



Monitoring Kittlitz's and Marbled Murrelets in Glacier Bay National Park

2021 Annual Report

Natural Resource Report NPS/SEAN/NRR—2023/2559





ON THIS PAGE

A Kittlitz's murrelet trails wing-tip vortices on a calm sea
NPS/STEVEN HOEKMAN

ON THE COVER

Murrelets on Glacier Bay
NPS/STEVEN HOEKMAN

Monitoring Kittlitz's and Marbled Murrelets in Glacier Bay National Park

2021 Annual Report

Natural Resource Report NPS/SEAN/NRR—2023/2559

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Executive Summary

Since 2009, the Southeast Alaska Network (SEAN) has monitored the abundance and spatial distribution of Kittlitz's (*Brachyramphus brevirostris*, "KIMU") and marbled murrelets (*B. marmoratus*, "MAMU") in Glacier Bay National Park, an important summer residence for both species. Species-specific, on-water density and abundance of murrelets is estimated from vessel-based line transect surveys, while accounting for detection probability and partial identification (identification only to genus). Design of the monitoring program focuses on KIMU, with secondary consideration of MAMU.

Due to the global pandemic, surveys were not conducted in 2020. In 2021, we only surveyed permanent panel transects, which totaled 56% of the length of transects planned for 2021. Permanent panel transects are primarily located in the middle and upper areas of Glacier Bay and sample regions within the total survey area that have relatively high expected densities of KIMU. Inference was limited to the 339 km² "high-density area" formed by these regions, which comprised 29% of the total survey area. To provide context for 2021 results, we also estimated species-specific densities in the high-density area from 2011 to 2019.

We surveyed 25 transects totaling 130 km from 13 to 21 July 2021. Within the high-density area, we estimated an abundance of 2,921 (SE = 734) KIMU and 21,710 (2,421) MAMU and densities of 8.6 (2.2) and 64.0 (7.1) individuals/km². Estimated densities of each species in the high-density area were similar between 2019 and 2021, with KIMU estimates near the lower end of the range from 2011 to 2021 and MAMU estimates near the upper end.

Observations of KIMU were concentrated in smaller, glacially influenced middle and upper reaches of Glacier Bay, especially in Johns Hopkins Inlet in the upper West Arm (~40% of observations). MAMU were more evenly dispersed, with the densest aggregations located in the upper east side of the central bay and at the mouth of the East Arm.

While estimated abundance of MAMU in the total survey area showed no clear trend from 2011 to 2019, the percent of MAMU occupying the high-density area steadily increased from ~20% to >40%, suggesting a northward shift in their spatial distribution. The estimated percent of the total KIMU population occupying the high-density area jumped from ~45% from 2011 to 2018 to 85% in 2019. This change coincided with exceptionally low estimated abundance in the total survey area, which resulted primarily from very low estimated density outside the high-density area. Resuming full survey effort should help clarify the nature and persistence of these changes and their implications for conservation and monitoring.

Acknowledgments

We could not accomplish surveys without contributions of motivated and talented individuals. L. Pearson assisted with logistics, survey observations, and data acquisition. Captain J. Smith safely piloted the R/V *Capelin*, and B. McDonough and D. Dallas provided vessel maintenance support. B. Furr, M. Hutten, T. Lewis, M. Tatum, and J. Todd provided critical logistical support. The report benefitted from review by H. Coletti and T. Lewis. R. Sarwas has been integral to maintaining the iOS-based survey software *Park Observer*.



A black-legged kittiwake arrives at a cliff-side nesting colony (NPS/STEVEN HOEKMAN)

Introduction

The Southeast Alaska Network (SEAN) has monitored populations of Kittlitz's murrelets (*Brachyramphus brevirostris*, "KIMU") and marbled murrelets (*B. marmoratus*, "MAMU") in Glacier Bay National Park during early July since 2009, building on prior monitoring efforts in Glacier Bay (Drew et al. 2008, Kirchhoff 2008, Kirchhoff et al. 2010, Kirchhoff and Lindell 2011). In response to conservation concerns arising from possible declining abundance of Kittlitz's murrelets (Piatt et al. 2011, USFWS 2013, Kirchhoff et al. 2014, Day et al. 2020) and the hypothesis that murrelet populations respond to fluctuations in marine and terrestrial ecosystems (Moynahan et al. 2008), KIMU were identified as a vital sign with specific objectives of monitoring abundance, trend, and spatial distribution in Glacier Bay.

The KIMU is a seabird endemic to Alaska and northeastern Russia, with the highest breeding season densities in the northern Gulf of Alaska (Day et al. 2020). During summer, KIMU are often associated with tidewater glacier and fjord habitats, but also occur in non-glacially influenced areas (Arimitsu et al. 2011, Kissling et al. 2011, Madison et al. 2011, Day et al. 2020). These open-water, pursuit foragers often forage in proximity to glacier outflows (Day and Nigro 2000, Kuletz et al. 2003) and nest in recently deglaciated areas with sparse vegetation (Day 1995, Felis et al. 2016).

The SEAN's long-term Kittlitz's murrelet monitoring protocol (hereafter, the Protocol; Hoekman et al. 2013) focuses on estimating population abundance and trend, primarily for KIMU and secondarily for MAMU. To increase precision of abundance estimates for KIMU, sampling effort was spatially allocated in proportion to their expected densities. Several challenges are inherent to monitoring murrelets in Glacier Bay: uncertain species identification (species misidentification and partial identification, which is identification only to genus) for these morphologically similar species, incomplete detection of murrelets along transects, large spatial and temporal variation in densities, and irregular topography that complicates transect placement.

Due to the global pandemic surveys did not occur in 2020, and logistical challenges limited effort in 2021. Objectives for 2021 surveys were to gain operational experience with new personnel and to focus survey effort on acquiring data most useful to monitoring trend in KIMU abundance.

Methods

This section briefly outlines survey design, survey methods, and analytic approach, which are described in detail in the Protocol. Logistical challenges associated with the global pandemic altered timing of 2021 surveys and curtailed sampling to approximately 50% below normal effort. Below, we also note modifications to standard Protocol methods for 2021 surveys.

Survey Area

Glacier Bay is an estuarine, tidewater glacier fjord located in southeastern Alaska. The “total survey area” normally encompasses 1,170 km² of waters in Glacier Bay (Figure 2.1 in the Protocol).

However, the survey area for 2021 included only regions with relatively high expected densities of KIMU (density groups 4 to 6 in Figure B.6 in the Protocol), and we refer to this survey area as the “high-density area” (Figure 1). The high-density area comprised 339 km² (29%) of the total survey area, with the remaining area (71%) comprising the “low-density area.”

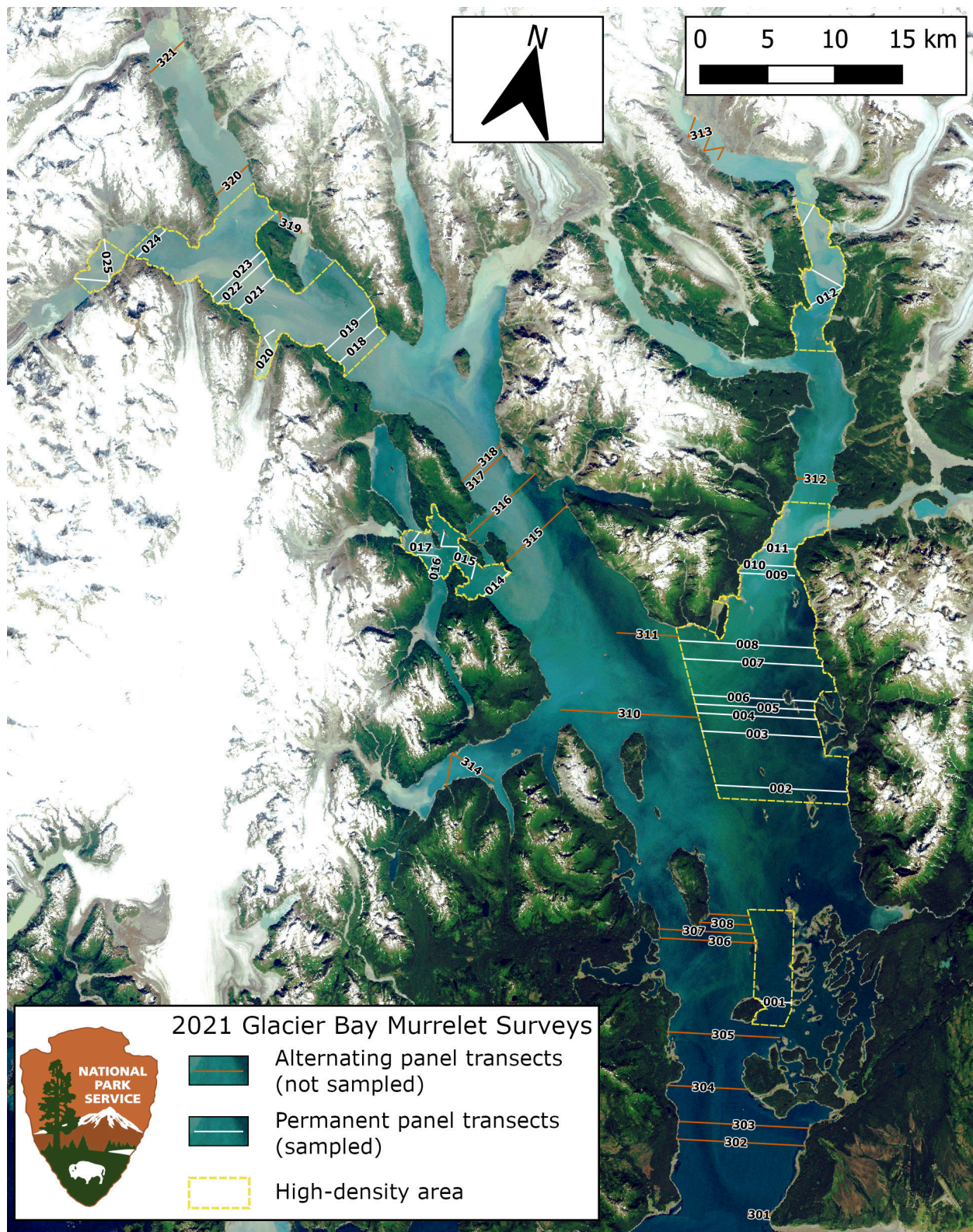


Figure 1. Line transects surveys for murrelets during July 2021 excluded alternating panel transects (red-orange lines) and included permanent panel transects (white lines). Permanent panel transects were drawn from the high-density area (yellow dashed outlines), which comprised the 2021 survey area.

Survey Design

We used a generalized random tessellation stratified sampling design (GRTS; Stevens and Olsen 2004) to minimize deleterious effects of large spatial variation in murrelet abundance (Drew et al. 2008, Hoekman et al. 2011a, 2013) by providing a random, spatially-balanced sample. We allocated survey effort relative to expected densities of KIMU using unequal probability sampling (Stevens and Olsen 2004). To avoid placing transects parallel to the observed density gradient of murrelets (Drew et al. 2008, Kirchhoff et al. 2010) and to provide representative coverage across water depths, we oriented linear transects perpendicular to the local prevailing shoreline. In more enclosed waters we used shore-to-shore zigzag transects to avoid undesirably short transects. Transects are sampled using an augmented, serially alternating panel design (McDonald 2003), where one permanent panel (set of transects drawn from the high-density area) with higher expected densities of KIMU is sampled annually and three alternating panels (set of transects drawn from the low-density area) are sampled on a three-year rotation, with 2021 scheduled to include panel three (Figure B.7 in the Protocol). To accommodate reduced survey effort in 2021, we elected to forego sampling alternating panel transects (107 km) and only sample permanent panel transects (136 km), amounting to 56% of the planned total.

Survey Methods

We conducted vessel-based line transect surveys (Buckland et al. 2001) at a speed of ≤ 10 km/hr aboard the R/V *Capelin*, a 9 m landing craft with a large front deck that provided a viewing height of ~ 3 m above the water for two observers. For all murrelet groups (closely associated murrelets within 5 m of others) initially located on the water, binocular-equipped observers recorded group size, species classes (KIMU, MAMU, or genus *Brachyramphus* murrelet), and their ocular estimates of distance and angle (using an angle board) to the group. The allowable Beaufort Sea State was ≤ 2 . Program *Park Observer* (R. Sarwas and W. Johnson, National Park Service), iOS-based software, was used to record observations of murrelets and associated GPS-based date/time/location stamps.

We conducted surveys from 13 to 21 July, approximately one week later than is typical. Consequently, we anticipated increased observations of recently fledged juveniles. Because *Park Observer* does not accommodate age classes, we recorded counts of juveniles as described in deliverable KM_B (<https://irma.nps.gov/DataStore/Reference/Profile/2287612>) to document their numbers and locations. Juveniles were identified on the basis of resemblance to definitive basic (adult winter) plumage of their species (Day et al. 2020, Nelson 2020).

Abundance Estimation

We estimated detection probability and group size using Program DISTANCE version 6.2 (Thomas et al. 2010) and species-specific abundance using the R statistical computing environment version 4.1 (R Development Core Team 2021) following distance sampling methods (Buckland et al. 2001), modified to account for incomplete detection near the transect center line and partial identification (Hoekman et al. 2013). Methods accommodating partial identification assumed correct species identification and identical proportions of each species in the identified and partially identified classes. We pooled observers for all analyses. Density estimates were based on estimates of several

component parameters: detection probabilities, group size for each species class, and encounter rates (groups/km of transect) for each species class (Hoekman et al. 2011b, 2013).

For 2021 surveys, we estimated species-specific abundance as the product of estimated species-specific densities and area of the high-density area. To provide context for 2021 results, we also estimated species-specific densities in the high-density area for each survey from 2011 to 2019. For these analyses, methods were as above, except we included only encounter rates from permanent panel transects. This approach was expedient but imperfect, as it applied each survey's estimated detection probability and group sizes for the entire survey area to the high-density area. We felt these methods reasonable for our purposes, because very large spatial and temporal variation in encounter rates have dominated density estimates. In contrast, spatial and temporal variation in estimated group sizes (~85% size two or fewer) and detection probabilities have been relatively small, and detection probabilities within each survey likely are similar because probabilities largely reflect characteristics of each survey's observers.

Results

We surveyed 130 km along 25 permanent panel transects (Figure 1) from 13 to 21 July 2021. Observers recorded 2,806 murrelets in 921 on-water groups, of which 17% were classified as KIMU, 75% as MAMU, and 8% as (partially identified) genus *Brachyramphus* murrelets. Observers recorded 25 juveniles, with 1 classified as KIMU, 5 as MAMU, and the remaining as genus *Brachyramphus*.

“Mixed-species groups” contain individual(s) classified to both species classes. Of all groups containing KIMU, 27% were mixed-species groups. Of all groups containing MAMU, 6% were mixed-species groups. Cloudy, hazy skies (62% of records with >50% cloud cover, none with precipitation or fog) and variable sea conditions (Beaufort Sea States 0, 1, and 2 each with ~33% of records) characterized weather during surveys.

Detection Function

A hazard rate function was selected to estimate the detection function (Figure 2), which showed a strong shoulder of high detection probability near the transect center line and a smooth, monotonic decline at larger distances (Buckland et al. 2001). We right-truncated data at a 200 m perpendicular distance from the transect centerline, where detection probability dropped to low levels. The 200 m transect width in combination with moderately high detection probability (Table 1) resulted in a relatively high estimated effective strip half-width (130 m).

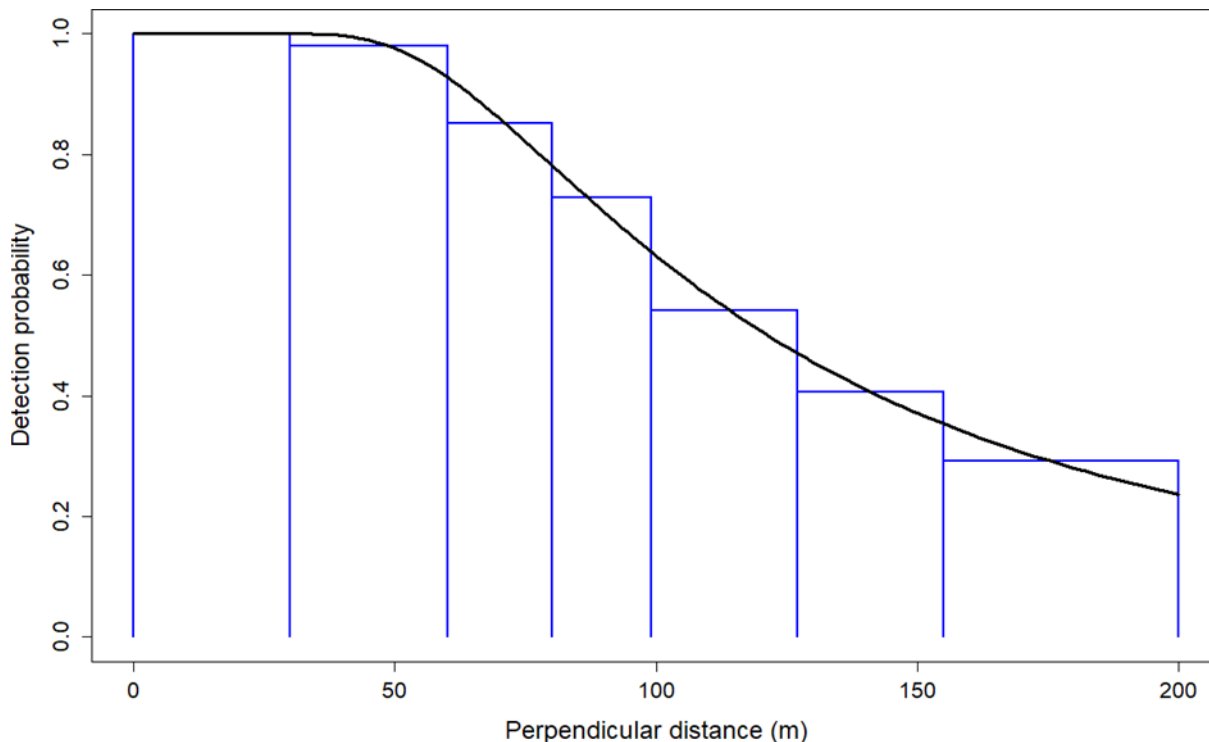


Figure 2. Estimated detection function for murrelet groups during line transect surveys in Glacier Bay during July 2021, illustrating declining estimated detection probability (black line) relative to perpendicular distance from the transect center line.

Table 1. Component parameter values used to estimate density and abundance of Kittlitz's and marbled murrelets in Glacier Bay during July 2021. For each species, a regression of group size on detection probability predicted group sizes (see SOP 11 in the Protocol).

Category	Parameter	Estimate	SE	P-value	Degrees of freedom
Detection	Detection across transect width	0.65	0.04	–	890
	Detection near transect center line ^A	0.94	0.03	–	66
Group Size: Average	Kittlitz's murrelet	2.33	0.08	–	158
	Marbled murrelet	3.08	0.04	–	666
	Genus <i>Brachyramphus</i> murrelet ^B	4.21	0.20	–	65
Group Size: Regression estimate	Kittlitz's murrelet ^B	1.99	0.05	0.01	157
	Marbled murrelet ^B	2.84	0.03	0.02	665
	Genus <i>Brachyramphus</i> murrelet	3.00	0.14	0.11	64
Encounter Rate (groups/km)	Kittlitz's murrelet	1.00	0.23	–	24
	Marbled murrelet	4.75	0.48	–	24
	Genus <i>Brachyramphus</i> murrelet	0.47	0.06	–	24

^A Estimate from Hoekman et al. 2011b.

^B Estimate selected for estimation of density and abundance.

Density and Abundance

Larger group sizes and higher encounter rates for MAMU (Table 1) produced estimates of on-water abundance in the high-density area (21,543, 95% CL 17,107 – 27,128) approximately seven times greater than for KIMU (2,921, 95% CL 1,798 – 4,746). High imprecision for the KIMU estimate (coefficient of variation = standard error / abundance = 0.25) largely reflected high variation in encounter rates among transects. Similarly, estimated densities in the high-density area for both species from 2011 to 2021 typically were imprecise (Figure 3A, B). Estimates for KIMU were variable but did not exhibit a clear trend, with estimates from 2019 and 2021 falling near the low end of the range. Estimates for MAMU showed an increasing trend, with 2019 and 2021 estimates at or near the high end of the range.

Densities for the high-density area versus the total survey area (Table 2) are not directly comparable, as estimates for the same species and year have often strongly differed between areas. Further, estimated relative abundance of each species in the high- versus low-density area has varied over time. From 2011 to 2018, the high-density area consistently housed ~45% of KIMU (Figure 3C), despite wide annual variation in estimated abundance for the total survey area (Table 2). A jump to ~85% in 2019 reflected sharply decreased density in the low-density area. Percent of MAMU in the high-density area has increased from ~20% to >40% (Figure 3D) as a result of gradually increasing densities there. An unusually high percentage of each species occupied the high-density area in 2019.

Table 2. Estimated population density and abundance of Kittlitz's and marbled murrelets in the total survey area of Glacier Bay during July from 2009 to 2019. Methods and survey area for pilot surveys in 2009 differed slightly from other years (Hoekman et al. 2011a).

Year	Kittlitz's Murrelet				Marbled Murrelet			
	Density ^A	SE	Abundance	SE	Density ^A	SE	Abundance	SE
2019	3.6	0.8	4,155	934	55.4	10.9	64,868	12,725
2018	9.0	2.3	10,517	2,655	44.7	6.6	52,302	7,752
2017	7.5	1.3	8,810	1,513	50.5	7.2	59,126	8,390
2016	6.0	1.1	7,026	1,345	51.8	10.3	60,624	12,018
2015	9.2	2.2	10,778	2,598	71.6	10.3	83,793	12,044
2014	8.9	1.3	10,422	1,522	35.4	3.4	41,474	3,998
2013	6.2	1.7	7,210	2,046	72.2	13.2	84,428	15,394
2012	14.1	2.2	16,469	2,581	44.9	4.5	52,560	5,216
2011	6.4	1.0	7,477	1,119	63.1	6.0	73,766	7,055
2010	11.4	1.2	13,308	1,357	52.7	4.6	61,717	5,372
2009	12.0	3.7	13,124 ^B	4,062	26.5	3.7	28,978 ^B	4,077
All	8.6	1.0	9,961	1,096	51.8	4.3	60,417	5,167

^A Individuals/km²

^B Abundance extrapolated over a 1,092 km² survey area; all others extrapolated over 1,170 km².

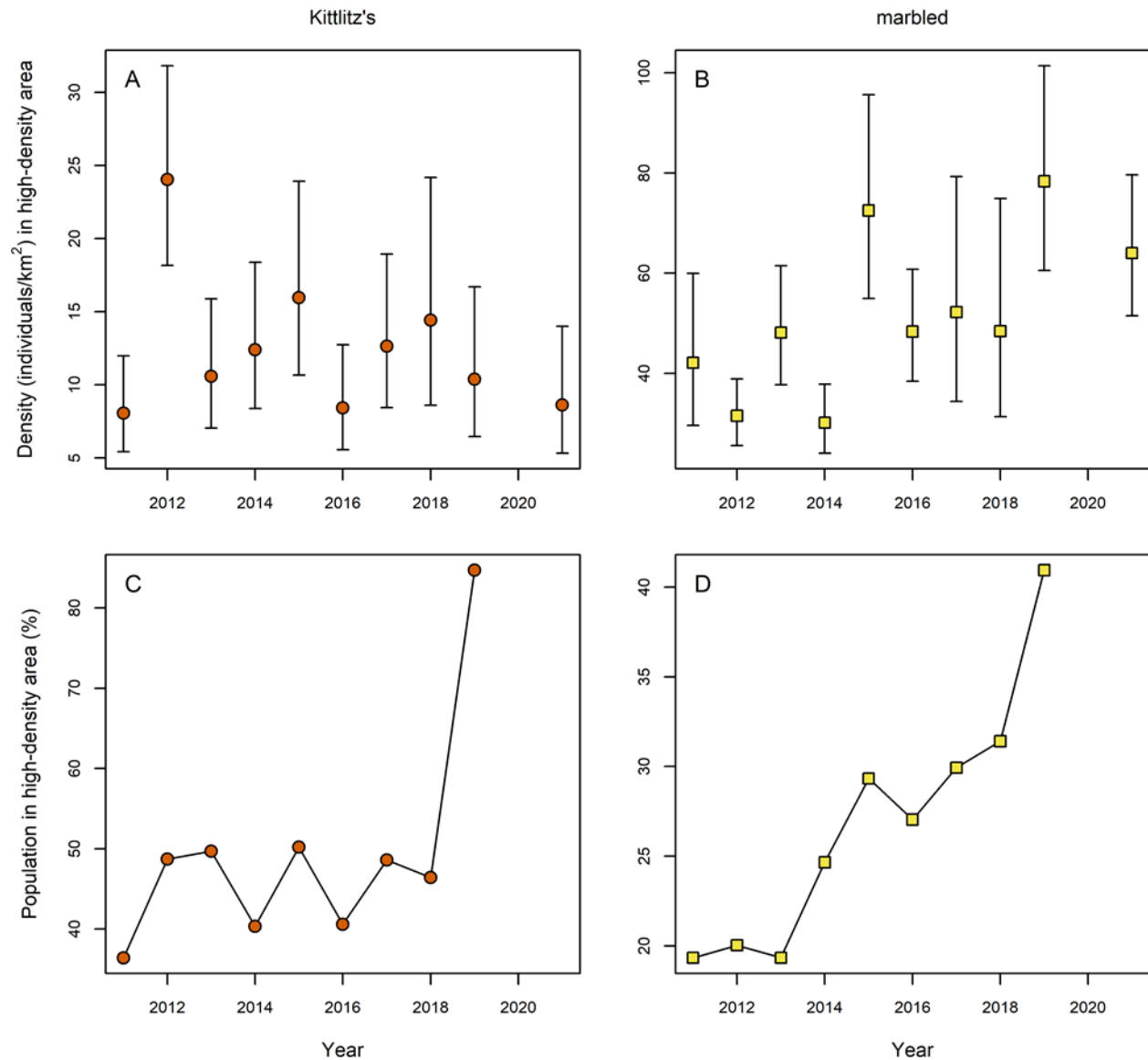


Figure 3. Estimated density (95% confidence interval) of Kittlitz's (orange-red circles) and marbled (yellow squares) murrelets (A, B) in the high-density area of Glacier Bay during July from 2011 to 2021 and estimated percent of each population in the total survey area that occupied the high-density area (C, D) from 2011 to 2019.

Spatial Distributions

During 2021, observations of KIMU were concentrated in glacially influenced areas (Figure 4), particularly in Johns Hopkins Inlet (~40% of observations), Reid Inlet, Hugh Miller Inlet, and Scidmore Inlet. Moderate use of the upper east side of the central bay increased with proximity to the mouth of the East Arm. Observations were sparse in more open waters in the upper West Arm. Observations of MAMU were more evenly distributed (Figure 5), with highest concentrations in Hugh Miller Inlet and the upper east side of the central bay from South Sandy Cove to the mouth of the East Arm.

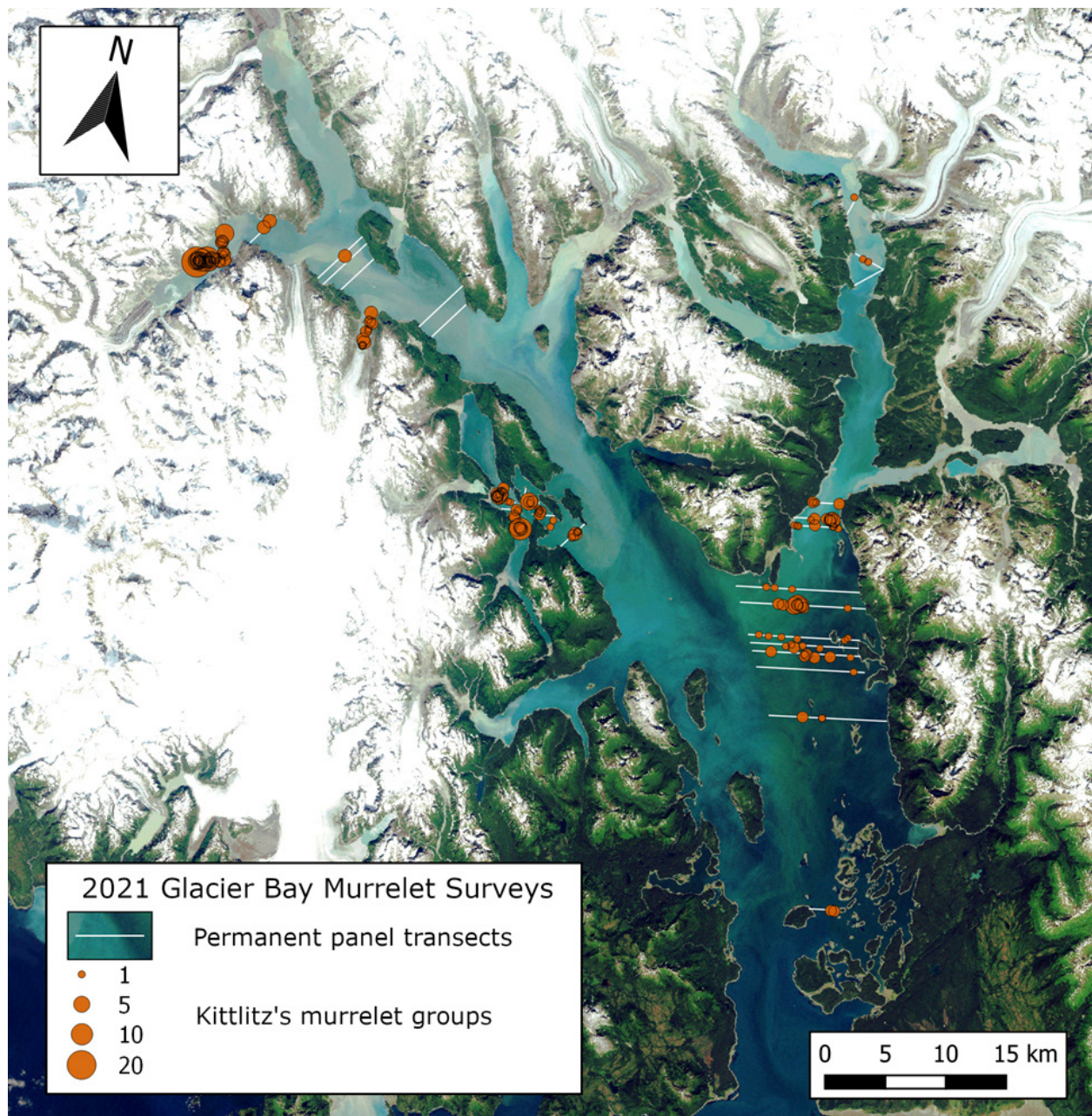


Figure 4. Spatial distribution of Kittlitz's murrelets (area of orange-red circles denotes group size) observed on permanent panel transects (white lines) during line transect surveys in Glacier Bay during July 2021.

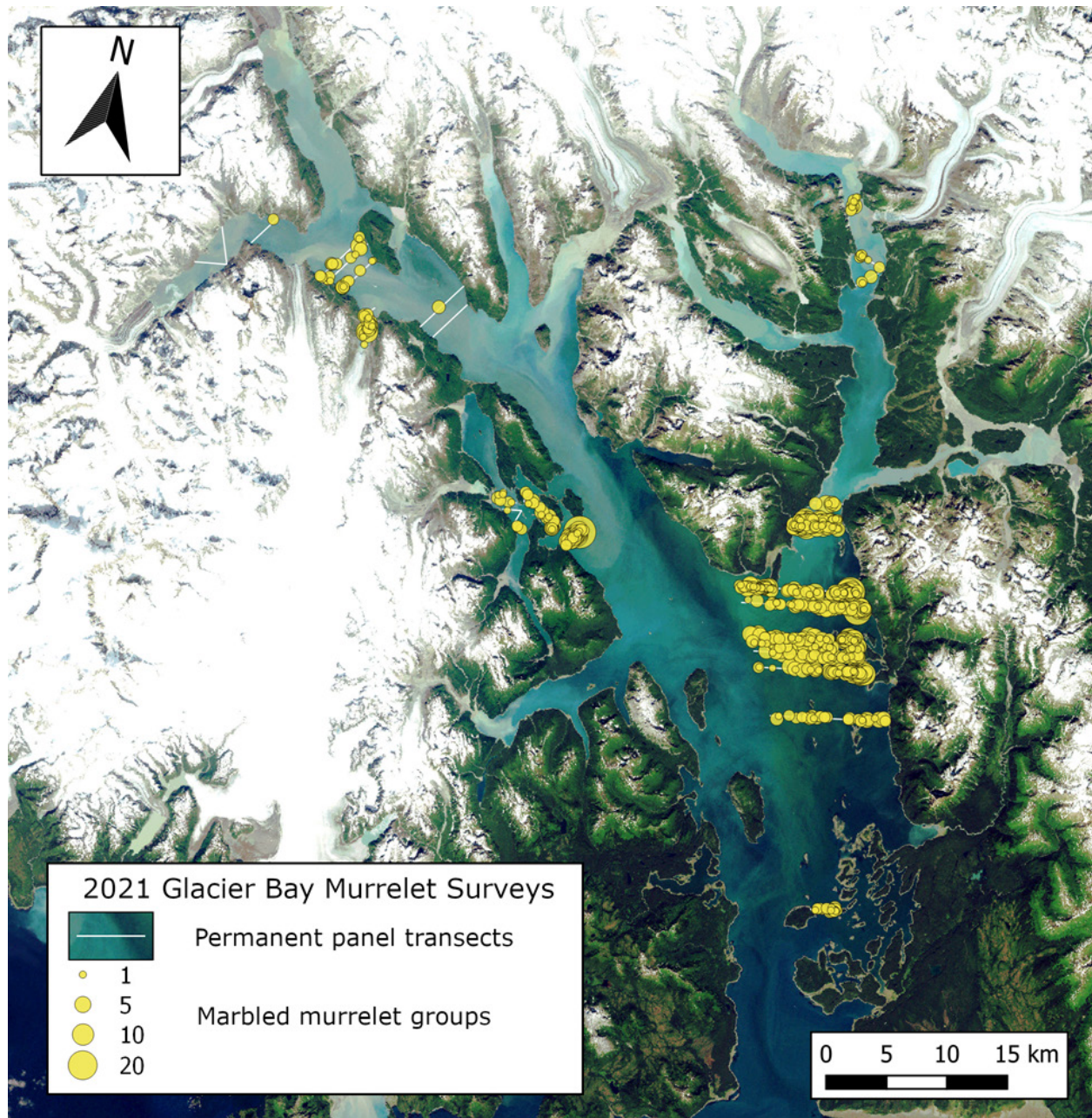


Figure 5. Spatial distribution of marbled murrelets (area of yellow circles denotes group size) observed on permanent panel transects (white lines) during line transect surveys in Glacier Bay during July 2021.

Discussion

Abundance, Density, and Spatial Distributions

Estimated densities of each species in the high-density area in 2021 largely mirrored those from 2019. Estimated KIMU densities in the high-density area in 2019 and 2021 were slightly below average, but no clear trend was evident over 2011 to 2021. However, KIMU were exceptionally sparse in the low-density area in 2019, resulting in an estimated abundance for the total survey area almost half the prior minimum from SEAN monitoring (Table 2; Hoekman and Johnson 2020). The low-density area was not sampled in 2021, and only opportunistic observations suggested continued low density there. As expected, KIMU density estimates for the high-density area have consistently exceeded those for the total survey area.

MAMU density estimates remained robust in the high-density area in 2021, about seven times that of KIMU. Estimated MAMU densities in the high-density area showed an increasing trend from 2011 to 2021 (Figure 3B), a pattern not apparent in estimates for the total survey area (Table 2). Evidence supports that Glacier Bay continues to host globally-significant populations of KIMU and MAMU during July (Piatt et al. 2007, USFWS 2013).

For both species, density and abundance estimates should be interpreted cautiously. Considerable annual variation in estimates likely reflects a combination of factors: imprecise estimates (primarily due to high spatial variation in encounter rates), potential bias in estimates resulting from uncertain identification of these similar species (Schaefer et al. 2015, Hoekman 2019, 2021), and variation in abundance arising from demographic processes (survival, reproduction, site fidelity). In Glacier Bay and elsewhere, annual fluctuations in estimated abundance during the breeding season appear larger than can be explained by plausible variation in reproduction and survival, and movement among summering areas likely has contributed to these fluctuations (Kissling et al. 2015, Bertram et al. 2015, Hoekman 2019). For KIMU in Icy Bay, Kissling and others (2015) found low annual site fidelity and low breeding propensity. We hypothesize that large annual fluctuations in estimated breeding season abundance observed in Glacier Bay and elsewhere may result both from use of alternate summering areas in response to locally available resources and from variation in body condition and hence breeding propensity driven by resources at pre-breeding areas.

MAMU were widely distributed across the high-density area in 2021, but were especially dense in the upper east side of the central bay from South Sandy Cove to the mouth of the East Arm. Although causes are uncertain, ephemeral aggregations of foraging murrelets and other avian predators are thought to reflect high prey availability (Kissling et al. 2007, Raphael et al. 2015, Urbanski et al. 2017). Further, the densest MAMU aggregations in 2021 overlapped in space with concurrent aggregations of other marine predators, including humpback whales (*Megaptera novaeangliae*), Steller sea lions (*Eumetopias jubatus*), and several seabird species.

Similar aggregations of MAMU in this area in 2019 (Hoekman and Johnson 2020) continued a trend of increasing use of the high-density area (Figure 3). In contrast, density estimates for the total survey area have not shown a clear trend (Table 2), suggesting that over 2011 to 2019 MAMU have shifted their spatial distribution toward middle and upper areas of Glacier Bay. Early in this period,

the highest densities of MAMU often occurred near the mouth of Glacier Bay, a pattern attributed to an influx of local “day-commuters” to forage in Glacier Bay (Drew et al. 2008, Kirchhoff 2008, Hoekman 2019).

KIMU in 2021 were strongly associated with glacially influenced habitats, particularly Johns Hopkins Inlet. In prior SEAN surveys, transects in Johns Hopkins Inlet has often had dense concentration of ice and few KIMU, but large areas of open water and/or increased prey availability may have driven increased use in 2021. Close association of KIMU with glacially influenced habitats during summer has been common in other areas with tidewater glaciers (Day and Nigro 2000, Kuletz et al. 2003, Kissling et al. 2011), but in Glacier Bay KIMU have often aggregated in areas without strong glacial influence, including Beardslee Entrance and the upper east side of the central bay (Hoekman 2019).

From 2011 to 2018, an estimated 40-50% of KIMU occupied the high-density area (Figure 3C). However, exceptionally low overall KIMU abundance in 2019 (Table 2) coincided with their almost complete absence from the low-density area. Estimated density in the high-density area only declined slightly from 2018 (Figure 3B), suggesting that the diminished 2019 KIMU population persisted in areas heavily used in the past. Causes of the changes in distribution in 2019 are unknown.

More than a quarter of KIMU and 6% of MAMU occurred in mixed-species groups. Such groups were even more common in 2019 (61% and 11% for KIMU and MAMU), but infrequent in previous years. Recent increase in spatial overlap between species likely has contributed higher frequencies of mixed-species groups, as MAMU densities have increased in the high-density area where KIMU densities are high. Mixed-species groups could increase risk of species misidentification, which can result in large positive bias in KIMU abundance estimates and degrade monitoring results (Hoekman 2019).

It will be important to discern whether reduced KIMU abundance in 2019 (Hoekman and Johnson 2020) and recent changes in spatial distributions of both species are ephemeral or persistent. In addition to conservation concern arising from decline in KIMU abundance, altered spatial distributions may reflect changes in distribution and availability of prey. Further, large and persistent changes in spatial distribution of KIMU may warrant revising allocation of sampling effort to more closely track these changes. Future surveys at full effort are needed to clarify these issues.

Altered Survey Methods

Surveys were about a week later than typical, with uncertain implications for results. Advanced nesting phenology likely increased prevalence of post-breeding adults among the local population, perhaps altering spatial distributions and increasing emigration from the survey area. In Glacier Bay and elsewhere in southeast Alaska, KIMU abundance typically has peaked in early July. In contrast, MAMU abundance has increased through the summer, perhaps because of northward migration of post-breeding adults (Romano et al. 2004, Arimitsu et al. 2011, Bertram et al. 2016).

As expected, observations of juveniles (25) exceeded prior surveys (typically few), but juveniles comprised <1% of individuals and minimally influenced results. Most (72%) were observed in the

upper east side of the central bay (transects 2-8) where MAMU aggregated. Juvenile plumages are poorly described (Day et al. 2020, Nelson 2020), and few were classified to species because individual heterogeneity in plumage was higher than anticipated. Further, juvenile KIMU likely were undercounted, because some closely resemble breeding rather than wintering adults (M. L. Kissling, personal communication).

Surveying only the high-density area restricted inference to this area and limited comparisons to prior results. However, this approach likely increased sampling efficiency by reducing transit and downtime, as transects in the high- versus low-density area are more spatially-aggregated and less prone to sampling disruptions (e.g., high Beaufort Sea State). Further, the high-density area has averaged ~2.5x higher KIMU densities and is thought vital to breeding KIMU due to proximity to suitable nesting habitat (Felis et al. 2016). Therefore, we felt our approach helped optimize limited survey effort to inform resource management and meet KIMU monitoring objectives.

Recommendations

Resuming monitoring at full survey effort will be useful to clarify whether relatively low KIMU abundance since 2019 and recent alterations to spatial distributions of both species constitute ephemeral or persistent changes. Understanding the nature and persistence of ongoing changes will help both to inform development of explanatory hypotheses and to assess implications for conservation and monitoring. Because of difficulties encountered in identifying juveniles versus adults of each species, conferring with subject-matter experts to develop reliable diagnostic criteria is needed to document abundance of and resource use by juveniles during future surveys.



Killer whale in the West Arm of Glacier Bay. (Tom Ziomek/NPS Photo).

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