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Summer movements of marbled murrelets from Canada to Alaska

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ABSTRACT: Knowledge of seasonal marine bird migration patterns is required to inform marine bird conservation and management efforts. We deployed solar-powered satellite transmitters to track the movements of threatened marbled murrelet *Brachyramphus marmoratus* during the breeding and post breeding periods. We tagged birds (n = 27) in British Columbia (BC), Canada, over 3 years (2014–2016) from 3 different marbled murrelet conservation regions as defined by the species' recovery strategy. Of 4 tagged birds which provided movement data for more than 57 d, 3 (1 in each year) revealed long-distance movements from BC to Alaska, USA, during breeding or post-breeding periods. The 3 birds which moved northward originated from the 3 different conservation regions. We found limited support for the concept that birds tracked cooler waters as they headed northward. One bird remained in unusually warm waters near the capture sight in Desolation Sound in 2016. Importantly, the arrival of BC birds in Alaska during summer could contribute to at-sea survey estimates of marbled murrelet abundance during the Alaska breeding season, and their occcurence in Alaska has implications for BC populations with respect to anthropogenic threats in the marine habitat, including the potential for incidental take in gillnet fisheries and risks from oiling. Our results demonstrate connectivity between BC and Alaska marbled murrelet populations. Overall, tracking duration was relatively short, and locations were confined to the deployment areas in BC. Our results indicate capture and tagging impacted study individuals and may have contributed to increased mortality. Our research, coupled with that of others, suggests that long-distance northerly migrations patterns may not be unusual in *Brachyramphus* murrelets.

KEY WORDS: Marbled murrelet · *Brachyramphus marmoratus* · Satellite tracking · Movement ecology · Migration · Seabird · British Columbia · Gulf of Alaska

1. INTRODUCTION

Conservation of bird populations requires knowledge of year-round habitat use and potential threats associated with those habitats (Grémillet & Boulinier 2009, Gaston et al. 2017, Carneiro et al. 2020). For marbled murrelet *Brachyramphus marmoratus*, a species that feeds on forage fish in coastal areas and

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nests in low densities in old growth forests, threats occur in both marine foraging and terrestrial nesting habitats. In Canada, the marbled murrelet is listed as threatened under the Species at Risk Act (ECCC 2023) due to loss of old growth forest nesting habitat. Consequently the bulk of conservation action in Canada has been aimed at identifying and preserving forest nesting habitat (Mather et al. 2010, BCFLNRO 2018). Recently, research and conservation focus has expanded to include identification of marine critical habitat, threats from gillnet fishing, ocean climate warming impacts on prey populations, oil pollution, and risks from increasing vessel traffic (ECCC 2023).

Previous satellite tagging of marbled murrelets revealed a long-distance post-breeding movement from BC to Alaska (Bertram et al. 2016), perhaps as a part of a molt migration strategy similar to ancient murrelets *Synthliboramphus antiquus* (Gaston et al. 2017) and Kittlitz's murrelets *Brachyramphus brevirostris* (Piatt et al. 2021) and possibly related to longer day length at northern latitudes and availability of forage fish such as capelin *Mallotus villosus*, Pacific sand lance *Ammodytes hexapterus,* Pacific herring *Clupea pallasii,* and lanternfish (Myctophidae). For example, capelin are cold water fish with high caloric value which spawn in Alaska at predictable coastal locations including Glacier Bay (Arimitsu et al. 2007, 2008) attracting an abundance of *Brachyramphus* murrelets during July and August (Piatt et al. 2007, Hoekman & Johnson, 2020). If a long-distance movements pattern occurs periodically or consistently across the range of the species, it could have conservation implications because marbled murrelets are listed as threatened in Canada (ECCC 2023) and under the US Endangered Species Act in Washington, Oregon, and California (USFWS 1997), but not in Alaska. In addition, abundance estimates of local populations in Alaska could be inflated during the late summer (July–August) if influxes of migrating birds from BC are a regular part of their life history.

We tagged marbled murrelets in summer 2014–2016 in 3 areas along the BC coast with with solar-powered platform transmitter terminals (PTTs). Our primary goal was to identify movement patterns and marine habitat use at various scales. Here we evaluate the utility PTTs for assessing marine habitat use and for tracking previously unknown long-distance movements. We consider the implications of movement patterns and habitat use identified by PTTs on at-sea population monitoring efforts and known threats, including gillnet mortality and oiling risks in the marine environment associated with these habitats.

Here we focus on the northward movements during and after the breeding period of marbled murrelets from BC to Alaska in 2014–2016. Our study coincided with unusually warm sea surface temperatures (SST; Chandler 2018), including a record strength El Niño Southern Oscillation (ENSO) event in 2015–2016 (multivariate ENSO index; NOAA 2022). Marbled murrelets may move northward during summer, possibly in search of cooler water with increased prey availability or for other reasons. Here we attempt to tease apart the effects of cooler temperature versus latitude on migrating birds, and determine how these effects might influence bird movements by modeling SST with latitude and removing the correlation between latitude and water temperature.

2. MATERIALS AND METHODS

2.1. Capture and PTT attachment

We captured birds using the night lighting technique (Whitworth et al. 1997) in 3 of the 7 marbled murrelet conservation regions of BC (Fig. 1). We captured birds near Hartley Bay, BC, during 2014 (n = 6; Northern Mainland Coast), in Desolation Sound during 2015 (n = 9; Southern Mainland Coast) and 2016 (n = 7), and in Clayoqout Sound during 2016 (n = 5; West and North Vancouver Island). Captured birds were weighed to the nearest gram (±1.0 g), and tarsus, wing, and culmen length were measured (±0.1 mm). A small blood sample (<50 µl) from the metatarsal vein spotted on Whatman 903 protein saver cards (Sigma-Aldrich) was taken for molecular gender determination (Griffiths et al. 1998). We tagged birds using 5 g (2.2% average murrelet body mass equivalent) solar-powered satellite transmitters (solar PTT 100-5, Microwave Telemetry; 24 × 14 × 7.5 mm, length × width × height, antenna 213 mm). Methods followed those previously used for radio-tagging marbled murrelets (Bertram et al. 2016) which are modified from methods tested by Newman et al. (1999). The tags were affixed to a loose fold of skin (or 'scruff') located at the base of the dorsal neck using 2 sets of transverse sutures, one securing the anterior aspect of the transmitter and one securing the posterior. The correct placement of the transmitter was first determined by positioning the unit on the dorsal surface of the neck with the skin lying flat. The loose fold of skin underneath the cranial aspect of the transmitter was then gently grasped at the appropriate transmitter width using the thumb and forefinger. A

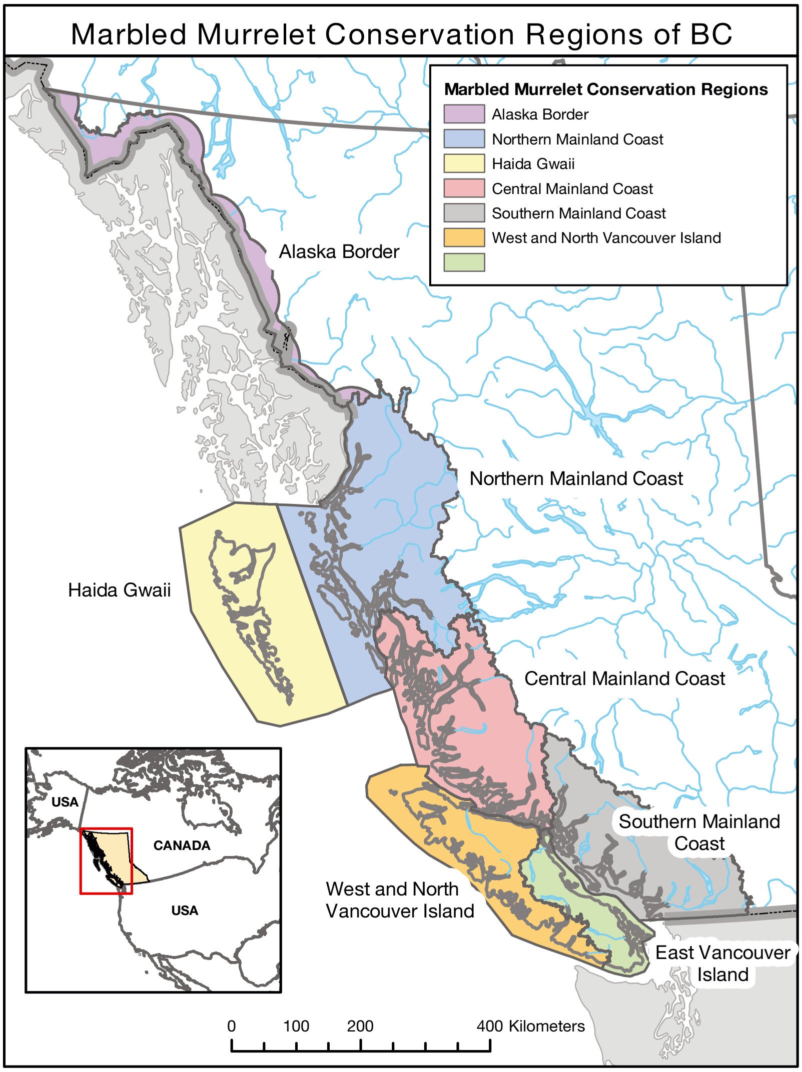

Fig. 1. Marbled murrelet conservation regions in British Columbia (ECCC 2023). Marbled murrelets were tagged in the Central Mainland Coast (2014), the Southern Mainland Coast (2015, 2016), and the West and North Vancouver Island (2016) regions

1.5 inch, 18-gauge needle (inner diameter 0.838 mm) was inserted through the pinched skin. One or 2 strands of a sterile, 2-0 synthetic, non-absorbable monofilament suture (Ethilon™, Ethicon, Johnson and Johnson) was then threaded through the lumen of the needle. The needle was then withdrawn, resulting in a portion of the suture being retained subcutaneously under a 5–10 mm wide section of skin and its 2 ends being free and exposed. One free end of the suture was fed through the transverse channel at the cranial aspect of the transmitter. The 2 free ends of each suture were then tied together using a surgeon's knot with 4 to 5 throws. This resulted in a transverse suture, with a cranial knot located lateral to the corner of the transmitter. If 2 strands of suture were used, lateral knots were placed on opposite sides of the transmitter. A haemostat was used to temporarily secure the second strand of suture, while the first strand was being tied. This procedure was then repeated to secure the caudal channels of the transmitter. Care was taken to ensure that the sutures were snug and posed no risk for entanglement (Kissling et al. 2015). Care was also taken to confirm that the transmitter and its antenna had an appropriate cranial–caudal, midline orientation, that the 4 corners of sutures were even in their tension, and that the skin underneath the transmitter remained flat and unpuckered. The transmitter was sutured as close to the skin as possible while allowing the contour feathers to assume normal positioning. A small bead of superglue was applied to the knots to facilitate suture security. In some instances, the curved, swaged-on suture needle was used to seed the subcutaneous sutures. However, the straight 18-gauge needle allowed for better placement of the transmitter. Birds were not anesthetized and were released within 1.5 h after the time of capture. The PTTs were attached by a Wildlife Veterinarian under Animal Care Certificate (1121 B-06 from Simon Fraser University) and Environment Canada banding permit (10667 A). In 2014, and 2016, transmitters were programmed to signal for 10 h followed by a 48 h off cycle to optimize the discharge/recharge cycle of the battery. In 2015, we selected XT programming, which uses the standard 10–48 h on/off schedule but will turn on to transmit additional location data during the programmed 'off' cycle whenever there is sufficient battery power to do so.

2.2. Satellite data processing

Argos data were downloaded to Movebank (www.movebank.org) and processed using the Douglas Argos-Filter (Douglas et al. 2012). This filter flags Argos locations that exceed thresholds for distance between consecutive locations and velocity and bearing between consecutive movement vectors; the filter settings are provided as metadata in Bertram et al. (2022).

Many of the birds did not transmit from new locations for extended periods or appeared to be transmitting repeatedly from the same location, indicating that birds likely died or that the tags fell off on land. We did not attempt to locate stationary birds/tags so we could not confirm that birds had died. We used a combination of location patterns and temperature and voltage recordings to infer the fate of the birds (dead or unknown fate or tag failure) and to identify movements of living birds. We defined bird movements as long-distance for birds that moved outside of the conservation regions where they were tagged. For suspected stationary tags that appeared to be moving due to Argos errors, we tested for movement in 2 wk bins by visual inspection of kernel density estimates (KDEs), derived assigning an error radius (KDE bandwidth in km) based on Argos location classes (LC = 3, 2, 1, 0, A, B) to each set of points, indicating the probability of encountering a tracked individual.

2.3. Monthly mean SST and latitude

We downloaded monthly mean multi-scale ultra-high resolution (MUR) SST analysis (fv04.1, Global, 0.01) data from NOAA's Coastwatch program (https://coastwatch.pfeg.noaa.gov/erddap/griddap/index.html?page=1&itemsPerPage=1000) for the months August 2014, July 2015, and June 2016. We constrained the downloaded data to a bounding box with the following coordinates: 120–165° W and 45–64° N. In ArcGIS (ESRI v.10.6) we created a buffer of 20 km from the BC coastline including islands and eliminated MUR data outside of the buffer. For each month–year, we fit a linear model for SST with latitude and derived residuals for each MUR SST within the buffer (see Fig. 1) in R using the package 'nlme' (R v.4.2.2). We assigned residual values to each marbled murrelt location to test for birds seeking colder waters without the effect of latitude and tested for the effects of these residuals (local SST variability) on the locations of northward migrating birds fitting a linear model as we did for SST and latitude. Linear models were constrained to individuals that were tracked for longer than 57 d. In addition, the 2016 linear model was constrained to the marbled murrelet banded in Clayoquot Sound that was tracked for longer than 57 d and moved north. The other 2016 bird banded in Desolation Sound tracked for more than 57 d did not leave the conservation region where it was banded.

2.4. At-sea distribution and abundance patterns

We used data on the at-sea distribution and abundance of marbled murrelet from the North Pacific Pelagic Seabird Database (NPPSD v.3; Drew & Piatt 2015) to gauge broad scale seasonal pattterns in relation to satellite tracking results. The NPPSD is the largest publicly available repository for at-sea survey data in the North Pacific, with data contributions spanning years between 1973 and 2019 (Drew & Piatt 2015). It includes seabird surveys that ranged widely over shelf and deep-ocean waters (e.g, Piatt & Springer 2003, Hunt et al. 2005, Renner et al. 2013) and includes specific surveys designed to estimate *Brachyramphus* murrelet abundance (e.g. Arimitsu et al. 2011, Kissling et al. 2011, Kuletz et al. 2011, Piatt et al. 2011). To identify general spatial and temporal trends in BC and Alaska during summer months, we mapped monthly median log(x+1)-transformed densities for marbled murrelets present in June through August within 6495 km^2 hexagonal blocks (100 km diameter at the widest point).

3. RESULTS

3.1. Performance of PTT tags

We captured and tagged 27 marbled murrelets during the breeding seasons in 2014–2016. Of these birds, 11 were male and 16 were female. The duration of tag function ranged from 0 d (tag failure) to 153 d with 0–670 locations bird^{-1}. Four female birds exhibited movement past 57 d, and 3 of those exhibited long-distance movements. The bird that did not exhibit long-distance movement resided within 60 km of the Desolation Sound capture area throughout the summer of 2016 (Tag 159047). Location data, morphometrics, gender, and estimates of movement duration and fate are provided for all individual birds in Sections S1.1 and S1.2 in the Supplement at www.int-res.com/articles/suppl/n051p215_supp.pdf and on Movebank (Bertram et al. 2022).

Most tags showed limited movements and/or functioned for only a short duration. In 2016, 87 % (n = 7) birds from Desolation Sound appeared to have died or lost their tags within 38 d. In 2016, in Clayoquot Sound, 2 birds (Tags 159054 and 159055) showed evidence of moving north from the capture site over time (ca. 100 km) along the west coast of Vancouver Island, but both either died or lost their tags within 57 d. No tagged bird ever moved south more than 60 km from its capture location. For birds/tags that likely did not move, there was wide variation in location (mean variation in latitude among individuals = 0.35 ± 0.069 SE degrees; mean variation in longitude among individuals = 0.83 ± 0.14 SE degrees), demonstrating poor location precision (e.g. Tag 146871 and 146872 from Desolation Sound 2015). Of the 27 tags deployed, the fate of 15 were unknown, 11 were classified as dead (including 2 of 3 long-distance migrants, and the bird which resided in Desolation Sound during summer 2016), and 1 failed.

3.2. Long-distance movements

Long-distance movements from BC to Alaska were observed in 3 individuals, including 1 bird in each year of the 3 study years. In addition, birds that moved to Alaska were tagged and originated from 3 different marbled murrelet conservation regions of BC. In 2014, 1 bird travelled from Douglas Channel to the Katmai coast (2050 km, revised from the value of 1886 km of Bertram et al. 2016 due to the slightly different set of points resulting from additional data cleaning processes) (Fig. 2a); place names are mapped in Section S1.3). In 2015, a bird travelled from Desolation Sound to Glacier Bay (2912 km; Fig. 2b) and in 2016, from Clayoquot Sound to the Alexander Archipelago in Southeast Alaska (2158 km; Fig. 2c). Below we examine the tracks of these 3 birds and their northward movement during summer.

3.3. Monthly mean SST and latitude

There was a significant relationship between latitude and SST for each of the month–years. In August 2014, SST declined at a rate of (mean ± SE) −0.15 ± 0.0006°C with degrees latitude ($p < 0.0001$), July 2015 at −0.23 ± 0.0006°C with latitude ($p < 0.0001$), and June 2016 at −0.078 ± 0.0006°C with latitude ($p < 0.0001$). We found that northward migrating marbled murrelet generally moved in cooler waters as expected by latitude but apparently sought out cooler than expected temperatures (accounting for latitude) for 1 of the 3 month–years, July 2015 (Fig. 2d, Table 1). Furthermore, it appears that the trend in this year was driven by tagging marbled murrelets in Desolation Sound in that year, where SST is unexpectedly high for that latitude (i.e. higher intercept for both month–years, than for August 2014). Once the bird moved out of Desolation Sound, the relationship between latitude and residual SST dissapeared.

3.4. At-sea distribution and abundance patterns

Historic at-sea survey data (NPPSD; Drew & Piatt 2015) identified the greatest density of marbled murrelets in southeast Alaska during June and into July (Fig. 3). In BC, densities were greatest in June, and lesser densities occurred in July and August.

4. DISCUSSION

In 3 consective years, marbled murrelets moved northward from disparate conservation regions of BC into Alaska waters. Our results are consistent with the historic long-term at-sea survey data from the NPPSD (Drew & Piatt 2015), which identified the greatest density of marbled murrelets in southeast Alaska during June and into July. In BC, densities were greatest in June, and lower densities in July and August, which would be consistent with northward migrations to coastal Alaska by non-breeding (failed or otherwise) or post-breeding murrelets. Note that the southeast Alaska surveys have not been updated since 1994 and were focussed on June and July (Agler et al. 1998), so movements into and out of the region in August or later in the fall could be more extensive than currently known.

SSTs began increasing on the BC coast in 2014 (Chandler 2021), and in 2015–2016, our study coincided with a record high multivariate ENSO index (NOAA 2022). The ENSO event contributed to profound negative impacts on pelagic marine food webs (Suryan et al. 2021), including forage fish populations in Alaska (Arimitsu et al. 2021) and the survival and reproduction of marine birds in the Northeast Pacific (Jones et al. 2018, Piatt et al. 2020). Despite removing the effects of latitude on SST, we did not find strong evidence to support the idea that birds tracked cooler waters as they headed northward. The only signifcant relationship (2015) was driven by unusally high temperatures near Desolation Sound part of the protected, shallow 'inland' waters of the northern Strait of Georgia. In addition, the 1 bird that did not move northward stayed in the warmest waters near Desolation Sound for the entire summer.

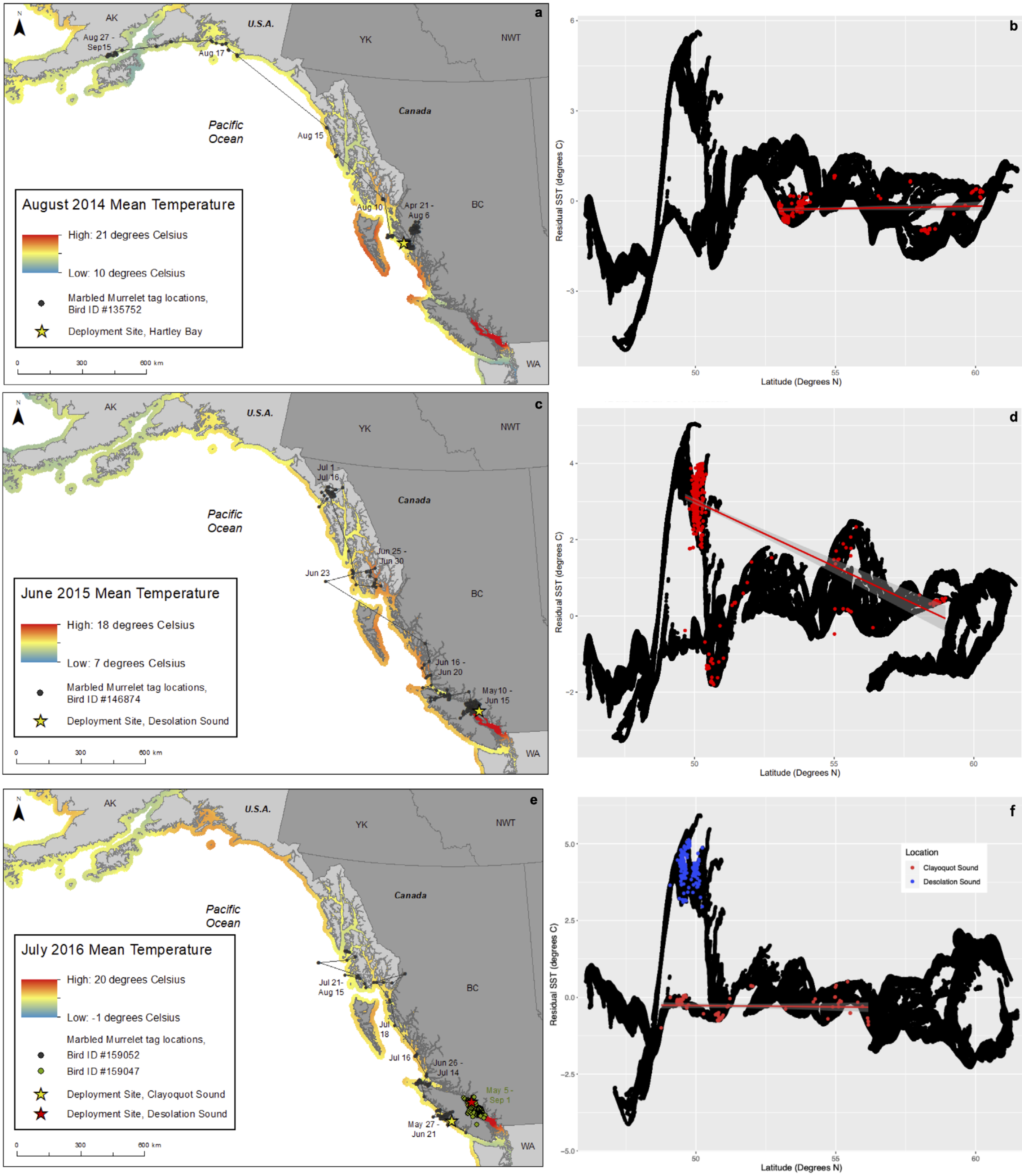

Fig. 2. Mean sea surface temperature (SST) values within a 20 km buffer from the BC coastline and positions for each marbled murrelet location for (a) August 2014, (c) June 2015, and (e) July 2016. Residual SST-latitude (black dots), with assigned residuals based on marbled murrelet positions (red or blue dots), and regression between marbled murrelet residual SST and latitude (red line with confidence intervals) for (b) August 2014, (d) June 2015 and (f) July 2016

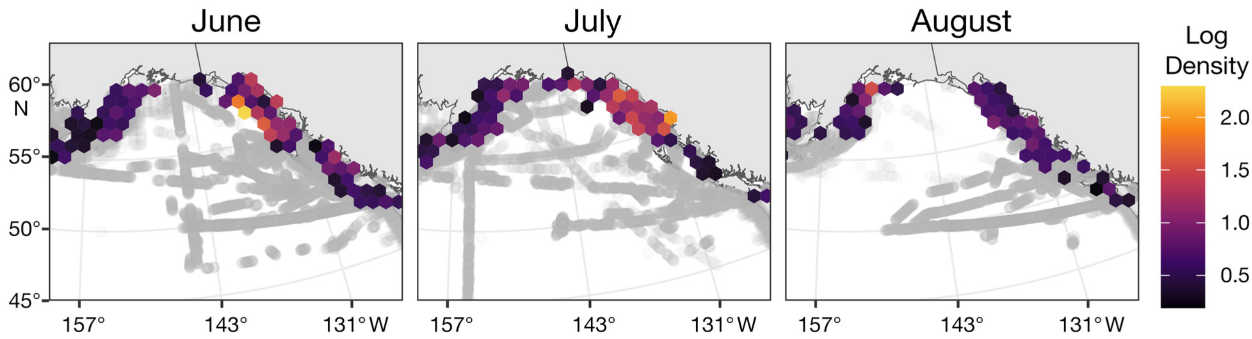

Fig. 3. Monthly marbled murrelet distribution (log(x+1) density where present, birds km^{-2}) on at-sea surveys compiled (1974–2019) in the North Pacific Pelagic Seabird Database. Samples with zero birds observed are shown in grey, with greater transparency where fewer samples were collected

Table 1. Relationship between sea surface temperature–latitude residuals and marbled murrelet locations with latitude

	Slope (±SE)	t	p
Aug 2014	0.02 (0.01)	1.37	0.17
Jun 2015	−0.34 (0.02)	−17.28	<0.0001
Jul 2016	−0.01 (0.02)	0.5	0.61

Birds that moved northward did so at various times in each year. In 2014, the bird migrated north in August likely after completion of chick rearing prior to departure (Bertram et al. 2016). In 2015 and 2016, the birds that migrated north likely did not attempt, or failed to breed and left the capture region in June, earlier than would be expected if breeding was successul (Ronconi & Burger 2008). This early departure could have been related to detrimental effects of the tagging, but alternatively it could have been due to negative effects of ocean warming on sand lance (Hedd et al. 2006) and herring production and recruitment (Boldt et al. 2019) in BC. Recent models based on time series data (1999–2018) of inland occupany counts in Oregon found that murrelet colonization rates were reduced during years when ocean temperatures were high and prey availability was low (Betts et al. 2020). Notably, declines in breeding effort in BC were not detected from radar surveys conducted in the subregions where birds were tagged (2014–2016; Drever et al. 2021).

In addition to the 3 birds which moved to Alaska, 2 birds from Clayoquot Sound also began to move northward off coastal Vancouver Island before tag loss or mortality in 2016. Historic VHF radio-tagging of juvenile marbled murrelets also revealed northward movements (200 km) from Desolation Sound (Parker et al. 2003) and Clayoquot Sound (N. Parker unpubl. data) during late summer. In California, historic VHF telemetry revealed that a bird travelled 724.5 km north of Redwood Creek, to Cape Johnson, WA (erroneously called Port Johnson), although most birds travelled less than 25 km away from their capture location in summer (Hébert & Golightly 2008). The authors concluded that birds from northern California were more likely to move north than south, which contributes to the genetic isolation of central California murrelets (Friesen et al. 2005). More recently, VHF telemetry revealed that during the 2017 breeding season individual birds exhibited movements of >750 km to the south and >400 km to the north from their capture locations along the central Oregon coast, although the distance that birds could be tracked to the north did not extend into Canada (J. Rivers et al. unpubl. data).

Based upon historical marine bird surveys in Alaska, our results of northward summer movements of marbled murrelets in the Gulf of Alaska are not unique to our study period. In Alaska, marbled murrelet densities increase from June to late July (and sometimes August) and usually depart en mass in August in many coastal regions (Fig. 3; Kuletz & Kendall 1998, Romano et al. 2004, Kuletz et al. 2008, Arimitsu et al. 2011). For example, marbled murrelet densities increased by 2- to 3-fold from June to late July and early August in Glacier Bay (13.5 to 42.7 birds km^{-2}; Romano et al. 2004) and Kenai Fjords (14.3 to 35.3 birds km^{-2}; Arimitsu et al. 2011). Similarly, extensive surveys at 3 locations around the Kodiak Archipelago also showed large increases in bird numbers in August compared to June (2011–2013; Corcoran 2016). Numbers swelled at all Kodiak sites but most strikingly at Afognak, where almost 50 000 were estimated in August 2012, up from 20 000 in June 2012. The increase in density could be the result of both local breeders who are finished with incubation and are congregating at sea, young of the year, and birds from elsewhere. Historical observations on the west coast of Vancouver Island in Barkley Sound noted that most adult birds departed from the sound after breeding in early August and presumably underwent prebasic molt elsewhere (Carter & Stein 1995).

From a demographic perspective, movements of marbled murrelets in and out of study regions presents challenges for at-sea abundance and trend estimation (Bertram et al. 2015). Long-distance movement of birds from BC to Alaska in summer could contribute to variation in at-sea abundance estimates and trend detection efforts in Alaska. The 2014 migration track of 1 our tagged birds generally overlapped with areas where at-sea surveys are conducted for murrelets to identify at-sea abundance status and trends (Prince William Sound, Kenai Fjords) and ended adjacent to lands managed by the National Park Service and the U.S Fish and Wildlife National Wildlife refuge system and U.S. Forest Service. In Glacier Bay National Park and Preserve an intensive, long-term at-sea abundance *Brachyramphus* monitoring program show marked interannual variability in July marbled murrelet counts, ranging from 29 000 to 84 500 (mean 2009–2019 = 60 417; Hoekman & Johnson, 2020). The surveys estimated almost 84 000 ± 12044 marbled murrelets (mean ± SE) in July 2015, the second highest count on record. Our tracking study revealed that the BC bird from Desolation Sound was in the Glacier Bay area from 1–15 July and could have been included in the large count from the 2015 survey. In our study, birds moved to Alaska in June, July, and August. The degree of regularity, timing, and duration of northward migrations from BC to Alaska warrants further investigation to guage how immigration contributes to variation in local at-sea abundance estimates and the statistical power to detect trends.

Throughout their range, high variation in year to year at-sea counts of marbled murrelet are commonly reported (e.g. Pacific Northwest: Lorenz & Raphael 2018, Pearson et al. 2022, McIver et al. 2023; BC: Yakimishyn & Zharikov 2017, Parks Canada 2018, Pattison et al. 2023; Glacier Bay, Alaska: Hoekman & Johnson, 2020; Prince William Sound, Alaska: Agler et al. 1998). Our study and others demonstrate that birds can move long distances, taking them between countries and study regions. Inter-year variation in at-sea counts may therefore be related to large-scale bird movements. For marbled murrelet conservation, there is a growing need to combine range-wide at-sea count datasets to look for evidence of large-scale movements and their underlying causes. Such a program would also benefit by integrating concurrent tracking work.

We have stopped using the PTTs because they may have contributed to mortality among tagged birds or impacted mobility and their decision to breed (Bertram et al. 2016), consistent with congeneric Kittlitz's murrelet *B. brevirostris* tracked by researchers in Alaska (Piatt et al. 2021). Relatively high mortality (41 %) was consistent with observations from Oregon in 2016 which used the same PTTs (although the range of transmissions was shorter and ranged between 9 and 25 d; Northrup et al. 2018). In Oregon, 3 birds (out of 7 tagged, 42 %) were found dead (2 from depredation and/or scavenging, 1 intact in poor condition), and the other 4 were unrecoverable, leading the authors to 'suspect that tagging negatively affected welfare of these birds' (Northrup et al. 2018, p 47). However, it is important to note that both the Oregon and BC PPT studies were conducted during years with unprecedented marine heatwave conditions which may have contributed to stress and poor reproductive performance (Betts et al. 2020) and led to large scale die offs of common murres in the Gulf of Alaska (Piatt et al. 2020).

Tags did not provide sufficient spatial precision to identify marine habitat use patterns. We seek smaller, more streamlined tags with greater location precision to quantify the timing and duration of movements. In addition, knowledge of marine habitat use will facilitate the identification of areas and times of known threats such as salmon gillnet fishery openings (Carter et al. 1995, Piatt & Naslund 1995, Smith & Morgan 2005, Manly 2007, 2009, 2015, Piatt et al. 2007, Bertram et al. 2021) and oiling risks from vessel traffic (Carter & Kuletz 1995, Kuletz 1996). GPS tags currently available are smaller, lighter, lower profile in shape, less prominent, with smaller antennas, but they run on batteries with a limited lifespan so are not best suited for detecting long-distance movements. Despite their drawbacks, the PTTs provided new information demonstrating long-distance movements of birds from 3 marbled murrelet conservation regions of BC to Alaskan waters, in the 3 consecutive years of our study. Although our sample size was low, long-distance northerly migrations in the congeneric Kittlitz's murrelet following breeding or failed breeding attempts has been described using similar methods (Piatt et al. 2021; see also Day et al. 2011). We suggest that the patterns we observed may not be unusual in *Brachyramphus* murrelets.

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