AT-SEA HABITAT USE BY THE KITTLITZ'S MURRELET *BRACHYRAMPHUS BREVIROSTRIS* IN NEARSHORE WATERS OF PRINCE WILLIAM SOUND, ALASKA

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SUMMARY

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We studied factors affecting at-sea habitat use by the alcid Kittlitz's Murrelet *Brachyramphus brevirostris* in four bays in Prince William Sound, Alaska, in 1996–1998. Kittlitz's Murrelets preferred College and Harriman Fjords, which were the two bays with the greatest effects of glaciers. Habitat type was the factor having the greatest effect on the distribution and abundance of Kittlitz's Murrelets; glacial-affected and glacial-stream-affected habitats were preferred. Water clarity (as indicated by Secchi depth) was third in importance, with birds preferring highly turbid waters with Secchi depths of 1 m. Ice cover was of lesser importance, with birds preferring waters with light ice cover (0.5–15%) and avoiding waters with heavy ice cover (≥50%). Sea-surface salinity was of least importance and indicated attraction to areas of input of fresh water and to areas of high salinity. Sea-surface temperature was important in the one test in which it was involved, with murrelets preferring segments with low sea-surface temperatures (4–6°C) and occurring in segments with high temperatures (10–17°C) less than expected; however, this factor was so highly correlated with the other factors that we were unable to examine its importance in most tests. The preference of this species for limited areas of heavy glaciation, high turbidity, and partial ice cover associated with glacial-affected areas, suggests that these habitats are of greatest importance in conserving this rare species.

INTRODUCTION

The Kittlitz's Murrelet *Brachyramphus brevirostris* is a poorly known, rare seabird of the evolutionary centre known as Beringia (that region associated with the Bering Sea and nearby areas). Concerns about the conservation of this species have led at various times to its classification as a Species of Special Concern under the US Endangered Species Act (a category that no longer exists) and its listing in the *Red Book of the USSR* (Flint & Golovkin 1990). Concern about this species increased when Kittlitz's Murrelets were killed in the *Exxon Valdez* oil spill (van Vliet & McAllister 1994, *Exxon Valdez* Oil Spill Trustee Council 1995). So little is known about the biology of Kittlitz's Murrelet, however, that any new information will help wildlife managers and scientists define conservation goals and research needs for this species throughout its entire range.

Information on at-sea habitat use by Kittlitz's Murrelet essentially is nonexistent. In south-eastern 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 low numbers around Baranof Island, which is the only glaciated island in the Alexander Archipelago (Day *et al.* 1999). It also is found primarily in the glaciated fjords of northern and western Prince William Sound (Gabrielson & Lincoln 1959, Isleib & Kessel 1973, Kendall & Agler 1998, Day & Nigro 1999), although it also occurs in the Sound in low numbers in non-glaciated fjords with suitable nesting habitat (i.e. scree slopes) along their margins (Day *et al.* 1999). Unakwik Inlet, and the vicinity of its marine sill (a former terminal moraine generated by a glacier when it extended farther into a bay) in particular, reportedly was used in the past by large numbers of Kittlitz's Murrelets (Isleib & Kessel 1973).

During our studies on the biology of Kittlitz's Murrelet in Prince William Sound in 1996–1998 (Day & Nigro 1999), we investigated at-sea habitat use by this species to understand what factors are critical in determining its at-sea distribution and abundance. The results of analyses on distribution and abundance indicated that this species occurred in a clumped, rather than a random or even, distribution (R.H. Day & D.A. Nigro unpubl. data). The objectives of this study were to describe at-sea habitat use of Kittlitz's Murrelets and to explain which habitat characteristics lead to this clumped distribution.

METHODS

Study area

Prince William Sound is a large, complex embayment of the northern Gulf of Alaska (Fig. 1). Most of the central and northern Sound is either glaciated or recently deglaciated and con-

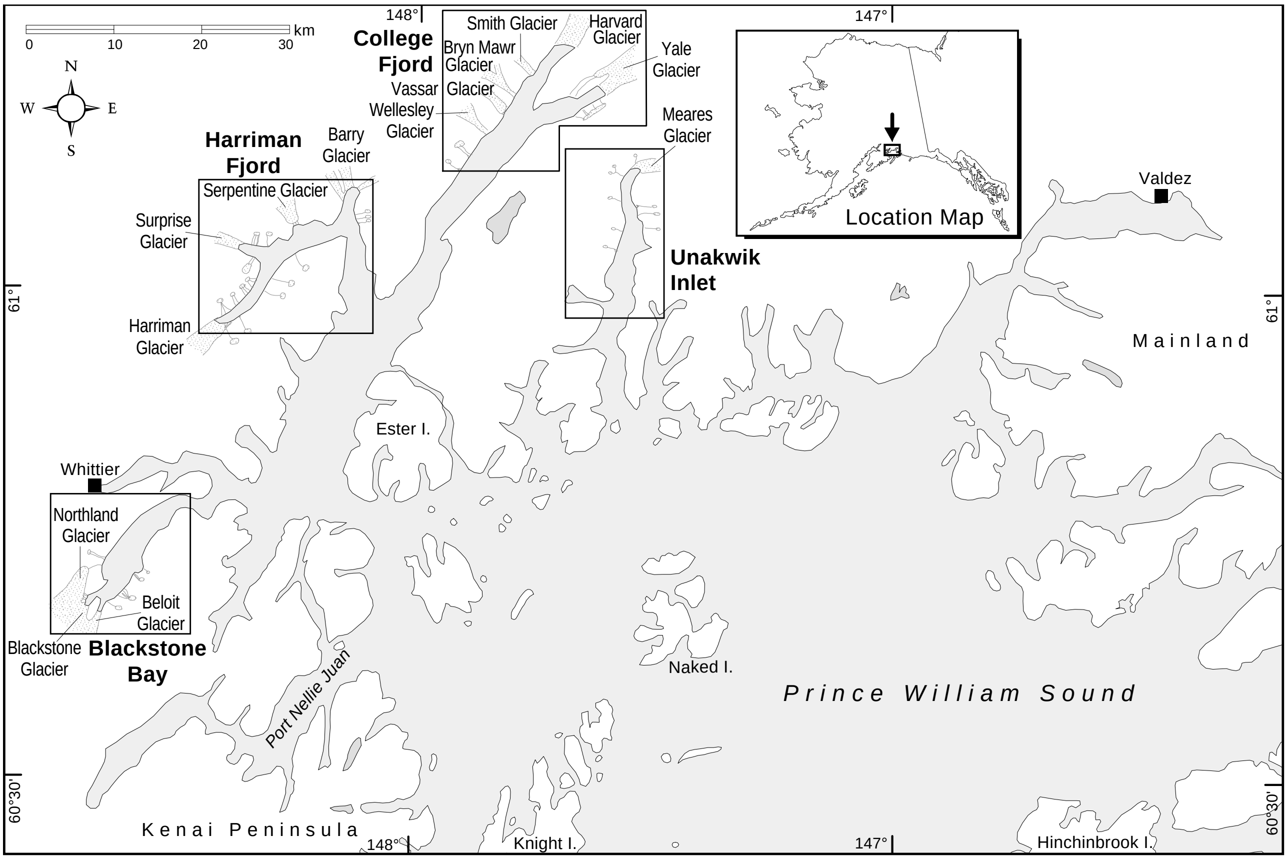

Fig. 1. *Locations of study bays in Prince William Sound, Alaska, in 1997–1998.*

tains numerous fjords and complex, rocky shorelines with abundant islands, islets, and reefs (Isleib & Kessel 1973). Fresh water that enters the Sound from glaciers, rivers, and precipitation mixes with the Alaska Coastal Current to form an 'inland sea' (Niebauer *et al.* 1994). The region has cool temperatures and frequent precipitation, cloud cover, fog, and strong winds (Wilson & Overland 1986). Most deglaciated areas are ice-free all year, although the glaciated fjords are partially covered with glacial ice during all except the warmest months.

The four study bays, which were located in the north-western quarter of the Sound (Fig. 1), are believed to contain a significant percentage of the Sound's Kittlitz's Murrelets (Isleib & Kessel 1973, Kendall & Agler 1998, Day *et al.* 1999). These glaciated fjords generally are deep, and each has one to five tidewater and several hanging (i.e. retreated) glaciers. The terrestrial vegetation consists of conifers and shrubs at low elevations, forbs at moderate elevations, and bare rock and permanent snowfields above *c.* 750 m elevation and near recently deglaciated areas.

Those parts of the nearshore zone in the four bays that we sampled varied in area between 11.3 km^2 (Unakwik Inlet) and 15.6 km^2 (Harriman Fjord; Table 1). One bay had one tidewater glacier (Unakwik Inlet), one had two (Blackstone Bay),

TABLE 1

Areas (km^2) of the nearshore zone sampled, total areas sampled, and total areas by habitat types in four study bays in Prince William Sound, Alaska in 1997–1998

		Area by habitat type			
Bay	**Total area sampled**	**Glacial-affected**	**Glacial-stream-affected**	**Marine-sill-affected**	**Glacial-unaffected**
Unakwik Inlet	11.33	0.34	3.51	1.55	5.93
College Fjord	13.69	2.16	2.77	0	8.76
Harriman Fjord	15.57	1.92	4.42	0	9.23
Blackstone Bay	12.42	0.37	1.70	0.51	9.84
Total	**53.01**	**4.79**	**12.40**	**2.06**	**33.76**

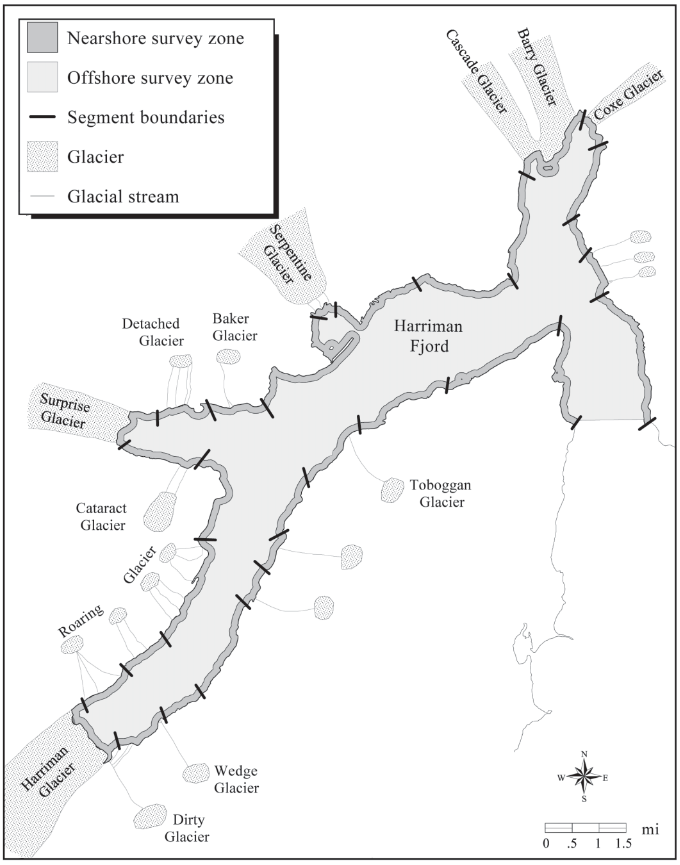

Fig. 2. *Locations of nearshore survey segments in Harriman Fjord, Alaska, in 1997–1998.*

and two had five each (College and Harriman Fjords). All four bays also had glacial-fed streams from both tidewater and hanging glaciers, and two bays (Unakwik Inlet and Blackstone Bay) had shallow marine sills.

Data collection

In 1997–1998, we studied Kittlitz's Murrelets during two 20-day research cruises/year that were conducted from 1 to *c.* 20 June (early summer) and from *c.* 15 July to 4 August (late summer); in 1998, we also had a mid-summer cruise from 28 June to 5 July. (Because not all habitat data were available for 1996, we have excluded those data from this paper.) We sampled most bays two times each during each early- and late-summer cruise and sampled each bay once during the mid-summer cruise; we also sampled Unakwik Inlet three times each in early summer and sampled the other bays two to four times each in late summer.

During each cruise, we used nearshore surveys to determine the distribution, abundance, and habitat use of Kittlitz's Murrelets in each bay (Fig. 2). Following Day *et al.* (1995, 1997) and Murphy *et al.* (1997), among others, we used nearshore surveys to sample murrelets in the nearshore zone (i.e. ≤200 m from the shoreline) and flying above it. On these surveys, we counted from a boat all Kittlitz's Murrelets seen ≤200 m from the shoreline, flying over this zone, or flushing from the water ahead of the boat. Although we also used offshore surveys to sample Kittlitz's Murrelets >200 m from shore (following Day *et al.* 1995, 1997), the nearshore zone is where most feeding occurs (Day & Nigro 2000) and where most habitat variation occurs (Day & Nigro 1999); hence, this paper discusses the results of analyses for the nearshore zone only.

We divided the nearshore zone in each bay into a series of segments, with the segments reflecting habitat types (see below). Then, we recorded the following information for each segment: habitat type; percent ice cover; Secchi depth; sea-surface temperature; and sea-surface salinity. We also recorded numbers of birds and location (in the air, on the water) for each murrelet observation.

We classified each segment into one of four habitat types that had been determined *a priori* and that reflected the general level of influence of glaciers on the nearby marine habitat (Table 1): glacial-affected (≤200 m from a tidewater glacier); glacial-stream-affected (>200 m from a tidewater glacier but with ≥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 (having none of these characteristics). These habitat types represented (from first to last) a trend of decreasing strength of effect of glaciers. If a segment had two characteristics of different strengths (e.g. a tidewater glacier and glacial streams), we classified it as that of the stronger characteristic. The number of segments having such multiple characteristics was small, so misclassification would not affect the results of statistical tests.

Because of heavy ice cover, we were unable to sample all or significant portions of 47 of 1040 total nearshore 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 segments. Because we saw no evidence that substantial numbers of murrelets used areas of such heavy ice cover (only three of 2606 birds were seen in ice cover ≥90%, and those were in patches of open water within heavier ice; Day & Nigro

1999), we assumed that those areas that we could not search well also had no Kittlitz's Murrelets.

We examined the relationship between the distribution of Kittlitz's Murrelets and four environmental variables (ice cover, Secchi depth [as an indicator of water clarity], sea-surface temperature, sea-surface salinity). We estimated ice cover for each segment as a whole (0%, <1% [i.e. trace], 1%, 3%, and 5–100% in 5% units). At the beginning of each segment, we measured the Secchi depth to the nearest 0.5 m, sea-surface temperature (0.5 m below the water's surface) to the nearest 0.1°C, and sea-surface salinity (0.5 m below the water's surface) to the nearest 0.1‰. Then, we assigned the value of each environmental variable to all birds recorded on that segment.

Data analysis

Statistical summarization and analytical techniques are described by topic. All statistical tests were 2-tailed, and the level of significance (α) was 0.05. Because only two Kittlitz's Murrelets were recorded in marine-sill-affected habitat and that habitat was recorded in only two of four bays, we pooled those records into the glacial-unaffected habitat category. In tests involving densities, ice cover, and Secchi depth, we used ln-transformed values because that transformation allowed the data to meet the assumptions of a parametric test (normality and homoscedasticity). Before transformation, we added 0.167 to the ice and Secchi depth data (following Mosteller & Tukey 1977), to avoid computing the logarithm of zero; because the density data were involved in a test only when their densities were non-zero values (see below), we did not have to add 0.167 before transformation.

We calculated Pearson Correlation Coefficients for the four environmental variables. Because sea-surface temperature was highly correlated ($r > 0.5$) with both ice cover and Secchi depth, it was excluded from analyses that involved more than one environmental variable. In those first analyses, the effects of each variable were examined separately, so the inclusion of temperature would not affect results or conclusions.

The statistical analysis consisted of three parts. First, we compared overall habitat use with overall habitat availability separately for all factors. Second, we determined which factors were important in determining which segments were and were not used by Kittlitz's Murrelets. Finally, we determined which factors influenced density in those segments where Kittlitz's Murrelets occurred.

We compared overall habitat use with overall habitat availability separately for the factors habitat type (glacial-affected, glacial-stream-affected, glacial-unaffected), location (Unakwik Inlet, College Fjord, Harriman Bay, Blackstone Bay), and the four environmental variables (ice cover, Secchi depth, sea-surface temperature, sea-surface salinity). We divided each continuous environmental variable into four categories. Then, for each factor, we compared the actual distribution of birds with an expected random distribution based on the percentage of total area of segments within that category (e.g. if 10% of the area of all segments had a Secchi depth of 1 m, 10% of all Kittlitz's Murrelets would occur in Secchi depth 1 m if they [the birds] were randomly distributed). We calculated Chi-square values to test for differences in observed and expected distributions for each factor (Neu *et al.* 1974, Byers *et al.* 1984), then used Bonferroni multiple comparisons to test whether or not each category showed significant differences between use and availability.

We used a logistic regression model to determine which factors were important in determining which segments were and were not used by Kittlitz's Murrelets. The dependent variable was the presence or absence of Kittlitz's Murrelets in densities >1 bird/km^2. This measure, rather than strict presence or absence, was used to account for differences in segment length. With this criterion, very large segments with very low densities were included in the group of segments with no murrelets present. Different combinations of independent variables of increasing complexity were considered. We selected the final model by considering the Akaike Information Criterion (AIC; Akaike 1973, Burnham and Anderson 1998) and comparing competing nested models with likelihood-ratio Chi-square tests.

We included only those segments containing Kittlitz's Murrelet densities >1 bird/km^2 in an Analysis of Covariance (ANCOVA) model to determine which factors influenced density in those segments where Kittlitz's Murrelets occurred. An ANCOVA model could not be used on all data as a whole because the large number of segments with zero densities violated the assumption of normality. We compared competing nested models with an F-test.

RESULTS

Use versus availability

Kittlitz's Murrelets used all six factors (habitat type, site, ice cover, Secchi depth, sea-surface temperature, and sea-surface salinity) in a nonrandom way ($P < 0.001$ for all; Table 2). They preferred glacial-affected and glacial-stream-affected segments and avoided glacial-unaffected segments ($\chi^2 = 1218.0$, df = 2; Fig. 3). They preferred College Fjord and Harriman Fjord and used Blackstone Bay less than expected by availability ($\chi^2 = 364.6$, df = 3; Fig. 4). They preferred segments with light ice cover (0.5–15%) and avoided segments with no ice or over 50% ice cover ($\chi^2 = 491.1$, df = 3; Fig. 5). They preferred Secchi depths of 1 m and avoided areas with Secchi depths ≥2 m ($\chi^2 = 509.5$, df = 3; Fig. 6). They preferred segments with low sea-surface temperatures (4–6°C) and occurred in segments with high temperatures (10–17°C) less than expected ($\chi^2 = 521.7$, df = 3; Fig. 7). They preferred segments with sea-surface salinities of 12–17‰ and 25–30‰ but occurred in segments with salinities of 18–24‰ less than expected ($\chi^2 = 154.5$, df = 3; Fig. 8).

Although densities of Kittlitz's Murrelets varied within habitat types by season and year, the preferred habitat type was glacial-affected (Table 3). The highest densities occurred in this habitat type in four of five season-year samples. The highest density occurred in glacial-stream-affected habitats in the fifth sample, probably because large amounts of ice in early summer 1998 altered many within-bay distributions (Day & Nigro 1999). The lowest densities occurred in glacial-unaffected habitats in all five season-year samples.

Logistic regression of factors affecting presence–absence

We compared seven different models of different complexity. The model with the lowest AIC value included year (1997, 1998), season (early, mid, late), site (College Fjord, Harriman

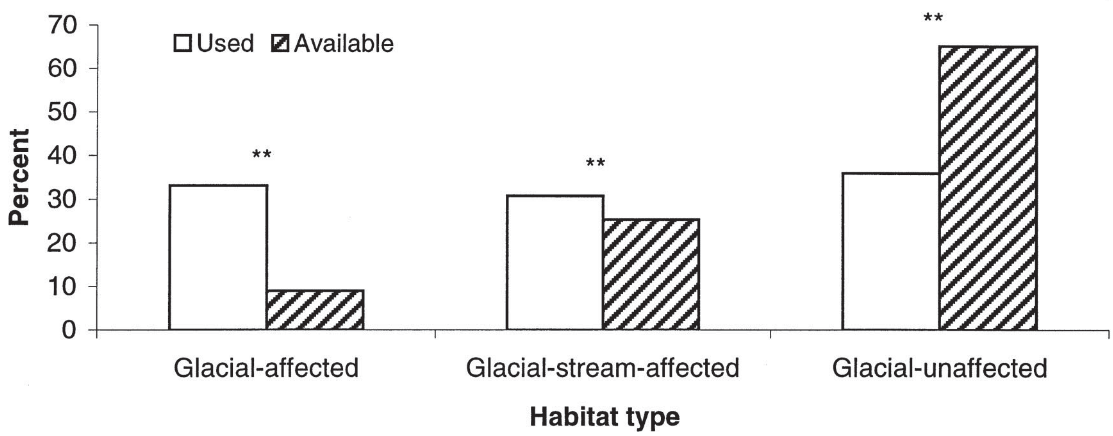

Fig. 3. *Use versus availability of habitat types by Kittlitz's Murrelets in Prince William Sound, Alaska, in 1997–1998. Significant differences are indicated by asterisks.*

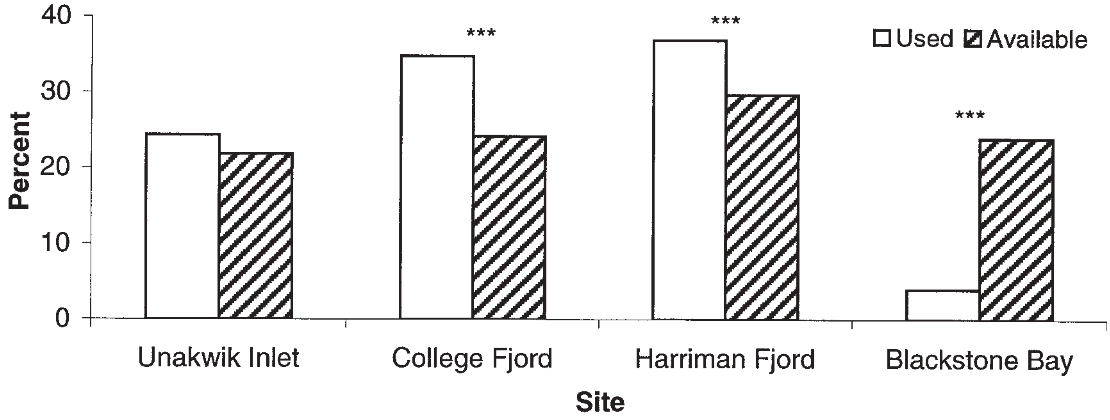

Fig. 4. *Use versus availability of sites (bays) by Kittlitz's Murrelets in Prince William Sound, Alaska, in 1997–1998. Significant differences are indicated by asterisks.*

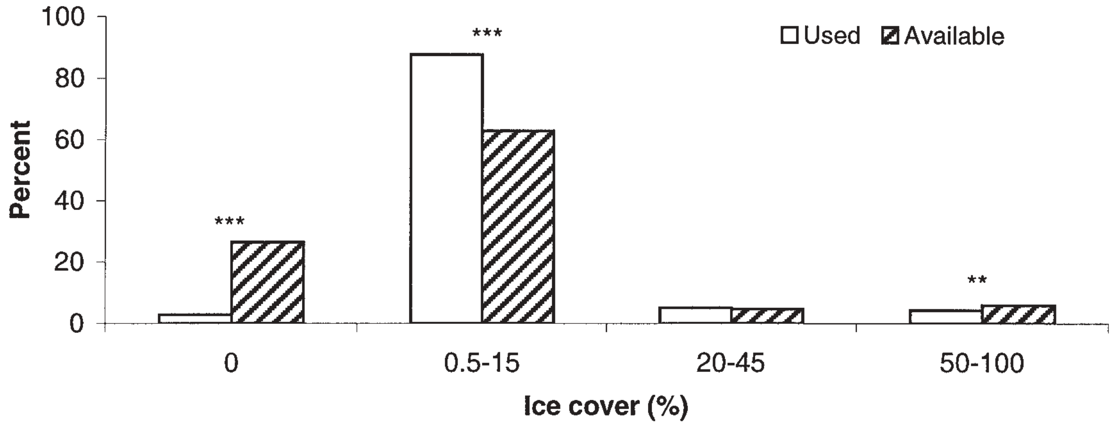

Fig. 5. *Use versus availability of ice cover by Kittlitz's Murrelets in Prince William Sound, Alaska, in 1997–1998. Significant differences are indicated by asterisks.*

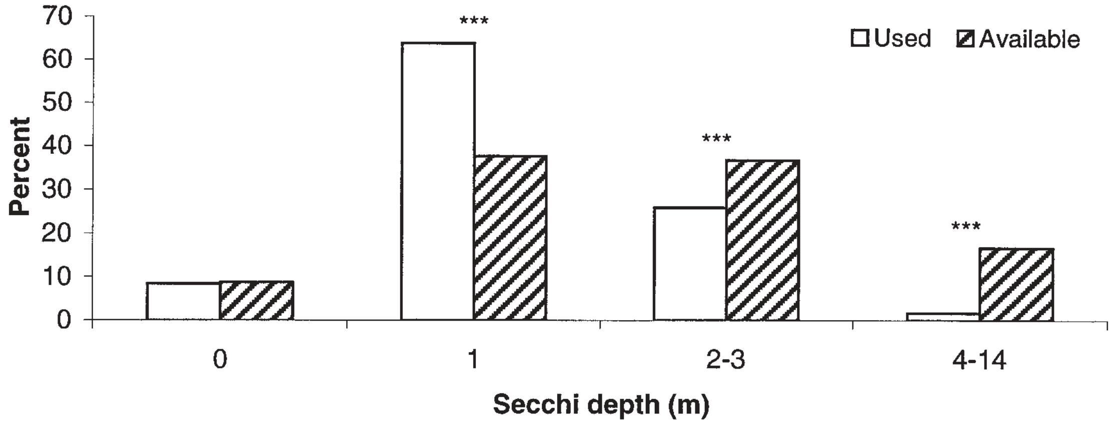

Fig. 6. *Use versus availability of water clarity (Secchi depths) by Kittlitz's Murrelets in Prince William Sound, Alaska, in 1997–1998. Significant differences are indicated by asterisks.*

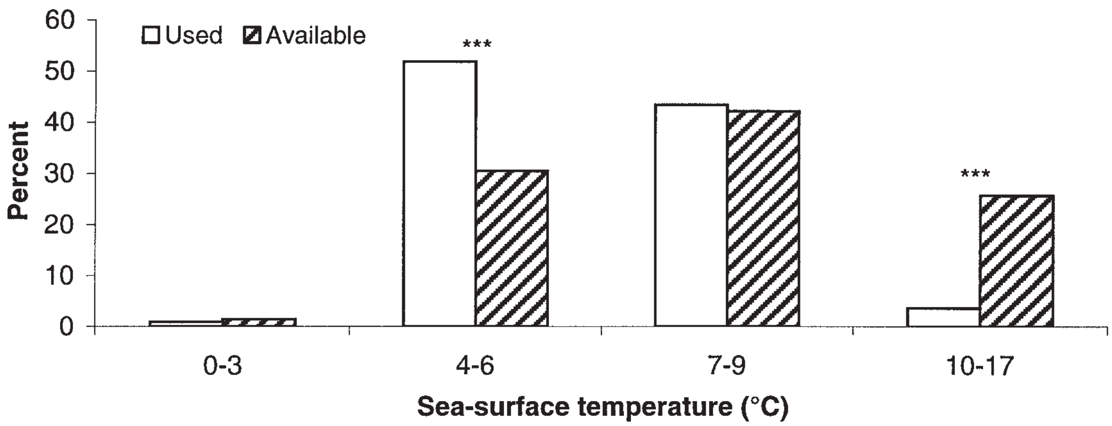

Fig. 7. *Use versus availability of sea-surface temperatures by Kittlitz's Murrelets in Prince William Sound, Alaska, in 1997–1998. Significant differences are indicated by asterisks.*

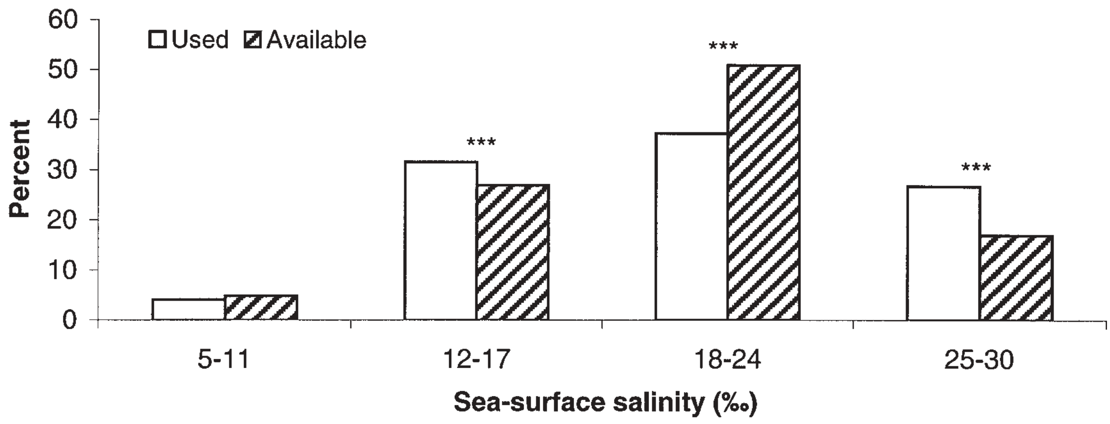

Fig. 8. *Use versus availability of sea-surface salinities by Kittlitz's Murrelets in Prince William Sound, Alaska, in 1997–1998. Significant differences are indicated by asterisks.*

Bay, Unakwik Inlet, and Blackstone Bay), the environmental variables (ln ice cover, ln Secchi depth, sea-surface salinity), habitat type (glacial-affected, glacial-stream-affected, and glacial-unaffected), two-way interactions with habitat type* environmental variables and season*environmental variables, and a three way interaction with season*habitat type*environmental variables ($\chi^2 = 345.8$, df = 35, $P < 0.001$). This model was significantly better than the simpler model without the three-way interaction ($\chi^2 = 32.2$, df = 12, $P = 0.001$), whereas the more complex model with a habitat*season interaction was not significantly better than this model ($\chi^2 = 7.7$, df = 4, $P = 0.102$).

The chosen model indicated that use of segments by Kittlitz's Murrelets was influenced by site, year, habitat type, ice cover, Secchi depth, and sea-surface salinity (Table 2). Overall, segments on Blackstone Bay were less likely to have Kittlitz's Murrelets present than were segments in the other three bays. More segments also had murrelets present in 1997 than in 1998. Kittlitz's Murrelets were more likely to be present on glacial-affected segments than on glacial-stream-affected or glacial-unaffected segments.

Kittlitz's Murrelets were more likely to be present on glacial-affected segments with low ice cover in all seasons and were more likely to be present on glacial-stream-affected and glacial-unaffected segments with low ice in early summer and higher than average ice in mid- and late summer). These murrelets selected glacial-affected segments with high Secchi depths and selected glacial-stream-affected and glacial-unaffected segments with low Secchi depths (Table 4). They also were more likely to be found on segments with higher sea-surface salinities in all seasons and habitats. The effect of salinity did not vary significantly with season, habitat type, or an interaction, however. Although none of the three-way interactions were significant, those with habitat type, season, and ice cover and with habitat type, season, and Secchi depth were marginally significant (Table 2) and together probably made this model slightly better than the simpler alternative.

ANCOVA model of factors affecting density

All of the seven different ANCOVA models examined included the factors year, season, site, segment area, and the three environmental variables (ln ice cover, ln Secchi depth, and sea-surface salinity). The model including environmental variables, habitat type, and the habitat type*environmental variable interactions was chosen as the best ($F = 7.792$, df = 18, $P < 0.001$). That model was significantly better than the model without the interaction terms ($P = 0.030$), and the model including both habitat*environmental variable interactions and season*environmental variable interactions was not significantly better ($P = 0.108$) than the model that we selected.

The selected model indicated that there were two significant main effects on densities of Kittlitz's Murrelets: area and habitat type (Table 2). The area effect indicated that shorter segments tended to have higher densities overall. The habitat-type effect occurred in spite of the significant area effect and indicated that densities were higher in glacial-affected segments

TABLE 2

Results of Chi-square, logistic regression, and ANCOVA tests of the distribution and abundance of Kittlitz's Murrelets on nearshore surveys in Prince William Sound, Alaska, with respect to various habitat factors (n = 1561 birds for Chi-square tests; n = 1012 nearshore segments for logistic regression; n = 307 nearshore segments with murrelet densities >1 bird/km^2 for ANCOVA)

Factor	χ^2 (P[a])	Logistic regression Parameter	Logistic regression P[a]	ANCOVA Parameter	ANCOVA P[a]
Area	–	–	–	–1.618	0.001*
Season	–	–	0.181	–	0.396
Year	–	0.530	0.007*	–0.038	0.764
Site	<0.001*	–	<0.001*	–	0.143
Habitat type	<0.001*	–	<0.001*	–	0.003*
Ice cover/ln ice cover[b]	<0.001*	1.392	<0.001*	0.114	0.116
Secchi depth/ln Secchi depth[b]	<0.001*	–1.284	<0.001*	–0.073	0.563
Sea-surface temperature	<0.001*	–	–	–	–
Sea-surface salinity	<0.001*	0.150	0.018*	0.023	0.305
Habitat*ice	–	–	<0.001*	–	0.276
Habitat*Secchi	–	–	0.001*	–	0.001*
Habitat*salinity	–	–	0.138	–	0.428
Season*ice	–	–	0.001*	–	–
Season*Secchi	–	–	<0.001*	–	–
Season*salinity	–	–	0.834	–	–
Season*habitat*ice	–	–	0.075	–	–
Season*habitat*Secchi	–	–	0.064	–	–
Season*habitat*salinity	–	–	0.433	–	–

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

[b] Ice cover and Secchi depth for χ^2 test; ln ice cover and ln Secchi depth for other two tests.

and that glacial-unaffected segments were avoided. The significant habitat type*Secchi depth interaction indicated that densities were higher in glacial-affected segments with high Secchi depths and higher in glacial-unaffected and glacial-stream-affected segments with low Secchi depths. Secchi depths within glacial-affected habitats were small and exhibited little variation overall, however.

DISCUSSION

Because Kittlitz's Murrelets exhibit a clumped distribution at several scales (Day & Nigro 1999), we wanted to determine which of several factors might be important in causing that clumped distribution. Although each of the six factors was significant in some analyses, few showed consistent importance across multiple analyses. Other factors, such as season and year, occasionally were significant. Inter-annual variation in abundance has been discussed in depth elsewhere (Day & Nigro 1999).

Site was significant in relative use and in determining presence or absence of Kittlitz's Murrelet but was not significant in determining the density of Kittlitz's Murrelets on segments with densities >1 bird/km^2. This species exhibited an overall preference for College and Harriman Fjords, occurred in Unakwik Inlet in proportion to availability, and avoided Blackstone Bay. The preference for College and Harriman Fjords and the avoidance of Blackstone Bay reflects the bay-scale clumping of this species and indicates an overall attraction to locations that are more heavily influenced by glaciers (Day & Nigro 1999).

TABLE 3

Densities (birds/km^2) of Kittlitz's Murrelets and number of segments, by season, year, and habitat type. Densities were calculated as total number of Kittlitz's Murrelets divided by total area, rather than as a mean of individual segment densities

		Habitat type		
Season	Year	Glacial-affected	Glacial-stream-affected	Glacial-unaffected
Early summer	1997	11.9	5.2	2.8
	1998	0.2	0.9	0.2
Mid-summer	1998	6.4	3.1	1.3
Late summer	1997	12.6	2.8	1.4
	1998	14.9	4.5	1.8

TABLE 4

Average values of the four environmental variables for nearshore segments in Prince William Sound, Alaska, on which Kittlitz's Murrelets were present (density >1 bird/km^2) or absent, by season and habitat type

		Ice cover (%)		Secchi depth (m)		Sea-surface salinity (‰)	
Season	Habitat	Present	Absent	Present	Absent	Present	Absent
Early summer	glacial-affected	19.9	43.0	0.5	0.5	24.7	21.0
	glacial-stream-affected	3.1	7.7	1.5	1.2	23.5	19.3
	glacial-unaffected	4.6	8.9	1.7	2.0	25.4	22.0
	total	6.1	12.3	1.4	1.6	24.6	21.2
Mid-summer	glacial-affected	11.9	42.5	0.4	0.1	17.7	17.8
	glacial-stream-affected	2.5	0.6	0.9	1.1	19.0	16.8
	glacial-unaffected	6.2	5.1	1.1	2.0	21.2	18.7
	total	5.8	7.4	0.9	1.6	19.8	18.2
Late summer	glacial-affected	16.3	38.0	0.6	0.4	16.2	15.9
	glacial-stream-affected	6.2	0.5	0.7	1.5	16.3	15.8
	glacial-unaffected	2.9	2.1	1.0	2.9	18.7	18.0
	total	7.2	3.9	0.8	2.3	17.4	17.2
Total	**glacial-affected**	**16.8**	**41.2**	**0.5**	**0.4**	**18.4**	**18.9**
	glacial-stream-affected	**4.4**	**3.5**	**1.0**	**1.3**	**19.5**	**17.4**
	glacial-unaffected	**3.9**	**5.3**	**1.3**	**2.5**	**21.5**	**19.8**
	total	**6.6**	**7.9**	**1.0**	**2.0**	**20.2**	**19.0**

Habitat type was a significant factor in affecting the distribution and abundance of Kittlitz's Murrelets in all three tests, both as main effects and as interactions. The Chi-square test indicated that this was clearly the most important factor. These birds exhibited an overall preference for glacial-affected and glacial-stream-affected habitats and avoided glacial-unaffected habitats. In addition, marine-sill-affected habitats were used very rarely; the lack of overall importance of this habitat type matches the lack of importance of turbulent flow over marine sills for feeding by Kittlitz's Murrelets (Day & Nigro 2000). Habitat type also was important in several interactions indicating that use of other factors varied with habitat type. In addition, a seasonal shift in the distribution of Kittlitz's Murrelets toward glacier faces, similar to what we saw in this study, was recorded at Muir Glacier in Glacier Bay, Alaska, between early and mid-summer (Bailey 1927). Glacial-affected habitats are preferred by other seabird species elsewhere; for example, densities of Arctic or Northern Fulmars *Fulmarus glacialis* and Black-legged Kittiwakes *Larus tridactyla* in the Canadian Arctic also are higher near tidewater glaciers than away from them (McLaren & Renaud 1982).

Ice cover was significant in relative use and in determining presence or absence of Kittlitz's Murrelet but was not significant in determining density on segments with densities >1 bird/km^2. The Chi-square test indicated that this factor was fourth most important in affecting distribution and abundance. These birds used segments with no ice less than expected, exhibited an overall preference for segments with light ice cover (0.5–15%), used segments with moderate ice cover (20–45%) in proportion to availability, and avoided segments with over 50% ice cover. Such use of primarily light ice and avoidance of heavy ice differs from the results of feeding studies, which found decreased feeding frequencies with increasing ice cover but the highest feeding frequencies in the heaviest ice cover (Day & Nigro 2000); these latter areas consisted of patches of open water within areas of otherwise solid ice cover and were occupied by few birds. Together, these results suggest that this species prefers to feed in zones of heavy ice (i.e., off the faces of tidewater glaciers) but that very heavy ice cover inhibits overall use of such areas. Although we are unclear why such an inhibition of use occurs, it may simply reflect the dangers associated with resurfacing in areas of rapidly moving ice. In addition, such glacial-affected areas also have high turbidity, making it even more difficult to find areas of open water for resurfacing safely, especially when tides and winds are moving the ice around within bays. Size also may play a role in ability to penetrate areas of high ice cover, in that the smaller alcids (Parakeet, Crested, and Least Auklets *Aethia psittacula, A. cristatella,* and *A. pusilla* and Dovekies or Little Auks *Alle alle*) tend to avoid areas of high ice cover (Divoky 1979, Durinck & Falk 1996), whereas the larger alcids (Thick-billed Murres or Brunnich's Guillemots *Uria lomvia*) tend to associate with areas of high ice cover (McLaren 1982). This relationship, however, is not entirely consistent, for moderately sized Black Guillemots *Cepphus grylle* winter in the Bering and Chukchi Seas in the heaviest ice of all alcids (Divoky 1979).

Water clarity clearly was a very important factors affecting the distribution and abundance of Kittlitz's Murrelets. It was a significant factor in the tests of relative use (with a Chi-square value indicating it was third most-important, after habitat type and sea-surface temperature) and presence–absence but was not significant in determining density on segments with densities >1 bird/km^2 as a main effect; it also was significant in several interactions. Kittlitz's Murrelets used areas with Secchi depths <1 m in proportion to their availability, preferred Secchi depths of 1 m, and avoided Secchi depths ≥2 m. Surprisingly, even though there was a preference for locations where glaciers were dumping large amounts of sediment into the water (as indicated by the preference for 1-m depths), these birds showed no difference in feeding frequency by Secchi depth (Day & Nigro 2000). The large numbers of birds using these turbid areas, however, indicated that they are biologically important feeding areas.

Sea-surface temperature was a significant factor in affecting relative use by Kittlitz's Murrelets. The Chi-square value for relative use was second only to habitat type and only slightly larger than that for Secchi depth. These birds occurred in very cold (<4°C) and intermediate (7–9°C) sea-surface temperatures in proportion to their availability, preferred segments with low temperatures (4–6°C), and avoided segments with high temperatures (10–17°C), reflecting a preference for areas where glaciers were adding cold water to the bays and an avoidance of the less glacial-affected outer parts of the bays. Because of its collinearity with other variables, however, we were unable to assess its importance in the other analyses.

Sea-surface salinity was significant in affecting relative use and presence/absence but was not important in affecting the density of Kittlitz's Murrelets. They preferred segments with low or high sea-surface salinities (12–17‰ and 25–30‰) but avoided segments with intermediate salinities (18–24‰). The higher salinities reflect mostly early-summer conditions, and the lower salinities clearly reflect an attraction to sources of freshwater input, such as glaciers and glacial-fed streams. This highly variable reaction to salinities follows the lack of significant association with of specific salinities for feeding (Day & Nigro 2000).

This study found that several factors are important in causing a clumped distribution of Kittlitz's Murrelets. Site was important, in that these birds prefer bays that are more heavily glaciated. Within bays, habitat type was the most important factor causing clumping, with glacial-affected habitats and glacial-stream-affected habitats being highly important to this species; such areas also are of great importance to feeding birds (Day & Nigro 2000). Secchi depths that reflect sites of input of large amounts of turbid fresh water from tidewater and hanging glaciers also are important and, because of their restricted distribution within bays, are of even greater importance than might appear at first. Hence, we consider that any conservation-based management incorporate the importance of site, habitat type, and water clarity as major areas to be protected for ensuring the long-term health of this species.

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