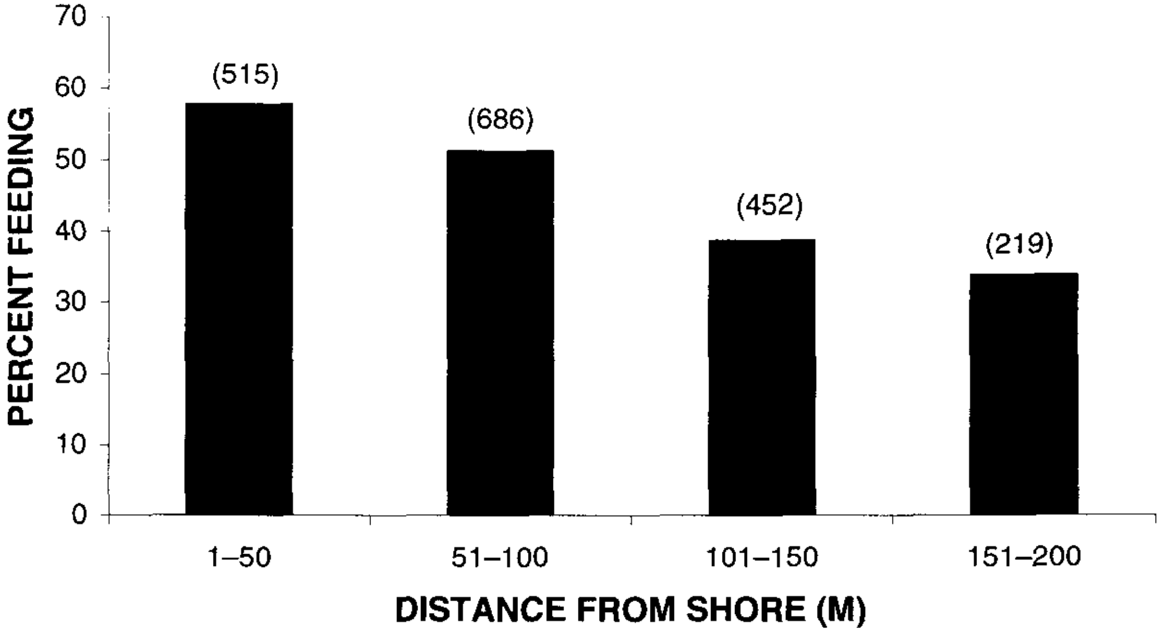

Fig. 45. Percentage of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996–1998, by distance from nearest shoreline. Data are pooled across all cruises and years but are for nearshore surveys only; sample sizes are in parentheses.

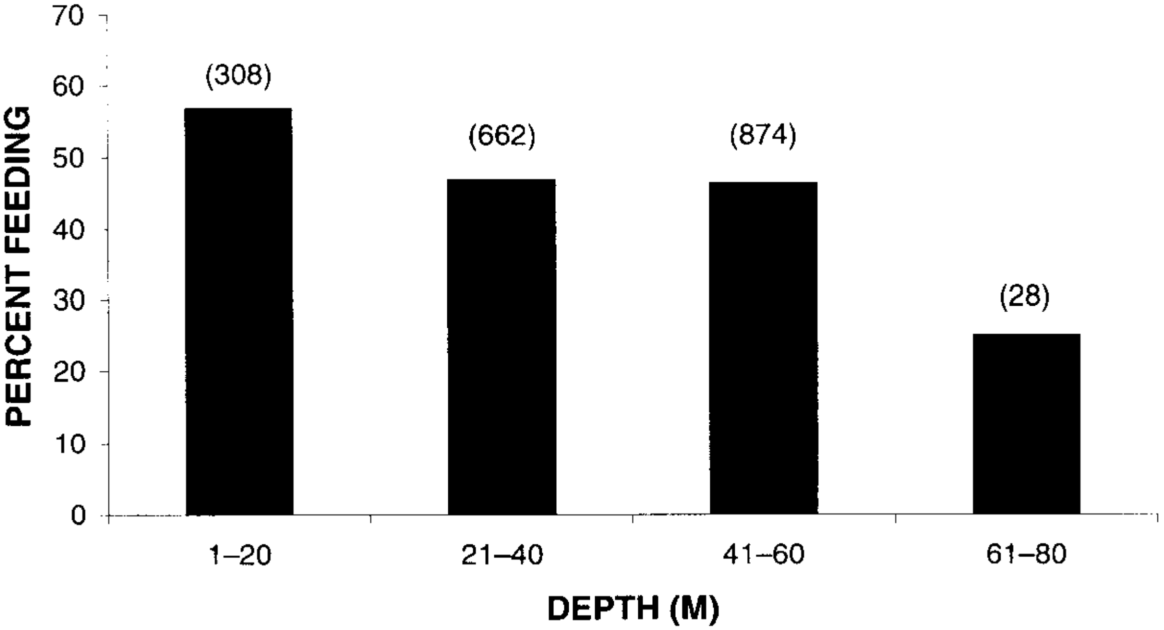

Fig. 46. Percentage of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996–1998, by water depth. Data are pooled across all cruises and years but are for nearshore surveys only; sample sizes are in parentheses.

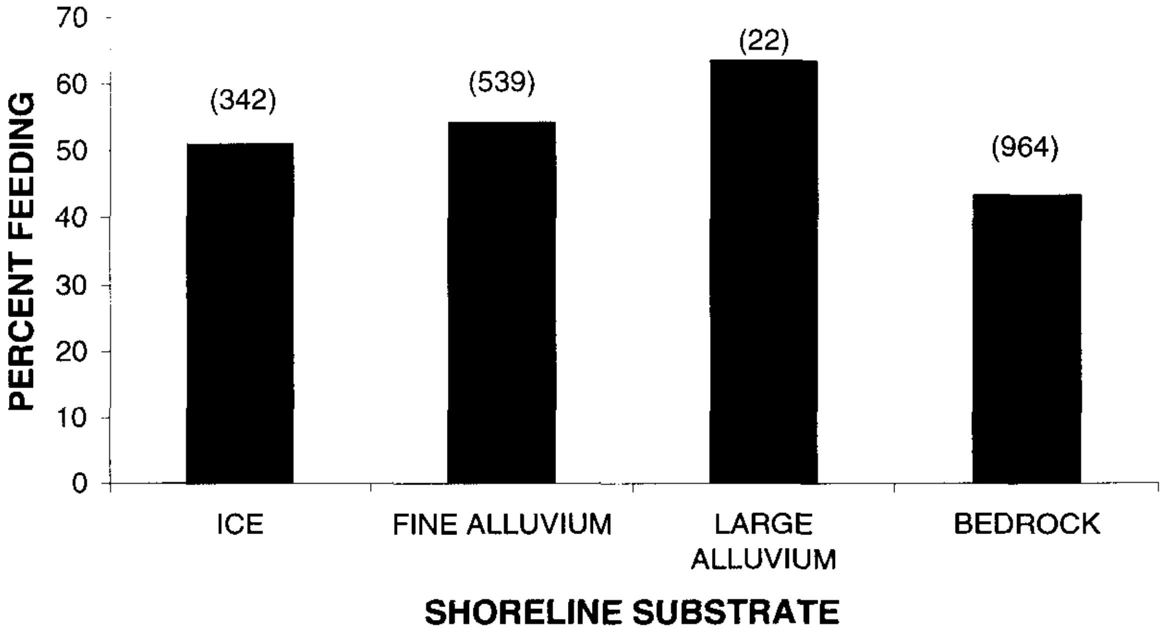

Fig. 47. Percentage of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996–1998, by shoreline substrate. Data are pooled across all cruises and years but are for nearshore surveys only; sample sizes are in parentheses.

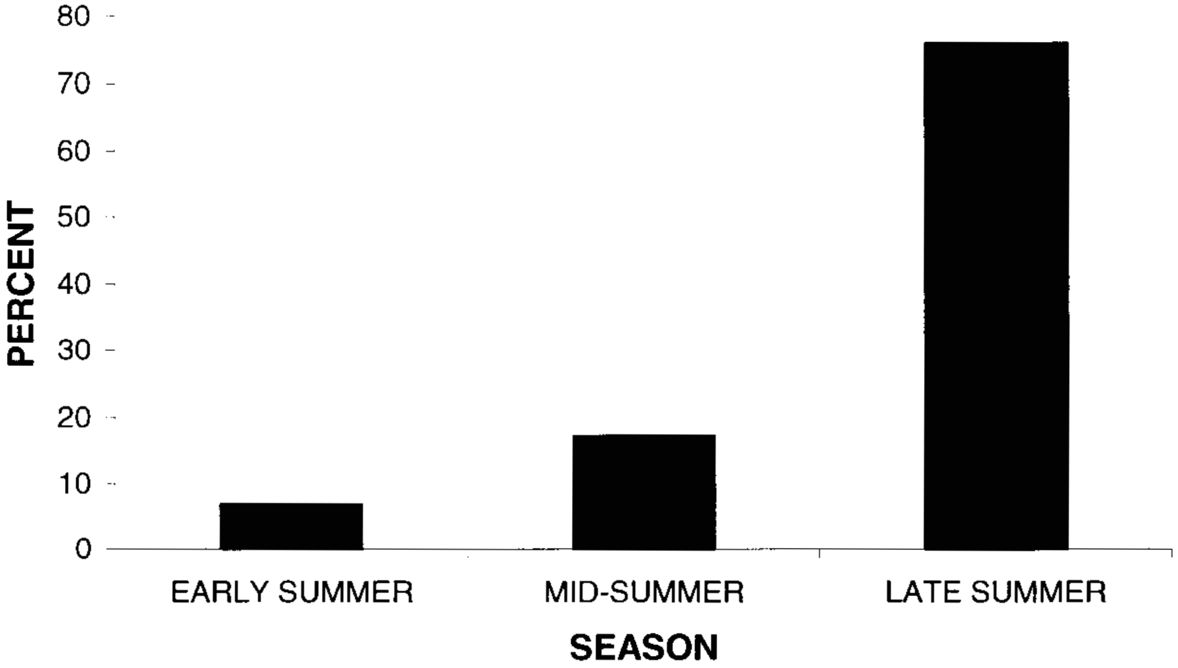

Fig. 48. Percentage of all records of Kittlitz's murrelets that were seen eating fishes in four bays in Prince William Sound, Alaska, in 1996–1998, by season. Data are from Table 51 and are pooled across all cruises and years and both survey types; sample sizes are in parentheses.

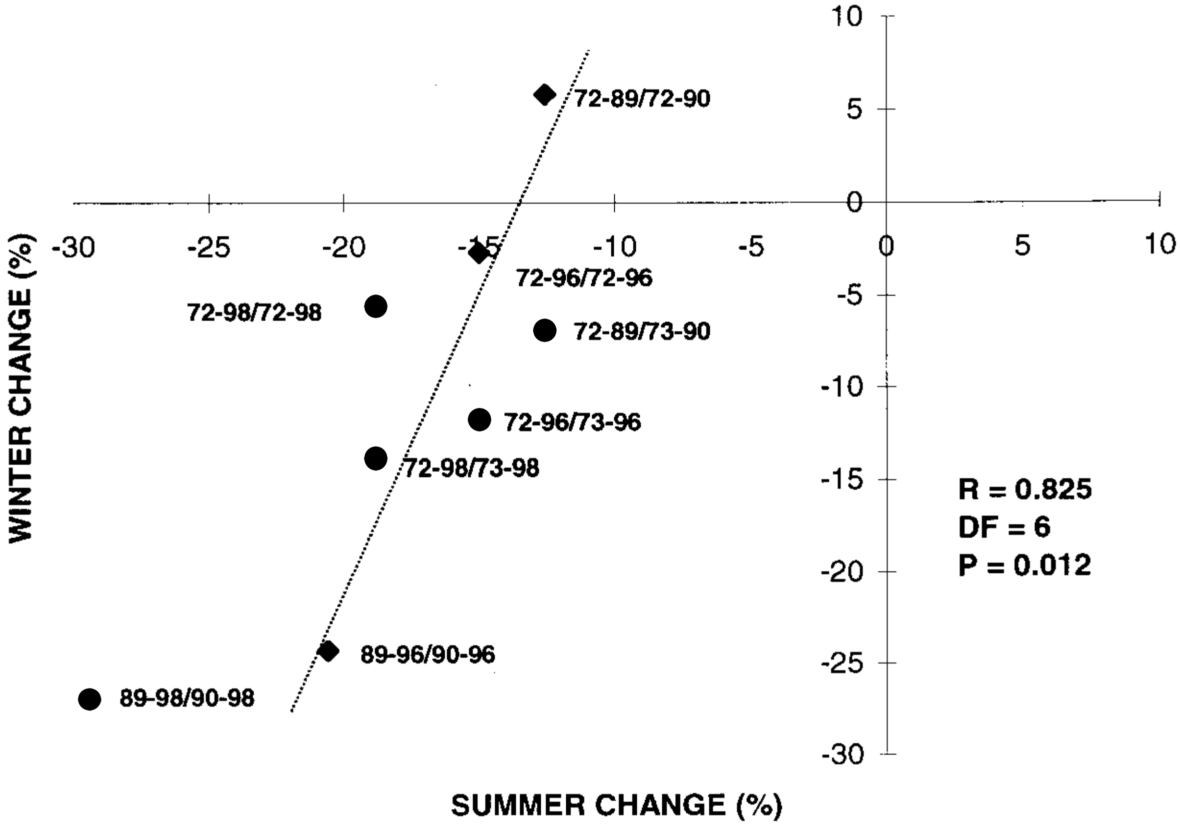

Fig. 49. Relationship between the percentage change of estimated Kittlitz's murrelet populations in Prince William Sound, Alaska, in summer and winter 1972–1998. Data are calculated from numbers presented in Table 56 and represent comparisons of changes between two summer periods (first set of years) and changes between two similar winter periods (second set of years). The dashed line is that predicted for a linear positive relationship; the line is fitted by hand.

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/comments
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/comments
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/comments
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/comments
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)	poor weather
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. Sampling activities conducted in Prince William Sound, Alaska, in early summer (1–19 June) 1998.

	Activity			
Date	Nearshore surveys	Offshore surveys	Pelagic survey lines[a]	Other/comments
1 June	Unakwik Inlet			
2 June		Unakwik Inlet	EL, WPL, PWOL	
3 June	College Fjord			
4 June		College Fjord	PWEL	
5 June	weather day (no work)	weather day (no work)	weather day (no work)	poor weather
6 June	Harriman Fjord[b]			poor weather
7 June			PWOL	poor weather
8 June			PWEL	poor weather
9 June	Harriman Fjord[b]	Harriman Fjord		
10 June	Blackstone Bay			
11 June		Blackstone Bay	WPL, EL	poor weather
12 June	Unakwik Inlet[b]	Unakwik Inlet		poor weather
13 June	Unakwik Inlet[b]			
14 June	College Fjord			
15 June		College Fjord, Harriman Fjord		
16 June	Harriman Fjord			
17 June	Blackstone Bay			
18 June		Blackstone Bay, Unakwik Inlet		
19 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.

Table 6. Sampling activities conducted in Prince William Sound, Alaska, in mid-summer (28 June–5 July) 1998.

	Activity			
Date	Nearshore surveys	Offshore surveys	Pelagic survey lines[a]	Other/comments
28 June	Blackstone Bay			
29 June		Blackstone Bay	WPL, EL	
30 June	Unakwik Inlet			
1 July		Unakwik Inlet	PWOL	poor weather
2 July	College Fjord			
3 July		College Fjord, Harriman Fjord		
4 July	Harriman Fjord			poor weather
5 July			PWEL	poor weather

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

Table 7. Sampling activities conducted in Prince William Sound, Alaska, in late summer (15 July–4 August) 1998.

	Activity			
Date	Nearshore surveys	Offshore surveys	Pelagic survey lines[a]	Other/comments
15 July	College Fjord	–	–	–
16 July	–	College Fjord	–	bathymetric measurements
17 July	Harriman Fjord	–	–	–
18 July	–	Harriman Fjord	PWEL	–
19 July	Blackstone Bay	–	–	bathymetric measurements
20 July	–	Blackstone Bay	–	poor weather
21 July	Unakwik Inlet	–	–	bathymetric measurements; poor weather
22 July	–	Unakwik Inlet	EL, WPL, PWOL	poor weather
23 July	College Fjord	–	–	bathymetric measurements
24 July	–	College Fjord	–	–
25 July	–	Harriman Fjord	–	–
26 July	Harriman Fjord	–	–	–
27 July	–	–	PWEL	–
28 July	Blackstone Bay[b]	–	–	bathymetric measurements; high winds
29 July	Blackstone Bay[b]	Blackstone Bay	–	–
30 July	Unakwik Inlet	–	–	–
31 July	–	Unakwik Inlet	–	bathymetric measurements
1 August	–	–	EL, WPL	–
2 August	Harriman Fjord	–	–	–
3 August	–	Harriman Fjord	–	bathymetric measurements
4 August	–	–	PWOL	–

[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 8. 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 1996–1998.

	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 9. Characteristics affecting observation abilities during nearshore, offshore, and pelagic surveys in Prince William Sound, Alaska, during cruises in summer 1996–1998, 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	218	0.3	0.5	204	0.1	0.4	204	0.3	0.5	218	28	12.8	218
	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
	1998	4.1	0.3	218	0.6	0.7	204	<0.1	0.1	204	0.5	0.6	218	57	26.2	218
Offshore	1996	4.4	0.6	86	0.4	0.6	76	0.2	0.6	76	0.4	0.6	86	8	9.3	86
	1997	4.4	0.5	87	0.7	0.8	86	0.1	0.4	86	0.6	0.7	87	22	25.3	87
	1998	4.0	0.3	87	1.0	0.9	83	0.3	0.8	83	0.9	0.8	87	32	36.8	87
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
	1998	3.6	0.6	65	2.3	1.3	65	2.6	1.1	65	2.5	1.5	65	34	52.3	65
MID-SUMMER																
Nearshore	1998	4.0	0.1	99	0.7	0.7	97	<0.1	0.2	97	0.7	0.7	99	17	17.2	99
Offshore	1998	4.0	0.2	40	0.6	0.6	37	0	0	37	0.6	0.5	40	3	7.5	40
Pelagic	1998	4.2	0.5	32	1.8	1.1	32	2.0	1.0	32	1.8	1.1	32	20	62.5	32
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	277	0.7	0.6	274	0.1	0.3	274	0.7	0.6	277	12	4.3	277
	1998	4.0	0.2	228	0.7	0.8	227	0.1	0.5	227	0.7	0.8	228	80	35.1	228

Table 9. Continued.

		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
LATE SUMMER (CONTINUED)																
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	113	0.9	0.6	110	0.4	0.6	110	0.9	0.6	113	16	14.2	113
	1998	4.0	0.4	92	0.9	0.9	92	0.4	0.8	92	0.9	0.9	92	24	26.1	92
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	11	16.7	66
	1998	3.9	0.6	64	2.0	1.1	64	2.3	1.0	64	2.0	1.1	64	25	39.1	64

[a] 1 = poor; 2 = fair; 3 = good; 4 = very good; 5 = excellent.

[b] Based on the Beaufort scale. Beaufort 0 = seas calm; sea + swell = 0 ft [0 m]; winds 0–1 kt. Beaufort 1 = seas slightly rippled; sea + swell = 0.25 ft [0.08 m]; winds 1–3 kt. Beaufort 2 = seas with small wavelets; sea + swell = 0.50 ft [0.15 m]; winds 4–6 kt. Beaufort 3 = large wavelets; sea + swell = 2 ft [0.61 m]; winds 7–10 kt.

[c] Number (percentage) of segment samples on which any precipitation was recorded.

Table 10. Environmental characteristics during nearshore, offshore, and pelagic surveys in Prince William Sound, Alaska, during cruises in summer 1996–1998, 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	8.9	19.7	216	1.7	1.3	210	6.9	2.4	211	24.9	2.8	211
	1998	12.4	27.0	218	1.6	1.7	205	6.5	2.2	205	19.1	4.9	205
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
	1998	10.7	24.7	87	1.7	1.1	83	7.2	2.4	84	19.8	4.3	84
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
	1998	0.1	0.2	65	–	–	0	9.4	1.0	65	24.2	2.4	65
MID-SUMMER													
Nearshore	1998	6.9	20.0	99	1.4	1.4	95	7.2	2.0	96	18.6	4.7	96
Offshore	1998	13.7	29.9	40	2.0	1.7	37	8.1	1.8	37	19.7	4.1	37
Pelagic	1998	<0.1	0.1	32	–	–	0	12.4	1.6	32	22.4	1.5	32
LATE SUMMER													
Nearshore	1996	5.0	14.3	253	–	–	0	7.1	2.6	253	–	–	0
	1997	4.9	15.8	276	2.0	2.6	275	8.5	2.2	275	17.1	3.4	275
	1998	5.2	15.7	228	1.7	1.7	225	7.0	2.3	226	17.6	3.7	226

Table 10. Continued.

		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
LATE SUMMER (CONTINUED)													
Offshore	1996	1.4	5.2	103	–	–	0	7.3	2.7	103	–	–	0
	1997	3.6	16.3	112	2.3	2.7	110	9.5	2.2	110	18.2	3.2	110
	1998	1.1	2.2	92	2.0	1.6	90	7.6	2.4	91	18.7	3.3	91
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
	1998	0	0	64	–	–	0	12.6	1.4	64	22.1	1.8	64

Table 11. Results of 5- (nearshore surveys) and 4- (offshore surveys) factor ANOVAs on ln-transformed densities (birds/km^2) of Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1996–1998. For nearshore surveys, analysis was by visit, season, year, site (bay), and standardized habitat type; for offshore surveys, analysis was by visit, season, year, and site.

Survey type/source	MS	df	F	*P*-value[a]	Observed power[b]	Multiple comparisons
NEARSHORE						
Overall model	2,608.6	212	5.667	<0.001*	1.000	
Visit	32.3	2	7.442	0.001*	0.942	
Season	70.5	2	16.232	<0.001*	1.000	MS = LS > ES[c]
Year	80.3	2	18.483	<0.001*	1.000	1997 > 1998 = 1996
Site	173.8	3	26.688	<0.001*	1.000	CF > HF = UI > BB[d]
Habitat type	66.3	3	10.171	<0.001*	0.999	GA > GS > GU > MS[e]
Site × year	25.2	6	1.933	0.072	0.719	
Habitat type × season	108.4	6	8.316	<0.001*	1.000	
Habitat type × year	24.6	6	1.885	0.080	0.707	
Habitat type × site	64.1	7	4.215	<0.001*	0.990	
OFFSHORE						
Overall model	582.3	60	5.275	<0.001*	1.000	
Visit	<0.1	2	0.010	0.990	0.051	
Season	10.0	2	2.719	0.067	0.537	
Year	3.5	2	0.964	0.382	0.218	
Site	130.6	3	23.665	<0.001*	1.000	CF = HF > UI = BB[d]
Site × year	71.5	6	6.478	<0.001*	0.999	

[a] * = Significant at $\alpha = 0.05$.

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

[c] ES = early summer; MS = mid-summer; LS = late summer.

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

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

Table 12. Results of 5- (nearshore surveys) and 4- (offshore surveys) factor ANOVAs on ln-transformed densities (birds/km^2) of Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1996–1998, after controlling for interannual differences in sampling dates. For nearshore surveys, analysis was by visit, season, year, site (bay), and standardized habitat type; for offshore surveys, analysis was by visit, season, year, and site.

Survey type/source	MS	df	F	*P*-value[a]	Observed power[b]	Multiple comparisons
NEARSHORE						
Overall model	1,336.1	123	5.516	<0.001*	1.000	
Visit	0.7	2	0.169	0.845	0.076	
Season	3.4	1	1.730	0.189	0.260	
Year	30.2	2	7.660	<0.001*	0.948	1997 > 1996 > 1998
Site	81.3	3	13.755	<0.001*	1.000	CF > HF = UI > BB[c]
Habitat type	44.9	3	7.596	<0.001*	0.988	GA > GS > GU > MS[d]
Site × year	53.0	6	4.483	<0.001*	0.987	
Habitat type × season	25.6	3	4.338	0.005*	0.870	
Habitat type × year	4.6	6	0.387	0.888	0.164	
Habitat type × site	48.0	7	3.482	0.001*	0.970	
OFFSHORE						
Overall model	291.8	34	4.838	<0.001*	1.000	
Visit	16.5	2	4.643	0.010*	0.780	
Season	0.5	1	0.263	0.609	0.080	
Year	5.0	2	1.407	0.247	0.301	
Site	57.5	3	10.807	<0.001*	0.999	HF = CF > UI = BB[c]
Site × year	59.8	6	5.621	<0.001*	0.997	

[a] * = Significant at $\alpha = 0.05$.

[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-unaffected; MS = marine-sill-affected habitat.

Table 13. Results of 5-factor ANOVAs on ln-transformed densities (birds/km^2) of Kittlitz's murrelets on nearshore and offshore surveys in four bays in Prince William Sound, Alaska, in 1996–1998, by visit, season, year, site (bay), and survey type.

Model/source	MS	df	F	*P*-value[a]	Observed power[b]	Multiple comparisons
ALL DATA						
Overall model	2,062.4	121	7.178	<0.001*	1.000	
Visit	8.7	2	1.826	0.161	0.383	
Season	29.2	2	6.145	0.002*	0.891	MS = LS > ES[c]
Year	53.6	2	11.289	<0.001*	0.993	1997 > 1998 > 1996
Site	286.6	3	40.227	<0.001*	1.000	CF > HF > UI > BB[d]
Survey type	1.2	1	0.502	0.479	0.109	
Season × survey type	14.5	2	3.044	0.048*	0.590	
Year × survey type	15.6	2	3.292	0.037*	0.626	
Site × survey type	41.4	3	5.815	0.001*	0.953	
DATA ONLY FOR GLACIAL-UNAFFECTED HABITATS						
Overall model	1,294.3	121	5.824	<0.001*	1.000	
Visit	6.5	2	1.782	0.169	0.374	
Season	15.0	2	4.075	0.017*	0.725	no difference among seasons, but overall variable is significant
Year	31.9	2	8.694	<0.001*	0.970	1997 > 1998 = 1996
Site	199.3	3	36.172	<0.001*	1.000	CF > HF = UI > BB[d]
Survey type	11.7	1	6.393	0.012*	0.715	offshore > nearshore
Season × survey type	4.6	2	1.265	0.283	0.276	
Year × survey type	6.5	2	1.783	0.168	0.375	
Site × survey type	46.9	3	8.516	<0.001*	0.994	

[a] * = Significant at $\alpha = 0.05$.

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

[c] ES -= early summer; MS = mid-summer; LS = late summer.

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

Table 14. Mean ice cover (%) and sea-surface temperature (°C) in four study bays in Prince William Sound, Alaska, in 1996–1998, by habitat variable, bay, year, season, and survey type.

Habitat variable/bay	Year	Season																	
		Early summer						Mid-summer						Late summer					
		Nearshore			Offshore			Nearshore			Offshore			Nearshore			Offshore		
		$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	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	–	–	0	–	–	0	1.3	3.4	40	1.0	2.6	14
	1997	6.9	18.8	60	17.1	27.6	21	–	–	0	–	–	0	2.0	8.0	40	0.5	0.2	14
	1998	10.9	27.7	60	9.3	21.5	21	1.5	2.5	20	18.9	37.4	7	2.1	6.7	40	0.5	0.3	14
College Fjord	1996	33.6	40.9	50	36.8	44.6	22	–	–	0	–	–	0	7.1	16.5	75	3.4	8.7	33
	1997	16.2	26.2	49	21.6	31.3	22	–	–	0	–	–	0	7.3	20.7	75	7.1	24.1	33
	1998	26.0	38.7	50	26.4	34.9	22	18.8	33.7	25	32.5	43.0	11	13.0	25.2	50	1.9	3.6	22
Harriman Fjord	1996	11.1	26.3	60	3.2	8.0	24	–	–	0	–	–	0	6.7	17.7	90	0.5	0.7	36
	1997	7.0	15.6	60	2.3	7.0	24	–	–	0	–	–	0	4.1	11.7	89	0.8	0.9	36
	1998	7.0	13.8	60	1.6	2.8	24	5.0	15.1	30	0.8	1.3	12	3.9	12.1	90	1.3	2.0	36
Blackstone Bay	1996	4.7	13.5	48	0.7	1.5	19	–	–	0	–	–	0	1.8	5.1	48	0.2	0.3	20
	1997	6.4	16.4	47	1.1	2.4	20	–	–	0	–	–	0	4.9	17.5	72	4.5	18.9	29
	1998	7.1	18.5	48	5.7	22.2	20	1.4	4.1	24	4.7	10.9	10	1.9	11.5	48	0.2	0.3	20
SEA-SURFACE TEMPERATURE																			
Unakwik Inlet	1996	5.8	2.1	57	5.8	1.4	18	–	–	0	–	–	0	9.3	2.2	40	9.4	1.7	14
	1997	6.3	2.4	54	7.2	2.2	21	–	–	0	–	–	0	9.2	1.8	40	9.2	1.3	14
	1998	6.6	2.3	55	7.4	2.3	21	7.7	2.2	20	9.2	1.4	6	7.9	2.0	40	8.4	2.1	14
College Fjord	1996	4.5	1.9	41	5.2	1.7	15	–	–	0	–	–	0	5.7	1.9	75	5.2	1.5	33
	1997	4.9	1.3	50	5.1	1.7	21	–	–	0	–	–	0	8.5	2.0	75	9.6	1.5	31
	1998	6.2	1.4	43	5.2	1.6	19	6.6	1.5	23	7.3	1.5	9	5.2	1.3	48	6.0	1.8	22
Harriman Fjord	1996	6.1	2.2	58	6.0	1.3	24	–	–	0	–	–	0	5.9	1.7	90	6.6	1.7	36
	1997	7.2	1.6	60	8.7	1.4	23	–	–	0	–	–	0	7.0	1.5	90	7.9	1.5	36
	1998	5.3	1.9	60	7.2	2.0	24	6.2	1.6	29	7.4	1.3	12	6.1	1.3	90	6.6	1.2	36
Blackstone Bay	1996	7.5	3.1	48	9.2	1.7	19	–	–	0	–	–	0	9.5	2.3	48	10.7	1.9	20
	1997	9.3	2.0	47	9.8	1.3	20	–	–	0	–	–	0	10.1	2.3	70	11.5	2.3	29
	1998	8.3	2.2	47	9.1	1.8	20	8.6	1.8	24	9.2	2.0	10	9.6	1.9	48	10.8	1.5	19

Table 15. Maximal estimates of Kittlitz's murrelet population sizes in four bays in Prince William Sound, Alaska, in 1996–1998, by bay and year. Data are presented by cruise, bay, and visit in Appendices 1–3.

	Year								
	1996			1997			1998		
Bay	Estimate	±	95% CI	Estimate	±	95% CI	Estimate	±	95% CI
Unakwik Inlet	679	±	1,081	133	±	76	147	±	222
College Fjord	184	±	96	504	±	202	506	±	168
Harriman Fjord	325	±	194	524	±	284	571	±	595
Blackstone Bay	222	±	306	119	±	181	48	±	108
Total	1,410	±	1,677	1,280	±	743	1,272	±	1,093

Table 16. 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 17. Mean densities (birds/km^2) of Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1996–1998, 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
		1998	0	0	3	0.42	1.11	21	0	0	6	**0.96**	4.75	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
		1998	0.84	2.09	10	**5.10**	11.20	10	–	–	0	0.28	1.04	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
		1998	0	0	8	**0.45**	1.23	24	–	–	0	0	0	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	1.56	4.10	30
		1998	0	0	4	0	0	10	0	0	4	**0.05**	0.26	30
Mid-summer	Unakwik Inlet	1998	0	–	1	**6.35**	8.00	7	0.57	0.80	2	3.48	6.43	10
	College Fjord	1998	**15.65**	21.51	5	6.04	3.16	5	–	–	0	2.52	3.17	15
	Harriman Fjord	1998	**5.86**	11.72	4	0.68	1.24	12	–	–	0	1.66	5.77	14
	Blackstone Bay	1998	**3.88**	5.48	2	0.96	2.15	5	0	0	2	0	0	15
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
		1998	4.37	2.06	2	**11.95**	30.97	14	0.38	0.75	4	4.10	11.41	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
		1998	**15.33**	12.65	10	3.92	5.10	10	–	–	0	4.63	5.83	30

Table 17. Continued.

			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 (CONTINUED)														
	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
		1998	**22.02**	33.26	12	4.47	8.23	36	–	–	0	0.94	2.41	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
		1998	**10.66**	12.41	6	0	0	10	0	0	4	0.20	0.75	30
OFFSHORE														
Early summer	Unakwik Inlet	1996	–	–	0	–	–	0	–	–	0	6.01	18.88	21
		1997	–	–	0	–	–	0	–	–	0	1.00	1.89	21
		1998	–	–	0	–	–	0	–	–	0	0.15	0.48	21
	College Fjord	1996	–	–	0	–	–	0	–	–	0	0.95	1.45	22
		1997	–	–	0	–	–	0	–	–	0	0.95	2.38	22
		1998	–	–	0	–	–	0	–	–	0	2.91	4.92	22
	Harriman Fjord	1996	–	–	0	–	–	0	–	–	0	5.06	6.96	24
		1997	–	–	0	–	–	0	–	–	0	6.95	7.19	24
		1998	–	–	0	–	–	0	–	–	0	1.12	2.36	24
	Blackstone Bay	1996	–	–	0	–	–	0	–	–	0	5.61	11.22	19
		1997	–	–	0	–	–	0	–	–	0	1.66	5.43	20
		1998	–	–	0	–	–	0	–	–	0	0.71	3.17	20
Mid-summer	Unakwik Inlet	1998	–	–	0	–	–	0	–	–	0	3.06	6.33	7
	College Fjord	1998	–	–	0	–	–	0	–	–	0	3.71	3.85	11
	Harriman Fjord	1998	–	–	0	–	–	0	–	–	0	8.48	12.37	12
	Blackstone Bay	1998	–	–	0	–	–	0	–	–	0	0	0	10

Table 17. Continued.

Survey type/			Habitat type											
			Glacial affected			Glacial stream affected			Marine sill affected			Glacial unaffected		
season	Bay	Year	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n
OFFSHORE (CONTINUED)														
Late summer	Unakwik Inlet	1996	–	–	0	–	–	0	–	–	0	0	0	14
		1997	–	–	0	–	–	0	–	–	0	0.79	1.99	14
		1998	–	–	0	–	–	0	–	–	0	1.14	2.68	14
	College Fjord	1996	–	–	0	–	–	0	–	–	0	0.97	1.84	33
		1997	–	–	0	–	–	0	–	–	0	2.87	3.91	33
		1998	–	–	0	–	–	0	–	–	0	5.42	5.43	22
	Harriman Fjord	1996	–	–	0	–	–	0	–	–	0	0.05	0.32	36
		1997	–	–	0	–	–	0	–	–	0	2.02	3.15	36
		1998	–	–	0	–	–	0	–	–	0	3.27	10.10	36
	Blackstone Bay	1996	–	–	0	–	–	0	–	–	0	0	0	20
		1997	–	–	0	–	–	0	–	–	0	0	0	30
		1998	–	–	0	–	–	0	–	–	0	0.27	1.22	20

Table 18. 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 1996–1998, by comparison, survey type, and cruise.

		Habitat variable											
Comparison/		Ice cover			Secchi depth			Sea-surface temperature			Sea-surface salinity		
survey type	Cruise[a]	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	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	8.9	19.7	216	1.7	1.3	210	6.9	2.4	211	24.9	2.8	211
	LS97	4.9	15.8	276	2.0	2.6	275	8.5	2.2	275	17.1	3.4	275
	ES98	12.4	27.0	218	1.5	1.1	205	6.5	2.2	205	19.1	4.9	205
	MS98	6.9	20.0	99	1.4	1.4	95	7.2	2.0	96	18.7	4.5	96
	LS98	5.2	15.7	228	1.7	1.7	225	7.0	2.3	226	17.6	3.7	226
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	3.6	16.3	113	2.3	2.7	110	9.5	2.2	110	18.2	3.2	110
	ES98	10.7	24.7	87	1.7	1.1	83	7.2	2.4	84	19.8	4.3	84
	MS98	13.7	29.9	40	2.0	1.7	37	8.1	1.8	37	19.7	4.1	37
	LS98	1.1	2.2	91	2.0	1.6	90	7.6	2.4	91	18.7	3.3	91
KITTLITZ'S MURRELET (USE)													
Nearshore	ES96	4.3	11.8	142	–	–	0	5.9	2.1	142	–	–	0
	LS96	14.1	20.1	184	–	–	0	4.7	1.3	184	–	–	0
	ES97	5.6	11.0	504	1.6	1.1	467	6.3	1.8	469	25.6	2.4	469
	LS97	6.9	13.4	428	0.7	0.6	428	7.5	1.6	428	17.2	3.5	428
	ES98	1.1	2.1	44	1.1	0.3	44	6.7	1.3	44	19.4	3.3	44
	MS98	5.8	11.6	122	0.8	0.7	122	6.2	1.5	122	19.1	4.5	122
	LS98	9.0	15.5	463	0.8	0.5	463	5.3	1.2	463	17.5	4.2	463

Table 18. Continued.

		Habitat variable											
		Ice cover			Secchi depth			Sea-surface temperature			Sea-surface salinity		
Comparison/ survey type	Cruise[a]	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n
KITTLITZ'S MURRELET (CONTINUED)													
Offshore	ES96	9.9	13.9	234	–	–	0	6.2	1.9	234	–	–	0
	LS96	1.9	1.8	25	–	–	0	5.2	1.6	25	–	–	0
	ES97	7.2	12.1	130	1.6	0.9	129	8.0	1.9	129	24.7	2.1	129
	LS97	1.2	2.1	107	2.4	3.5	107	8.3	2.1	107	17.8	3.6	107
	ES98	5.4	4.9	67	1.2	0.4	67	6.3	1.9	67	21.1	3.9	67
	MS98	9.7	16.3	94	1.1	0.9	94	7.3	1.2	94	19.6	4.2	94
	LS98	2.2	4.0	157	1.2	0.7	157	5.9	1.5	157	19.7	3.2	157

[a] ES96 = early summer 1996; LS96 = late summer 1996; ES97 = early summer 1997; LS97 = late summer 1997; ES98 = early summer 1998; MS = mid-summer 1998; LS = late summer 1998.

Table 19. Results of 3-factor MANOVA on large-scale availability of ice cover, secchi depth, sea-surface temperature, and sea-surface salinity to Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1997–1998, by season, year, and survey type.

Habitat variable[a]	Source	MS	df	F	*P*-value[b]	Observed power[c]	Results of multiple comparisons
Ice	Overall model	57,889,145.0	9	3.961	<0.001*	0.996	
	Season	237,000,000.0	2	16.193	<0.001*	1.000	ES = MS > LS[d]
	Year	736,377.8	1	0.050	0.822	0.056	
	Survey type	626,500.2	1	0.043	0.836	0.055	
	Year × season	3,856,578.4	1	0.264	0.608	0.081	
	Year × survey type	11,522,612.0	1	0.788	0.375	0.144	
	Survey type × season	14,324,626.0	2	0.980	0.375	0.221	
Secchi	Overall model	36,501,522.0	9	4.178	<0.001*	0.997	
	Season	8,434,319.6	2	0.965	0.381	0.219	
	Year	20,099,441.0	1	2.301	0.130	0.329	
	Survey type	198,000,000.0	1	22.643	<0.001*	0.997	offshore > nearshore
	Year × season	33,160,969.0	1	3.796	0.052	0.495	
	Year × survey type	7,671,287.5	1	0.878	0.349	0.155	
	Survey type × season	5,465,462.1	2	0.626	0.535	0.155	
SST	Overall model	343,000,000.0	9	22.844	<0.001*	1.000	
	Season	400,000,000.0	2	26.626	<0.001*	1.000	LS > MS = ES[d]
	Year	944,000,000.0	1	62.843	<0.001*	1.000	1997 > 1998
	Survey type	445,000,000.0	1	29.607	<0.001*	1.000	offshore > nearshore
	Year × season	304,000,000.0	1	20.242	<0.001*	0.994	
	Year × survey type	7,541,802.4	1	0.502	0.479	0.109	
	Survey type × season	3,805,085.2	2	0.253	0.776	0.090	

Table 19. Continued.

Habitat variable[a]	Source	MS	df	F	P-value[b]	Observed power[c]	Results of multiple comparisons
SSS	Overall model	614,000,000.0	9	106.991	<0.001*	1.000	
	Season	1,300,000,000.0	2	226.730	<0.001*	1.000	ES > MS > LS[d]
	Year	673,000,000.0	1	117.209	<0.001*	1.000	1997 > 1998
	Survey type	48,237,907.0	1	8.403	0.004*	0.826	offshore > nearshore
	Year × season	1,040,000,000.0	1	180.372	<0.001*	1.000	
	Year × survey type	1,135,699.8	1	0.198	0.657	0.073	
	Survey type × season	6,980,213.1	2	1.216	0.297	0.266	

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

[b] * = Significant at $\alpha = 0.05$.

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

[d] ES = early summer; MS = mid-summer; LS = late summer.

Table 20. Results of 3-factor MANOVA on large-scale availability of ice cover and sea-surface temperature to Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1996–1998, by season, year, and survey type.

Habitat variable[a]	Source	MS	df	F	*P*-value[b]	Observed power[c]	Results of multiple comparisons
Ice	Overall model	68,333,258.0	13	4.239	<0.001*	1.000	
	Season	194,000,000.0	2	12.056	<0.001*	0.995	ES = MS, ES > LS, MS = LS[d]
	Year	164,000,000.0	2	10.183	<0.001*	0.987	1997 = 1998 > 1996
	Survey type	8,878.6	1	0.001	0.981	0.050	
	Year × season	48,012,087.0	2	2.979	0.051	0.580	
	Year × survey type	6,645,837.2	2	0.412	0.662	0.117	
	Survey type × season	8,943,784.4	2	0.555	0.574	0.142	
SST	Overall model	328,000,000.0	13	20.830	<0.001*	1.000	
	Season	504,000,000.0	2	32.057	<0.001*	1.000	LS = MS > ES[d]
	Year	862,000,000.0	2	54.811	<0.001*	1.000	1997 > 1998 = 1996
	Survey type	393,000,000.0	1	24.967	<0.001*	0.999	offshore > nearshore
	Year × season	158,000,000.0	2	10.038	<0.001*	0.985	
	Year × survey type	28,531,303.0	2	1.813	0.163	0.380	
	Survey type × season	4,189,481.0	2	0.266	0.766	0.092	

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

[b] * = Significant at $\alpha = 0.05$.

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

[d] ES = early summer; MS = mid-summer; LS = late summer.

Table 21. Results of 3-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 1997–1998, by season, year, and survey type.

Habitat variable[a]	Source	MS	df	F	*P*-value[b]	Observed power[c]	Results of multiple comparisons
Ice	Overall model	163,000,000.0	9	21.750	<0.001*	1.000	
	Season	25,712,343.0	2	3.432	0.033*	0.646	LS > MS = ES[d]
	Year	2,517,448.6	1	0.336	0.562	0.089	
	Survey type	22,213,720.0	1	2.965	0.085	0.406	
	Year × season	211,000,000.0	1	28.209	<0.001*	1.000	
	Year × survey type	375,000,000.0	1	49.999	<0.001*	1.000	
	Survey type × season	466,000,000.0	2	62.186	<0.001*	1.000	
Secchi	Overall model	246,000,000.0	9	47.198	<0.001*	1.000	
	Season	113,000,000.0	2	21.704	<0.001*	1.000	ES > MS = LS[d]
	Year	120,000,000.0	1	22.933	<0.001*	0.998	1997 > 1998
	Survey type	353,000,000.0	1	67.739	<0.001*	1.000	offshore > nearshore
	Year × season	19,222,907.0	1	3.689	0.055	0.484	
	Year × survey type	17,447,670.0	1	3.348	0.067	0.448	
	Survey type × season	72,377,295.0	2	13.889	<0.001*	0.998	
SST	Overall model	758,000,000.0	9	94.538	<0.001*	1.000	
	Season	126,000,000.0	2	15.783	<0.001*	1.000	ES = MS, ES > LS, MS = LS[d]
	Year	1,460,000,000.0	1	181.940	<0.001*	1.000	1997 > 1998
	Survey type	1,210,000,000.0	1	150.574	<0.001*	1.000	offshore > nearshore
	Year × season	651,000,000.0	1	81.213	<0.001*	1.000	
	Year × survey type	306,000,000.0	1	38.204	<0.001*	1.000	
	Survey type × season	80,381,193.0	2	10.030	<0.001*	0.985	

Table 21. Continued.

Habitat variable[a]	Source	MS	df	F	*P*-value[b]	Observed power[c]	Results of multiple comparisons
SSS	Overall model	1,390,000,000.0	9	273.617	<0.001*	1.000	
	Season	1,530,000,000.0	2	300.168	<0.001*	1.000	ES > MS > LS[d]
	Year	420,000,000.0	1	82.472	<0.001*	1.000	1997 > 1998
	Survey type	61,457,804.0	1	12.074	0.001*	0.935	offshore > nearshore
	Year × season	998,000,000.0	1	196.006	<0.001*	1.000	
	Year × survey type	69,596,562.0	1	13.673	<0.001*	0.959	
	Survey type × season	55,253,422.0	2	10.855	<0.001*	0.991	

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

[b] * = Significant at $\alpha = 0.05$.

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

[d] ES = early summer; MS = mid-summer LS = late summer.

Table 22. 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 1996–1998, by season, year, and survey type.

Habitat variable[a]	Source	MS	df	F	*P*-value[b]	Observed power[c]	Results of multiple comparisons
Ice	Overall model	246,000,000.0	13	27.375	<0.001*	1.000	
	Season	224,000,000.0	2	24.970	<0.001*	1.000	LS > MS = ES[d]
	Year	5,750,774.8	2	0.640	0.527	0.158	
	Survey type	674,088.6	1	0.075	0.784	0.059	
	Year × season	295,000,000.0	2	32.822	<0.001*	1.000	
	Year × survey type	236,000,000.0	2	26.262	<0.001*	1.000	
	Survey type × season	464,000,000.0	2	51.659	<0.001*	1.000	
SST	Overall model	678,000,000.0	13	84.398	<0.001*	1.000	
	Season	231,000,000.0	2	28.743	<0.001*	1.000	MS = ES > LS[d]
	Year	1,710,000,000.0	2	213.107	<0.001*	1.000	1997 > 1998 > 1996
	Survey type	955,000,000.0	1	118.919	<0.001*	1.000	offshore > nearshore
	Year × season	421,000,000.0	2	52.483	<0.001*	1.000	
	Year × survey type	190,000,000.0	2	23.608	<0.001*	1.000	
	Survey type × season	76,576,582.0	2	9.535	<0.001*	0.981	

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

[b] * = Significant at $\alpha = 0.05$.

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

[d] ES = early summer; MS = mid-summer; LS = late summer.

Table 23. Results of 3-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 1997–1998, by season, year, and survey type.

Habitat variable[a]	Source	MS	df	F	*P*-value[b]	Observed power[c]	Results of multiple comparisons
Ice	Overall model	600,000,000.0	9	56.262	<0.001*	1.000	used ice cover > availability
	Season	155,000,000.0	4	14.545	<0.001*	1.000	
	Year	9,144,226.1	2	0.585	0.424	0.198	
	Survey type	103,000,000.0	2	9.676	<0.001*	0.982	
Secchi	Overall model	410,000,000.0	9	60.918	<0.001*	1.000	used secchi depth < availability
	Season	236,000,000.0	4	35.031	<0.001*	1.000	
	Year	34,951,127.0	2	5.198	0.006*	0.831	
	Survey type	341,000,000.0	2	50.664	<0.001*	1.000	
SST	Overall model	1,190,000,000.0	9	105.039	<0.001*	1.000	used temperature < availability
	Season	424,000,000.0	4	37.494	<0.001*	1.000	
	Year	2,590,000,000.0	2	228.953	<0.001*	1.000	
	Survey type	1,300,000,000.0	2	114.633	<0.001*	1.000	
SSS	Overall model	1,710,000,000.0	9	279.989	<0.001*	1.000	used salinity > availability
	Season	3,030,000,000.0	4	495.059	<0.001*	1.000	
	Year	389,000,000.0	2	63.498	<0.001*	1.000	
	Survey type	58,437,105.0	2	9.546	<0.001*	0.981	

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

[b] * = Significant at $\alpha = 0.05$.

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

Table 24. 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 1996–1998, by season, year, and survey type.

Habitat variable[a]	Source	MS	df	F	*P*-value[b]	Observed power[c]	Results of multiple comparisons
Ice	Overall model	776,000,000.0	11	62.066	<0.001*	1.000	used ice cover > availability
	Season	258,000,000.0	4	20.618	<0.001*	1.000	
	Year	116,000,000.0	4	9.245	<0.001*	1.000	
	Survey type	25,465,833.0	2	2.036	0.131	0.422	
SST	Overall model	1,270,000,000.0	11	106.869	<0.001*	1.000	used temperature < availability
	Season	440,000,000.0	4	37.180	<0.001*	1.000	
	Year	1,890,000,000.0	4	159.530	<0.001*	1.000	
	Survey type	1,420,000,000.0	2	120.253	<0.001*	1.000	

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

[b] * = Significant at $\alpha = 0.05$.

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

Table 25. 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 1996–1998, by survey type, cruise, and habitat variable.

		Habitat variable											
Comparison/		Ice cover			Secchi depth			Sea-surface temperature			Sea-surface salinity		
survey type	Cruise[a]	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n
SEGMENT (AVAILABILITY)													
Nearshore	ES96	7.9	15.5	19	–	–	0	–	–	0	–	–	0
	LS96	15.3	23.2	45	–	–	0	–	–	0	–	–	0
	ES97	6.8	12.8	97	1.5	1.0	43	6.4	1.8	45	25.4	2.4	46
	LS97	6.3	15.0	84	0.8	1.0	44	7.5	1.7	45	17.1	3.7	45
	ES98	1.9	2.7	17	1.1	0.4	13	6.1	1.6	13	18.7	4.5	13
	MS98	5.8	13.5	34	0.9	1.0	17	6.6	1.4	17	20.6	3.4	17
	LS98	8.1	16.1	79	0.7	0.6	21	5.4	1.7	21	16.6	4.1	21
	Total	7.7	15.7	375	1.0	0.9	138	6.6	1.8	141	20.3	5.1	142
Offshore	ES96	3.1	4.5	14	–	–	0	–	–	0	–	–	0
	LS96	1.5	1.6	7	–	–	0	–	–	0	–	–	0
	ES97	6.5	11.9	31	1.2	0.6	5	9.4	1.3	5	26.4	1.3	5
	LS97	1.2	2.3	34	–	–	0	–	–	0	–	–	0
	ES98	4.9	5.5	19	1.2	0.3	9	6.7	2.9	9	20.9	2.2	9
	MS98	10.9	22.9	18	1.5	1.0	8	7.5	1.3	8	22.8	2.7	8
	LS98	1.7	2.9	30	–	–	0	–	–	0	–	–	0
	Total	4.2	10.2	153	1.3	0.7	22	7.6	2.3	22	22.8	3.0	22

Table 25. Continued.

		Habitat variable											
Comparison/ survey type	Cruise[a]	Ice cover			Secchi depth			Sea-surface temperature			Sea-surface salinity		
		$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n	$\bar{x}$	SD	n
KITTLITZ'S MURRELET (USE)													
Nearshore	ES96	1.5	3.0	60	–	–	0	–	–	0	–	–	0
	LS96	3.5	6.8	158	–	–	0	–	–	0	–	–	0
	ES97	1.8	4.4	501	1.3	1.0	118	6.5	1.8	124	24.7	2.9	125
	LS97	2.4	6.2	422	0.9	1.1	88	7.5	1.6	87	17.0	3.1	87
	ES98	0.8	1.6	44	1.0	0.4	25	6.4	1.7	25	19.3	3.6	25
	MS98	2.2	5.1	121	0.6	0.6	28	6.7	1.3	28	20.2	3.4	28
	LS98	2.0	3.2	454	0.5	0.5	43	5.8	1.4	43	17.0	3.4	43
	Total	2.2	4.9	1,760	0.9	0.9	302	6.7	1.7	307	20.1	4.6	308
Offshore	ES96	0.8	1.9	51	–	–	0	–	–	0	–	–	0
	LS96	2.2	3.5	14	–	–	0	–	–	0	–	–	0
	ES97	2.6	5.7	117	1.1	0.4	12	8.5	0.9	12	26.8	1.2	12
	LS97	1.0	2.8	96	–	–	0	–	–	0	–	–	0
	ES98	1.1	1.3	65	0.6	0.4	25	6.1	2.2	22	20.8	2.6	21
	MS98	0.9	1.7	83	1.1	0.4	13	5.6	1.6	13	21.9	2.2	13
	LS98	1.3	2.8	134	–	–	0	–	–	0	–	–	0
	Total	1.4	3.4	560	0.9	0.4	50	6.3	2.0	47	22.3	3.1	46

[a] ES96 = early summer 1996; LS96 = late summer 1996; ES97 = early summer 1997; LS97 = late summer 1997; ES98 = early summer 1998; MS98 = mid-summer 1998; LS98 = late summer 1998.

Table 26. Results of 3-factor ANOVAs on large-scale availability, small-scale use, and availability versus use of ice cover by Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1996–1998, by season, year, and survey type.

Comparison/source	MS	df	F	*P*-value[a]	Observed power[b]	Results of multiple comparisons
AVAILABILITY						
Overall model	1,049,142.4	13	2.109	0.012*	0.952	
Season	250,072.0	2	0.503	0.605	0.133	
Year	133,170.4	2	0.268	0.765	0.092	
Survey type	321,027.2	1	0.645	0.422	0.126	
Year × season	2,370,010.3	2	4.764	0.009*	0.793	
Year × survey type	1,072,508.5	2	2.156	0.117	0.441	
Survey type × season	1,366,397.0	2	2.747	0.065	0.542	
USE						
Overall model	6,514,703.1	13	10.934	<0.001*	1.000	
Season	6,544,943.9	2	10.984	<0.001*	0.991	LS = MS > ES[c]
Year	3,094,714.1	2	5.194	0.006*	0.830	1998 = 1996, 1998 > 1997, 1996 = 1997
Survey type	2,835,944.3	1	4.760	0.029*	0.587	nearshore > offshore
Year × season	8,217,387.4	2	13.791	<0.001*	0.998	
Year × survey type	4,735,706.6	2	7.948	<0.001*	0.955	
Survey type × season	4,612,236.1	2	7.741	<0.001*	0.950	
AVAILABILITY VS. USE						
Overall model	11,421,372.0	11	19.275	<0.001*	1.000	used ice cover < availability
Season	4,223,556.4	4	7.128	<0.001*	0.996	
Year	1,989,068.9	4	3.357	0.009*	0.849	
Survey type	5,103,477.3	2	8.613	<0.001*	0.968	

[a] * = Significant at $\alpha = 0.05$.

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

[c] ES = early summer; MS = mid-summer; LS = late summer.

Table 27. Results of 3-factor ANOVAs on large-scale availability, small-scale use, and availability versus use of secchi depth by Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1997–1998, by season, year, and survey type.

Comparison/source	MS	df	F	*P*-value[a]	Observed power[b]	Results of multiple comparisons
AVAILABILITY						
Overall model	44,044.4	7	4.236	<0.001*	0.988	
Season	67,943.2	2	6.535	0.002*	0.904	ES = MS, ES > LS, MS = LS[c]
Year	51.1	1	0.005	0.944	0.051	
Survey type	19,052.6	1	1.832	0.178	0.270	
Year × season	606.1	1	0.058	0.810	0.057	
Year × survey type	554.0	1	0.053	0.818	0.056	
Survey type × season	12,090.3	1	1.163	0.283	0.188	
USE						
Overall model	63,425.7	7	6.190	<0.001*	1.000	
Season	42,057.9	1	4.105	0.044*	0.524	ES = MS, ES > LS, MS = LS[c]
Year	53,878.1	1	5.259	0.022*	0.628	1997 > 1998
Survey type	59,672.2	2	5.824	0.003*	0.870	offshore > nearshore
Year × season	47,480.2	1	4.634	0.032*	0.574	
Year × survey type	40,331.0	1	3.936	0.048*	0.507	
Survey type × season	123,538.4	1	12.058	0.001*	0.934	
AVAILABILITY VS. USE						
Overall model	77,503.0	9	6.918	<0.001*	1.000	used secchi depth < availability
Season	97,707.5	4	9.322	<0.001*	1.000	
Year	26,933.5	2	2.570	0.078	0.513	
Survey type	17,272.3	2	1.648	0.193	0.348	

[a] * = Significant at $\alpha = 0.05$.

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

[c] ES = early summer; MS = mid-summer; LS = late summer.

Table 28. Results of 3-factor ANOVAs on large-scale availability, small-scale use, and availability versus use of sea-surface temperature by Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1997–1998, by season, year, and survey type.

Comparison/source	MS	df	F	*P*-value[a]	Observed power[b]	Results of multiple comparisons
AVAILABILITY						
Overall model	61,608.3	7	5.137	<0.001*	0.997	
Season	22,622.5	2	1.886	0.155	0.388	
Year	212,274.6	1	17.700	<0.001*	0.987	1997 > 1998
Survey type	149,067.3	1	12.430	0.001*	0.939	offshore > nearshore
Year × season	79,107.1	1	6.596	0.011*	0.723	
Year × survey type	46,672.0	1	3.892	0.050*	0.500	
Survey type × season	2,999.9	1	0.250	0.618	0.079	
USE						
Overall model	95,438.9	7	10.219	<0.001*	1.000	
Season	921.2	2	0.099	0.906	0.065	
Year	413,830.9	1	44.308	<0.001*	1.000	1997 > 1998
Survey type	11,085.5	1	1.187	0.277	0.192	
Year × season	86,369.6	1	9.529	0.002*	0.868	
Year × survey type	88,997.1	1	9.247	0.003*	0.858	
Survey type × season	26,857.9	1	2.876	0.091	0.394	
AVAILABILITY VS. USE						
Overall model	81,808.1	9	7.601	<0.001*	1.000	used temperature > availability
Season	38,960.5	4	3.620	0.006*	0.875	
Year	281,978.3	2	26.199	<0.001*	1.000	
Survey type	99,792.8	2	9.272	<0.001*	0.977	

[a] * = Significant at $\alpha = 0.05$.

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

Table 29. Results of 3-factor ANOVAs on large-scale availability, small-scale use, and availability versus use of sea-surface salinity by Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1997–1998, by season, year, and survey type.

Comparison/source	MS	df	F	*P*-value[a]	Observed power[b]	Results of multiple comparisons
AVAILABILITY						
Overall model	191,177.2	7	32.118	<0.001*	1.000	
Season	234,353.7	2	39.371	<0.001*	1.000	ES > MS > LS[c]
Year	136,608.0	1	22.950	<0.001*	0.997	1997 > 1998
Survey type	25,599.6	1	4.301	0.040*	0.540	offshore > nearshore
Year × season	136,595.8	1	22.948	<0.001*	0.997	
Year × survey type	739.3	1	0.124	0.725	0.064	
Survey type × season	410.1	1	0.069	0.793	0.058	
USE						
Overall model	401,513.0	7	88.293	<0.001*	1.000	
Season	433,152.8	2	95.251	<0.001*	1.000	ES > MS > LS[c]
Year	347,934.4	1	76.511	<0.001*	1.00	1997 > 1998
Survey type	35,926.2	1	7.900	0.005*	0.800	offshore > nearshore
Year × season	197,492.3	1	43.429	<0.001*	1.000	
Year × survey type	13,676.6	1	3.007	0.084	0.409	
Survey type × season	8,342.2	1	1.834	0.176	0.272	
AVAILABILITY VS. USE						
Overall model	408,186.0	9	69.632	<0.001*	1.000	used salinity > availability
Season	698,084.0	4	119.085	<0.001*	1.000	
Year	269,063.9	2	45.899	<0.001*	1.000	
Survey type	4,409.7	2	0.752	0.472	0.178	

[a] * = Significant at $\alpha = 0.05$.

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

[c] ES = early summer; MS = mid-summer; LS = late summer.

Table 30. 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 1996–1998, by survey type, year, and bay.

Survey		HY density			AHY density[a]			HY:AHY ratio	
type/year	Bay	$\bar{x}$	n	Maximal	$\bar{x}$	n	Maximal	$\bar{x}$	Maximal
NEARSHORE									
1996	Unakwik Inlet	0	2	0	0.38	3	1.03	0:1	0:1
	College Fjord	0.02	3	0.04	1.16	2	2.19	0.02:1	0.02:1
	Harriman Fjord	0	3	0	2.61	2	2.94	0:1	0:1
	Blackstone Bay	0	2	0	2.73	2	3.76	0:1	0:1
	Total	0.01	10	0.04	1.69	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	1.96	2	3.02	0:1	0:1
	Total	0	11	0	5.34	9	10.76	0:1	0:1
1998	Unakwik Inlet	0	2	0	0.63	3	1.89	0:1	0:1
	College Fjord	0	2	0	1.35	2	2.42	0:1	0:1
	Harriman Fjord	0[b]	3	0	0.18	2	0.36	0:1[b]	0:1
	Blackstone Bay	0	2	0	0.03	2	0.06	0:1	0:1
	Total	0[b]	9	0	0.54	9	2.42	0:1[b]	0:1
OFFSHORE									
1996	Unakwik Inlet	0	2	0	6.01	3	17.66	0:1	0:1
	College Fjord	0	3	0	0.95	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	5.61	2	6.10	0:1	0:1
	Total	0	10	0	4.36	9	17.66	0:1	0:1
1997	Unakwik Inlet	0	2	0	1.00	3	1.53	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	2.78	9	7.60	0:1	0:1

Table 30. Continued.

Survey		HY density			AHY density[a]			HY:AHY ratio	
type/year	Bay	$\bar{x}$	n	Maximal	$\bar{x}$	n	Maximal	$\bar{x}$	Maximal
OFFSHORE (CONTINUED)									
1998	Unakwik Inlet	0	2	0	0.15	3	0.45	0:1	0:1
	College Fjord	0	2	0	2.91	2	5.46	0:1	0:1
	Harriman Fjord	0[b]	3	0	1.12	2	1.47	0:1[b]	0:1
	Blackstone Bay	0	2	0	0.71	2	1.42	0:1	0:1
	Total	0[b]	9	0	1.24	9	5.46	0:1[b]	0:1

[a] Assumes that all unknown-age birds were AHY birds.

[b] We saw an adult carrying a fish into the hills in the outer part of this bay but did not see any HY birds later in the summer; hence, it appears that reproduction was not successful here.

Table 31. Plumage characteristics of after-hatching-year (AHY) Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1996–1998, 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	132	93.0	8	5.6	2	1.4	0	0	142
Early summer 1997	484	96.0	18	3.6	2	0.4	0	0	504
Early summer 1998	37	84.1	7	15.9	0	0	0	0	44
Mid-summer 1998	120	98.4	2	1.6	0	0	0	0	122
Late summer 1996	175	95.6	8	4.4	0	0	0	0	183
Late summer 1997	413	96.5	15	3.5	0	0	0	0	428
Late summer 1998	451	97.4	12	2.6	0	0	0	0	463
OFFSHORE									
Early summer 1996	215	91.9	18	7.7	1	0.4	0	0	234
Early summer 1997	126	96.9	4	3.1	0	0	0	0	130
Early summer 1998	61	91.0	6	9.0	0	0	0	0	67
Mid-summer 1998	94	100.0	0	0	0	0	0	0	94
Late summer 1996	24	96.0	1	4.0	0	0	0	0	25
Late summer 1997	104	97.2	3	2.8	0	0	0	0	107
Late summer 1998	147	93.6	10	6.4	0	0	0	0	157
NEARSHORE + OFFSHORE									
Early summer 1996	347	92.3	26	6.9	3	0.8	0	0	376
Early summer 1997	610	96.2	22	3.5	2	0.3	0	0	634
Early summer 1998	98	88.3	13	11.7	0	0	0	0	111
Mid-summer 1998	214	99.1	2	0.9	0	0	0	0	216
Late summer 1996	199	95.7	9	4.3	0	0	0	0	208
Late summer 1997	517	96.6	18	3.4	0	0	0	0	535
Late summer 1998	598	96.5	22	3.5	0	0	0	0	620

Table 32. Results of multiway contingency tests on percentages of after-hatching-year (AHY) Kittlitz's murrelets that were in breeding plumage in four bays in Prince William Sound, Alaska, in 1996–1998.

Source	χ^2	df	*P*-value[a]	Conclusion
Model	25.025	5	<0.001*	
Survey type	0.321	1	0.571	
Season	12.360	2	0.002*	MS = LS > ES[b]
Year	6.500	2	0.039*	1997 > 1998 = 1996

[a] * = Significant at $\alpha = 0.05$.

[b] ES = early summer; MS = mid-summer; LS = late summer.

Table 33. Percentage of after-hatching-year (AHY) Kittlitz's murrelet observations that consisted of single birds in four bays in Prince William Sound, Alaska, in 1996–1998, by survey type and cruise.

	Group size				
	1 bird		>1 bird		
Survey type/cruise	Number	Percent	Number	Percent	Total
NEARSHORE					
Early summer 1996	46	50.5	45	49.5	91
Early summer 1997	196	61.8	121	38.2	317
Early summer 1998	27	81.8	6	18.2	33
Mid-summer 1998	75	78.1	21	21.9	96
Late summer 1996	118	81.9	26	18.1	144
Late summer 1997	254	77.4	74	22.6	328
Late summer 1998	264	75.6	75	24.4	339
OFFSHORE					
Early summer 1996	58	43.6	75	56.4	133
Early summer 1997	56	63.6	32	36.4	88
Early summer 1998	27	60.0	18	40.0	45
Mid-summer 1998	44	66.7	22	33.3	66
Late summer 1996	23	95.8	1	4.2	24
Late summer 1997	66	76.7	20	23.3	86
Late summer 1998	64	63.4	37	36.6	101
NEARSHORE + OFFSHORE					
Early summer 1996	104	46.4	120	53.6	224
Early summer 1997	252	62.2	153	37.8	405
Early summer 1998	54	69.2	24	30.8	78
Mid-summer 1998	119	73.5	43	26.5	162
Late summer 1996	141	83.9	27	16.1	168
Late summer 1997	320	77.3	94	22.7	414
Late summer 1998	328	74.5	112	25.5	440

Table 34. Results of multiway contingency tests on percentages of Kittlitz's murrelet observations that consisted of single birds in four bays in Prince William Sound, Alaska, in 1996–1998.

Source	χ^2	df	*P*-value[a]	Conclusion
Model	85.240	5	<0.001*	
Season	52.079	2	<0.001*	LS > MS > ES[b]
Year	2.424	2	0.298	
Survey type	7.812	1	0.005*	nearshore > offshore

[a] * = Significant at $\alpha = 0.05$.

[b] ES = early summer; MS = mid-summer; LS = late summer.

Table 35. Records of mixed-species Kittlitz's/marbled murrelet "pairs" in Prince William Sound, Alaska, in 1996–1998, 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
Late summer 1998	Unakwik Inlet	21 July	1
	College Fjord	15 July	1
	College Fjord	24 July	1

Table 36. Number of records of mixed-species Kittlitz's/marbled murrelet "pairs" and estimated ratio of marbled murrelet populations to Kittlitz's murrelet populations in Prince William Sound, Alaska, in 1996–1998, by nay and year. The number of records is summarized from Table 35. The estimated number of Kittlitz's murrelets in each bay is from Table 15, and the estimated number of marbled murrelets is from Appendix 11.

	Number of records			Marbled:Kittlitz's ratio		
Bay	1996	1997	1998	1996	1997	1998
Unakwik Inlet	0	6	1	1.6:1	12.3:1	31.7:1
College Fjord	2	1	2	4.0:1	1.8:1	2.4:1
Harriman Fjord	0	9–11	0	3.2:1	4.8:1	4.7:1
Blackstone Bay	0	0	0	2.8:1	3.9:1	12.3:1

Table 37. Sampling effort and catch rates of Kittlitz's murrelets with floating mist nets in Prince William Sound, Alaska, in early summer 1996.

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

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

Table 38. Results of multiway contingency table analyses of the effects of 15 variables on percentages of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996–1998. Analyses were conducted only for birds on the water. The 2-yr data set is for 1997–1998 only, and the "basic + shoreline" model is for nearshore data only.

	Model type[a]				
	Basic variables	Basic + water variables		Basic + shoreline variables	
Variable	(3-yr data set)	(3-yr data set)	(2-yr data set)	(3-yr data set)	Conclusion
Survey type	<0.001*	<0.001*	<0.001*	–	nearshore > offshore
Time of day	0.051	0.130	0.179	0.136	
Season	0.019*	0.022*	0.758	0.023*	LS > ES = MS[b]
Year	<0.001*	<0.001*	<0.001*	<0.001*	1997 > 1998 > 1996
Tidal stage	0.642	0.220	0.203	0.344	
Current strength	0.251	0.186	0.010*	0.364	
Habitat type	0.049*	0.563	0.067	0.001*	no specific habitat types are significant, although overall variable is
Percent ice cover	–	<0.001*	<0.001*	–	40 = 0 > 15 > 3[c]
Secchi depth	–	–	0.300	–	
Sea-surface temperature	–	0.173	0.462	–	
Sea-surface salinity	–	–	0.089	–	
Distance from fresh water	–	–	–	0.065	
Distance from shore	–	–	–	<0.001*	1 > 51 > 101 > 151[d]
Depth	–	–	–	0.006*	1 > 21 = 41 = 61[e]
Shoreline substrate	–	–	–	<0.001*	LA = FA = IC > BE[f]

[a] * = Significant at $\alpha = 0.05$.

[b] ES = early summer; MS = mid-summer; LS = late summer.

[c] 0 = 0–1%; 3 = 3–10%; 15 = 15–35%; 40 = 40–100%.

[d] 1 = 1–50 m; 51 = 51–100 m; 101 = 101–150 m; 151 = 151–200 m.

[e] 1 = 1–20 m; 21 = 21–40 m; 41 = 41–60 m; 61 = 61–80 m.

[f] IC = ice; FA = sand-gravel; LA = cobble-boulder; BE = bedrock.

Table 39. Number (percentage) of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996–1998, by season, survey type, year, and time of day. Analyses were conducted only for birds on the water. Highest frequency of feeding for each season-year sample is in boldface.

		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)	
	1998	13	19	32	4	8	12	17	27	44
(Percent)		**(40.6)**	(59.4)		(33.3)	(66.7)		(38.6)	(61.4)	
	1996–1998	196	198	394	128	167	295	324	365	689
(Percent)		**(49.7)**	(50.3)		(43.4)	(56.6)		(47.0)	(53.0)	
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)	
	1998	11	34	45	3	17	20	14	51	65
(Percent)		**(24.4)**	(75.6)		(15.0)	(85.0)		(21.5)	(78.5)	
	1996–1998	21	118	139	34	229	263	55	347	402
(Percent)		**(15.1)**	(84.9)		(12.9)	(87.1)		(13.7)	(86.3)	
MID-SUMMER										
Nearshore	1998	22	22	44	34	43	77	56	65	121
(Percent)		**(50.0)**	(50.0)		(44.2)	(55.8)		(46.3)	(53.7)	
Offshore	1998	2	34	36	11	36	47	13	70	83
(Percent)		(5.6)	(94.4)		**(23.4)**	(76.6)		(15.7)	(84.3)	

Table 39. Continued

		Time of day								
		Morning[a]			Afternoon[a]			Total		
Season/ survey type	Year	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total
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)	
	1998	69	64	133	120	201	321	189	265	454
(Percent)		**(51.9)**	(48.1)		(37.4)	(62.6)		(41.6)	(58.4)	
	1996–1998	230	215	445	287	330	617	517	545	1,062
(Percent)		**(51.7)**	(48.3)		(46.5)	(53.5)		(48.7)	(51.3)	
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)	
	1998	9	99	108	3	23	26	12	122	134
(Percent)		(8.3)	(91.7)		**(11.5)**	(88.5)		(9.0)	(91.0)	
	1996–1998	31	194	225	3	25	28	34	219	253
(Percent)		**(13.8)**	(86.2)		(10.7)	(89.3)		(13.4)	(86.6)	
TOTALS										
Nearshore	1996–1998	448	435	883	449	540	989	897	975	1,872
(Percent)		**(50.7)**	(49.3)		(45.4)	(54.6)		(47.9)	(52.1)	
Offshore	1996–1998	54	346	400	48	290	338	102	636	738
(Percent)		(13.5)	(86.5)		**(14.2)**	(85.8)		(13.8)	(86.2)	
Combined	1996–1998	502	781	1,283	497	830	1,327	999	1,611	2,610
(Percent)		**(39.1)**	(60.9)		(37.5)	(62.5)		(38.3)	(61.7)	

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

Table 40. Number (percentage) of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996–1998, by season, year, and standardized habitat type. Analyses were conducted only for birds on the water. Highest frequency of feeding for each season-year sample is in boldface.

		Habitat type											
		Glacial-affected			Glacial-stream-affected			Marine-sill-affected			Glacial-unaffected		
Season/ survey type	Year	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total
EARLY SUMMER													
Nearshore	1996	9	9	18	4	27	31	0	0	0	21	71	92
(Percent)		**(50.0)**	(50.0)		(12.9)	(87.1)		(0)	(0)		(22.8)	(77.2)	
	1997	47	75	122	99	62	161	0	0	0	127	94	221
(Percent)		(38.5)	(61.5)		**(61.4)**	(38.5)		(0)	(0)		(57.5)	(42.5)	
	1998	1	1	2	13	16	29	0	0	0	3	10	13
(Percent)		**(50.0)**	(50.0)		(44.8)	(55.2)		(0)	(0)		(23.1)	(76.9)	
	1996–1998	57	85	142	116	105	221	0	0	0	151	175	326
(Percent)		(40.1)	(59.9)		**(52.5)**	(47.5)		(0)	(0)		(46.3)	(53.7)	
Offshore	1996	0	0	0	0	0	0	0	0	0	15	203	218
(Percent)		(–)	(–)		(–)	(–)		(–)	(–)		**(6.9)**	(93.1)	
	1997	0	0	0	0	0	0	0	0	0	26	93	119
(Percent)		(–)	(–)		(–)	(–)		(–)	(–)		**(21.8)**	(78.2)	
	1998	0	0	0	0	0	0	0	0	0	14	51	65
(Percent)		(–)	(–)		(–)	(–)		(–)	(–)		**(21.5)**	(78.5)	
	1996–1998	0	0	0	0	0	0	0	0	0	55	347	402
(Percent)		(–)	(–)		(–)	(–)		(–)	(–)		**(13.7)**	(86.3)	
MID-SUMMER													
Nearshore	1998	5	26	31	24	19	43	1	0	1	26	20	46
(Percent)		(16.1)	(83.9)		(55.8)	(44.2)		**(100.0)**	(0)		(56.5)	(43.5)	
Offshore	1998	0	0	0	0	0	0	0	0	0	13	70	83
(Percent)		(–)	(–)		(–)	(–)		(–)	(–)		**(15.7)**	(84.3)	

Table 40. Continued.

		Habitat type											
		Glacial-affected			Glacial-stream-affected			Marine-sill-affected			Glacial-unaffected		
Season/ survey type	Year	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total
LATE SUMMER													
Nearshore	1996	45	32	77	17	28	45	0	0	0	37	25	62
(Percent)		**(65.2)**	(34.8)		(42.5)	(57.5)		(0)	(0)		(49.3)	(50.7)	
	1997	107	76	183	45	58	103	0	0	0	77	61	138
(Percent)		**(58.5)**	(41.5)		(43.7)	(56.3)		(0)	(0)		(55.8)	(44.2)	
	1998	53	118	171	65	77	142	1	0	1	70	70	140
(Percent)		(31.0)	(69.0)		(45.8)	(54.2)		**(100.0)**	(0)		(50.0)	(50.0)	
	1996–1998	205	226	431	127	163	290	1	0	1	184	156	340
(Percent)		(47.6)	(52.4)		(43.8)	(56.2)		**(100.0)**	(0)		(54.1)	(45.9)	
Offshore	1996	0	0	0	0	0	0	0	0	0	1	21	22
(Percent)		(–)	(–)		(–)	(–)		(–)	(–)		**(4.5)**	(95.5)	
	1997	0	0	0	0	0	0	0	0	0	21	76	97
(Percent)		(–)	(–)		(–)	(–)		(–)	(–)		**(21.6)**	(78.4)	
	1998	0	0	0	0	0	0	0	0	0	12	122	134
(Percent)		(–)	(–)		(–)	(–)		(–)	(–)		**(9.0)**	(91.0)	
	1996–1998	0	0	0	0	0	0	0	0	0	34	219	253
(Percent)		(–)	(–)		(–)	(–)		(–)	(–)		**(13.4)**	(86.6)	
TOTALS													
Nearshore	1996–1998	267	337	604	267	287	554	2	0	2	361	351	712
(Percent)		(44.2)	(55.8)		(48.2)	(51.8)		**(100.0)**	(0)		(50.7)	(49.3)	
Offshore		0	0	0	0	0	0	0	0	0	102	636	738
(Percent)		(–)	(–)		(–)	(–)		(–)	(–)		**(13.8)**	(86.2)	
Combined		267	337	604	267	287	554	2	0	2	463	987	1,450
(Percent)		(44.2)	(55.8)		(48.2)	(51.8)		**(100.0)**	(0)		(31.9)	(68.1)	

Table 41. Number (percentage) of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996–1998, by season, survey type, year, and percent sea-ice cover. Analyses were conducted only for birds on the water. Highest frequency of feeding for each season-year sample is in boldface.

		Ice cover (%)											
		0–1			3–10			15–35			40–100		
Season/ survey type	Year	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total
EARLY SUMMER													
Nearshore	1996	31	73	104	1	15	16	0	18	18	2	1	3
(Percent)		(29.8)	(70.2)		(6.3)	(93.7)		(0)	(100.0)		**(66.7)**	(33.3)	
	1997	175	108	283	73	95	168	12	24	36	13	4	17
(Percent)		(61.8)	(38.2)		(43.5)	(56.5)		(33.3)	(66.7)		**(76.5)**	(23.5)	
	1998	15	25	40	2	2	4	0	0	0	0	0	0
(Percent)		(37.5)	(62.5)		**(50.0)**	(50.0)		(–)	(–)		(–)	(–)	
	1996–1998	221	206	427	76	112	188	12	42	54	15	5	20
(Percent)		(51.8)	(48.2)		(40.4)	(59.6)		(28.6)	(77.8)		**(75.0)**	(25.0)	
Offshore	1996	6	118	124	8	22	30	1	63	64	0	0	0
(Percent)		(4.8)	(95.2)		**(26.7)**	(73.3)		(1.6)	(98.4)		(–)	(–)	
	1997	12	56	68	8	17	25	4	12	16	2	8	10
(Percent)		(17.6)	(82.4)		**(32.0)**	(68.0)		(25.0)	(75.0)		(20.0)	(80.0)	
	1998	3	21	24	9	23	32	2	7	9	0	0	0
(Percent)		(12.5)	(87.5)		**(28.1)**	(71.9)		(22.2)	(77.8)		(–)	(–)	
	1996–1998	21	195	216	25	62	87	7	82	89	2	8	10
(Percent)		(9.7)	(90.3)		**(28.7)**	(71.3)		(7.9)	(92.1)		(20.0)	(80.0)	
MID-SUMMER													
Nearshore	1998	49	39	88	4	14	18	3	9	12	0	3	3
(Percent)		**(55.7)**	(44.3)		(22.2)	(77.8)		(25.0)	(75.0)		(0)	(100.0)	
Offshore	1998	12	39	51	0	11	11	0	16	16	1	4	5
(Percent)		**(23.5)**	(76.5)		(0)	(100.0)		(0)	(100.0)		(20.0)	(80.0)	

Table 41. Continued.

Season/ survey type	Year	Ice cover (%)											
		0–1			3–10			15–35			40–100		
		Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total
LATE SUMMER													
Nearshore	1996	39	30	69	19	15	34	29	27	56	12	13	25
(Percent)		**(56.5)**	(43.5)		(55.9)	(44.1)		(51.8)	(48.2)		(48.0)	(52.0)	
	1997	99	66	165	76	113	189	40	9	49	14	7	21
(Percent)		(60.0)	(40.0)		(40.2)	(59.8)		**(81.6)**	(18.4)		(66.7)	(33.3)	
	1998	108	110	218	43	71	114	24	64	88	14	20	34
(Percent)		**(49.5)**	(50.5)		(37.8)	(62.3)		(27.3)	(72.3)		(41.2)	(58.8)	
	1996–1998	246	206	452	138	199	337	93	100	193	40	40	80
(Percent)		**(54.4)**	(45.6)		(40.9)	(59.1)		(48.2)	(51.8)		(50.0)	(50.0)	
Offshore	1996	1	16	17	0	5	5	0	0	0	0	0	0
(Percent)		**(5.9)**	(94.1)		(0)	(100.0)		(–)	(–)		(–)	(–)	
	1997	20	68	88	1	8	9	0	0	0	0	0	0
(Percent)		**(22.7)**	(77.3)		(11.1)	(88.9)		(–)	(–)		(–)	(–)	
	1998	12	109	121	0	5	5	0	8	8	0	0	0
(Percent)		**(9.9)**	(90.1)		(0)	(100.0)		(0)	(100.0)		(–)	(–)	
	1996–1998	33	193	226	1	18	19	0	8	8	0	0	0
(Percent)		**(14.6)**	(85.4)		(5.3)	(94.7)		(0)	(100.0)		(–)	(–)	
TOTALS													
Nearshore	1996–1998	516	451	967	218	325	543	108	151	259	55	48	103
(Percent)		**(53.4)**	(46.6)		(40.1)	(59.9)		(41.7)	(58.3)		**(53.4)**	(46.6)	
Offshore	1996–1998	66	427	493	26	91	117	7	106	113	3	12	15
(Percent)		(13.4)	(86.6)		**(22.2)**	(77.8)		(6.2)	(93.8)		(20.0)	(80.0)	
Combined	1996–1998	582	878	1,460	244	416	660	115	257	372	58	60	118
(Percent)		(39.9)	(60.1)		(37.0)	(63.0)		(30.9)	(69.1)		**(49.2)**	(50.8)	

Table 42. Number (percentage) of Kittlitz's murrelets that were feeding in nearshore waters of four bays in Prince William Sound, Alaska, in 1996–1998, by season, year, and distance from nearest shore (m). Analyses were conducted only for birds on the water. No data are presented for offshore surveys, because all sampling there occurred away from shorelines. Highest frequency of feeding for each season-year sample is in boldface.

		Distance from shore (m)											
		1–50			51–100			101–150			151–200		
Season	Year	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total
Early summer	1996	13	14	27	5	21	26	10	29	39	6	43	49
(Percent)		**(48.1)**	(51.9)		(19.2)	(80.8)		(25.6)	(74.4)		(12.2)	(87.8)	
	1997	87	34	121	107	85	192	61	84	145	18	28	46
(Percent)		**(71.9)**	(28.1)		(55.7)	(44.3)		(42.1)	(57.9)		(39.1)	(60.9)	
	1998	5	3	8	7	11	18	2	3	5	3	10	13
(Percent)		**(62.5)**	(37.5)		(38.9)	(61.1)		(40.0)	(60.0)		(23.1)	(76.9)	
	1996–1998	105	51	156	119	117	236	73	116	189	27	81	108
(Percent)		**(67.3)**	(32.7)		(50.4)	(49.6)		(38.6)	(61.4)		(25.0)	(75.0)	
Mid-summer	1998	18	17	35	27	12	39	9	25	34	2	11	13
(Percent)		(51.4)	(48.6)		**(69.2)**	(30.8)		(26.5)	(73.5)		(15.4)	(84.6)	
Late summer	1996	40	27	67	44	28	72	10	23	33	5	7	12
(Percent)		(59.7)	(40.3)		**(61.1)**	(38.9)		(30.3)	(69.7)		(41.7)	(58.3)	
	1997	83	61	144	91	70	161	36	44	80	19	20	39
(Percent)		**(57.6)**	(42.4)		(56.5)	(43.5)		(45.0)	(55.0)		(48.7)	(51.3)	
	1998	51	62	113	70	108	178	47	69	116	21	26	47
(Percent)		**(45.1)**	(54.9)		(39.3)	(60.7)		(40.5)	(59.5)		(44.7)	(55.3)	
	1996–1998	174	150	324	205	206	411	93	136	229	45	53	98
(Percent)		**(53.7)**	(46.3)		(49.9)	(50.1)		(40.6)	(59.4)		(45.9)	(54.1)	
TOTAL Nearshore	1996–1998	297	218	515	351	335	686	175	277	452	74	145	219
(Percent)		**(57.7)**	(42.3)		(51.2)	(48.8)		(38.7)	(61.3)		(33.8)	(66.2)	

Table 43. Number (percentage) of Kittlitz's murrelets that were feeding in nearshore waters of four bays in Prince William Sound, Alaska, in 1996–1998, by season, year, and mean depth of water on a segment (m). Analyses were conducted only for birds on the water. No data are presented for offshore surveys, because all sampling there occurred away from shorelines. Highest frequency of feeding for each season-year sample is in boldface.

		Mean water depth (m)											
		1–20			21–40			41–60			61–80		
Season	Year	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total
Early summer	1996	22	40	62	11	54	65	1	11	12	0	2	2
(Percent)		**(35.5)**	(64.5)		(16.9)	(83.1)		(8.3)	(91.7)		(0)	(100.0)	
	1997	55	22	77	128	95	223	90	110	200	0	4	4
(Percent)		**(71.4)**	(28.6)		(57.4)	(42.6)		(45.0)	(55.0)		(0)	(100.0)	
	1998	9	13	22	5	5	10	3	9	12	0	0	0
(Percent)		(40.9)	(59.1)		**(50.0)**	(50.0)		(25.0)	(75.0)		(–)	(–)	
	1996–1998	86	75	161	144	154	298	94	130	224	0	6	6
(Percent)		**(53.4)**	(46.6)		(48.3)	(51.7)		(42.0)	(58.0)		(0)	(100.0)	
Mid-summer	1998	25	7	32	8	22	30	22	36	58	1	0	1
(Percent)		**(78.1)**	(21.9)		(26.7)	(73.3)		(37.9)	(62.1)		(100.0)	(0)	
Late summer	1996	11	7	18	41	39	80	46	39	85	1	0	1
(Percent)		(61.1)	(38.9)		(51.3)	(48.7)		(54.1)	(45.9)		**(100.0)**	(0)	
	1997	20	15	35	54	77	131	154	102	256	1	1	2
(Percent)		(57.1)	(42.9)		(41.2)	(58.8)		**(60.1)**	(39.9)		(50.0)	(50.0)	
	1998	33	29	62	63	60	123	89	162	251	4	14	18
(Percent)		**(53.2)**	(46.8)		(51.2)	(48.8)		(35.5)	(64.5)		(22.2)	(77.8)	
	1996–1998	64	51	115	158	176	334	289	303	592	6	15	21
(Percent)		**(55.7)**	(44.3)		(47.3)	(52.7)		(48.8)	(51.2)		(28.6)	(71.4)	
TOTAL													
Nearshore	1996–1998	175	133	308	310	352	662	405	469	874	7	21	28
(Percent)		**(56.8)**	(43.2)		(46.8)	(53.2)		(46.3)	(53.7)		(25.0)	(75.0)	

Table 44. Number (percentage) of Kittlitz's murrelets that were feeding in nearshore waters of four bays in Prince William Sound, Alaska, in 1996–1998, by season, year, and shoreline substrate. Analyses were conducted only for birds on the water. No data are presented for offshore surveys, because all sampling there occurred away from shorelines. Highest frequency of feeding for each season-year sample is in boldface.

		Shoreline substrate											
		Ice			Sand-gravel			Cobble-boulder			Bedrock		
Season	Year	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total
Early summer	1996	3	2	5	21	31	52	0	0	0	10	74	84
(Percent)		**(60.0)**	(40.0)		(40.4)	(59.6)		(–)	(–)		(11.9)	(88.1)	
	1997	16	14	30	150	95	245	4	2	6	103	120	223
(Percent)		(53.3)	(46.7)		(61.2)	(38.8)		**(66.7)**	(33.3)		(46.2)	(53.8)	
	1998	0	0	0	13	12	25	3	0	3	1	15	16
(Percent)		(–)	(–)		(52.0)	(48.0)		**(100.0)**	(0)		(6.3)	(93.7)	
	1996–1998	19	16	35	184	138	322	7	2	9	114	209	323
(Percent)		(54.3)	(45.7)		(57.1)	(42.9)		**(77.8)**	(22.2)		(35.3)	(64.7)	
Mid-summer	1998	2	13	15	21	21	42	0	0	0	33	31	64
(Percent)		(13.3)	(86.7)		(50.0)	(50.0)		(–)	(–)		**(51.6)**	(48.4)	
Late summer	1996	32	18	50	19	3	22	0	1	1	48	63	111
(Percent)		(64.0)	(36.0)		**(86.4)**	(13.6)		(0)	(100.0)		(43.2)	(56.8)	
	1997	89	54	143	30	32	62	3	2	5	107	102	209
(Percent)		**(62.2)**	(37.8)		(48.4)	(51.6)		(60.0)	(40.0)		(51.2)	(48.8)	
	1998	32	67	99	38	53	91	4	3	7	115	142	257
(Percent)		(32.3)	(67.7)		(41.8)	(58.2)		**(57.1)**	(42.9)		(44.7)	(55.3)	
	1996–1998	153	139	292	87	88	175	7	6	13	270	307	577
(Percent)		(52.4)	(47.6)		(49.7)	(50.3)		**(53.4)**	(46.2)		(46.7)	(53.2)	
TOTAL Nearshore	1996–1998	174	168	342	292	247	539	14	8	22	417	547	964
(Percent)		(50.9)	(49.1)		(54.2)	(45.8)		(63.6)	(36.4)		(43.3)	(56.7)	

Table 45. Number (percentage) of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996–1998, by season, survey type, year, and tidal stage. Analyses were conducted only for birds on the water. Highest frequency of feeding for each season-year sample is in boldface.

		Tidal stage					
		Rising tide[a]			Falling tide[a]		
Season/ survey type	Year	Feeding	Not feeding	Total	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)	
	1998	2	5	7	15	22	37
(Percent)		(28.6)	(71.4)		**(40.5)**	(59.5)	
	1996–1998	147	190	337	177	175	352
(Percent)		(43.6)	(56.4)		**(50.3)**	(49.7)	
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)	
	1998	2	20	22	12	31	43
(Percent)		(9.1)	(90.9)		**(27.9)**	(72.1)	
	1996–1998	21	119	140	34	228	262
(Percent)		**(15.0)**	(85.0)		(13.0)	(87.0)	
MID-SUMMER							
Nearshore	1998	14	20	34	42	45	87
(Percent)		(41.2)	(58.8)		**(48.3)**	(51.7)	
Offshore	1998	13	46	59	0	24	24
(Percent)		**(22.0)**	(78.0)		(0)	(100.0)	

Table 45. Continued.

		Tidal stage					
Season/		Rising tide[a]			Falling tide[a]		
survey type	Year	Feeding	Not feeding	Total	Feeding	Not feeding	Total
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)	
	1998	142	179	321	47	86	133
(Percent)		**(44.2)**	(55.8)		(35.3)	(64.7)	
	1996–1998	351	341	692	166	204	370
(Percent)		**(50.7)**	(49.3)		(44.9)	(55.1)	
Offshore	1996	1	17	18	0	4	4
(Percent)		**(5.6)**	(94.4)		(0)	(100.0)	
	1997	15	59	74	6	17	23
(Percent)		(20.3)	(79.7)		**(26.1)**	(73.9)	
	1998	8	80	88	4	42	46
(Percent)		**(9.1)**	(90.9)		(8.7)	(91.3)	
	1996–1998	24	156	180	10	63	73
(Percent)		(13.3)	(86.7)		**(13.7)**	(86.3)	
TOTALS							
Nearshore	1996–1998	512	551	1,063	385	424	809
(Percent)		**(48.2)**	(51.8)		(47.6)	(52.4)	
Offshore	1996–1998	58	321	379	44	315	359
(Percent)		**(15.3)**	(84.7)		(12.3)	(87.7)	
Combined	1996–1998	570	872	1,442	429	739	1,168
(Percent)		**(39.5)**	(60.5)		(36.7)	(63.3)	

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

Table 46. Number (percentage) of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996–1998, by season, survey type, year, and strength of tidal current. Analyses were conducted only for birds on the water. Highest frequency of feeding for each season-year sample is in boldface.

		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)	
	1998	5	8	13	9	6	15	3	13	16
(Percent)		(38.5)	(61.5)		**(60.0)**	(40.0)		(18.8)	(81.2)	
	1996–1998	138	171	309	80	73	153	106	121	227
(Percent)		(44.7)	(55.3)		**(52.3)**	(47.7)		(46.7)	(53.3)	
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)	
	1998	1	15	16	3	22	25	10	14	24
(Percent)		(6.3)	(93.7)		(12.0)	(88.0)		**(41.7)**	(58.3)	
	1996–1998	8	54	62	19	92	111	28	201	229
(Percent)		(12.9)	(87.1)		**(17.1)**	(82.9)		(12.2)	(87.8)	
MID-SUMMER										
Nearshore	1998	12	14	26	12	36	48	32	15	47
(Percent)		(46.1)	(53.8)		(25.0)	(75.0)		**(68.1)**	(31.9)	
Offshore	1998	10	20	30	1	41	42	2	9	11
(Percent)		**(33.3)**	(66.7)		(2.4)	(97.6)		(18.2)	(81.8)	

Table 46. Continued.

		Current strength								
		Weak[a]			Moderate[a]			Strong[a]		
Season/ survey type	Year	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total
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)	
	1998	57	86	143	75	73	148	57	106	163
(Percent)		(39.9)	(60.1)		**(50.7)**	(49.3)		(35.0)	(65.0)	
	1996–1998	183	196	379	191	188	379	143	161	304
(Percent)		(48.3)	(51.7)		**(50.4)**	(49.6)		(47.0)	(53.0)	
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)	
	1998	0	20	20	2	40	42	10	62	72
(Percent)		(0)	(100.0)		(4.8)	(95.2)		**(13.9)**	(86.1)	
	1996–1998	6	47	53	9	74	83	19	98	117
(Percent)		(11.3)	(88.7)		(10.8)	(89.2)		**(16.2)**	(83.8)	
TOTALS										
Nearshore	1996–1998	333	381	714	283	297	580	281	297	578
(Percent)		(46.6)	(53.4)		**(48.8)**	(51.2)		(48.6)	(51.4)	
Offshore	1996–1998	24	121	145	29	207	236	49	308	357
(Percent)		**(16.6)**	(83.4)		(12.3)	(87.7)		(13.7)	(86.3)	
Combined	1996–1998	357	502	859	312	504	816	330	605	935
(Percent)		**(41.6)**	(58.4)		(38.2)	(61.8)		(35.3)	(64.7)	

[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 47. Number (percentage) of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996–1998, by season, survey type, year, and secchi depth (as an indicator of water clarity). Analyses were conducted only for birds on the water. Highest frequency of feeding for each season-year sample is in boldface.

		Secchi depth (m)								
		0–1			2–3			4–14		
Season/ survey type	Year	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total
EARLY SUMMER										
Nearshore	1996	0	0	0	0	0	0	0	0	0
(Percent)		(–)	(–)		(–)	(–)		(–)	(–)	
	1997	104	129	233	134	82	216	13	5	18
(Percent)		(44.6)	(55.4)		(62.0)	(38.0)		**(72.2)**	(27.8)	
	1998	15	16	31	2	11	13	0	0	0
(Percent)		**(48.4)**	(51.6)		(15.4)	(84.6)		(–)	(–)	
	1996–1998	119	145	264	136	93	229	13	5	18
(Percent)		(45.1)	(55.3)		(59.4)	(40.6)		**(72.2)**	(27.8)	
Offshore	1996	0	0	0	0	0	0	0	0	0
(Percent)		(–)	(–)		(–)	(–)		(–)	(–)	
	1997	14	33	47	11	59	70	0	1	1
(Percent)		**(29.8)**	(70.2)		(15.7)	(84.3)		(0)	(100.0)	
	1998	12	27	39	2	24	26	0	0	0
(Percent)		**(30.8)**	(69.2)		(7.7)	(92.3)		(–)	(–)	
	1996–1998	26	60	86	13	83	96	0	1	1
(Percent)		**(30.2)**	(69.8)		(13.5)	(86.5)		(0)	(100.0)	
MID-SUMMER										
Nearshore	1998	44	57	101	10	8	18	2	0	2
(Percent)		(43.6)	(56.4)		(55.6)	(44.4)		**(100.0)**	(0)	
Offshore	1998	9	58	67	4	5	9	0	7	7
(Percent)		(13.4)	(86.6)		**(44.4)**	(55.6)		(0)	(100.0)	

Table 47. Continued.

		Secchi depth (m)								
		0–1			2–3			4–14		
Season/ survey type	Year	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total
LATE SUMMER										
Nearshore	1996	0	0	0	0	0	0	0	0	0
(Percent)		(–)	(–)		(–)	(–)		(–)	(–)	
	1997	195	168	363	30	26	56	4	1	5
(Percent)		(53.7)	(46.3)		(53.6)	(46.4)		**(80.0)**	(20.0)	
	1998	154	227	381	35	38	73	0	0	0
(Percent)		(40.4)	(59.6)		**(47.9)**	(52.1)		(–)	(–)	
	1996–1998	349	395	744	65	64	129	4	1	5
(Percent)		(46.9)	(53.1)		(50.4)	(49.6)		**(80.0)**	(20.0)	
Offshore	1996	0	0	0	0	0	0	0	0	0
(Percent)		(–)	(–)		(–)	(–)		(–)	(–)	
	1997	12	46	58	6	17	23	3	13	16
(Percent)		(20.7)	(79.3)		**(26.1)**	(73.9)		(18.8)	(81.2)	
	1998	9	86	95	3	32	35	0	4	4
(Percent)		**(9.5)**	(90.5)		(8.6)	(91.4)		(0)	(100.0)	
	1996–1998	21	132	153	9	49	58	3	17	20
(Percent)		(13.7)	(86.3)		**(15.5)**	(84.4)		(15.0)	(85.0)	
TOTALS										
Nearshore	1996–1998	512	597	1,109	211	165	376	19	6	25
(Percent)		(46.2)	(53.8)		(56.1)	(43.9)		**(76.0)**	(24.0)	
Offshore	1996–1998	56	250	306	26	137	163	3	25	28
(Percent)		**(18.3)**	(81.7)		(16.0)	(84.0)		(10.7)	(89.3)	
Combined	1996–1998	568	847	1,415	237	302	539	22	31	53
(Percent)		(40.1)	(59.9)		**(44.0)**	(56.0)		(41.5)	(58.5)	

Table 48. Number (percentage) of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996–1998, by season, survey type, year, and sea-surface temperature (°C). Analyses were conducted only for birds on the water. Highest frequency of feeding for each season-year sample is in boldface.

		Sea-surface temperature (°C)											
		0–3			4–6			7–9			10–17		
Season/ survey type	Year	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total
EARLY SUMMER													
Nearshore	1996	3	8	11	15	58	73	16	37	53	0	4	4
(Percent)		(27.3)	(72.7)		(20.5)	(79.5)		**(30.2)**	(69.8)		(0)	(100.0)	
	1997	0	1	1	121	131	252	118	83	201	12	3	15
(Percent)		(0)	(100.0)		(48.0)	(52.0)		(58.7)	(41.3)		**(80.0)**	(20.0)	
	1998	0	0	0	4	6	10	13	21	34	0	0	0
(Percent)		(–)	(–)		**(40.0)**	(60.0)		(38.2)	(61.8)		(–)	(–)	
	1996–1998	3	9	12	140	195	335	147	141	288	12	7	19
(Percent)		(25.0)	(75.0)		(41.8)	(58.2)		(51.0)	(49.0)		**(63.2)**	(36.8)	
Offshore	1996	1	3	4	3	154	157	11	40	51	0	6	6
(Percent)		**(25.0)**	(75.0)		(1.9)	(98.1)		(21.6)	(78.4)		(0)	(100.0)	
	1997	0	0	0	6	22	28	8	37	45	11	34	45
(Percent)		(–)	(–)		(21.4)	(78.6)		(17.8)	(82.2)		**(24.4)**	(75.6)	
	1998	4	3	7	3	14	17	7	26	33	0	8	8
(Percent)		**(57.1)**	(42.9)		(17.6)	(82.4)		(21.2)	(78.8)		(0)	(100.0)	
	1996–1998	5	6	11	12	190	202	26	103	129	11	48	59
(Percent)		**(45.5)**	(54.5)		(5.9)	(94.1)		(20.2)	(79.8)		(18.6)	(81.4)	
MID-SUMMER													
Nearshore	1998	0	0	0	28	36	64	27	29	56	1	0	1
(Percent)		(–)	(–)		(43.8)	(56.2)		(48.2)	(51.8)		**(100.0)**	(0)	
Offshore	1998	0	0	0	1	10	11	12	60	72	0	0	0
(Percent)		(–)	(–)		(9.1)	(90.9)		**(16.7)**	(83.3)		(–)	(–)	

Table 48. Continued.

		Sea-surface temperature (°C)											
		0–3			4–6			7–9			10–17		
Season/ survey type	Year	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total
LATE SUMMER													
Nearshore	1996	12	14	26	82	69	151	5	2	7	0	0	0
(Percent)		(46.2)	(53.8)		(54.3)	(45.7)		**(71.4)**	(28.6)		(–)	(–)	
	1997	1	8	9	46	29	75	170	131	301	12	27	39
(Percent)		(11.1)	(88.9)		**(61.3)**	(38.7)		(56.5)	(43.5)		(30.8)	(69.2)	
	1998	8	4	12	147	231	378	34	30	64	0	0	0
(Percent)		**(66.7)**	(33.3)		(38.9)	(61.1)		(53.1)	(46.9)		(–)	(–)	
	1996–1998	21	26	47	275	329	604	209	163	372	12	27	39
(Percent)		(44.7)	(55.3)		(45.5)	(54.5)		**(56.2)**	(43.8)		(30.8)	(69.2)	
Offshore	1996	0	4	4	0	16	16	1	1	2	0	0	0
(Percent)		(0)	(100.0)		(0)	(100.0)		**(50.0)**	(50.0)		(–)	(–)	
	1997	0	0	0	2	13	15	9	37	46	10	26	36
(Percent)		(–)	(–)		(13.3)	(86.7)		(19.6)	(80.4)		**(27.8)**	(72.2)	
	1998	0	0	0	11	79	90	1	38	39	0	5	5
(Percent)		(–)	(–)		**(12.2)**	(87.8)		(2.6)	(97.4)		(0)	(100.0)	
	1996–1998	0	4	4	13	108	121	11	76	87	10	31	41
(Percent)		(0)	(100.0)		(10.7)	(89.3)		(12.6)	(87.4)		**(24.4)**	(75.6)	
TOTALS													
Nearshore	1996–1998	24	35	59	443	560	1,003	383	333	716	25	34	59
(Percent)		(40.7)	(59.3)		(44.2)	(55.8)		**(53.5)**	(46.5)		(42.4)	(57.6)	
Offshore	1996–1998	5	10	15	26	308	334	49	239	288	21	79	100
(Percent)		**(33.3)**	(66.7)		(7.8)	(92.2)		(17.0)	(83.0)		(21.0)	(79.0)	
Combined	1996–1998	29	45	74	469	868	1,337	432	572	1,004	46	113	159
(Percent)		(36.5)	(60.8)		(35.1)	(64.9)		**(43.0)**	(57.0)		(28.9)	(71.1)	

Table 49. Number (percentage) of Kittlitz's murrelets that were feeding in four bays in Prince William Sound, Alaska, in 1996–1998, by season, survey type, year, and sea-surface salinity (‰). Analyses were conducted only for birds on the water. Highest frequency of feeding for each season-year sample is in boldface.

		Sea-surface salinity (‰)											
		4–10			11–17			18–24			25–30		
Season/ survey type	Year	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total
EARLY SUMMER													
Nearshore	1996	0	0	0	0	0	0	0	0	0	0	0	0
(Percent)		(–)	(–)		(–)	(–)		(–)	(–)		(–)	(–)	
	1997	0	0	0	0	0	0	56	40	96	195	178	373
(Percent)		(–)	(–)		(–)	(–)		**(58.3)**	(41.7)		(52.3)	(47.7)	
	1998	1	0	1	3	4	7	12	23	35	1	0	1
(Percent)		**(100.0)**	(0)		(42.9)	(57.1)		(34.3)	(65.7)		**(100.0)**	(0)	
	1996–1998	1	0	1	3	4	7	68	63	131	196	178	374
(Percent)		**(100.0)**	(0)		(42.9)	(57.1)		(51.9)	(48.1)		(52.4)	(47.6)	
Offshore	1996	0	0	0	0	0	0	0	0	0	0	0	0
(Percent)		(–)	(–)		(–)	(–)		(–)	(–)		(–)	(–)	
	1997	0	0	0	0	0	0	6	37	43	19	56	75
(Percent)		(–)	(–)		(–)	(–)		(14.0)	(86.0)		**(25.3)**	(74.7)	
	1998	0	3	3	0	6	6	13	41	54	1	1	2
(Percent)		(0)	(100.0)		(0)	(100.0)		(24.1)	(75.9)		**(50.0)**	(50.0)	
	1996–1998	0	3	3	0	6	6	19	78	97	20	57	77
(Percent)		(0)	(100.0)		(0)	(100.0)		(19.6)	(80.4)		**(26.0)**	(74.0)	
MID-SUMMER													
Nearshore	1998	1	0	1	21	24	45	27	29	56	6	10	16
(Percent)		(100.0)	(0)		(46.7)	(53.3)		**(48.2)**	(51.8)		(37.5)	(62.5)	
Offshore	1998	3	0	3	8	36	44	1	24	25	1	10	11
(Percent)		**(100.0)**	(0)		(18.2)	(81.8)		(4.0)	(96.0)		(9.1)	(90.9)	

Table 49. Continued.

Season/ survey type	Year	Sea-surface salinity (‰) 4–10 Feeding	4–10 Not feeding	4–10 Total	11–17 Feeding	11–17 Not feeding	11–17 Total	18–24 Feeding	18–24 Not feeding	18–24 Total	25–30 Feeding	25–30 Not feeding	25–30 Total
LATE SUMMER													
Nearshore	1996	0	0	0	0	0	0	0	0	0	0	0	0
(Percent)		(–)	(–)		(–)	(–)		(–)	(–)		(–)	(–)	
	1997	4	6	10	143	100	243	80	88	168	0	0	0
(Percent)		(40.0)	(60.0)		**(58.8)**	(41.2)		(47.6)	(52.4)		(–)	(–)	
	1998	7	5	12	71	125	196	95	118	213	12	9	21
(Percent)		**(58.3)**	(41.7)		(36.2)	(63.8)		(44.6)	(55.4)		(57.1)	(42.9)	
	1996–1998	11	11	22	214	225	439	175	206	381	12	9	21
(Percent)		(50.0)	(50.0)		(48.7)	(51.3)		(45.9)	(54.1)		**(57.1)**	(42.9)	
Offshore	1996	0	0	0	0	0	0	0	0	0	0	0	0
(Percent)		(–)	(–)		(–)	(–)		(–)	(–)		(–)	(–)	
	1997	0	0	0	12	45	57	9	31	40	0	0	0
(Percent)		(–)	(–)		(21.1)	(78.9)		**(22.5)**	(77.5)		(–)	(–)	
	1998	0	0	0	6	27	33	6	95	101	0	0	0
(Percent)		(–)	(–)		**(18.2)**	(81.8)		(5.9)	(94.1)		(–)	(–)	
	1996–1998	0	0	0	18	72	90	15	126	141	0	0	0
(Percent)		(–)	(–)		**(20.0)**	(80.0)		(10.6)	(89.4)		(–)	(–)	
TOTALS													
Nearshore	1996–1998	13	11	24	238	253	491	270	298	568	214	197	411
(Percent)		**(54.2)**	(45.8)		(48.5)	(51.5)		(47.5)	(52.5)		(52.1)	(47.9)	
Offshore	1996–1998	3	3	6	26	114	140	35	228	263	21	67	88
(Percent)		**(50.0)**	(50.0)		(18.6)	(81.4)		(13.3)	(86.7)		(23.9)	(77.3)	
Combined	1996–1998	16	14	30	264	367	631	305	526	831	235	264	499
(Percent)		**(53.3)**	(46.7)		(41.8)	(58.2)		(36.7)	(63.3)		(47.1)	(52.9)	

Table 50. Number (percentage) of Kittlitz's murrelets that were feeding in nearshore waters of four bays in Prince William Sound, Alaska, in 1996–1998, by season, year, and distance from nearest input of fresh water (m). Analyses were conducted only for birds on the water. No data are presented for offshore surveys, because all sampling there occurred away from shorelines. Highest frequency of feeding for each season-year sample is in boldface.

		Distance from nearest fresh water (m)											
		1–100			101–250			251–1,000			>1,000		
Season	Year	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total	Feeding	Not feeding	Total
Early summer	1996	2	9	11	4	43	47	19	35	54	9	20	29
(Percent)		(18.2)	(81.8)		(8.5)	(91.5)		**(35.2)**	(64.8)		(31.0)	(69.0)	
	1997	43	19	62	97	68	165	94	128	222	39	16	55
(Percent)		(69.4)	(30.6)		(58.8)	(41.2)		(42.3)	(57.7)		**(70.9)**	(29.1)	
	1998	4	4	8	6	7	13	7	13	20	0	3	3
(Percent)		**(50.0)**	(50.0)		(46.2)	(53.4)		(35.0)	(65.0)		(0)	(100.0)	
	1996–1998	49	32	81	107	118	225	120	176	296	48	39	87
(Percent)		**(60.5)**	(39.5)		(47.6)	(52.4)		(40.5)	(59.5)		(55.2)	(44.8)	
Mid-summer	1998	13	7	20	8	25	33	30	23	53	5	10	15
(Percent)		**(65.0)**	(35.0)		(24.2)	(75.8)		(55.6)	(42.6)		(33.3)	(66.7)	
Late summer	1996	38	12	50	22	31	53	18	26	44	21	16	37
(Percent)		**(76.0)**	(24.0)		(41.5)	(51.5)		(40.9)	(59.1)		(56.8)	(43.2)	
	1997	87	53	140	40	56	96	70	64	134	32	22	54
(Percent)		**(62.1)**	(37.9)		(41.7)	(58.3)		(52.2)	(47.8)		(59.3)	(40.7)	
	1998	40	62	102	50	79	129	68	81	149	31	43	74
(Percent)		(39.2)	(60.8)		(38.8)	(61.2)		**(45.6)**	(54.4)		(41.9)	(58.1)	
	1996–1998	165	127	292	112	166	278	156	171	327	84	81	165
(Percent)		**(56.5)**	(43.5)		(40.3)	(59.7)		(47.7)	(52.3)		(50.9)	(49.1)	
TOTAL													
Nearshore	1996–1998	227	166	393	227	309	536	306	370	676	137	130	267
(Percent)		**(57.8)**	(42.2)		(42.4)	(57.6)		(45.3)	(54.7)		(51.3)	(48.7)	

Table 51. Records of Kittlitz's murrelets seen holding prey items in four bays in Prince William Sound, Alaska, in 1996–1998, by season, bay, date, and prey type and length.

			Prey type				
Season/bay	Date	Number of birds (n)	Pacific sand lance	Pacific herring	Unidentified fish	Approximate length of prey (cm)	Comments
EARLY SUMMER							
College Fjord	2 JN 1996	1			X	8–10	
Blackstone Bay	7 JN 1996	1			X		
MID-SUMMER							
College Fjord	2 JL 1998	1			X		ate fish at surface
Harriman Fjord	3 JL 1998	1			X	10	carrying fish into hills
	3 JL 1998	1			X		
	3 JL 1998	1			X	9	
	4 JL 1998	1			X		ate fish
LATE SUMMER							
Unakwik Inlet	29 JL 1997	2			X	~3	mixed-species feeding flock with marbled murrelets and black-legged kittiwakes; eating larval fishes
	21 JL 1998	1			X	8	
	21 JL 1998	1			X	8–10	ate fish
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		

Table 51. Continued.

			Prey type				
Season/bay	Date	Number of birds (n)	Pacific sand lance	Pacific herring	Unidentified fish	Approximate length of prey (cm)	Comments
LATE SUMMER (CONTINUED)							
College Fjord	24 JL 1997	1			X		
(continued)	24 JL 1997	1			X		carrying fish
	1 AU 1997	1	X				ate fish
	15 JL 1998	1			X	5	
	23 JL 1998	1			X	10–12	
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		
	17 JL 1998	1			X	10–12	
	17 JL 1998	1			X		ate fish at surface
Blackstone Bay	28 JL 1998	1		X		8	
Total			6	1	22		

Table 52. Prey items and mean approximate lengths of prey items being held by Kittlitz's and marbled murrelets in four bays in Prince William Sound, Alaska, in 1996–1998, by bird species. Data are pooled across all seasons.

Species	Number (percentage) of prey items				Prey length (cm)		
	Pacific sand lance	Pacific herring	Unidentified fish	Total	$\bar{x}$	SD	n
Kittlitz's murrelet	6 (20.7)	1 (3.4)	22 (75.9)	29	8.1	2.5	16
Marbled murrelet	17(22.1)	6 (7.8)	54 (70.1)	77	8.7	3.0	40

Table 53. Numbers of birds in mixed-species feeding flocks containing Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in 1996–1998, by season, bay, and species.

			Species						
Season/bay	Date[a]	Time	Kittlitz's murrelet	Marbled murrelet	Mew gull	Glaucous-winged gull	Black-legged kittiwake	Arctic tern	Comments
EARLY SUMMER									
College Fjord	15 JN 1998	0815	20	–	–	45	5	–	murrelets around outer edge of feeding flock
Harriman Fjord	5 JN 1997	1810	4	6	–	–	–	–	loose flock feeding near another loose flock of ~10 feeding marbled murrelets
MID-SUMMER									
College Fjord	2 JL 1998	1105	10	20	–	–	–	–	
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 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.
	23 JL 1998	1519	1	9	–	–	–	–	
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
	17 JL 1998	1555	2	4	–	–	5	3	
COMBINED									
Frequency (%)				80.0	10.0	10.0	50.0	20.0	

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

[b] Present but numbers not recorded.

Table 54. Mean size of feeding groups of Kittlitz's and marbled murrelets in Prince William Sound, Alaska, in 1996–1998, by species, survey type, season, and year.

		Species					
		Kittlitz's murrelet			Marbled murrelet		
Survey type/season	Year	$\bar{x}$	SD	n	$\bar{x}$	SD	n
NEARSHORE							
Early summer	1996	1.5	0.5	23	1.9	1.6	288
	1997	1.4	0.7	195	1.9	2.0	642
	1998	1.1	0.3	16	1.6	0.6	373
Mid-summer	1998	1.2	0.4	45	1.5	0.6	256
Late summer	1996	1.3	1.1	74	1.4	0.8	652
	1997	1.3	1.0	176	1.6	1.6	896
	1998	1.2	0.4	160	1.7	4.7	1,058
Total		1.3	0.8	689	1.7	2.7	4,165
OFFSHORE							
Early summer	1996	1.5	0.8	10	2.4	2.5	17
	1997	1.4	0.5	18	1.6	0.7	36
	1998	1.4	0.5	10	1.7	0.6	42
Mid-summer	1998	1.1	0.3	12	1.6	0.6	17
Late summer	1996	1.0	–	1	1.6	0.7	99
	1997	1.2	0.4	18	2.2	2.4	116
	1998	1.5	0.5	8	1.6	0.7	144
Total		1.3	0.5	77	1.8	1.4	471

Table 55. Estimated size of the Kittlitz's murrelet population in all of Prince William Sound, 1972–1998. Data are from Agler and Kendall (1997) and D. B. Irons and B. K. Lance (unpubl. data).

	March			July		
Year	Estimate	±	95% CI	Estimate	±	95% CI
					±	
1972	346	±	657	63,229	±	80,122
1973	3,219	±	3,827	–	±	–
1989	–	±	–	6,436	±	3,151
1990	958	±	1,599	5,231	±	8,457
1991	466	±	398	1,184	±	1,121
1993	448	±	326	2,710	±	1,343
1994	0	±	0	–	±	–
1996	181	±	238	1,280	±	1,364
1998	78	±	96	279	±	192

Table 56. Estimated population sizes and estimated annual rates of change of Kittlitz's murrelet populations required to cause those changes in population sizes over time in Prince William Sound, Alaska, in 1972–1998, by season and years compared. Data on estimated population size are from Table 55.

Season/years compared	Estimated population First year's estimate	 Second year's estimate	Estimated annual rate of change (%/year)
SUMMER			
1972–1989	63,229	6,436	–12.58
1972–1996	63,229	1,280	–15.00
1972–1998	63,229	279	–18.83
1989–1996	6,436	1,280	–20.60
1989–1998	6,436	279	–29.43
WINTER			
1972–1990	346	958	+5.82
1972–1996	346	181	–2.67
1972–1998	346	78	–5.56
1973–1990	3,219	958	–6.88
1973–1996	3,219	181	–11.77
1973–1998	3,219	78	–13.84
1990–1996	958	181	–24.28
1990–1998	958	78	–26.90

Appendix 1. Estimated population sizes of Kittlitz's murrelets in four study bays, Prince William Sound, Alaska, in 1996, by season, bay, and visit. The largest estimate for each bay is in boldface.

Season/bay	Visit	Date[a]	Total nearshore count	Offshore density (birds/km^2) $\bar{x}$	Offshore density (birds/km^2) 95% CI	Offshore area (km^2)	Total offshore Population	Total offshore 95% CI	Overall total Population	Overall total 95% CI
EARLY SUMMER										
Unakwik Inlet	1	26 MY	0	0	0	37.92	0	0	0	0
	2	2 JN	1	0.37	0.90	37.92	14	34	15	234
	3	14 JN	9	17.66	28.51	37.92	670	1,081	**679**	**1,081**
College Fjord	1	28 MY	2	0.70	0.81	64.28	45	52	47	52
	2	4 JN	24	1.21	1.12	64.28	78	72	102	72
Harriman Fjord	1	30 MY	35	4.98	5.40	56.54	282	305	317	305
	2	6 JN	35	5.13	3.43	56.54	290	194	**325**	**194**
Blackstone Bay	1	31 MY	20	5.05	7.74	33.75	170	261	190	261
	2	7 JN	16	6.10	9.08	33.75	206	306	**222**	**306**
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	1.50	64.28	114	96	**184**	**96**
	2	8 AU	29	0.93	1.38	64.28	60	89	89	89
	3	14 AU	16	0.20	0.29	64.28	13	19	29	19
Harriman Fjord	1	3 AU	30	0	0	56.54	0	0	30	0
	2	10 AU	28	0.16	0.35	56.54	9	20	37	20
	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.

Appendix 2. Estimated population sizes of Kittlitz's murrelets in four study bays, Prince William Sound, Alaska, in 1997, by season, bay, and visit. The largest estimate for each bay is in boldface.

			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	1.03	37.92	24	39	82	39
	2	9 JN	102	0.82	2.00	37.92	31	76	**133**	**76**
	3	17 JN	47	1.53	2.16	37.92	58	82	107	82
College Fjord	1	4 JN	53	0	0	64.28	0	0	53	0
	2	13 JN	31	1.89	2.12	64.28	121	136	152	136
Harriman Fjord	1	5 JN	93	6.31	4.24	56.54	357	240	450	240
	2	12 JN	94	7.60	5.03	56.54	430	284	**524**	**284**
Blackstone Bay	1	7 JN	19	0	0	33.75	0	0	19	0
	2	14 JN	7	3.32	5.36	33.75	112	181	**119**	**181**
LATE SUMMER										
Unakwik Inlet	1	23 JL	37	1.24	2.49	37.92	47	94	84	94
	2	30 JL	12	0.34	0.84	37.92	13	32	25	32
College Fjord	1	17 JL	81	6.58	3.14	64.28	423	202	**504**	**202**
	2	25 JL	99	1.50	0.95	64.28	96	61	195	61
	3	1 AU	26	0.53	0.87	64.28	34	56	60	56
Harriman Fjord	1	19 JL	59	3.48	2.38	56.54	197	135	256	135
	2	27 JL	59	2.21	2.14	56.54	125	121	184	121
	3	3 AU	36	0.37	0.55	56.54	21	31	57	31
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] JN = June; JL = July; AU = August.

Appendix 3. Estimated population sizes of Kittlitz's murrelets in four study bays, Prince William Sound, Alaska, in 1998, by season, bay, and visit. The largest estimate for each bay is in boldface.

			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	0	0	0	37.92	0	0	0	0
	2	13 JN	0	0	0	37.92	0	0	0	0
	3	19 JN	14	0.45	0.71	37.92	17	27	31	27
College Fjord	1	4 JN	2	0.36	0.54	64.28	23	35	25	35
	2	15 JN	22	5.46	4.03	64.28	351	259	373	259
Harriman Fjord	1	9 JN	0	0.77	0.93	56.54	44	53	44	53
	2	16 JN	5	1.47	1.93	56.54	83	109	88	109
Blackstone Bay	1	11 JN	1	0	0	33.75	0	0	1	0
	2	18 JN	0	1.42	3.21	33.75	48	108	**48**	**108**
MID-SUMMER										
Unakwik Inlet	1	1 JL	31	3.06	5.86	37.92	116	222	**147**	**222**
College Fjord	1	3 JL	58	3.71	2.58	64.28	238	166	296	166
Harriman Fjord	1	4 JL	30	8.48	7.86	56.54	479	444	509	444
Blackstone Bay	1	29 JN	3	0	0	33.75	0	0	3	0
LATE SUMMER										
Unakwik Inlet	1	22 JL	37	2.08	3.36	37.92	79	127	116	127
	2	31 JL	42	0.20	0.50	37.92	8	19	50	19
College Fjord	1	16 JL	108	6.19	2.61	64.28	398	168	**506**	**168**
	2	24 JL	63	4.65	4.54	64.28	299	292	362	292
Harriman Fjord	1	18 JL	82	8.64	10.52	56.54	489	595	**571**	**595**
	2	26 JL	100	0.43	0.72	56.54	24	41	124	41
	3	3 AU	18	0.73	0.91	56.54	41	51	59	51
Blackstone Bay	1	20 JL	7	0.54	1.23	33.75	18	42	25	42
	2	29 JL	6	0	0	33.75	0	0	6	0

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

Appendix 4. 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[a]
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	34	1	0	0	35	97.1
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			132	8	2	0	142	
Percent[a]			93.0	5.6	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[a]			91.9	7.7	0.4	–		

[a] Excluding unknown-plumaged birds.

Appendix 5. 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[a]
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[a]			95.6	4.4	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[a]			96.0	4.0	0	–		

[a] Excluding unknown-plumaged birds.

Appendix 6. 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[a]
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[a]			96.0	3.6	0.4	–		
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[a]			96.9	3.1	0	–		

[a] Excluding unknown-plumaged birds.

Appendix 7. 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[a]
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[a]			96.5	3.5	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[a]			97.2	2.8	0	–		

[a] Excluding unknown-plumaged birds.

Appendix 8. Plumage characteristics of after-hatching-year Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in early summer 1998, by survey type, bay, and visit.

			Plumage					Percent
Survey type/bay	Visit	Date	Breeding	Molting	Winter	Unknown	Total	breeding plumage[a]
NEARSHORE								
Unakwik Inlet	1	1 JN	0	0	0	0	0	–
College Fjord	1	3 JN	2	0	0	0	2	100.0
Harriman Fjord	1	9 JN	0	0	0	0	0	–
Blackstone Bay	1	10 JN	1	0	0	0	1	100.0
Unakwik Inlet	2	13 JN	0	0	0	0	0	–
College Fjord	2	14 JN	18	4	0	0	22	81.8
Harriman Fjord	2	16 JN	5	0	0	0	5	100.0
Blackstone Bay	2	17 JN	0	0	0	0	0	–
Unakwik Inlet	3	19 JN	11	3	0	0	14	78.6
Total			37	7	0	0	44	84.1
Percent[a]			84.1	15.9	0	–		
OFFSHORE								
Unakwik Inlet	1	2 JN	0	0	0	0	0	–
College Fjord	1	4 JN	2	1	0	0	3	66.7
Harriman Fjord	1	9 JN	3	2	0	0	5	60.0
Blackstone Bay	1	11 JN	0	0	0	0	0	–
Unakwik Inlet	2	12 JN	0	0	0	0	0	–
College Fjord	2	15 JN	39	0	0	0	39	100.0
Harriman Fjord	2	15 JN	9	1	0	0	10	90.0
Blackstone Bay	2	18 JN	5	2	0	0	7	71.4
Unakwik Inlet	3	18 JN	3	0	0	0	3	100.0
Total			61	6	0	0	67	91.0
Percent[a]			91.0	9.0	0	–		

[a] Excluding unknown-plumaged birds.

Appendix 9. Plumage characteristics of after-hatching-year Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in mid-summer 1998, by survey type, bay, and visit.

			Plumage					Percent
Survey type/bay	Visit	Date	Breeding	Molting	Winter	Unknown	Total	breeding plumage[a]
NEARSHORE								
Blackstone Bay	1	28 JN	3	0	0	0	3	100.0
Unakwik Inlet	1	30 JN	30	1	0	0	31	96.8
College Fjord	1	2 JL	57	1	0	0	58	98.3
Harriman Fjord	1	4 JL	30	0	0	0	30	100.0
Total			120	2	0	0	122	98.4
Percent[a]			98.4	1.6	0	–		
OFFSHORE								
Blackstone Bay	1	29 JN	0	0	0	0	0	–
Unakwik Inlet	1	1 JL	14	0	0	0	14	100.0
College Fjord	1	3 JL	28	0	0	0	28	100.0
Harriman Fjord	1	3 JL	52	0	0	0	52	100.0
Total			94	0	0	0	94	100.0
Percent[a]			100.0	0	0	–		

[a] Excluding unknown-plumaged birds.

Appendix 10. Plumage characteristics of after-hatching-year Kittlitz's murrelets in four bays in Prince William Sound, Alaska, in late summer 1998, by survey type, bay, and visit.

			Plumage					Percent
Survey type/bay	Visit	Date	Breeding	Molting	Winter	Unknown	Total	breeding plumage[a]
NEARSHORE								
College Fjord	1	15 JL	105	3	0	0	108	97.2
Harriman Fjord	1	17 JL	78	4	0	0	82	95.1
Blackstone Bay	1	19 JL	7	0	0	0	7	100.0
Unakwik Inlet	1	21 JL	37	0	0	0	37	100.0
College Fjord	2	23 JL	62	1	0	0	63	98.4
Harriman Fjord	2	26 JL	97	3	0	0	100	97.0
Blackstone Bay	2	28 JL	6	0	0	0	6	100.0
Unakwik Inlet	2	30 JL	42	0	0	0	42	100.0
Harriman Fjord	3	2 AU	17	1	0	0	18	94.4
Total			451	12	0	0	463	97.4
Percent[a]			97.4	2.6	0	–		
OFFSHORE								
College Fjord	1	16 JL	44	5	0	0	49	89.8
Harriman Fjord	1	18 JL	47	3	0	0	50	94.0
Blackstone Bay	1	20 JL	2	0	0	0	2	100.0
Unakwik Inlet	1	22 JL	12	1	0	0	13	92.3
College Fjord	2	24 JL	34	1	0	0	35	97.1
Harriman Fjord	2	25 JL	3	0	0	0	3	100.0
Blackstone Bay	2	29 JL	0	0	0	0	0	–
Unakwik Inlet	2	31 JL	1	0	0	0	1	100.0
Harriman Fjord	3	3 AU	4	0	0	0	4	100.0
Total			147	10	0	0	157	93.6
Percent[a]			93.6	6.4	0	–		

[a] Excluding unknown-plumaged birds.

Appendix 11. Maximal estimates of Marbled Murrelet population sizes in four bays in Prince William Sound, Alaska, in 1996–1998, by bay and year.

	Year								
	1996			1997			1998		
Bay	Estimate	±	95% CI	Estimate	±	95% CI	Estimate	±	95% CI
Unakwik Inlet	1,102	±	796	1,637	±	452	4,665	±	6,283
College Fjord	729	±	314	893	±	253	1,198	±	422
Harriman Fjord	1,053	±	557	2,525	±	4,104	2,695	±	1,837
Blackstone Bay	618	±	278	463	±	659	589	±	399
Total	3,502	±	1,945	5,518	±	5,468	9,147	±	8,941

Appendix 12. Records of marbled murrelets holding prey items in four bays in Prince William Sound, Alaska, in 1996–1998, by season, bay, date, and prey type and length.

			Prey type				
Season/bay	Date[a]	Number of birds (n)	Pacific sand lance	Pacific herring	Unidentified fish	Approximate length of prey (cm)	Comments
EARLY SUMMER							
Unakwik Inlet	15 JN 1997	1	X			~10	ate at surface
	1 JN 1998	1			X	10–12	
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
Blackstone Bay	10 JN 1998	1			X		ate at surface
	17 JN 1998	1		X		~8	ate fish
Pelagic survey	15 JN 1997	1	X			~10	
	18 JN 1997	1			X		
MID-SUMMER							
Unakwik Inlet	30 JN 1998	1		X		3–4	ate under water
College Fjord	2 JL 1998	1			X	8	ate under water
Harriman Fjord	3 JL 1998	1			X	8–10	carrying fish
	4 JL 1998	1			X		
	4 JL 1998	1			X	10	ate at surface
Blackstone Bay	28 JN 1998	1			X	~5	ate at surface

Appendix 12. Continued.

Season/bay	Date[a]	Number of birds (n)	Prey type Pacific sand lance	 Pacific herring	 Unidentified fish	Approximate length of prey (cm)	Comments
LATE SUMMER							
Unakwik Inlet	27 JL 1996	1			X	~10	ate fish
	27 JL 1996	1			X		ate 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
	21 JL 1998	1			X	8–10	ate at surface
	22 JL 1998	1			X		carrying fish
	30 JL 1998	1		X		7	
	31 JL 1998	1			X	8–10	
	31 JL 1998	1			X		carrying fish
	31 JL 1998	1		X		8–10	
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	

Appendix 12. Continued.

			Prey type				
Season/bay	Date[a]	Number of birds (n)	Pacific sand lance	Pacific herring	Unidentified fish	Approximate length of prey (cm)	Comments
LATE SUMMER (CONTINUED)							
College Fjord	24 JL 1997	1			X		
(continued)	24 JL 1997	1	X				
	24 JL 1998	1			X		carrying fish
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		ate fish
	17 JL 1998	1			X		ate at surface
	18 JL 1998	1			X		carrying fish
	3 AU 1998	1			X		carrying fish
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	

Appendix 12. Continued.

			Prey type				
Season/bay	Date[a]	Number of birds (n)	Pacific sand lance	Pacific herring	Unidentified fish	Approximate length of prey (cm)	Comments
LATE SUMMER (CONTINUED)							
Blackstone Bay	4 AU 1997	1	X			12–14	ate fish
(continued)	29 JL 1998	1			X	8	
Pelagic surveys	28 JL 1996	1			X	10–12	
	23 JL 1997	1	X				
	25 JL 1997	1			X		
Total			17	6	54		

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