MARBLED MURRELET *BRACHYRAMPHUS MARMORATUS* MOVEMENTS AND MARINE HABITAT USE NEAR PROPOSED TANKER ROUTES TO KITIMAT, BC, CANADA

DOUGLAS F. BERTRAM[1], CHRISTIE A. MacDONALD[2], PATRICK D. O'HARA[1], JENNA L. CRAGG[3], MICHAEL H. JANSSEN[2], MALCOLM McADIE[3], & W. SEAN BOYD[3]

[1]*Environment Canada, c/o Institute for Ocean Sciences, 9860 West Saanich Road, P.O. Box 6000, Sidney, British Columbia V8L 4B2, Canada (douglas.bertram@dfo-mpo.gc.ca)*
[2]*Environment Canada, National Wildlife Research Centre, 1125 Colonel By Drive, Ottawa, Ontario K1A 0H3, Canada*
[3]*Environment Canada, Pacific Wildlife Research Centre, 5421 Robertson Road, Delta, British Columbia V4K 3N2, Canada*

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SUMMARY

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We report on movements and marine habitat use of breeding Marbled Murrelets *Brachyramphus marmoratus* offshore of Kitimat, British Columbia, Canada, with particular reference to the proposed "Northern Gateway" tanker traffic routes. Adult Marbled Murrelets were captured at night on the water during the pre-laying period (April 2014) in Wright Sound, near Hartley Bay, BC. Six birds were tagged with 5 g solar satellite transmitters. We had short-lived or no detections for two birds, detections for two weeks for three birds, and detections throughout the breeding season and beyond for one bird whose tag continued to transmit signals. Marine habitat use in relation to three alternative proposed tanker routes was examined for individual murrelets by using kernel density estimation to generate probability density functions of location, incorporating Argos location errors. Areas of high, medium and low encounter probabilities for each bird were generated. Use of marine habitats, coupled with a large population of birds in the area during the breeding season, suggests that there is a strong potential for interaction between tankers and murrelets along the proposed routes. However, based on the movement of one bird to south-central Alaska, individuals may migrate out of the area, reducing the likelihood of interactions post-breeding.

Keywords: British Columbia, Marbled Murrelet, shipping, satellite telemetry, kernel density, species at risk

INTRODUCTION

The Marbled Murrelet *Brachyramphus marmoratus* (hereafter, murrelet) is a small seabird that nests in coastal old-growth forests. The species is listed as Threatened in Canada under the Species at Risk Act because of high rates of loss of old-growth forest nesting habitats (Environment Canada 2014). As well, marine threats include gill net mortality, ocean climate change effects on marine food webs, and oil pollution from increasing ship traffic (COSEWIC 2012, Environment Canada 2013).

The Recovery Strategy for the Marbled Murrelet (Environment Canada 2014) aims to identify critical marine habitats, as well as critical terrestrial nesting habitats, for the species throughout its range. One such important area for habitat is the northern region of coastal British Columbia (BC), which supports the breeding of tens of thousands of these birds (Bertram *et al*. 2015).

Studying the habitat use of such a small (200 g), secretive species in remote areas has proven challenging. The recent development of solar-powered satellite tracking devices has facilitated the tracking of murrelets (Piatt *et al*. 2010; John Piatt, USGS, pers. comm.), and this study represents the first of its kind in Canada to describe murrelet movement patterns using this technology. Satellite tracking devices can provide a time series of spatial information from individuals over a broad geographic range. We present a novel technique for integrating location error, based on signal strength and reliability, into our analyses of movement patterns.

As well, we show how satellite tracking data can be used to investigate marine habitat use and movements of murrelets in relation to anthropogenic stressors such as the proposed tanker routes on the approach to and from Kitimat, BC. The "Northern Gateway" pipeline project proposes a twin pipeline from Bruderheim, Alberta, to a marine shipping port at Kitimat, located at the head of Douglas Channel. An eastbound pipeline would import natural gas condensate and a westbound pipeline would export diluted bitumen from the Athabasca oil sands to the terminal in Kitimat, where the bitumen would be transferred to oil tankers for transportation to Asian markets (http://www.gatewayfacts.ca/). Condensate is already shipped into Kitimat for transport to Alberta via railway, and the increased capacity for transportation of these products through the pipeline is expected to lead to increased marine shipping in this region.

Therefore, this study used solar-powered satellite tracking devices to gauge murrelet movements and habitat use on the approach to the port of Kitimat, BC, in order to contribute to projections of interactions between tankers and this threatened species as shipping traffic increases.

STUDY AREA AND METHODS

Murrelet capture and tag attachment

We captured murrelets in Wright Sound, near Hartley Bay, BC (53°15′10.8″N, 129°9′1.79″W) 17–20 April 2014. Adult birds were captured on the water between 22h00 and 05h00 using night-lighting (Whitworth *et al*. 1997). We tagged birds using 5 g solar-powered satellite transmitters (Solar platform transmitter terminal [PTT] 100-5, Microwave Telemetry Inc., MD, USA; dimensions = length 24 mm × width 14 mm × height 7.5 mm, antenna 213 mm) attached to the loose fold of skin of the dorsal neck with four simple, interrupted, transverse sutures (Fig. 1, modified from Newman *et al*. 1999, J. Piatt pers. comm.). Birds were not anesthetized and were released within 1.5 h after the time of capture. Transmitters were programmed to signal for 10 h followed by a 48-h off cycle to optimize the discharge/recharge cycle of the battery.

Sex determination

We collected blood samples (<50 μL) from the metatarsal vein spotted on Whatman 903 protein saver cards (Sigma-Aldrich, USA) and stored them at room temperature until laboratory analysis. Genetic sex determination was conducted at the National Wildlife Research Centre (Ottawa, Ontario, Canada) according to methods described in Griffiths *et al.* (1998).

Spatial data analyses

Location data were received by the Argos system (CLS 2011) and processed using the Kalman filter (KF) algorithm and an estimated mean flight velocity of 23 m/s, based on murrelet flight speeds documented by Elliott *et al*. (2004). An advantage of this processing algorithm over the traditional least-squares (LS) method is the ability to derive locations from as few as one transmission message (Lopez & Malardé 2011). This was an important advantage in our study, in which 33% of transmissions contained only one message, presumably due to a combination of behavioural and environmental (habitat) characteristics that obscured reception of the PTT signal by orbiting satellites (for example, incubation in dense forest cover and steep mountainous terrain). The resulting KF data were filtered using the Douglas Argos Filter (DAF; Douglas *et al*. 2012), available online through the animal tracking website Movebank (www.movebank.org). The DAF has been found to improve data accuracy by 50%–90% by removing implausible locations flagged

Fig. 1. Location of attachment of a 5 g solar satellite platform transmitter terminal (PTT) to a Marbled Murrelet on 18 April 2014 in Hartley Bay, BC, Canada. Photo Jenna Cragg.

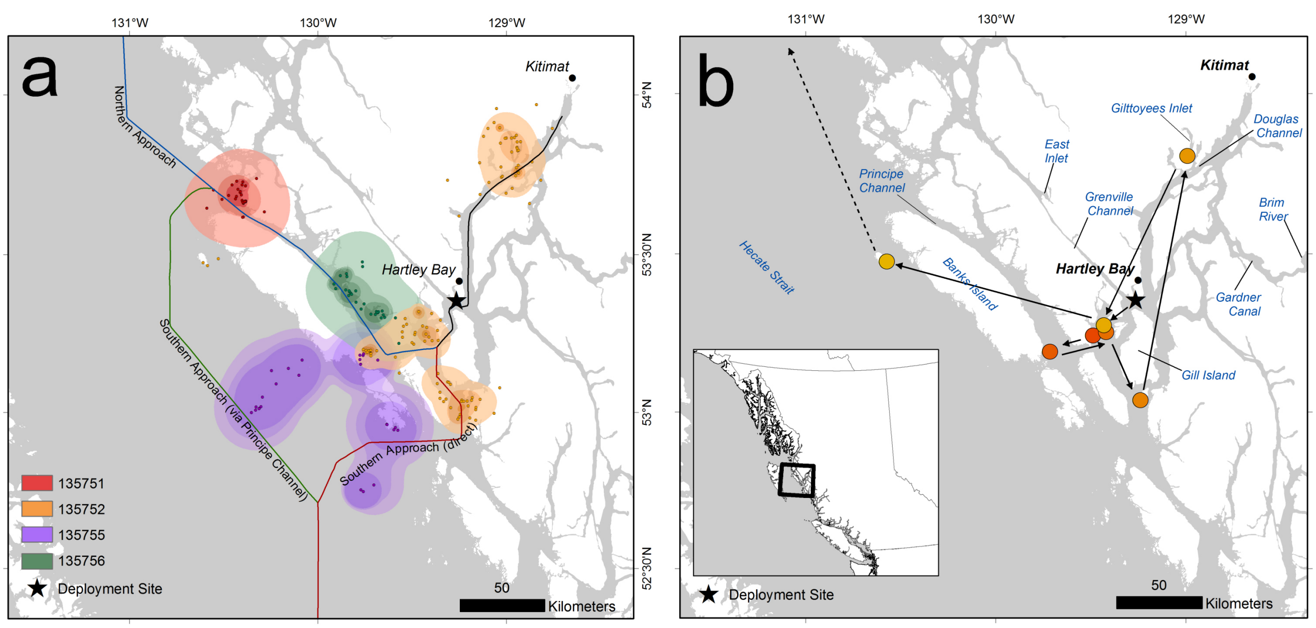

Fig. 2. (a) Kernel density estimates for four Marbled Murrelets tracked during pre-breeding (April; birds # 135751, 135752, 135755 and 135756) and breeding periods (May–August 2014; bird #135752). The star represents the capture site in Wright Sound. From darkest to lightest, colours represent contours of 1, 2 and 3 standard deviations of the total probability distribution for each tagged individual. The coloured dots within each of the shaded areas are the actual locations as detected by the satellite. (b) Generalized seasonal movements of bird #135752; points ranging from darker to lighter orange indicate the following significant events — 1: 19 April (deployment), 2: 21–22 April (n = 12 signals detected by the satellite), 3: 24 April (n = 3), 4: 26 April (n = 3), 5: 26 April–3 May (n = 27), 6: 5 May–29 June (n = 39), 7: 11–23 July (n = 6), 8: 25 July–6 August (n = 3), after which this bird migrated north, away from the study area (shown in Figure 3).

by user-defined and/or taxonomically specific variables such as the maximum rate of movement (Douglas *et al*. 2012). We used the "best hybrid" filtering method with a maximum spatial redundancy threshold (MAXREDUN) of 15 km (the recommended user-defined input variable for DAF for datasets representing periods of foraging as well as longer-distance movements of >100 km; Douglas *et al*. 2012). To account for the potential impacts of capture and tagging on bird behaviour, any locations transmitted within 48 h following tag deployment (one transmission cycle) were excluded from analyses.

To quantify potential overlap of murrelet distribution with three proposed tanker routes to and from Kitimat, BC (54°02′40″N, 128°37′33″W), we performed kernel density estimation (KDE) to generate a probability density function for the distribution of each tagged bird (Fig. 2a). Differences between the Argos-estimated locations and the true position of the transmitter (Argos location error) can be caused (and confounded) by factors including satellite location and speed, transmitter location and speed, signal obstruction, weather, and processing algorithm selected (LS or KF). Although these errors are typically thought to be <2 km (CLS 2011), in extreme cases Argos location errors reaching >100 km have been documented (Douglas *et al*. 2012). Despite these known positional errors in wildlife tracking studies, KD analyses are commonly used to map an animal's home range, a technique that assumes a high degree of positional accuracy of input locations. As a novel approach to account for Argos location errors, we grouped Argos location data (points) by their assigned location classes (LC = 3, 2, 1, 0, A, B) and assigned an error radius (in kilometres) to each set of points. Douglas *et al.* (2012) estimated the average location error by comparing >20 000 locations estimated by Argos with temporally paired locations derived by the global positioning system (GPS) for tracked free-ranging birds. We assigned the 95 percentile error radii calculated by Douglas *et al*. (2012) for each LC, which ranged from 1.5 km for LC = 3 to 20.9 km for LC = B (see Table 2 in Douglas *et al*. 2012). The assigned error radii were used as the input parameter "Search Radius" for the KD analyses performed on each set of data. Finally, we calculated the sum of the KD surfaces to generate a final probability distribution for each tagged murrelet. The resulting probability density surfaces (i.e., indicating the probability of encountering a tracked individual during the study period) were classified by standard deviations to display areas of high, moderate and low probability. Finally, we determined the linear distance of the proposed tanker routes that intersected with areas of high, moderate and low probability density (standard deviation = 1, 2, and 3 respectively, for the probability density surfaces) for each tracked bird. All spatial analyses were performed using ArcGIS v10.2 (ESRI, Redlands, CA, USA).

RESULTS

We attached satellite tags to and collected blood samples from six murrelets. Sex-determination indicated a single band of DNA for individuals tagged with PTT# 135750, 135751 and 135755 (= male) and a second band for birds tagged with PTT# 135748, 135752 and 135756 (= female).

One satellite tag (#135748) did not transmit any Argos locations following deployment (reason unknown). Another tag (#135751) transmitted only three Argos locations within the first 48 h of deployment (assume tag lost or failed, or bird died) and these data were excluded from the analyses. The remaining tags (135750, 135755, 135756 and 135752) transmitted tracking data for periods of 6, 11, 13, 110 d, respectively. A combined total of 297 unique locations were transmitted over the study period of 18 April–6 August 2014 (n = 38–180 locations per bird). Processing the data using the KF algorithm resulted in an overall 8% increase in the number of derived Argos locations compared with the LS processing method. Additional processing using the DAF to remove implausible locations reduced the final dataset to 186 Argos locations across four individuals (n = 26–101 locations per bird).

For the first two weeks following capture, the tagged birds remained within the study region west of the capture site but showed some spatial variability in the encounter probability density surfaces among individuals (Fig. 2a). Two birds stayed within 50 km of the capture site, while the other two ventured into Hecate Strait 85 km southwest (#135755) and 95 km northwest (#135751). Female 135752 moved 100 km east of the capture site to the Gilttoyees Inlet area at the head of Douglas Channel near Kitimat. She remained in the Gilttoyees region during the incubation and chick-rearing periods from 5 May

TABLE 1
Distance of proposed tanker routes that intersects with the probability density functions of satellite-tagged Marbled Murrelets

Route	Intersection region	Intersection distance (km)[a]; bird identification				Total (km)
		135 751	135 752	135 755	135 756	
Northern Approach	High	10.3	2.9	12.8	1.7	26.1
	Moderate	11.7	2.1	3.2	11.7	28.7
	Low	30.3	51.7	3.8	22.6	70.5
Southern Approach (direct)	High	0	5.4	14.3	0	19.7
	Moderate	0	11.5	5.6	0	17.2
	Low	0	44.7	8.4	0	53.2
Southern Approach (via Principe Channel)	High	10.3	2.9	12.8	1.7	38.9
	Moderate	11.7	2.1	11.1	11.7	36.7
	Low	30.3	33.6	11.9	26.3	82.2

[a] High, moderate and low represent 1, 2 and 3 standard deviations of the total probability distribution for each tagged individual, respectively. Data for tags #135751, 135755 and 135756 represent the pre-breeding period (18 April–1 May 2014). Data from tag #135752 represents local pre-breeding and breeding distribution (18 April–6 August 2014).

to 29 June before returning to an area near the initial capture site from 11 to 23 July. At the end of July she moved briefly into Hecate Strait and then left the study area on 6 August (Fig. 2b).

The KD analysis generated regions of relative high, moderate and low probability of encountering a tagged murrelet during the breeding period. The degree of overlap between tanker traffic and murrelet distribution varied by tagged individual and by tanker route option (Table 1). The southern tanker approach (direct) had the shortest route distances that intersected with regions of high probability (19.7 km), moderate probability (17.2 km) and low probability (53.2 km) of murrelet encounter, whereas the southern tanker approach via Principe Channel (indirect) had the longest route distances that intersected with regions of high (38.7 km), moderate (36.7 km) and low (82.8 km) probability of murrelet encounter. The northern approach route option showed intermediate tanker route distances of intersection with regions of high, moderate and low probability of murrelet encounter (26.1 km, 28.7 km and 70.5 km, respectively).

Female 135752 moved 174 km northward to southeast Alaska, close to the Canadian border (Table 2, Fig. 3a), then to the outer coast and farther north, up the Alaskan Panhandle, until mid-August. She then quickly moved (>500 km in 2 d, Fig. 3b) to Prince William Sound and finally west near Takli Island (58°03′43″N, 154°29′49″W) off the Alaska Peninsula, north of Kodiak Island. Presumed "live" transmissions ceased in mid-September (temperature data declined markedly after 15 September, indicating either that the bird had died or the transmitter had become detached from the bird), but the tag continued to transmit locations from this area until 17 November 2014. The cumulative distance of the post-breeding movement was 1 886 km (Table 2).

DISCUSSION

Our study is the first to use solar satellite PTTs to track murrelets in Canada, and it provides new information on the use of marine habitats and movements during the breeding season as well as the first report of a long-distance, post-breeding movement to Alaska. For two weeks immediately following capture, the tagged birds remained within the study region west of the capture site. This period coincides with the pre-laying period for this population. Subsequently, one female (135752) moved east to Gilttoyees Inlet and remained in that region for 56 d from early May to late June, which encompasses the egg-laying, incubation and chick-rearing periods.

Gilttoyees Inlet is the site of a long-term radar monitoring station to detect trends in the breeding population of murrelets in Canada (Bertram *et al.* 2015). In 2014, radar surveys on 12, 13 and 17 July indicated 99, 104 and 223 murrelets entering the watersheds adjacent to the inlet before sunrise (Schroeder *et al.* 2015). Concurrent at-sea surveys (Schroeder *et al.* 2015) indicated high densities of birds (> 20/km^2) on six segments (n = 39 segments, mean = 13 birds/km^2, range 3.16–50.58 birds/km^2) on the water in Gilttoyees Inlet adjacent (<5 km) to suspected nesting areas.

Note that this knowledge of spatial relationships between terrestrial breeding sites and marine foraging sites is vital for local conservation planning. Furthermore, proximity to nesting habitats has been identified as a key variable in predicting murrelet marine distribution patterns during breeding in the nearshore waters of California, Oregon and Washington (Raphael *et al.* 2015), BC (Ronconi 2008) and Alaska (Cragg 2013).

Based on the location and movement data, we infer that female 135752 was actively nesting in the Gilttoyees region and remained primarily in the inlet during the incubation and initial chick-rearing period. There were no locations for this female between 29 June and 10 July, and she was again detected near the capture site on 11 July. The 56 d duration in the Gilltoyees area is just enough time for the female to have fledged a chick, according to the results of Peery *et al.* (2004), who inferred successful breeding from radio telemetry if nest attendance lasted 54–70 d from onset of incubation. Note that adult murrelets do not care for their young on the ocean. In late July, female 135752 began migrating northwest and departed from the study area on 6 August, consistent with the end of the breeding period.

During breeding, the study region provides important marine and nesting habitats for thousands of murrelets (Bertram *et al.* 2015). In addition to the radar monitoring station at Gilttoyees Inlet, the next-closest long-term radar monitoring stations also showed high levels of breeding activity at East Inlet (number of incoming birds pre-sunrise range: 97–107, n = 2 surveys) and Brim River (number of incoming birds pre-sunrise range: 187–206, n = 3 surveys) in 2014 (Schroeder *et al.* 2015). Between the radar surveys, concurrent at-sea surveys throughout Douglas and Grenville channels and

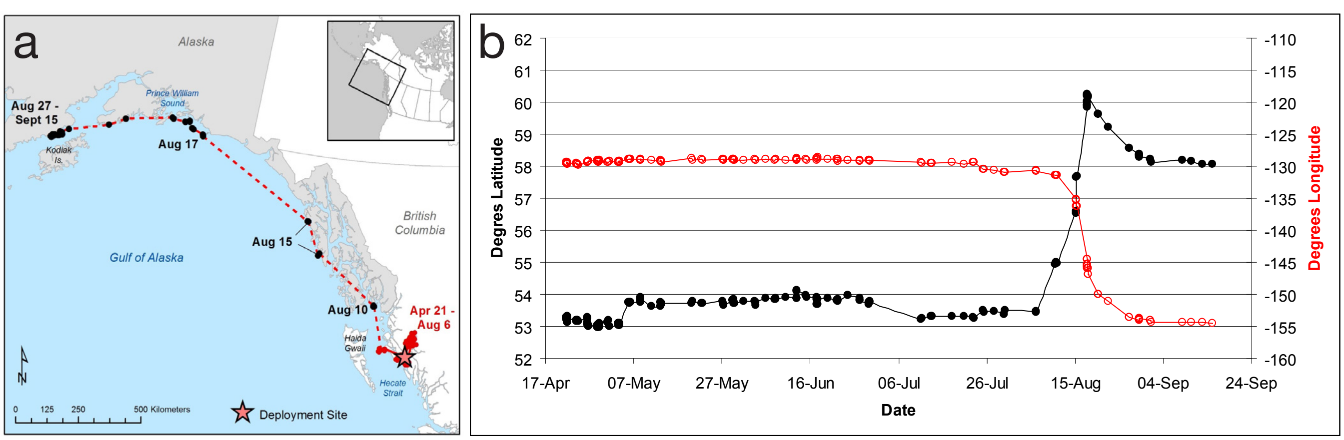

Fig. 3. (a) Post-breeding migration to Alaska (black circles) for bird #135752, revealed by satellite telemetry. (b) Latitude (filled black circles) and longitude (open red circles) of location by date for bird #135752.

adjacent areas in 2014 (Schroeder *et al*. 2015) recorded the highest counts in Gardner Canal (1 141 birds on 13 July) and in Gilttoyees Inlet (189 birds on 11 July 2014). The high at-sea counts in our study area were similar to those observed near other large breeding populations of murrelets on the west coast of Vancouver Island (Ronconi & Burger 2009). These survey data sets indicate large numbers of murrelets in the region and support our ability to scale up our inferences to the population level from the telemetry results of our few birds.

Our results show significant overlap of murrelet marine habitat use with the proposed tanker routes to Kitimat, BC. All of the routes intersected with at-sea distributions of birds, with the greatest potential for overlap on the southern indirect route and lowest overlap on the southern direct approach. The tanker routes are not as straight as the lines depicted on Figure 2a but, rather, have multiple turns which could increase risks of accidents that threaten marine birds. Simulation models of manoeuvring of escorted tankers show 14 required turns along the southern direct route and 15 turns for the northern direct route (FORCE Technology 2010). We note that Wright Sound, the capture location for the murrelets in this study, had a high concentration of pre-breeding murrelet pairs (DFB pers. obs.). Wright Sound was also the location of the sinking of the BC Ferry "Queen of the North," which failed to make a course change to manoeuvre around Gill Island the night of 22 March 2006.

The 1 886 km post-breeding movement of one bird to south-central Alaska was striking, as few data exist on post-breeding dispersal for this species. A banding study in southern BC (Desolation Sound) showed post-breeding movements 220 km south to Washington State waters and suggested that migratory and non-migratory individuals are found in the same summering population (Beauchamp *et al.* 1999). A radio telemetry study of post-fledging juveniles showed that one individual moved up to 200 km north of Desolation Sound (Parker *et al*. 2003). In Central California, radio telemetry revealed that the mean post-breeding dispersal distance was 256 km (n = 12; Peery *et al*. 2008), with most birds heading south. Our migrant from northern BC was last located near Takli Island off the Alaska Peninsula, north of Kodiak Island. This finding was during a period when Gulf of Alaska waters were the warmest ever recorded (Timmermann 2014), and it is not known how anomalous ocean temperatures may have affected bird movements in that year. Nonetheless, extensive repeated at-sea surveys near Kodiak Island have recently revealed marked increases (1.7-fold in 2011, 2.5-fold in 2012) of murrelet numbers during the post-breeding period of August–September (Kodiak National Wildlife Refuge, Robin Corcoran, USFWS, pers. comm.). The migration data presented here are consistent with the possibility that some of the influx of post-breeding murrelets to the Kodiak region likely originates from Canada.

TABLE 2
Timing and distance of post breeding migration to Alaska for bird #135752

Significant events	Date	Cumulative migration distance (km)
Departure for post breeding migration	6 Aug	0
Arrival to southeast Alaska	10 Aug	174
Crossed 60°N	17 Aug	1 225
Crossed 150°W	20 Aug	1 529
Last "live" transmission	15 Sept	1 886

Alcids, especially smaller species that forage by pursuit diving, such as the murrelet (reviewed in Burger & Shaffer 2008), are considered particularly vulnerable to the effects of tag deployment. Device attachment effects observed in breeding alcids include reduced parental body mass, reduced chick provisioning and growth rates, and reduced chick mass at fledging (e.g., Paredes *et al.* 2005, Kidawa *et al*. 2011, Robinson & Jones 2014). Potential effects of device attachment on murrelets include hydrodynamic drag, aerodynamic drag, increased energetic costs of flight due to added weight, reduced waterproofing of feathers, infection, increased predation probability, and acute handling effects. Several studies have used various techniques to deploy radio telemetry devices on murrelets, including Kittlitz's Murrelet *Brachyramphus brevirostris* (e.g., Bradley *et al*. 2004, Peery *et al*. 2004, Kuletz 2005, Kissling *et al*. 2014), but reports on observed or potential effects of tags on murrelet behaviour, productivity and survival are limited. MacFarlane Tranquilla (2001) and Barbaree *et al*. (2014) both noted reduced breeding propensity in some female murrelets following capture and VHF radio tag (2.5 g) deployment using subcutaneous anchors. Peery *et al*. (2006) found reduced survival of VHF radio-tagged murrelets (2.3 g, attached using subcutaneous anchors while under anesthetic) in the year following tag deployment compared with banded birds. Through examination of recovered carcasses and recaptured murrelets fitted with radio tags, Peery *et al*. attributed the reduced survival of tagged murrelets to increased energetic costs from hydrodynamic drag and concluded that effects such as reduced waterproofing, infection, and stress from capture (including anesthetic use) had minimal impacts on survival. The authors speculated that increased probability of predation could be an important source of mortality, but did not find evidence of this in their study (Peery *et al*. 2006). No evidence of reduced survival was found for Kittlitz's Murrelets fitted with 3.2 g VHF radio tags (attached using subcutaneous anchors and local anesthetic in some years), although that study measured survival for only one breeding season (60 d; Kissling *et al*. 2014). Kissling *et al*. (2014) found high predation rates of radio-tagged Kittlitz's Murrelets (100% of confirmed fatalities, n = 16) but the rates of predation of radio-tagged and unmarked birds appeared to be similar.

We attached PTTs to birds that were not in full breeding plumage, and it is possible that the three radios that functioned only for a short period of time fell off as the birds molted. For future studies we recommend deployment of devices after the birds are in full breeding plumage.

In conclusion, our work on murrelet movement patterns and use of marine habitats shows a strong potential for interaction between tankers along the proposed routes to Kitimat, during the pre-breeding and breeding seasons. Post-breeding, some individuals may migrate out of the area, reducing the likelihood of interactions, although additional autumn and winter surveys would be required to determine that other birds do not enter the area. The new satellite tags have enabled the identification of foraging habitats at the spatial scales reported here and facilitate confidence to identify areas where foraging birds are most likely to interact with tankers along proposed shipping routes. The satellite telemetry also revealed a rapid long-distance movement to Alaska and demonstrates connectivity between Alaskan and Canadian populations. The murrelet is protected in both Canada and the United States under the Migratory Bird Treaty, but the degree of movement and population connectivity between BC and Alaska remains to be determined to inform conservation planning.

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