Progress report:
Radar monitoring of *Brachyramphus* murrelets on Kodiak Island, 2010

Jenna L. Cragg, Alan E. Burger, Matthew M. Osmond

Biology Department
University of Victoria
PO Box 3020 STN CSC
Victoria, BC V8W 3N5

Contact: aburger@uvic.ca and jenna.cragg@gmail.com
Phone: 250-378-2468

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U.S. Geological Survey, Anchorage, Alaska
Kodiak National Wildlife Refuge, U.S. Fish & Wildlife Service, Kodiak, Alaska

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Abstract:

Kittlitz's Murrelet (*Brachyramphus brevirostris*) is a rare and poorly understood seabird found in Alaska and Eastern Russia. On Kodiak Island, Alaska, it is sympatric with the well-studied and more widespread Marbled Murrelet (*B. marmoratus*). Although these species share behavioral traits including non-colonial, highly cryptic nesting behavior and nearshore piscivorous foraging, they exhibit some subtle behavioral differences that are not well understood. Both species commute to and from the nest in dark twilight, making visual studies of this behavior impossible. Marine radar has become a standard tool to study the inland flight behavior of Marbled Murrelets in forested watersheds throughout B.C. and in the U.S., and has shown high statistical power to detect population trends; however, radar has not been used for monitoring populations of either murrelet species in Alaska.

In 2010 we conducted a pilot study using marine radar to investigate diurnal, seasonal, and spatial patterns of inland flight behavior of *Brachyramphus* murrelets on Kodiak Island. We conducted 181.7 hours of radar surveys from 6 June – 27 July 2010, yielding 2098 observations of potential murrelet tracks that we classified as "Likely" or "Possible" murrelets using a combination of flight speed and behavior criteria. This study confirmed the suitability of radar for tracking murrelets in Alaska, and identified challenges in radar monitoring that are unique to the Alaskan landscape. These included prolonged murrelet activity patterns due to the lengthened twilight period of high latitude summer, greater numbers of other bird species that could be confused with murrelets on radar, frequent high winds that affected the reliability of species identification, and the presence of two murrelet species that are indistinguishable on radar. Our study showed that coastal radar sites were likely to be good monitoring stations if flight paths are constrained by topography, and because murrelet flight behavior was 99% direct compared to other species that often circled. We observed seasonal and diurnal activity patterns in murrelet detections. Murrelet activity was greatest from approximately 23:00-05:00. A broad activity peaks occurred at approximately sunset (6 hours before sunrise) and at one hour before sunrise, but overnight activity patterns were inconsistent from day to day. The number of detections per hour in overnight surveys increased throughout the season. Our study also documented the presence of a possible breeding population of Marbled Murrelets in treeless habitat on southwest Kodiak Island.

We will continue radar surveys on Kodiak Island in 2011 to refine radar monitoring protocols for Kittlitz's and Marbled Murrelets which would be applicable throughout Alaska.

1.0 Introduction

Kittlitz's Murrelet (*Brachyramphus brevirostris*) and the Marbled Murrelet (*B. marmoratus*) are small, diving seabirds found in the North Pacific. The bulk of the populations of both species are found in Alaska, where they are sympatric across large areas of the southern Alaska coast (Nelson 1997, Day et al. 1999). These two species share traits unique to the *Brachyramphus* genus such as non-colonial, inland nesting, and dispersed cryptic nesting behavior. They also forage in similar ways in nearshore marine habitat and are both mainly piscivorous. Despite their similarities they exhibit subtle ecological specialization that varies across habitats and is not well understood. Behavioral studies in areas of sympatry can provide insights into this ecological specialization and mechanisms of coexistence of these two species, which are important in developing effective monitoring protocols to estimate population size and trends. Such tools are urgently needed given the threatened status of both species. Marbled Murrelets are listed as Threatened in Canada and in Washington, Oregon and California. Although the Alaska population has no special status, this is under review due to concerns of the species rapid decline in that state (Piatt et al. 2007). Kittlitz's Murrelet is a candidate species for listing as Endangered due to its low global population (20,000 birds, USFWS 2010), recent rapid population decline of 80-90% over the last 20 years (Kuletz et al. 2003), and low reproductive rate (Day and Nigro 2004, Kaler et al. 2009).

These species are sympatric in large areas of Alaska, but niche differentiation produces habitat segregation at finer scales, and in the species global distributions. Kittlitz's Murrelet has a more northerly distribution than the Marbled Murrelet, and is found in Alaska and Eastern Russia. It is known as the "glacier murrelet" (Day et al. 1999) due to its association with tidewater glaciers in both its foraging habitat (selecting turbid glacial runoff) and nesting habitat (nesting on the ground in talus of glacial moraines). The Marbled Murrelet is much more widespread, ranging from central California into the Aleutian Islands. Although Marbled Murrelets generally nest in mossy platforms on branches of large old conifers (Nelson 1997), a small proportion (≥ 5%) of the Alaskan population nests on the ground, mainly in areas where forested nesting habitat is patchy or nonexistent (Piatt et al. 2007). These ground-nesting populations exhibit some morphological similarities to Kittlitz's Murrelets in traits related to both flight (wing length) and foraging (gape size), but these morphological changes have not been accompanied by genetic divergence from tree-nesting populations (Pitocchelli et al. 1995, Pacheco et al. 2002). On the treeless southwestern end of Kodiak Island, ground-nesting populations of both species overlap in tundra habitat, providing an opportunity to compare their breeding flight behavior.

The goal of this pilot study in 2010 was to test the applicability of marine radar for tracking murrelets on southwest Kodiak Island. Both murrelet species commute at high speed to and from inland nest sites in dark twilight, making visual studies of this behavior impossible, therefore marine radar has been developed as a tool to track flying birds. This technique has become a well-established method for counting Marbled Murrelets flying into forested watersheds in Canada and the U.S. (Washington and Oregon), and has high statistical power to detect population trends (Arcese et al. 2005, Cooper et al. 2006, Bigger et al. 2006). However, this method has been tested in Alaska only in a short pilot study on Kittlitz's Murrelet (Day and Barna 2007). In order to develop radar monitoring protocols for Alaska, there are several challenges that need to be addressed: 1) greater numbers of other bird species with similar flight characteristics that could be confused with murrelets on radar; 2) many areas of Alaska have both *Brachyramphus* species, which are currently impossible to distinguish on the basis of radar tracks; 3) high winds typical of the Alaska coast affect the flight speed and behavior of all birds, making it difficult to distinguish between murrelets and other species; 4) the long twilight periods of high-latitude summer result in prolonged activity peaks for murrelets, that are detected flying throughout the night, so that there is no obvious optimal dawn survey period as in southern latitudes.

The Kodiak Archipelago supports large populations of Marbled Murrelets, mainly concentrated around the northeastern end of the archipelago where suitable forested nesting habitat is abundant (Piatt et al. 2007, W. Pyle, KNWR personal communication). High densities of Marbled Murrelets at sea correspond to the distribution of forested nesting habitat, but these populations have not yet been estimated by radar. By comparison, the number of Kittlitz's Murrelets observed at sea in the Kodiak Archipelago was much smaller than the number of Marbled Murrelets. Breeding populations of Kittlitz's Murrelets were suspected to exist on Kodiak Island, but the first nest was only recently discovered in the summer of 2006, on Mt. Glotoff (Stenhouse et al. 2008). Subsequently, a program of research on the breeding ecology of Kittlitz's Murrelet has been conducted in the Kodiak National Wildlife Refuge (KNWR). This work included three seasons of nest site studies focused on site selection, nest visitation, behavior at the nest, predation (Burkett and Piatt 2008, Lawonn 2009), and a four-day pilot study of flight behavior using radar (Day and Barna 2007) that was curtailed due to destruction of equipment by a wind storm.

In 2010 we conducted a two-month pilot radar study in the Kodiak National Wildlife Refuge. Our objectives were:

1. To test the suitability of radar for tracking, counting, and analyzing the flight behavior of *Brachyramphus* murrelets in Alaska.

2. To compare the similarities and differences in commuting flight behavior of the two *Brachyramphus* species using a combination of audio-visual and radar observations, to investigate possible mechanisms of co-existence.

3. To help develop a radar protocol for population censusing and monitoring of both species of *Brachyramphus* murrelets, but with emphasis on *B. brevirostris*, in Alaskan conditions.

We will build on the results of the 2010 pilot study in the summer of 2011.

2.0 Study Area

Based on surveys of potential Kittlitz's Murrelet nesting habitat conducted in 2008-2009 (Burkett and Piatt 2008, Lawonn 2009), we selected Grant Lagoon on southwest Kodiak Island as a coastal radar station because of its suitable location to track Kittlitz's Murrelets flying into known inland nesting habitat (Figures 1-3). When this location was selected, it was believed that only Kittlitz's Murrelets were nesting inland of this location, providing an opportunity to study the behavior of this species in isolation. Unlike most other areas on Kodiak Island, no Marbled Murrelets had been observed to breed in this area.

The location of the radar scanner was 57° 27.650' N, 154° 39.379'W (UTM Zone 05V 0400635 6369898). See photographs of the radar screen (Figure 2) and radar station (Figure 3). Grant Lagoon provided an ideal location for radar for several reasons: 1) headlands and ridges on either side of the lagoon funneled birds into the Ayakulik valley, and the scanning radius of the radar was large enough to cover the entire mouth of the watershed; 2) a continuous berm across the mouth of the watershed provided a screen to block radar interference from wave clutter of the open ocean, but allowed the radar to detect birds flying out at sea above the waves; 3) we had a clear radar view over the lagoon and over much inland habitat; and, 4) the lagoon provided float plane access.

3.0 Methods

We used a combination of ornithological radar and audio-visual (AV) surveys to track and observe flying murrelets. The radar unit was a Furuno FR8122, (X-band, 12 kW transmitter, 9410 ± 30 MHz, 6 ft array) that had been modified according to standard adjustments for murrelet surveys (scanning arc tilted upwards by ~15˚). Tilted scanners have been shown to be more effective at detecting murrelets than unmodified units (Harper et al. 2004). Radar surveys were conducted throughout the 24-hour cycle to identify diurnal activity patterns. Overnight surveys were conducted from 23:00-05:00 to capture peak activity. Dawn surveys in conjunction with AV surveys from ~03:30-06:30 were conducted to maximize identification of radar detections of murrelets by AV. The remaining surveys were conducted throughout daylight hours (06:00-12:00, 12:00-18:00, 18:00-00:00) to capture the full diurnal activity pattern of all species.

Audio-visual (AV) surveys were conducted in conjunction with radar watches except during darkness (after civil twilight). We used AV protocols developed for inland surveys of Kittlitz's Murrelet on Kodiak Island (Piatt, pers. comm., data sheet in Appendix 1), which were modified from standard Pacific Seabird Group protocols for Marbled Murrelet (Evans Mack et al. 2003). The AV surveys were used to identify the species of murrelet when possible, and document vocalization, flight behavior, and group size of murrelets, in addition to the presence and behavior of other non-murrelet species (commonly waterfowl, gulls, shorebirds). Since murrelet AV detections were rare, we also recorded detailed characteristics of flight behavior of all species likely to be confused with murrelets. During dawn AV surveys, we recorded the time of first activity of potential murrelet predators.

For each detection of a bird by radar (all species) we recorded its flight behavior focusing on criteria that would allow us to distinguish between potential murrelets and other species (Table 1). "Likely" and "Possible" murrelet targets were determined based on four criteria: flight speed ≥ 50 km/h; flight type D, DS or T (see Table 1); flight path shows bird flying between land and sea (or sea to land); and number of sequential images of the target (hits) ≥ 4. If all four criteria were met the target was recorded as Likely murrelet, if three of the four it was considered a Possible murrelet. Targets with fewer than three of these criteria were recorded as Unknown species. The actual species was recorded if known, usually from AV detections. We also traced samples of Likely murrelet and non-murrelet flight radar paths on transparencies for later comparison.

For each radar and AV survey, weather was recorded at the start and end of the survey, along with significant changes during the survey; this included air temperature, wind force (estimated using the Beaufort scale), wind direction, precipitation, cloud cover, cloud ceiling and cloud type. For surveys spanning twilight, we recorded light levels at 2-minute intervals throughout the survey.

To get a measure of the of the local abundance of other bird species likely to be confused with murrelets on the radar we recorded the daily maximum counts of all birds in the area throughout the season based on our daily outings and opportunistic observations. We recorded potential predators of murrelets (eagles and falcons) in the same way.

4.0 Results

4.1 Survey effort and total murrelet detections

We completed 37 radar surveys (181.7 hours), and 36 AV surveys (73.5 hours) from 4 June through 27 July 2010. Radar surveys yielded a total of 2098 Possible or Likely murrelet detections, including 1230 Likely and 868 Possible detections (mean of pooled data: 6.1 murrelet detections h^{-1}; maximum 27.4 detections h^{-1}). Audiovisual surveys recorded a total of 22 murrelet detections (6 visual, 16 audio; mean 0.47 detections h^{-1}; maximum 7.1 detections h^{-1}). All murrelets identified to species in AV surveys were Marbled Murrelets (audio detections of the distinctive “keer” calls only); visual detections of murrelets were rapidly-moving silhouettes and could not be identified to species. The mean overnight count (total Likely and Possible murrelet detections) for dusk to dawn overnight radar surveys was 96.3 ± 15.6 (SE), N = 17.

4.2 Other bird species recorded by radar and daily counts

Bird species recorded by radar (species confirmed by AV) are listed in Table 2. The most common of these species were Red-throated Loons with 24 detections, Bald Eagles (16), Glaucous-winged Gulls (13), and Red-breasted Mergansers (10). The relative frequency of detections by radar was not an accurate reflection of daily abundance in the study area, since detections of other species on radar were recorded only when the identity of these species could be confirmed by the AV observer (few were identified in the darker hours). This restricted the number of radar observations of other species compared to potential murrelet detections that were recorded regardless of visual confirmation.

To get a better picture of the relative abundance of local bird species likely to be confused with murrelets on radar, we also recorded the maximum daily count from all opportunistic observations (Table 3). The mean daily counts of potentially confusing species on radar identified Red-throated Loons, Red-breasted Mergansers, and American Widgeon as the species most often recorded (observed on the greatest proportion of days: 91%, 57%, and 46% respectively) and with the highest mean daily counts (2.1, 1.9 and 2.0 respectively) (Table 3). The only large species observed nearly as often as Red-throated Loons were Bald Eagles (observed 89% of days), with a mean daily count of 2.35.

The timing of first activity of potential predators recorded from dawn AV surveys (Table 4) showed that red foxes were, on average, active earlier than potential avian predators (10.6 minutes before sunrise). The mean times of first activity at dawn for Bald Eagles and Glaucous-winged Gulls were very similar (2.3 and 0.8 minutes after sunrise), while the first activity of Common Raven, Parasitic Jaeger and Peregrine Falcon was 20-30 minutes after sunrise. The earliest recorded potential predator was the Bald Eagle (47 minutes before sunrise).

4.3 Flight speeds recorded by radar: murrelets and other species

Mean flight speeds (± SE) were estimated from radar as 81.3 ± 0.7 km h^{-1} (N = 939 detections) for Likely and 63.4 ± 0.8 km h^{-1} (N = 553) for Possible murrelets (Table 2). For the pooled Likely and Possible murrelets mean speeds were 74.6 ± 0.55 km h^{-1} (N = 1492).

Of the species identified as potentially confusing on radar with the highest daily mean counts and observed on the greatest proportion of days, the flight speeds of three species were within the range, but at the low end of murrelet detections (≥ 50 km·h^{-1}) (Table 2). These species were the Red-throated Loon (mean speed 48.6 ± 1.4 km h^{-1}, N = 7), Red-breasted Merganser (50.0 ± 0.0 km h^{-1}, N = 4), and Bald Eagle (53.8 ± 7.1 km h^{-1}, N = 8).

4.4 Flight behavior recorded by radar

The flight behavior of Likely and Possible murrelet detections at Grant Lagoon was almost completely within the "direct flight" (D) category (Table 2, Figure 4). Out of a pooled total of 1492 detections there was only one possible murrelet recorded as "circling" (C). This was not surprising since more-or-less direct flight was one of the criteria for identifying potential murrelets. By comparison, other species having more than one detection were much more variable in their flight behavior (Table 2, Figure 4). The flight behavior of the two most commonly observed, potentially confusing non-murrelet species (Red-throated Loons and Red-breasted Mergansers) was recorded as direct in 61% and 88% of detections, respectively; the only other behavior category recorded for these two species was circling.

In addition to being mostly direct, murrelet flight paths at Grant Lagoon were fairly consistent in their bearing (Figure 5). Most of the incoming murrelets (going inland from the sea) flew towards the southeast, while outgoing murrelets flew northwest. Relatively few birds were not classified as incoming or outgoing, showing a wider range of flight directions.

For the sample of murrelets which crossed the berm which runs across the mouth of Grant Lagoon, we plotted the point along the berm where they crossed, heading inland (Incoming) or seaward (Outgoing; Figure 6). The coastal crossing points were broadly similar for incoming and outgoing flights (the dip in numbers around the zero point reflects difficulties in detecting murrelets close to the radar unit – the coast here was ~200 m from the radar scanner). Slightly more incoming birds came in on the southwest end of the berm, perhaps reflecting the orientation of foraging sites at sea from where they were coming.

4.5 Effects of weather

We found a significant positive association between the frequency of detections of Likely and Possible murrelets (pooled data) and wind speed (average of start and end of survey) (Figure 7A). This association was, however, driven by the few records at high wind speeds (> Beaufort scale 3, or 18.5 km h^{-1}). Since speed is one of the criteria for identifying potential murrelets, the effect of high winds might be to increase the proportion of false positives (i.e., slower birds look like murrelets with a strong tailwind). With data from winds greater than Beaufort 3 excluded, there was no significant association between detection frequency of murrelets and wind speed (R^2 = 0.006, N = 17, P = 0.77).

Detection frequency of unknown species (likely not murrelets) showed no significant association with wind speed (R^2 = 0.020, N = 19, P = 0.561) (Figure 7B). Cloud cover had no effect on the rate of murrelet detection (R^2 = 0.027, N = 19, P = 0.501) (Figure 8).

4.5 Diurnal and seasonal trends

The mean detection rate of murrelets per hour (Likely and Possible murrelets pooled) was much higher during overnight surveys (14.9 ± 2.3 SE, N = 17 surveys) than during daylight surveys (morning 06:00-12:00: 7.0 ± 5.2 detections h^{-1}, N = 2; afternoon 12:00-18:00: 1.5 ± 1.3, N = 3, evening 18:00-00:00: 7.5 ± 1.3, N = 8). The number of detections per hour relative to sunrise identified two activity peaks: one at about one hour before sunrise and another broad 3-hour peak at sunset, however activity was high throughout the night (Figure 9). Mean counts of unknown species were also higher at night compared to daylight surveys, but during overnight surveys we did not record all activity of unknown birds since this would have interfered with accurate records of potential murrelet detections. We recorded very high densities (up to 70 targets within 500 m of the radar) of unidentified, slow-moving (≤ 25 km h^{-1}) species at night. These were likely bats, and were not likely to be confused with murrelets. We did not routinely count these bat-like detections in each survey.

Although we observed overall activity peaks near sunset and one hour before sunrise, the timing of activity peaks were not consistent from night to night. For example, on June 13, activity peaks occurred from 00:00-01:00, and 03:00-04:00, while the next overnight survey on June 21 recorded uniform counts per hour from 01:00-05:00.

When only overnight surveys were considered, there was a significant increasing seasonal trend in total counts of murrelets (R^2 = 0.365, N = 16, P = 0.013) (Figure 10).

5.0 Discussion

This was the most comprehensive radar study conducted in Alaska testing the applicability of radar to track both Marbled and Kittlitz's Murrelets in treeless habitat. This was also the first use of a coastal radar station in Alaska, and our results demonstrated that the Grant Lagoon location was ideal for making observations of flight behavior due to the excellent radar view. Similar coastal sites, ideally with boundary hills or ridges providing topographic constraints to murrelet flight paths, should work well for long-term monitoring of murrelet populations. The plot of murrelets crossing the berm in front of the lagoon (Figure 6) showed that there were few detections at the edges of the radar scanning circle indicating that most of the murrelets passing across this valley were detected by the radar. These flight path plots are useful for showing the characteristics of survey sites and the likelihood of detecting or missing passing murrelets (Burger 1997, 2002).

Despite frequent precipitation which affected radar use, we conducted 37 radar surveys (181.2 hours) which provided 2098 Possible or Likely murrelet detections. In this preliminary analysis we pooled the Possible and Likely detections, but more detailed analysis could test whether there were differences between these categories, contributing to a more refined definition of probably murrelet targets on radar. Our study identified several differences in the methods required to assess murrelet populations and behavior between Alaska and the forested watersheds at lower latitudes.

5.1 Separating murrelets from other species

Kittlitz's and Marbled Murrelets were distinguished from other species on the basis of speed and flight behavior. The mean flight speeds of both "Likely" and "Possible" murrelet detections were greater than those of all other species we sampled with radar; however, the three most commonly observed species that could be confused with murrelets on radar had mean flight speeds near the minimum speed cut-off for murrelet detections (50 km h^{-1}). Radar targets of the large Bald Eagles are usually easily separated from those of murrelets, but the radar targets of loons and mergansers are often similar to those of murrelets and since speeds are similar these species might sometimes be confused with murrelets on radar. At the Grant Lagoon site over 99% of all murrelet detections showed "direct" flight paths, while other species often exhibited circling behavior. These differences in flight behavior might be less important for radar surveys made further inland, closer to nest sites, where murrelets are more likely to circle (Day and Barna 2007).

While there were clear differences in the mean speeds and frequency of flight behaviors between murrelets and other species, the vast majority of murrelet detections were recorded without species confirmation by AV (in contrast, all detections of other species were visually confirmed). Therefore our detections were classified as "Likely" or "Possible" murrelet on the basis of speed and behavior, biasing our data to favor typical murrelet-like traits (fast, direct flight). It is likely that some portion of the radar detections reported as unknown species included murrelets, and the criteria for separating murrelets from other species should always be refined with increasing knowledge. But we suggest that our criteria for reporting Likely and Possible murrelets provide a useful conservative method of identifying and classifying murrelet-like radar targets. It is important for all radar studies to document other species of birds occurring in the area which might be confused with murrelets on radar, and to measure a sample of their flight speeds under local conditions (Burger 1997, 2001, Cooper et al. 2001, Cooper and Hamer 2003).

5.2 Differentiating between *Brachyramphus* murrelets

Although we did not confirm any Kittlitz's Murrelets in our AV surveys and confirmed Marbled Murrelet by vocalizations in relatively few detections, we are confident that both species were regularly present in our radar surveys. Nests of Kittlitz's Murrelets have been documented in several nearby locations on southwest Kodiak Island (Burkett and Piatt 2008, Lawonn 2009, Lawonn 2010) including some active during our 2010 radar study within a few km of the radar site (M.J. Lawonn, pers. comm.). Kittlitz's Murrelets appear to be far less vocal during commuting flights than Marbled Murrelets which would explain the lack of detections of the former species even if they were numerically more common.

No Marbled Murrelet nests have been found in the vicinity of our radar station, but we heard Marbled Murrelet vocalizations regularly throughout the breeding season, from birds flying in and out of the Ayakulik Valley. We therefore assume that some proportion of the commuting murrelets we detected by radar were Marbled Murrelets and that there is a ground-nesting population of this species in the area.

We were unable to differentiate between Marbled and Kittlitz's Murrelets on the basis of radar targets, and had an extremely limited number of cases in which murrelet detections were confirmed by AV (in all cases, the species identity was confirmed by Marbled Murrelet vocalizations). There are no known differences between the species in flight speed, flight behavior, diurnal flight patterns or other features we could test. Separating the two species in radar surveys is highly desirable and our continued research in 2011 will focus on this issue, using radar in combination with automated sound recorders to test for differences in wing-beats and improve detection of the rare vocalizations (see below).

5.3 Diurnal and seasonal trends

Surveys throughout the 24-hour cycle demonstrated that murrelet activity was greatest from approximately 6 hours before sunrise until dawn. With data pooled across the season, mean activity peaks occurred at approximately one hour before sunrise, with another broad peak lasting three hours spanning sunset, but murrelets remained active throughout the night. This behavior indicates that the timing murrelets activity peaks depend on light levels, as has been shown with the more constrained activity peaks corresponding to rapid change from daylight to darkness at more southern latitudes. However, the higher detection rate from radar data at night differs from the trends in visitation rates observed from cameras placed at Kittlitz's Murrelet nests inland from our radar station (M.J. Lawonn, pers. comm.). Visitation rates at nests were lowest during the period from approximately 01:00-05:00, which corresponded to the highest mean detection rate by radar. There are several potential explanations for this discrepancy. Firstly, taking into account travel time might account for differences in timing of activity peaks, although flight time between the coast and inland nests should be relatively short if murrelet flight speed is > 50 km h^{-1} and nests are < 20 km inland. Secondly, these nest activity data came from a small sample of nests (16) near the coast while we recorded many more murrelets (mean 96.3 ± 15.6) each night that could have been accessing nest sites further inland. Another consideration is that the nest visitation data came from Kittlitz's Murrelet nests only, while we were tracking both Kittlitz's and Marbled Murrelets. It is possible that there are subtle differences in activity peaks between species. Finally, some of the murrelets detected by radar might have been prospecting birds seeking nest sites or failed breeders that possibly follow different diurnal patterns than active breeders.

We observed a moderate increase in murrelet detection rates throughout the season. This could be explained by the increased rate of nest visitation that would accompany the shift from incubation, where parents exchange duties roughly every 24 hours, to chick-rearing, where both parents visit the deliver fish to the nest every day, often making multiple visits. This seasonal trend has not been detected in radar studies of Marbled Murrelets at lower latitudes, possibly because these radar sites were not as intensively surveyed throughout the season and subtle seasonal trends were obscured by noise in the data. AV surveys at inland sites on Kodiak Island have also recorded an increase in detections corresponding to the shift from incubation to chick rearing, which occurs in early July (Lawonn 2009).

5.4 Effects of weather

While cloud cover has been shown to affect the behavior of Marbled Murrelets in forested watersheds (e.g., Burger 2001, 2002), we found no effect of cloud cover on detection rates at our radar site. However, the detection rate was significantly affected by wind. Our radar site was exposed to strong winds, and we experienced gale force winds during several surveys (the recorded Beaufort scale scores that we recorded were almost certainly underestimates of the wind speeds at the altitudes where birds were flying). As wind force increased, the number of "Likely" or "Possible" murrelet detections increased, while the number of unknown species recorded remained relatively constant. Therefore it is likely that our false positive detection rate increased with increasing wind force, since non-murrelets with tailwinds would have appeared to fly much faster and more directly and would therefore be classified as murrelets. We found no significant effect of wind for speeds of Beaufort scale 3 or less (i.e., mean winds <19 km h^{-1}). Consequently we advise restricting radar studies and long-term monitoring of murrelets to periods when winds at ground level are below 19 km h^{-1}.

5.5 Problems to be addressed in 2011

We intend to continue radar work on Kodiak Island in the summer of 2011. A more detailed analysis of all data will then be undertaken. Major concepts that will be addressed in the 2010 and 2011 data include:

a) Identifying diurnal, seasonal and spatial patterns of flight behavior.

   This is important in developing radar censusing and monitoring protocols, and in distinguishing murrelets from other species. These data will include radar surveys coupled with AV surveys, mapped flight paths from the radar screen, flight speeds recorded for murrelets and other species, classifying flight paths and flight behavior. These data will be analyzed in relation to light levels and weather conditions that could affect the reliability of observations. Because of the open treeless habitat and low topography, along with frequent high wind, flight is likely to be more affected by wind compared to forested watersheds. Our pilot study has shown significant wind effects in separating murrelets from other species leading to the tentative conclusion of limiting radar work to wind speeds ≤ Beaufort scale 3 (see above). Future statistical analyses might involve an ANOVA comparing flight speeds between murrelets and other species under low wind and high wind, an ANOVA of length of activity period vs. cloud cover, a regression of light intensity vs. murrelet counts, and a regression of counts per hour vs. date to test for seasonal patterns.

b) Examining central-place foraging and nest-site selection in murrelets.

These topics are important because flight is energetically expensive in all alcids, and murrelets are at risk to aerial predators such as peregrines and goshawks when flying over land. Both of these facts should lead to selection for minimizing commute times in both species of murrelets; but predation near the shoreline (eagles, ravens, crows, foxes and other predators are most common there) leads to selection for inland nesting. Flight paths, flight type, and speed might vary in response to predation risk, as light levels increase and predators become active, and when predators are actively hunting. The necessary data will come from radar surveys coupled with AV, light level recordings, and daily observations of predator presence and activity patterns. Concurrent studies of these two species by other research groups in Alaska will provide additional supporting data on nest locations, nesting activity and at-sea movements. Possible analyses might involve multi-model analyses comparing activity patterns in relation to light levels in the presence or absence of active predators, comparing flight speeds to light levels, and tests comparing the frequency of flight types to light levels.

c) Examining similarities and differences in flight behavior of the two murrelet species.

This is important in order to provide insights into past speciation and present mechanisms of coexistence in these species. The ability to distinguish between the two species would allow radar monitoring of *B. brevirostris* populations to occur in areas of sympatry, such as Kodiak Island and other areas of south-central Alaska, and an understanding of the unique behavior of this species could contribute to conservation efforts. A potential behavior difference between the species could arise from the fact that *B. brevirostris* has larger eyes as an adaptation to foraging in darker conditions (Day et al. 2003), and might therefore also be able to navigate safely in darker twilight than *B. marmoratus*. The necessary data will come from radar surveys coupled with AV (possibly using night vision technology in future surveys, as recommended by R. Day, ABR Consulting, pers. comm.), although it might be necessary to obtain data from sites where only one species is present in order to distinguish the species on radar and test for differences in behavior. Possible analyses will include comparing the frequency of different flight behaviors between the species and statistical tests comparing the timing of mean activity peaks. We are also investigating the combined application of radar and autonomous sound recording systems (e.g., Song Meter SM2; Wildlife Acoustics, Concord, MA) and sound-recognition software (Song Scope from Wildlife Acoustics, Concord, MA) to rapidly quantify occurrence and numbers of both species. This combination of autonomous sound recorders and sound recognition software is proving useful for monitoring other nocturnally active seabirds in Alaska (Buxton 2010). We propose to test identification of vocalizations and wing beats using recordings made at known nest sites of both Kittlitz's and Marbled Murrelets.

Conclusions

Complete analysis of the 2010 data will be undertaken in conjunction with the 2011 data. Our preliminary analysis of the 2010 radar and AV data from Grant Lagoon has, however, revealed facts and patterns which are important to developing radar monitoring protocols for Kittlitz's and Marbled Murrelets in Alaska:

- Radar stations located at coastal flyways provide good monitoring sites, especially if the topography constrains flight paths to the area covered by radar. Over 99% of Likely and Probably murrelet targets showed direct flight at the Grant Lagoon site facilitating separation on radar from other bird species which tend to circle more often.

- Our study revealed the presence and possible breeding of Marbled Murrelets in the treeless areas of southwest Kodiak Island where breeding had not hitherto been suspected.
- Despite a large sample of 2098 radar detections of Likely and Possible murrelets collected over a 53-day period at the peak of breeding, we were unable to separate radar detections of the two murrelet species and AV identifications were too sparse to facilitate species recognition. More refined techniques will be needed to separate these two similar species on radar.
- Using a combination of flight speed and flight behavior we developed a simple protocol for identifying Likely and Possible murrelets. Comparison with other bird species common at Grant Lagoon indicated that these criteria could separate murrelets from most other species; loons and mergansers, which fly at similar speeds and present similar targets on radar screens pose the greatest problems but these species are more likely to circle than murrelets. A larger sample of confirmed species identifications would allow us to refine the criteria for Likely and Possible murrelets.
- Wind had a significant effect on murrelet detection frequency but cloud cover did not. We recommend further testing of wind effects and restricting murrelet surveys to periods with wind speeds of Beaufort scale 3 or less (<19 km h^{-1}).
- Murrelets at Grant Lagoon showed greatest activity between sunset and sunrise, but during this period peaks of activity were inconsistent from day to day but were overall highest one hour before sunrise. The prolonged nocturnal activity from these radar records differs from the pattern seen in Marbled Murrelets from more southerly latitudes where there is most activity right after sunset and for an hour before sunrise but little activity in the night hours in between. This difference is probably due to the prolonged twilight at the higher Alaskan latitudes, but shows that Marbled Murrelet protocols developed further south need to be modified for Alaskan conditions. In common with the radar surveys from further south, we found little murrelet activity in daylight hours, especially in the afternoons.
- Diurnal periods of peak radar counts of murrelets did not correspond to peak periods of activity recorded at nearby nest sites of Kittlitz's Murrelet by a concurrent study. Additional research is needed to explain this discrepancy and understand the diurnal activity patterns of murrelets in Alaska.
- We found a significant increasing trend in radar detections between 4 June and 27 July indicating increased activity during the chick-rearing period. Our sampling ended before the expected post-fledging decline in activity occurred.

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Table 1. Variables recorded for each radar detection.

Variable	**Description**
Time	Time of the detection
Species	Species of bird detected, if known, or murrelet likelihood (LIK = Likely murrelet, POSS = Possible murrelet, murrelet = unidentified murrelet species, four-letter species codes used when bird was identified). See text for explanation of Likely and Possible murrelet.
Group	Number of birds per detection
In/Out	Direction of target flight (Incoming from the sea or Outgoing toward the sea)
Berm	Whether target crossed berm (Y or N), indicating whether the bird crossed between the ocean and land. The berm is the spit of land separating the lagoon from the ocean (see photos).
Bearing	Flight direction of the target along the eight primary compass bearings
Final Bearing	Final flight bearing of the target
Direction first seen	Direction from radar station that the target was first seen
Direction last seen	Direction from radar station that the target was last seen
Nearest distance	Nearest distance from radar station that the target crossed the berm (if did not cross berm, closest distance to radar)
Direction	Direction from radar that the target crossed the berm
Flight code	Flight behavior code: D = Direct (flight generally straight, includes minor course corrections and wide turns, direct-sinusoidal flight); C = Circling (bird changes course by ≥ 180˚ at least once); E = Erratic (bird changes speed and course frequently);
Hits	Number of sequential images of the target appearing on the radar screen.
Speed	Speed (km/hr) of target estimated from the distance between hits on the screen.
Speed category	Speed category (1 = 0-24 km/h, 2 = 25-49 km/h, 3 = 50-74 km/h, 4 = 75-99 km/h, 5 = 100-124 km/h, 6 ≥ 125 km/h). Average speed was used if the target changed speeds.

Table 2. Summary of flight speed and behavior categories for all bird species detected by radar at Grant Lagoon, Kodiak Island in 2010.

		Flight speed			Proportion of flight categories[1]			
Species	Total no. of detections	Mean speed (km/h)	N	SE	C	D	E	N
Murrelet type								
Likely murrelet	1230	81.3	939	0.7	0	1	0	1204
Possible murrelet	868	63.4	553	0.8	0.01	0.99	0	791
Loons								
Common Loon	1	-	-	-	0	1	0	1
Red-throated Loon	24	48.6	7	1.4	0.39	0.61	0	23
Waterfowl								
American Widgeon	2	-	-	-	0	1	0	1
Common Merganser	1	25	1	-	0	1	0	1
Red-breasted Merganser	10	50	4	0	0.13	0.88	0	8
Unidentified merganser	1	45	1	-	-	-	-	-
Scaup (unidentified spp.)	1	-	-	-	0	1	0	1
Gulls & Jaegers								
Black-legged Kittiwake	1	-	-	-	0	0	1	1
Glaucous-winged Gull	13	33.1	8	4.1	0.36	0.64	0	11
Parasitic Jaeger	5	40	1	-	0	1	0	4
Shorebirds								
Least Sandpiper	2	50	1	-	0.5	0.5	0	2
Semipalmated Plover	8	37	5	5.4	0.63	0.38	0	8
Raptors								
Bald Eagle	16	53.8	8	7.1	0.47	0.47	0.07	0.07
Peregrine Falcon	1	25	1	-	0	1	0	1
Other birds								
Common Raven	1	-	-	-	-	-	-	-
Bank Swallow	2	50	1		0.5	0.5	0	2
Swallow (unidentified spp.)	1	25	1	-	1	0	0	1
Total	2189	73.8	1532	0.6	0.02	0.98	0	0

[1]Flight categories include: C – circling; D – direct flight; E – erratic (see Table 1).

Table 3. Summary of daily bird observations at Grant Lagoon for species that could potentially be confused with murrelets on radar, for the period of 4 June through 27 July 2010.

Species	Mean daily count	Mean group size	Maximum daily count	Proportion of days observed
Loons				
Red-throated Loon	2.1	2.5	6	0.91
Common Loon	0.2	1.1	2	0.15
Cormorants				
Pelagic Cormorant	0.2	1	1	0.19
Red-faced Cormorant	0.0	1	1	0.02
Waterfowl				
Red-breasted Merganser	1.9	3.6	13	0.57
Common Merganser	1.8	8.1	20	0.26
Mallard	0.1	3.5	5	0.04
Green-winged teal	0.5	8.3	12	0.06
American Widgeon	2.0	4.5	13	0.46
Barrow's Goldeneye	0.1	3	3	0.04
Brant Goose	0.6	6.2	11	0.09
Harlequin Duck	0.1	1.7	2	0.06
White-winged Scoter	0.3	3.5	6	0.07
Scaup (Greater or Lesser)	1.5	8.2	20	0.19
Tundra Swan	0.0	1	1	0.04
Gulls & Jaegers				
Black-legged Kittiwake	9.4	20.9	60	0.57
Glaucous-winged Gull	6.9	16.7	100	0.85
Parasitic Jaeger	0.6	1.4	2	0.41
Mew Gull	0.2	1.5	4	0.11
Shorebirds				
Least Sandpiper	1.3	3	10	0.54
Semipalmated Plover	1.5	3.2	9	0.56
Surfbird	0.3	7.5	10	0.04
Raptors				
Bald Eagle	2.4	2.7	5	0.89
Peregrine Falcon	0.2	1	1	0.22

Table 4. Timing of first activity of potential predators of murrelets relative to sunrise from dawn AV surveys.

Species	Mean first activity relative to sunrise (min)	N	SE	Min	Max
Bald Eagle	2.3	7	9.3	-47	28
Peregrine Falcon	30	1	-	30	30
Common Raven	18.8	5	9.7	-3	47
Glaucous-winged Gull	0.8	4	10.4	-21	19
Parasitic Jaeger	22.3	4	15.1	-23	44
Red Fox	-10.6	5	13.8	-41	26

Figure 1. Map showing the location of the Grant Lagoon radar station on Kodiak Island.

A) Topographic map of Grant Lagoon with scanning radius of radar (0.75 nm; 1.39 km)

B) Radar screen

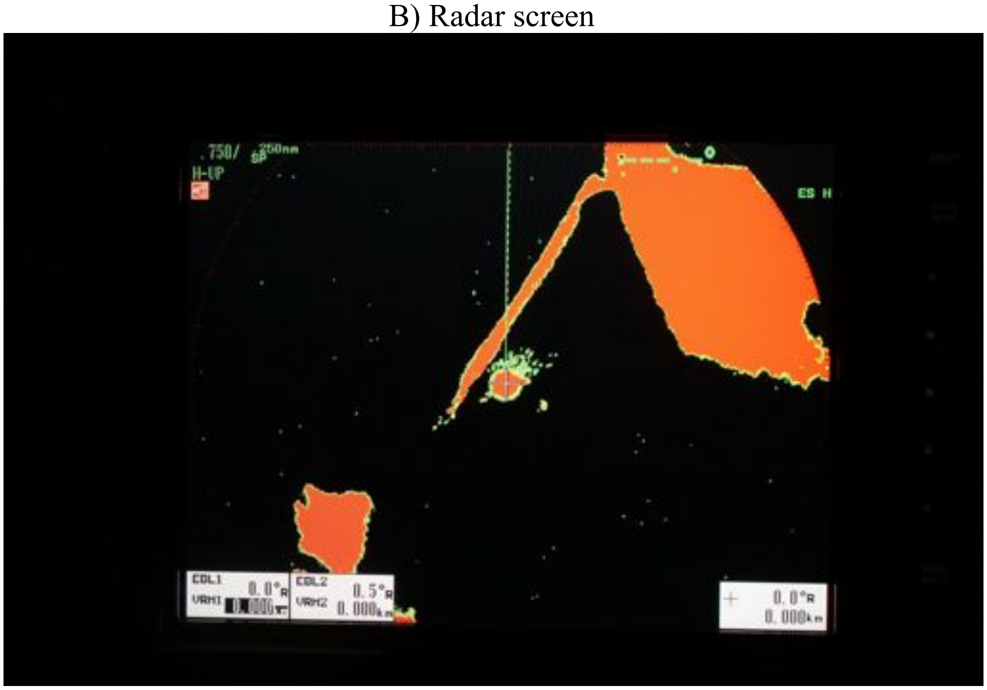
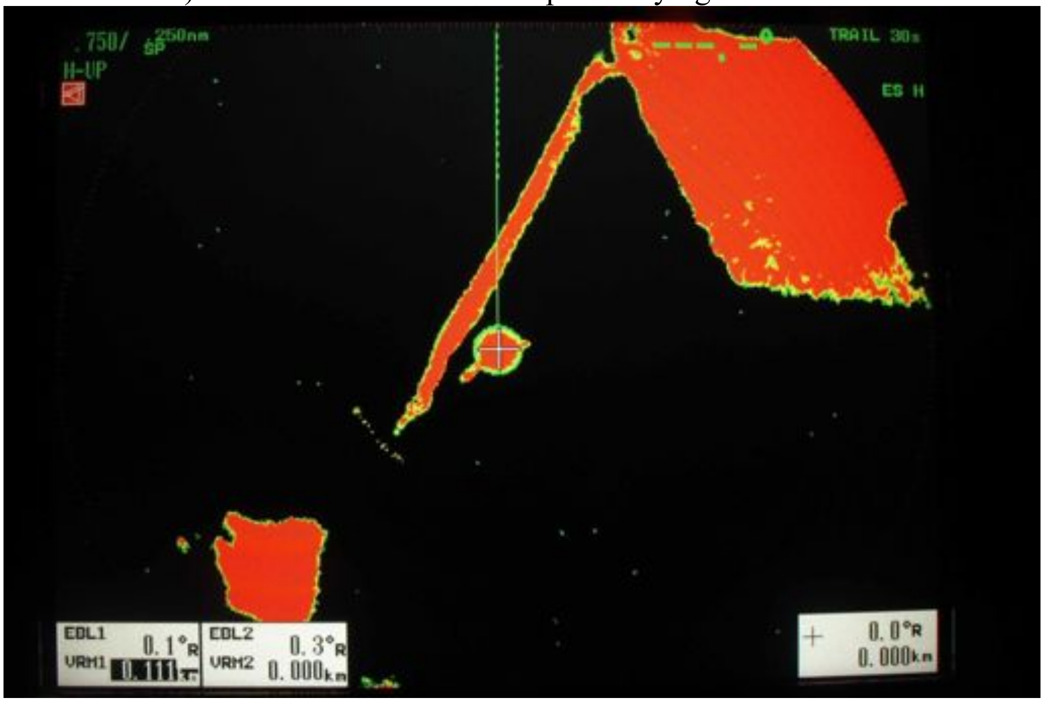


Figure 2. Images of the radar station: A – Topographic map showing the location of the radar station – the red circle is the approximate area of the radar scan; B – photograph of the radar screen showing (in red) the hills to the northeast and southwest of the lagoon and the berm running across the mouth of the lagoon.

Figure 3. Photographs of the radar station at Grant Lagoon. In the aerial photos the red arrow indicates the location of the radar station, just seaward of the low ridge. The lowest photo shows the hills on either side of the lagoon that constrain the flight paths of incoming and outgoing murrelets.

A) Radar tracks of unknown species flying < 50 km h^{-1}.



B) Radar tracks of two likely murrelets flying approximately 75 km h^{-1}.

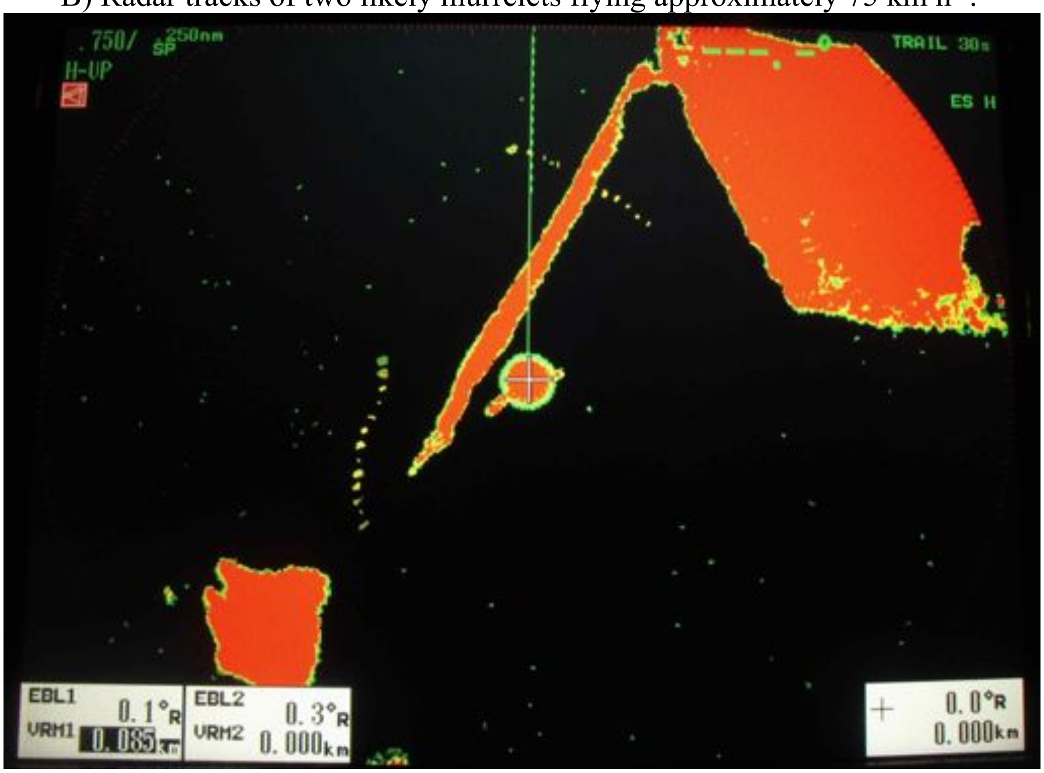
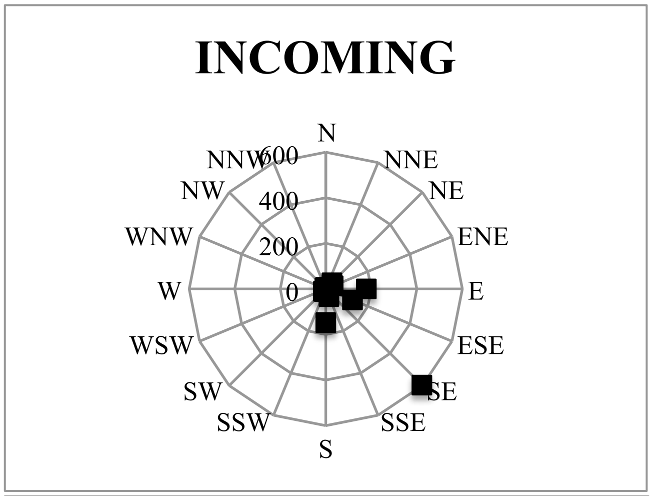
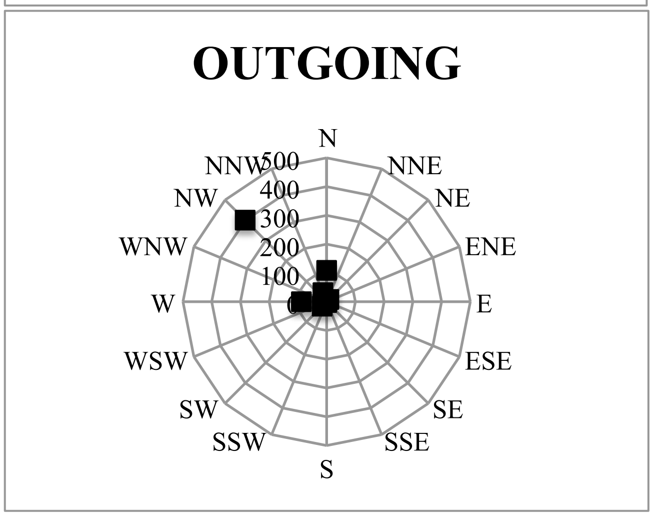


Figure 4. Radar tracks of (A) an unidentified species flying slowly (< 50 km h^{-1}) and (B) two likely murrelet detections flying at approximately 75 km h^{-1}. Notice the sinusoidal flight path of the lowest murrelet track.





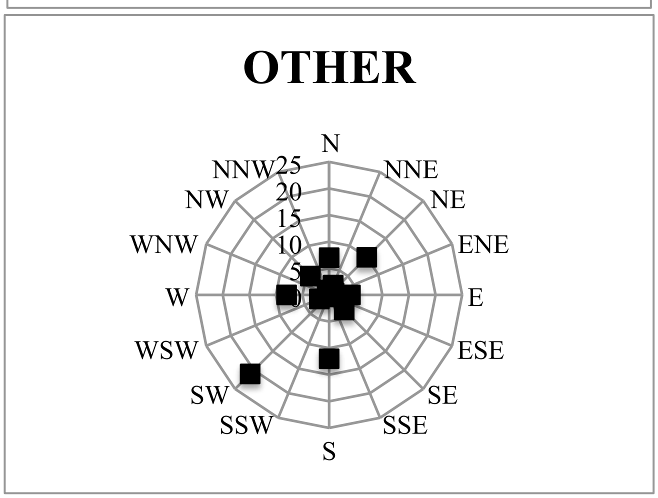


Figure 5. Most of the murrelets (Likely and Possible pooled) recorded on radar at Grant Lagoon showed strong directionality of flight. Most were either classified as Incoming (N = 1201 detections; most heading southeast) or Outgoing (N = 690; most heading northwest). The few classified as neither (Other) showed no directionality (N = 78).

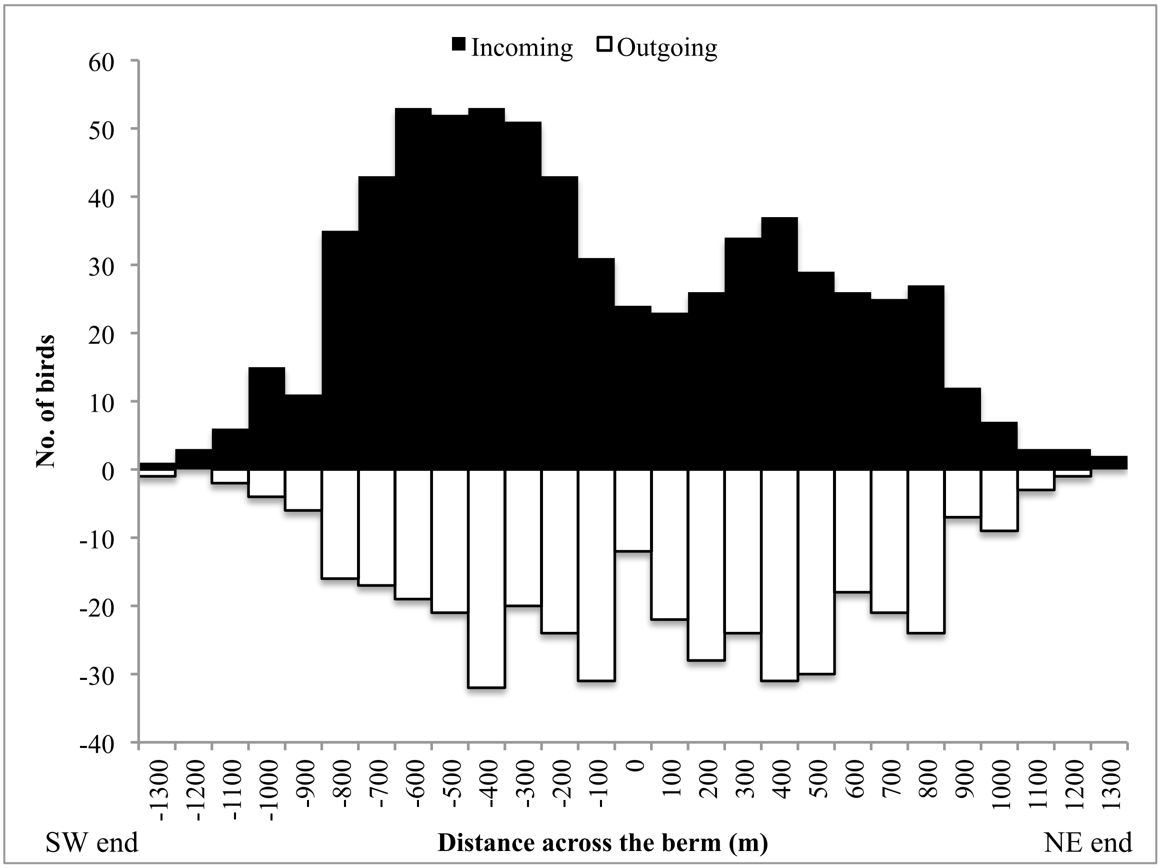
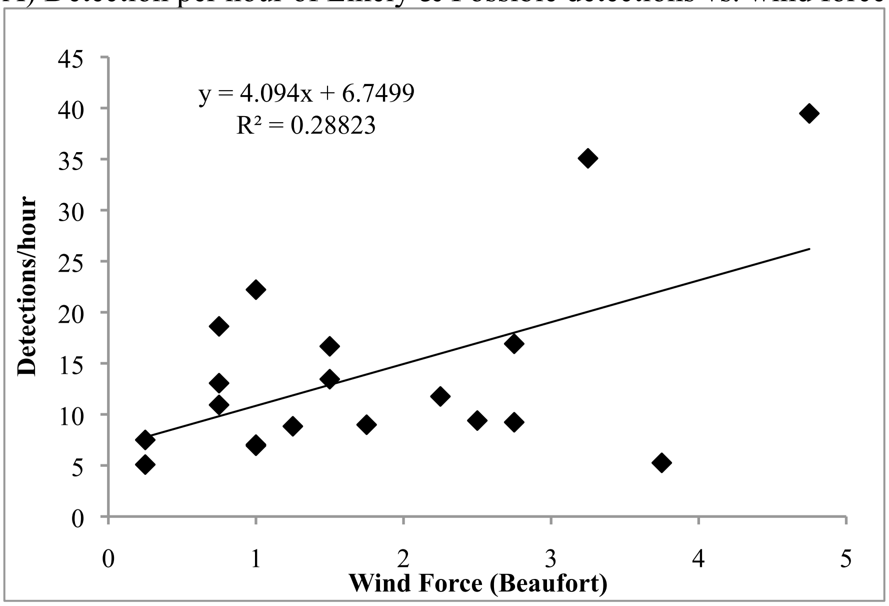


Figure 6. Plot of the location across the berm that Incoming and Outgoing murrelets crossed. The distances are plotted relative to the northwest point closest to the radar (shown as 0), with distances to the southwest shown as negative and to the northeast shown as positive. The numbers of outgoing birds are shown as negative to allow plotting below the x-axis.

A) Detection per hour of Likely & Possible detections vs. wind force



B) Detections per hour of unknown species vs. wind force.

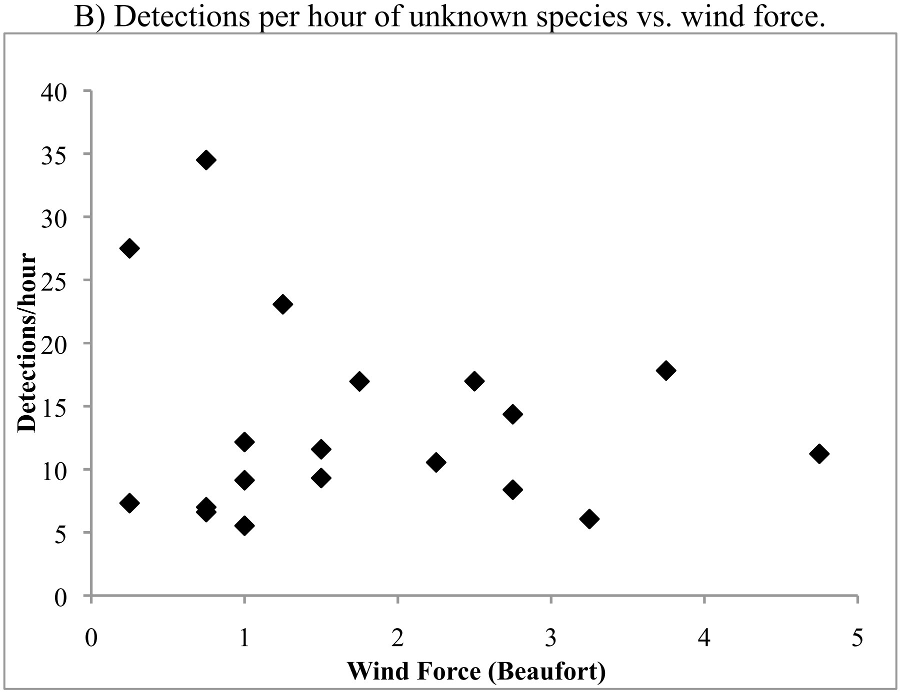


Figure 7. Regression of detections per hour of pooled Likely and Possible murrelets (R^2 = 0.288, N = 19, P = 0.018) (A) and unknown species (R^2 = 0.02, N = 19, P = 0.561) (B) relative to wind force (Beaufort scale). Approximate conversions of Beaufort scale: 0 = 0; 1 = 1.0-5.6 km h^{-1}; 2 = 5.7-11.1 km h^{-1}; 3 = 11.2-18.5 km h^{-1}; 4 = 18.6-29.6 km h^{-1}; 5 = 29.7-38.9 km h^{-1}.

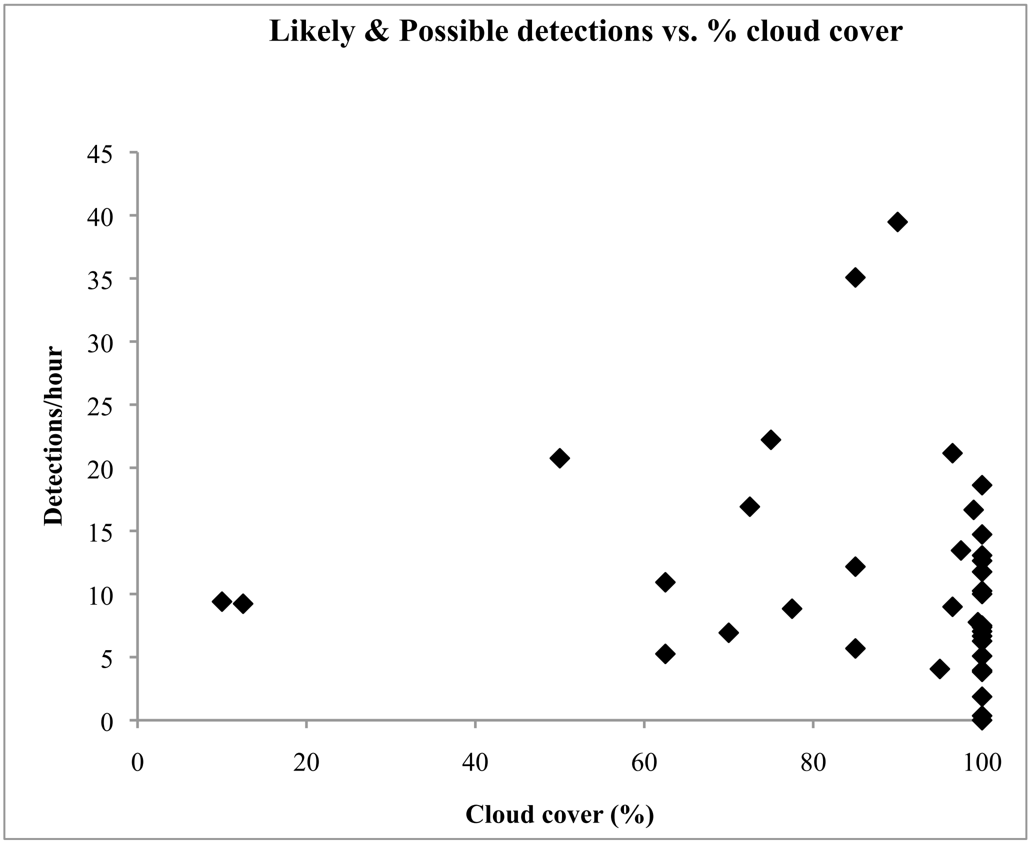


Figure 8. Radar detections of Likely and Possible murrelets showed no significant relationship to cloud cover (R^2 = 0.03, N = 19, P = 0.501).

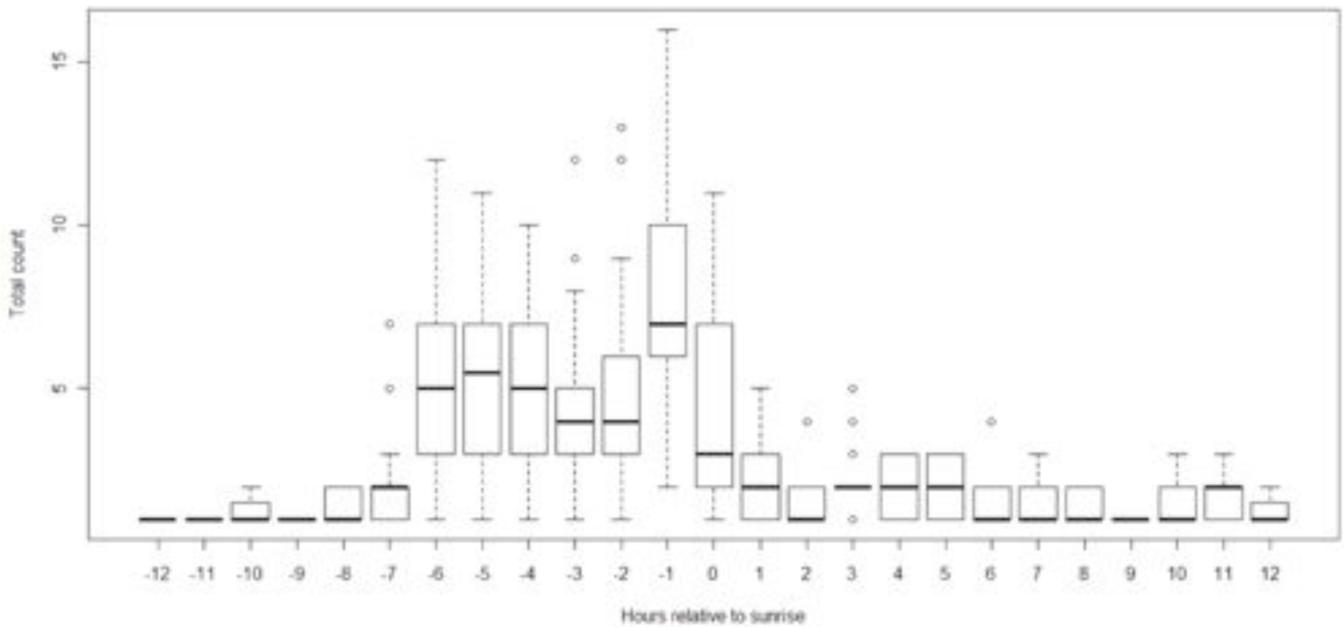


Figure 9. Boxplot (median and quartiles represented by boxes, whiskers represent the range, with outliers shown as circles) of murrelet detections (Likely & Possible combined) summarized by hour relative to sunrise (sunrise = 0).

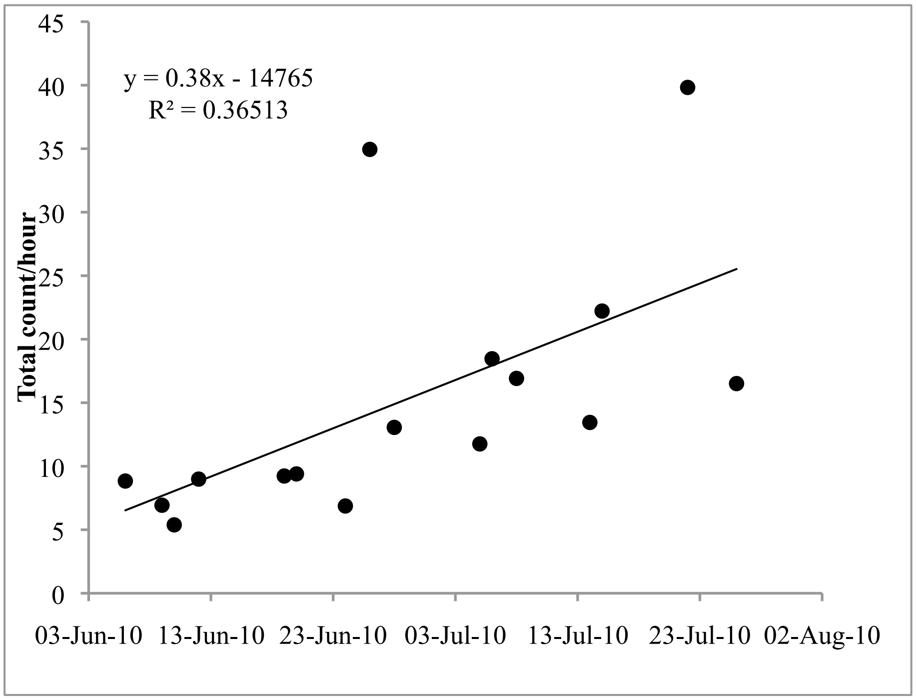


Figure 10. Seasonal trend in total murrelet counts per hour (Likely and Possible murrelet detections combined) during dusk to dawn overnight surveys ($R^2 = 0.365$, N = 16, P = 0.013).

Appendix 1. Datasheet used for the audiovisual (AV) surveys.

Watershed:.. Station: .... Date:Yr 20 .... Mo ....Day ....

Description of survey site:.. Georeference..

Observer: .... Elevation (m):.................... Veg cover (%) 100 m radius: 0-25, 26-50, 51-75, 76-100

Talus cover (%) 100 m radius: 0-25, 26-50, 51-75, 76-100

Official sunrise:.............................. Slope (circle one): B - valley bottom; L - lower 1/3; U - upper 1/3; R - ridge top

TIME	Cloud % cover	Cloud type/Ceiling	Precipitation	Wind (Direction & Beaufort)	Temp. (C)
START:	....	....	....	....	....
END:	....	....	....	....	....

Summary for survey (to be completed after all detections have been entered)

DETEC. vs. SUNRISE		NUMBER OF DETECTIONS				NO. KEER	OTHER	No. detections per bird height				
FIRST	LAST	TOTAL	VIS ONLY	AUD&VIS	AUD ONLY	CALLS	CALLS	0-50 m	50-100 m	100-200 m	> 200 m	Other

No. detections per behaviour type				No. Occupied		Group size of birds seen						
D	C	B	Other	detections	No. grps	1.........	2.........	3.........	4.........	....	....	....
					No. birds	....	....	....	....	....	....	....

PREDATORS: Estimate the maximum number of individuals of each predator species present during the survey (corvids, raptors, fox, Glaucous-winged gull), time of first detection and behaviour.

Predator Behaviour codes: (C=circling, GS=obvious ground search, D=direct flight, A=attracted to camp, SB=social behaviour)

Detec. No.	Time	Detection direction First	Detection direction Last	Major Direction of flight	Calls No.	Calls Type	No. birds seen	Behaviour	Closest dist. to bird (m)	Bird height code	Detec. type	Other notes

Watershed:.. Site: .... Date:Yr 20 .... Mo ....Day ....

Detec. No.	Time	Detection direction: First	Detection direction: Last	Major Direction of flight	Calls: No.	Calls: Type	No. birds seen	Behaviour	Closest dist. to bird (m)	Bird height code	Detec. type	Other notes

Behaviour:
(visual detections only)
D - direct flight
C - circle above/below trees
L - land or depart
B - circling below your elevation
A - aerial dive
S - call from stationary point
U - unknown

Call/sound types
K - keer call (typical)
Q - quack (alternate) call
KQ - keer to quack series
G - groan
O - other (describe)
W - wingbeats
J - jet sounds
Use 2 or more lines for more than one sound per detection

Cloud ceiling
UL: unlimited (clear)
HI: >100 m
Mid: 50-100 m
Low: <50 m
U: unknown

Common cloud types
ST - Stratus (low continuous cover)
NS - Nimbostratus (low heavy rain clouds)
SC - Stratocumulus (low fluffy)
AC - Altocumulus (mid fluffy)
AS - Altostratus (mid continuous)
CU - Cumulus (big tall fluffy)
CC - Cirrocumulus (high bands,puffy clouds)
CI - Cirrus (very high, wispy)

Precipitation:
RAIN: N = none; L = light(mist, drizzle, soft rain); M = Moderate(obscuring rain); H = Heavy(intense rain)
FOG: N = none; L = Light (translucent haze, thin fog); M = Moderate(obscuring fog); H = Heavy(dense fog).

Wind (Beaufort scale:
0 = calm (<2km/h); 1 = light air (2-5 km/h); 2 = light breeze, leaves rustle (6-12 km/h); 3 = gentle breeze, leaves & twigs constantly move (13-19 km/h); 4 = moderate breeze, small branches move, dust rises (21-29 km/h); 5 = fresh breeze, small trees sway (30-39 km/h); 6 = strong breeze, large branches moving, wind whistling (40-50 km/h).