Identifying Kittlitz's Murrelet Nesting Habitat in North America at the Landscape Scale

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Abstract

The Kittlitz's Murrelet (*Brachyramphus brevirostris*) is a small, non-colonial seabird endemic to marine waters of Alaska and eastern Russia that may have experienced significant population decline in recent decades, in part because of low reproductive success and terrestrial threats. Although recent studies have shed new light on Kittlitz's Murrelet nesting habitat in a few discrete areas, the location and extent of suitable nesting habitat throughout most of its range remains unclear. Here, we have compiled all existing nest records and locations to identify landscape-scale parameters (distance to coast, elevation, slope, and land cover) that provide potential nesting habitat in four regions: northern Alaska, Aleutian Islands, Alaska Peninsula Mountains and Kodiak Island, and Pacific Coastal Mountains (including nearshore interior Canada). We produced a final map classifying 12% (70,411 km^2) of the lands assessed as potential Kittlitz's Murrelet nesting habitat, with dense but distinct patches in northern Alaska and a more uninterrupted, narrow band extending across the Pacific Coastal Mountains, Alaska Peninsula Mountains, and Aleutian Islands. The extent of habitat-capable parameter values varied regionally, indicating that the Kittlitz's Murrelet may be able to use a variety of habitats for nesting, depending on availability. Future nesting habitat studies could employ spatially random sampling designs to allow for quantitatively robust modeling of nesting habitat and predictive extrapolation to areas where nests have not been located but likely exist.

Key Words: seabird, nesting habitat, landscape-scale parameters, Alaska, eastern Russia

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Introduction

The Kittlitz's Murrelet (*Brachyramphus brevirostris*, family *Alcidae*) is a small, diving seabird endemic to marine waters of Alaska and the Russian Far East where it spends its entire annual cycle (Day et al. 1999). During the summer breeding season, individuals occur in nearshore waters, where they feed primarily on small marine fish (Hatch 2011). During the last decade, the Kittlitz's Murrelet has been the subject of conservation concern (BirdLife International 2014; Butcher et al. 2007; U.S. Fish and Wildlife Service [USFWS] 2004, 2013) due to evidence of population declines in some portions of its range (Kuletz et al. 2011a, 2011b; Piatt et al. 2011), as well as an apparent association with glacially influenced marine habitats that are changing rapidly (Kuletz et al. 2003; Arendt et al. 2009). Until recently, little information was available describing Kittlitz's Murrelet natural history, particularly its breeding biology (Day et al. 1999).

Unlike most seabirds, Kittlitz's Murrelets are not colonial breeders but instead nest solitarily, selecting sites that often are far inland from marine foraging areas (up to 74 km; Day et al. 1983; Gaston and Jones 1998). Nests typically are located on un- to sparsely vegetated talus slopes, barren ground, and cliffs and ledges in near-coastal uplands and mountains, where a single egg is laid in a nest scrape on open ground (Figure 1; Day et al. 1999). Both adults incubate at 24–48-hour intervals for ~30 days, followed by a 20–30-day chick-rearing period during which time the chick is left unattended while its parents forage between chick-meal deliveries. Owing to its secretive nesting habits and cryptic breeding plumage, presumably aimed at avoiding detection by predators (Figure 1), only 17 nests had been discovered in Alaska before 1999, and most were found accidentally (Day et al. 1999).

Since 2005, three key studies in Alaska have filled information gaps in our knowledge of the nesting biology of Kittlitz's Murrelets. From 2006 to 2012, researchers located 95 nests by ground-searching foot-accessible areas on Agattu and Adak islands in the Aleutian Archipelago

(Kaler et al. 2009; Kaler, USFWS, unpublished data). Using similar methods, researchers at Kodiak Island in south-central Alaska discovered 74 nests from 2008 to 2012 (Lawonn 2012; Corcoran et al. 2014). Finally, in Icy Bay, a heavily-glaciated fjord system in southeastern Alaska, researchers found 35 nests from 2007 to 2012, primarily by using radiotelemetry to track murrelets captured at sea to inland nest sites (Kissling et al. 2015). Across these studies, 74% of monitored nests failed due to nest depredation, chick death (owing to starvation, exposure, or disease), or chick abandonment (USFWS 2013). Although the rates and causes of nest failure differed among study areas, overall reproductive output of Kittlitz's Murrelets in these studies appeared alarmingly low, raising concern that this species may be experiencing reproductive problems, as proposed by Day and Nigro (2004). Although it is unknown if the ultimate cause of reproductive failure is associated with the marine or terrestrial habitats, or a combination of both, management actions that reduce or eliminate factors contributing to nest failure may benefit this species.

Although these recent studies (summarized in USFWS 2013) have shed new light on Kittlitz's Murrelet nesting habitat in a few discrete areas, the location and extent of other possible nesting areas remains unclear. Our overall goal was to combine existing disparate datasets to identify potential Kittlitz's Murrelet nesting habitat throughout its North American range to assist managers responsible for guiding conservation directives and to provide researchers with a meaningful starting point for discovering new nesting areas. Specifically, we (1) characterized Kittlitz's Murrelet nesting habitat at the landscape scale; (2) defined criteria for delineating/identifying possible nesting habitat; and (3) mapped potentially suitable nesting habitat based on these criteria.

Study Area

We delineated geographic boundaries to our study area based on the regular at-sea occurrence of Kittlitz's Murrelets during the breeding season, which included nearly all of coastal Alaska (Figure 2). We did not consider the density of murrelets at sea as a factor in delineating boundaries, although we acknowledge that the greatest densities of this species occur in south-coastal Alaska (USFWS 2013). We excluded from consideration land east of 154°W (~100 km east of Point Barrow) in northern Alaska because breeding Kittlitz's Murrelets do not appear to use marine or terrestrial habitat along the Beaufort Sea coastline (Day et al. 2011). We did not include land in coastal British Columbia (south of 54.65°N and east of ~130°W; Figure 2) because Kittlitz's Murrelets are extremely rare south of Alaska (Carter et al. 2011). We considered all remaining land in Alaska and interior Canada within 100 km of the Alaska coastline in our analysis, following Day et al. (2011; Figure 2). We divided this area into four regions following Gallant et al. (1995): Northern Alaska (NOAK), Aleutian Islands (AI), Alaska Peninsula Mountains (APM, including Kodiak Island), and Pacific Coastal Mountains (PCM; Figure 2). These regions are ecologically distinct due to differing environmental factors such as topography, climate, and geology (Gallant et al. 1995).

Methods

We mapped potential nesting habitat of Kittlitz's Murrelets with a three-step procedure. First, we compiled available nest records and evaluated them for authenticity. Second, we used the available nest records to define thresholds for selected physical and biological parameters that were used to distinguish habitat-capable from non-habitat-capable lands for each parameter. Third, we mapped potential nesting habitat where all parameters were habitat-capable.

Nest Records

We compiled a database of all reported Kittlitz's Murrelet nests (n = 249; Table A1) between 1904 and 2012. We then determined the veracity and locational accuracy of these nests by consulting original information sources. We categorized a nest as (1) "Confirmed" if it was observed directly and species identification was unequivocal, (2) "Probable" if it was located using aerial telemetry tracking of radio-marked Kittlitz's Murrelets with at least two non-consecutive inland locations (suggesting incubation exchange between adults), or (3) "Possible" if it was either a terrestrial site where only one aerial telemetry location was obtained or a nest record with uncertain species identification (due to confusion with the Marbled Murrelet [*B. marmoratus*], a congeneric species that sometimes nests in similar habitat; Barbaree et al. 2014; Kissling et al. 2015). Additionally, we classified each nest into one of four locational accuracy categories: very low (>1 km), low (500 m – 1 km), medium (100 – 500 m), and high (<100 m; Table 1). We used only confirmed or probable nests with medium or high locational accuracy (n=215) for analysis.

Habitat parameters and mapping

We considered three physical parameters (distance to coastline, elevation, and slope) and one biological parameter (land cover) as potentially important characteristics of nesting habitat for this species (Day et al. 1999, 2011). We used the National Elevation Dataset (NED) digital elevation model (DEM) to represent elevation in Alaska (60 m x 60 m horizontal resolution; Gesch et al. 2002) and a DEM for Canada from Canadian Digital Elevation Data (25 m x 25 m horizontal resolution; Natural Resources Canada 1996). We filled small gaps in Alaska NED DEM coverage with Advanced Spaceborne Thermal Emission and Reflection Radiometer DEM data (ASTER, 30 m x 30 m horizontal resolution; Land Processes Distributed Active Archive Center 2006). We derived slope from this composite DEM (maximum elevation change with any adjacent cell) and generated a raster representation of distance to coastline from a 1:63,000 coastline shapefile for Alaska (Alaska Department of Natural Resources 1998). For land cover classification, we used the National Land Cover Dataset (NLCD; 30 m x 30 m horizontal resolution) for Alaska (Homer et al. 2007) and the Earth Observation for the Sustainable Development of Forests (25 m x 25 m horizontal resolution; Natural Resources Canada 2008) for Canada. We preprocessed data to a common projection and resampled to match the spatial resolution of the coarsest data set (NED DEM, 60 m) using ArcGIS (v10.1; ESRI, Redlands, CA).

We obtained values for distance to coastline, elevation, slope, and land cover class for nest sites based on their spatial intersection with habitat parameter layers. Although written descriptions and field measurements of nest habitat parameters were available for many nests, we did not use them because that information did not exist for all records and it often was measured or estimated at inconsistent scales or at finer resolutions than could be represented by the GIS data sets. Instead, we used the values extracted from the GIS habitat parameters to ensure that we produced a nesting habitat map at a common, range-wide scale and with standardized habitat measurements and classifications.

Regionally, we determined minimum and maximum values of the three physical parameters among nests to establish thresholds for each parameter. We then expanded the range of these values by proportionally fixed amounts in each region under the assumptions that (1) nests have been found near, but not at the extreme limit, of each parameter, and (2) those extreme limits vary regionally based on how local climate, topography, and geology interact to create potential habitat that is accessible to Kittlitz's Murrelets within their energetic limits (e.g., distance from coastline). These adjusted thresholds also absorbed the effects of uncertainty due to potential nest location or habitat parameter inaccuracies. We deemed land within these adjusted thresholds as habitat-capable for that particular parameter and land outside the threshold range was designated non-habitat-capable (following Raphael et al. 2006, 2011).

For distance from coastline, we excluded land less than 200 m from shore in all regions because *Brachyramphus* murrelets probably avoid nesting immediately along the shoreline where predators are abundant (Albert and Schoen 2007). To set the maximum distance from coastline threshold in each region, we identified the distance of the nest farthest from shore and added 30%. We chose an adjustment value of 30% in all regions to allow for consistency with Day et al. (2011) in NOAK. We did not set a maximum distance to coastline threshold in AI because the maximum possible value was too small (<20 km). For elevation and slope thresholds, we determined the minimum nest elevation and slope of nests in our database in each region and reduced each parameter by 15%; this value was arbitrary but seemed reasonable given that many nests in our dataset were subject to sampling bias. For similar reasons, we did not set upper limits to elevation or slope in any region. Kittlitz's Murrelets will nest on cliff ledges surrounded by terrain that is inaccessible by foot and at elevations up to 2555 m (Kissling et al. 2015). We assumed that high elevations in steep alpine areas have not been traversed as much as low elevations in flatter terrain, so it was less likely for nests to have been found opportunistically in the former areas. Although Kittlitz's Murrelets undoubtedly encounter physiological limitations that prevent them from nesting above a certain altitude, those limits are unknown. Further, the amount of snow- and ice-free land at the highest elevations was minimal (<0.1% above 2,555 m), so our liberal approach to setting thresholds for elevation and slope probably had little influence on our results.

We used land cover class as a biological parameter to designate habitat-capable land for Kittlitz's Murrelets in all regions. We identified the NLCD land cover class value at each nest site and then compared them to nest site descriptions to evaluate if they were biologically valid or could be erroneous due to potential nest site locational inaccuracy or NLCD error. Potentially erroneous land cover classes (e.g., ice/snow) were excluded.

In each region, we identified potential Kittlitz's Murrelet nesting habitat as lands within the habitat-capable bounds of all four parameters combined. To determine regional variation, we calculated the total land area (km^2) of potential habitat in each region and the proportion of that land by land cover class considered habitat-capable. We then joined regional maps to produce a final map of potential nesting habitat for Kittlitz's Murrelets in North America.

Results

Across all regions, the maximum distance between a Kittlitz's Murrelet nest and the coastline was 73.5 km, the minimum nest elevation was 128 m, and the minimum slope was 0° (n = 215 nests; Table 2). After adjusting thresholds to account for uncertainty, the maximum distance from coastline for habitat-capable land ranged from 36.9 km in PCM to 95.5 km in NOAK (Table 2). The minimum habitat-capable elevation was lowest in NOAK (109 m) and highest in AI (156 m); the minimum habitat-capable slope ranged from 0° in PCM to 5.6° in NOAK (Table 2).

Almost all nests (90%) were found on three land cover classes: barren (45% of nests), dwarf-shrub (33%), and grassland/herbaceous (12%). The remaining 10% of nests were located on perennial snow/ice (n = 19) or shrub/scrub (n = 2). All nests within the perennial snow/ice land cover class were located using aerial telemetry in the PCM region, were located adjacent to steep, barren habitat dominated by cliffs, and fell within the medium-level accuracy category. Hence, we assumed that these nests likely were located on barren habitat and did not consider perennial snow/ice to be habitat-capable. It also is possible that some nests in this land cover class were discovered in years of lower snow cover than the remote sensing data used to create the NLCD land cover product, suggesting that these nest sites may only be available in some years. Similarly, we assumed that shrub/scrub was not habitat-capable because the written habitat descriptions for both nests located in this land cover were not consistent with GIS-derived data. Additionally, both nests were adjacent to one of the predominant three land cover classes, indicating small-scale inaccuracies in the NLCD land cover or nest locations. Therefore, we ultimately defined only barren, dwarf-shrub, and grassland/herbaceous land cover classes as habitat-capable.

We classified 12% (70,411 km^2) of the land within our study area as potential nesting habitat (Table 3), with dense, but discrete, patches located in NOAK and a more uninterrupted, narrow band extending across the coastal mountainous areas in AI, APM, and PCM (Figure 3; Data A1). Regionally, the proportion of potential habitat was greatest in AI (39%) and least in

NOAK (9%; Table 3). Potential nesting habitat was present along much of the Pacific coast of Alaska (PCM, APM, and AI regions), although notable gaps existed in extreme southeastern Alaska (primarily on islands of the Alexander Archipelago) and in lowlands around upper Cook Inlet (Figure 3). Larger, higher elevation islands in AI tended to have more potential habitat (e.g., Adak Island) than smaller and lower islands. Along the Bering and Chukchi Sea coasts (NOAK), potential nesting habitat was present in the western Brooks Range, on the Seward Peninsula, east of Norton Sound in the Nulato Hills, and, to a lesser extent, in the Ahklun/Kilbuck Mountains between the Yukon–Kuskokwim Delta and Bristol Bay (Figure 3). Large habitat gaps occurred in the extensive lowlands near Bristol Bay, the Yukon–Kuskokwim Delta, Kotzebue Sound, and north of the Brooks Range on the Arctic Coastal Plain (Figure 3).

We found considerable regional variation in the proportional extent of habitat-capable land cover classes (Figure 4). The "barren" land class was most widespread in PCM (80%), decreased westward through APM (43%) and AI (31%), and was least common in NOAK (14%). This pattern was opposite for the "dwarf-shrub" land class, which was most extensive in NOAK (86%) and least common in PCM (19%). "Grassland/herbaceous" habitat was only common in APM (9%) and AI (27%).

Discussion

We provide the first comprehensive assessment of potential nesting habitat of the Kittlitz's Murrelet for North America (Figure 4). Our criteria identified 12% (70,411 km^2) of all land within regionally defined distance to coastline thresholds as potentially suitable for nesting, with most located in NOAK and PCM (72%; Table 3). Our classification scheme provides a tool to help resource managers and policy makers in North America make informed decisions for the management of potentially important Kittlitz's Murrelet nesting habitat. In addition, our classification of nesting habitat provides a baseline to evaluate future shifts in the breeding range of this species (e.g., Raphael et al. 2011).

Our results indicate that the Kittlitz's Murrelet uses a variety of habitats depending on availability. For example, Kittlitz's Murrelets may nest farther inland in NOAK (≤96 km; Table 3) because the nearshore topography is more subdued and maximum elevations (≤1,450 m) are lower and farther from shore than in PCM (≤37 km; Table 3), where the Chugach–St. Elias Mountains (maximum elevation 5,489 m) present a significant nearshore topographic barrier limiting inland travel of murrelets to nest sites that are comparatively closer to the coast. Indeed, nesting Kittlitz's Murrelets presumably would preferentially nest closer to the coastline to reduce flight energetic costs, especially during chick-rearing (Hatch 2011). The maximum distance flown inland by Kittlitz's Murrelets, therefore, may be negatively correlated with the amount of suitable habitat located near the coast. Additionally, constant physical disturbance by extensive, active glaciation in PCM provides substantial barren and sparsely vegetated habitat at very low slopes (≥0°), whereas low-slope areas in NOAK (≥5.6°; Table 3) are more likely to be covered by wet, vegetated tundra. These terrestrial factors may explain in part why Kittlitz's Murrelets reach their greatest densities at sea in PCM compared to other regions (Day et al. 2011; Kissling et al. 2011; Madison et al. 2011).

Kittlitz's Murrelet nesting habitat generally follows the near-coastal (<100 km inland) distribution of dry and alpine "upland tundra" vegetation zones in Alaska (Viereck et al. 1992). These zones manifest as *Dryas* spp. Dwarf-shrub tundra on exposed ridges and rocky sites in northern and western Alaska (NOAK), *Dryas* and ericaceous dwarf-shrub tundra above treeline in mountainous regions of south-central Alaska (eastern APM and western PCM), and *Empetrum* spp. heath, ericaceous dwarf-shrub, and mesic forb herbaceous vegetation in AI and, to a lesser extent, APM (Viereck et al. 1992). Barren habitat consisting of little to no vegetation is associated with these upland tundra zones across their range; however, it is most widespread in PCM where higher elevations, steep topography, extensive glaciation, and concomitant erosional processes prevent significant soil development (Gallant et al. 1995; Viereck et al. 1992). The regional proportion of potential habitat in each habitat-capable land cover class varied similarly (Figure 4), as did field measurements of vegetative type and cover at extant nest sites (Day et al. 2011; Kaler et al. 2009; Lawonn 2012; Kissling, USFWS, unpublished data). The regional variability in how habitat parameters manifest as suitable habitat, as well as the species' apparent high level of behavioral plasticity in regard to where breeding birds will go to locate nesting habitat, likely contributes to the broad, but irregular, distribution of Kittlitz's Murrelets at sea during the breeding season (USFWS 2013).

At the nest-site scale, field studies have shown that Kittlitz's Murrelets tend to nest among the least-vegetated areas available locally (Kaler et al. 2009; Kissling, USFWS, unpublished data) and sometimes avoid nesting near vegetated edges, perhaps to avoid predators (Lawonn 2012). The amount of vegetative cover measured within a 25 m radius of nest sites ranged from 0 – 75% (Kaler et al. 2009; Day et al. 2011; Lawonn 2012; Kaler, USFWS, unpublished data; Kissling, USFWS, unpublished data). At the landscape scale, grid cells in the NLCD product needed only to have >15% vegetative cover to be defined as a vegetated land cover class and realistically also contained barren or sparsely vegetated patches that were lost at the coarser resolution of these data. Therefore, we likely overestimated potentially suitable habitat by including these vegetated land cover classes. Our map product, however, provides a general representation of the spectrum of potential nesting habitat throughout the majority of this species' range.

Although we were not able to ground-truth the final product, we present three points that substantiate our regional habitat assessment. First, the known at-sea distribution of Kittlitz's Murrelets during the breeding season generally mirrors the distribution of potential nesting habitat we identified (see USFWS 2013 for summary of at-sea distribution). Second, our results in northern Alaska are similar to those of Day et al. (2011) who mapped nesting habitat for this species by using only land cover classes and elevation; the addition of slope (as recommended in that study) restricted the extent of potential habitat in our study, but the two efforts generally produced similar results. Third, the maximum annual nest density recorded in suitable, well-searched terrain is 0.118 nests km^{-2} (Kodiak Island, APM; Lawonn 2012), which produced a breeding population estimate of ~8,200 pairs (16,600 individuals) when applied uniformly to the areal extent of potential habitat we identified. Including the number of non-breeders (potentially 80% of the population; Kissling et al. 2015) and a Russian population of at least 1,000 murrelets (Artukhin et al. 2011) could increase this number to be similar to current range-wide population estimates of ~25,000 to ~42,000 individuals (USFWS 2013), generally supporting our mapping criteria. Additionally, the calculation of true surface area (instead of planimetric area, as used here) would increase the total area of potential nesting habitat, most of which is sloping, resulting in a greater estimate of nesting murrelets. Of course, it is unlikely that Kittlitz's Murrelets nest at similar densities across their entire range or use all habitat mapped in this study; the extent of suitable nesting habitat may drive regional distribution, whereas favorable at-sea conditions drive local abundance, or *vice versa* (Arimitsu et al. 2012; Raphael et al. 2014).

We did not calculate the probability associated with potential nesting habitat by quantitatively modeling the distribution of habitat parameters at extant nest sites because of spatial sampling bias (Raphael et al. 2011). Nests with reasonable location accuracy that were discovered accidently were few (n < 20), and, of the three focused nesting studies, those in AI (Kaler et al. 2009) and APM (Lawonn 2012) were biased towards restricted, foot-accessible areas that do not represent the full range of habitat parameters available in the regional landscape (Figure 3). In comparison, nest sites located using aerial telemetry around Icy Bay were sampled across the landscape without spatial biases. Those nests present the best opportunity for quantitative modeling of nest habitat suitability at the landscape scale, albeit only for PCM because of inter-regional variation in the availability of habitat parameters (e.g., land cover; Figure 4).

The framework and map presented herein provides the first management tool for identifying potential Kittlitz's Murrelet nesting habitat across the species' North American range. We used an approach that isolated common regional and range-wide characteristics for four habitat parameters, with an emphasis on using extant nesting information within its limit of inference. Although we probably have over-represented the true extent of nesting habitat with our criteria, the final map product can help focus future survey and research efforts to locate potentially important areas for conservation that can be refined further by ground-truthing. For example, the use of guano-facilitated vegetative growth at previously occupied nests has recently been used to locate active murrelet nests in the Aleutian Islands (Kenney and Kaler 2013); vegetative cues such as this could provide an important fine-scale tool in areas of potential nesting habitat identified herein. Our results suggest further analyses coupling at-sea distribution data with our nesting habitat map would assist investigations regarding relative importance of other factors—such as glaciation, habitat patchiness, or distance to vegetated edge—that may influence the distribution and abundance of Kittlitz's Murrelet nesting habitat at the landscape scale (Kuletz et al. 2003; Lawonn et al. 2012). Future nest surveys that employ non-biased, spatially random, or stratified-random sampling designs (e.g., telemetry, point-, or line-transect designs) would allow for quantitative modeling of nesting habitat and better extrapolation to areas where nests have not been located. In particular, very few nests with reliable locational accuracy have been discovered in the largest region in this study (NOAK; n = 7). Focused research in NOAK (as well as AI and APM) that evaluates the relative importance of the barren and vegetated land cover classes to nesting Kittlitz's Murrelets could help to refine further the overall extent of potential habitat estimated in our study.

Supplemental Material

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Table S1. Locations, veracities, and locational accuracies of all Kittlitz's Murrelet Brachyramphus brevirostris nest sites reported through 2012. Found at DOI: http://dx.doi.org/10.3996/112015-JFWM-116.S1 (29 KB XLSX).

Table S2. References. Full references for 'Source' field in Table A1. Found at DOI: http://dx.doi.org/10.3996/112015-JFWM-116.S2 (29 KB XLSX).

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Data A1. Geographic Information System (GIS) raster file of potential nesting habitat for the Kittlitz's Murrelet *Brachyramphus brevirostris* in North America. Archived at

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Table Captions

Table 1. Description of four categories used to classify locational accuracy of Kittlitz's Murrelet (*Brachyramphus brevirostris*) nests for mapping potential nesting habitat in North America.

Table 2. Summary of nest elevation, slope, and distance to coastline values extracted from GIS habitat parameter layers at Kittlitz's Murrelets (*Brachyramphus brevirostris*) nest sites (1904–2012) and value ranges used to define habitat-capable land for nesting in each region, North America. Regions include northern Alaska (NOAK), Aleutian Islands (AI), Alaska Peninsula Mountains (APM), and Pacific Coastal Mountains (PCM).

Table 3. Total land area in each region (within distance to coastline thresholds) considered in analysis and area and proportion of potential habitat for nesting Kittlitz's Murrelets (*Brachyramphus brevirostris*) that met all habitat parameter criteria (elevation, slope, land cover). Potential nesting habitat was identified using nest sites discovered through 2012. Regions are northern Alaska (NOAK), Aleutian Islands (AI), Alaska Peninsula Mountains (APM), and Pacific Coastal Mountains (PCM).

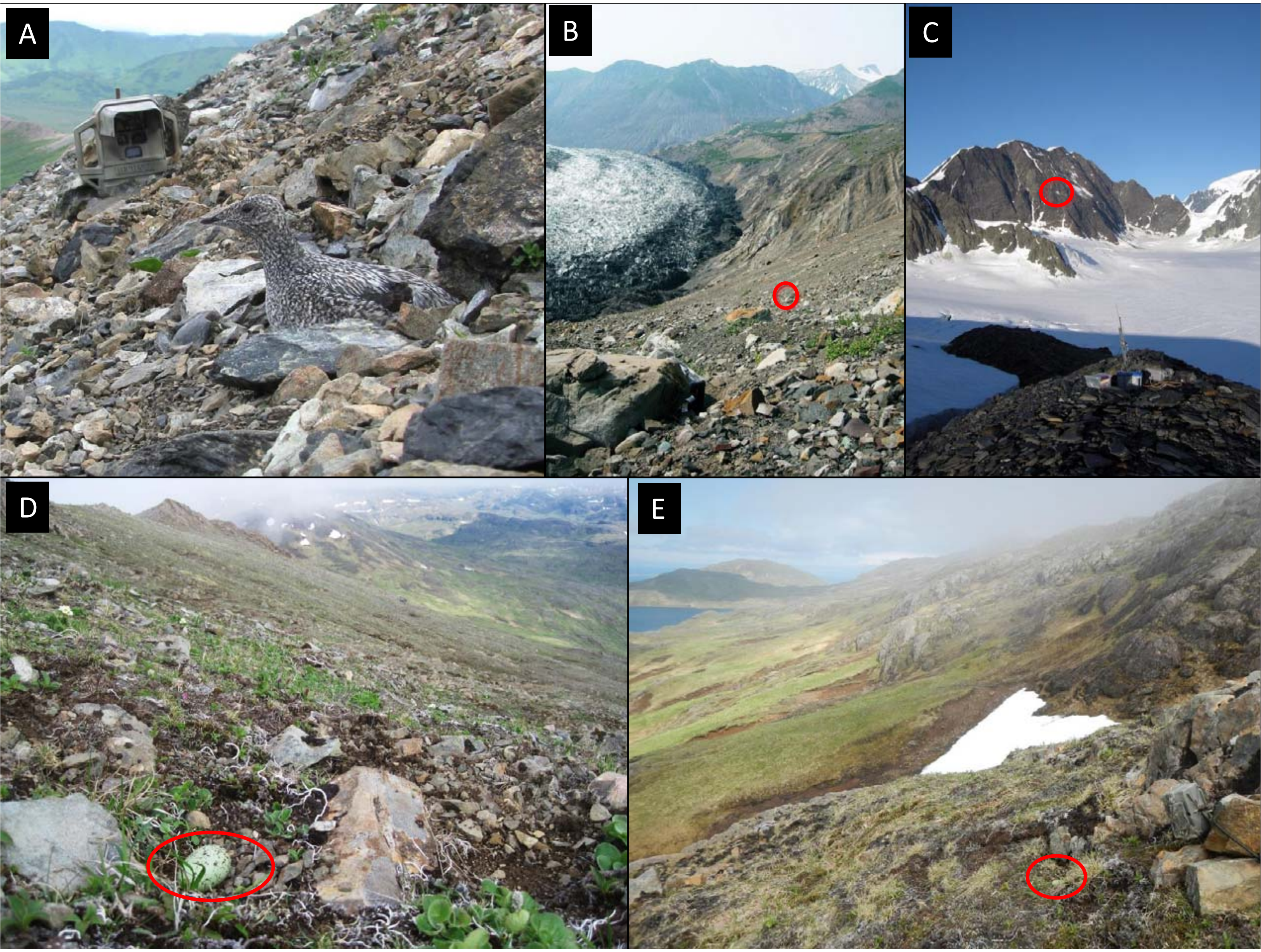
Figure Captions

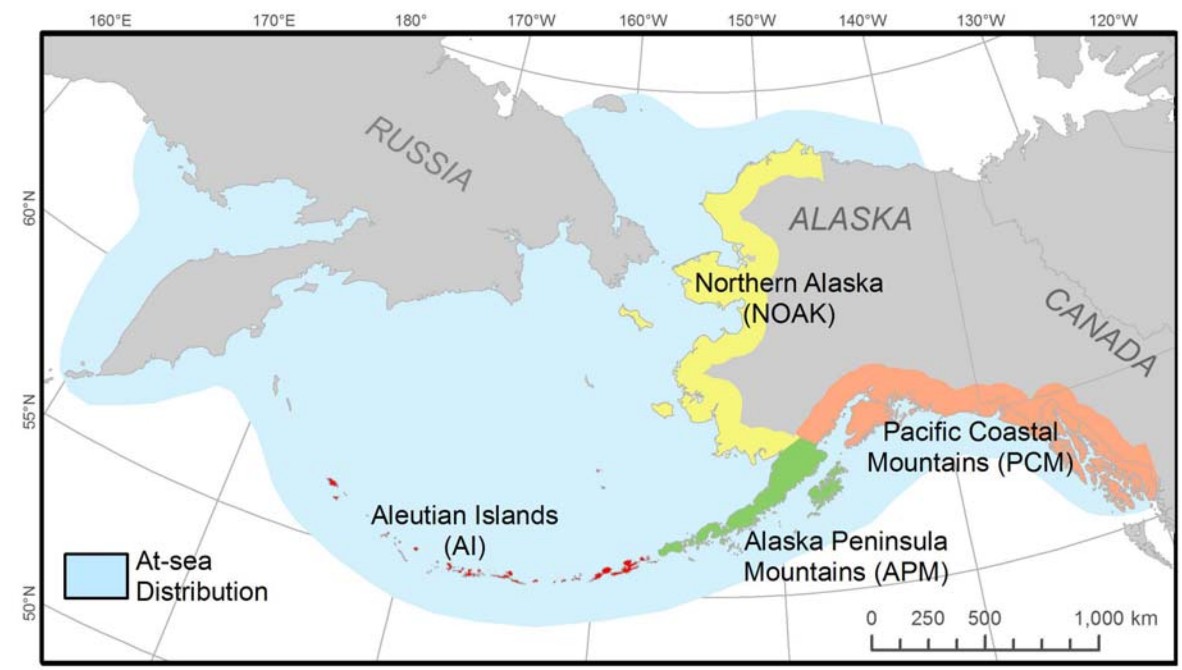
Figure 1. Examples of Kittlitz's Murrelet (*Brachyramphus brevirostris*) nest sites on Kodiak Island (A; photo credit: M.J. Lawonn), near Icy Bay (B, C; photo credit M.L. Kissling), and in Aleutian Islands (D, E; photo credit R.S.A. Kaler). Nest sites were photographed between 2007 and 2015.

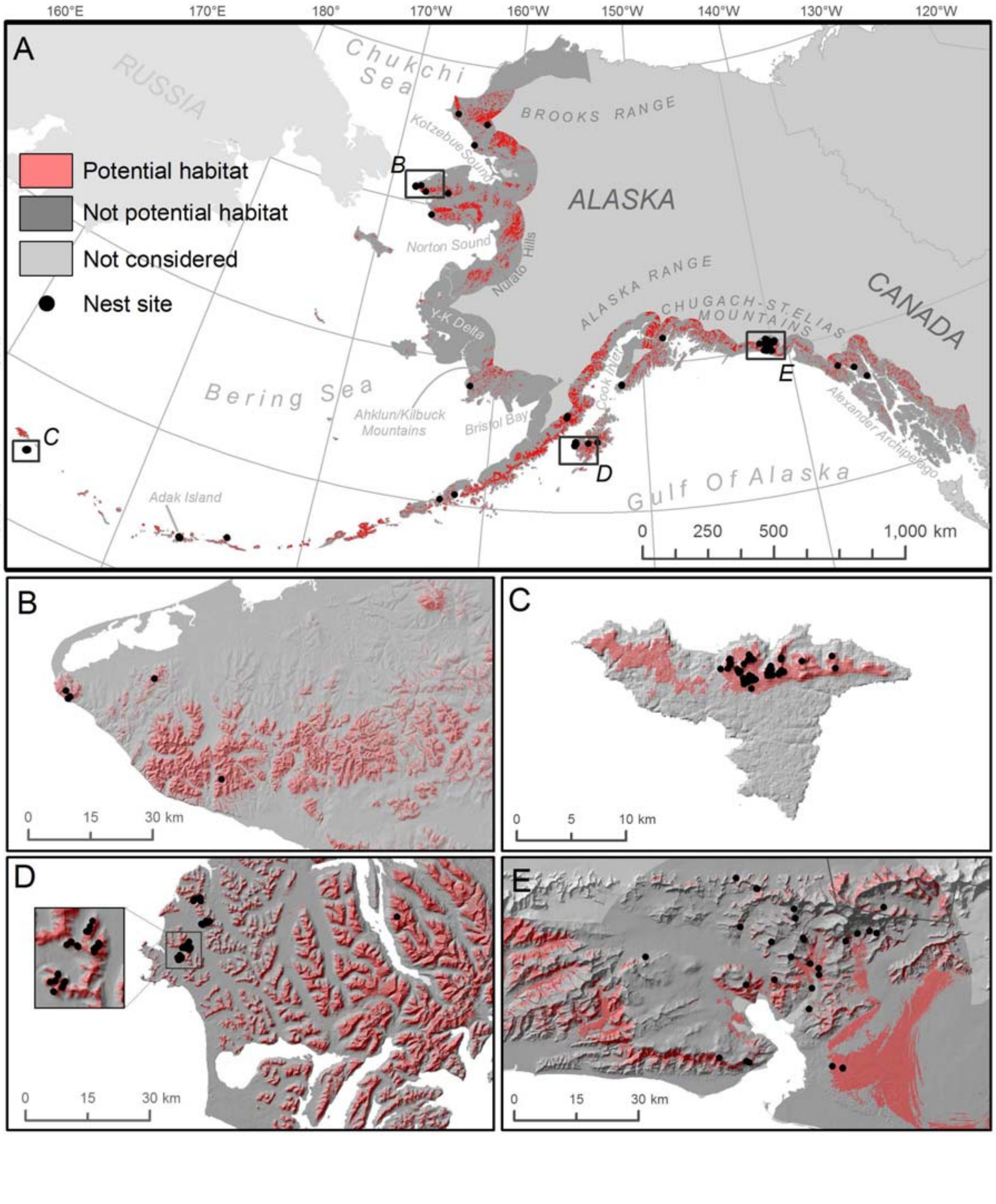
Figure 2. General, year-round marine distribution of Kittlitz's Murrelets (light blue; summarized from USFWS 2013) and boundaries of four regions used for establishing criteria and mapping potential nesting habitat of the Kittlitz's Murrelet (*Brachyramphus brevirostris*) in North America. Regions are northern Alaska (NOAK), Aleutian Islands (AI), Alaska Peninsula Mountains (APM), and Pacific Coastal Mountains (PCM).

Figure 3. Known nest sites (black dots; 1904–2012) and potential nesting habitat identified in this study (shown in red) for Kittlitz's Murrelets (*Brachyramphus brevirostris*) in North America (A). The initial geographic extent of land considered in analysis (within regional distance to coast thresholds) is shown in dark gray. Inset maps depict potential nesting habitat at Seward Peninsula (B), Agattu Island (C), Kodiak Island (D), and Icy Bay (E). The distribution of nest sites (black dots) on Agattu Island (C) and Kodiak Island (D and inset) are restricted to small areas thoroughly searched on foot, compared to Icy Bay (E) where nests were located by tracking telemetered birds that were sampled at sea and thus were not subject to spatial bias. Seward Peninsula nest sites (B) were discovered opportunistically or accidentally.

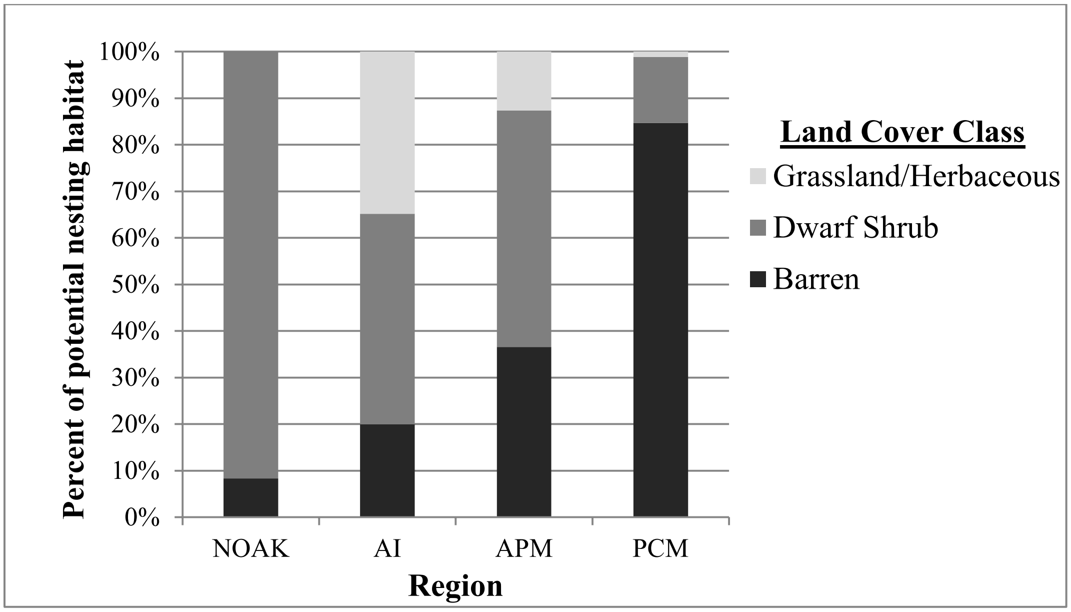
Figure 4. Proportion of potential Kittlitz's Murrelet nesting habitat identified in this study in the three habitat-capable land cover classes in each region. Regions are northern Alaska (NOAK), Aleutian Islands (AI), Alaska Peninsula Mountains (APM), and Pacific Coastal Mountains (PCM).


A
B
C
D
E


160°E
170°E
180°
170°W
160°W
150°W
140°W
130°W
120°W
60°N
55°N
50°N
RUSSIA
ALASKA
CANADA
Northern Alaska
(NOAK)
Pacific Coastal
Mountains (PCM)
Alaska Peninsula
Mountains (APM)
Aleutian Islands
(AI)
At-sea
Distribution
0 250 500 1,000 km



160°E
170°E
180°
170°W
160°W
150°W
140°W
130°W
120°W
60°N
55°N
50°N
A
RUSSIA
Chukchi Sea
BROOKS RANGE
Kotzebue Sound
Potential habitat
Not potential habitat
Not considered
Nest site
ALASKA
Norton Sound
Nulato Hills
ALASKA RANGE
CHUGACH-ST. ELIAS MOUNTAINS
CANADA
Y-K Delta
Bering Sea
Ahklun/Kilbuck Mountains
Bristol Bay
Cook Inlet
Alexander Archipelago
Gulf Of Alaska
Adak Island
0 250 500 1,000 km
B
C
D
E
0 15 30 km
0 5 10 km
0 15 30 km
0 15 30 km


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent of potential nesting habitat
NOAK
AI
APM
PCM
Region
Land Cover Class
Grassland/Herbaceous
Dwarf Shrub
Barren

Locational accuracy category	Description
High (≤ 100 m)	Nests are ground-truthed and locations determined with GPS or accurate maps
Medium (100 – 500 m)	Nests located from aerial telemetry but never ground-truthed; nest locations determined to within 500 m by written or verbal descriptions by nest discoverers
Low (500 m – 1 km)	Nest locations determined to within 1 km by written or verbal descriptions by nest discoverers
Very Low (≥ 1 km)	Nest locations not known at less than 1 km; reported coordinates only used to mark general area

Region	# of nests	Distance to Coast (km)		Elevation (m)		Slope (degrees)	
		Actual maximum	Range of habitat-capable land	Actual minimum	Range of habitat-capable land	Actual minimum	Range of habitat-capable land
NOAK	7	73.5	0.2 - 95.5	128	> 109	8	> 5.6
AI	95	4.9	≥ 0.2	184	> 156	2	> 1.4
APM	75	36.4	0.2 - 47.3	151	> 128	5	> 3.5
PCM	38	28.4	0.2 - 36.9	170	> 145	0	> 0.0
All	215	73.5		128		0	

Region	Total Area (km^2)	Potential Nesting Habitat	
		Area (km^2)	Proportion
NOAK	305,318	27,135	0.09
AI	11,779	4,536	0.39
APM	72,639	15,467	0.21
PCM	173,869	23,273	0.13
All Regions	563,605	70,411	0.12