INTRA-ANNUAL PATTERNS IN PASSAGE RATES AND FLIGHT ALTITUDES OF MARBLED MURRELETS *BRACHYRAMPHUS MARMORATUS* AT INLAND SITES IN NORTHERN CALIFORNIA

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SUMMARY

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The Marbled Murrelet *Brachyramphus marmoratus* is considered a threatened seabird under US federal legislation; it flies up to ~80 km inland to nest on limbs of old-growth coniferous trees. Little is known about intra-annual patterns in movement rates or flight altitudes of murrelets at inland sites, yet this information is critical for evaluating collision risk at wind turbines and other tall structures and the potential for disturbance impacts from timber operations (e.g. road construction). We used marine radar to study murrelets year-round during the peak dawn activity period (n = 78 mornings) at three high-use sites in northern California. Murrelet passage rates were relatively low in winter (11%–47% of summer rates), increased in spring, peaked during the summer breeding period (late April–July) and were lowest during the fall molt period. We observed large among-site differences in mean flight altitudes of murrelets between two sites along the coast (93 ± 3 m and 98 ± 3 m above ground level [agl]) and a single site further inland (257 ± 6 m agl). Flight altitudes during periods with fog or scattered rain did not differ significantly from altitudes during periods without precipitation. These results demonstrate the potential for different levels of disturbance and collision risk throughout the year and the importance of incorporating seasonal and site-specific variation into collision risk models. These results also provide new information for US Fish and Wildlife Service guidelines being developed for studies of murrelets at proposed wind energy projects.

Keywords: *Brachyramphus marmoratus*, collision risk, flight altitude, Marbled Murrelet, marine radar, northern California, passage rates, seasonal patterns

INTRODUCTION

The Marbled Murrelet *Brachyramphus marmoratus* is listed as Threatened under the US *Endangered Species Act* throughout the southern portion of its range (i.e. Washington, Oregon and California; USFWS 1992), where it flies up to ~80 km inland from nearshore waters to nest on limbs of old-growth coniferous trees (Nelson 1997, Piatt *et al.* 2007). Information on the seasonal activity and flight altitudes of murrelets at inland sites is lacking but important for evaluating disturbance impacts to murrelets from timber operations and other human activities and for determining collision risks associated with wind turbines, transmission lines, communication towers and other tall structures. Public agencies and developers are particularly interested in this information to assist in evaluating collision risk at land-based wind energy projects within the range of the Marbled Murrelet. Further, the information would assist the US Fish and Wildlife Service in development of protocols for studies of Marbled Murrelets at proposed wind energy projects. Studies of murrelets at inland sites have focused almost exclusively on the summer breeding period, when inland flight activity presumably is greatest (Nelson 1997). Most information on inland flight activity outside of the breeding period is based on audiovisual surveys by Naslund (1993) and O'Donnell (1993). The scope of inference for these studies is limited due to inherent biases in the detectability of murrelets at inland sites during audiovisual surveys (Jodice *et al.* 2001, Smith & Harke 2001, Cooper & Blaha 2002). Information on flight altitudes of murrelets traveling between the ocean and inland nest sites is similarly limited to a small number of radar-based studies (e.g. B. Cooper, unpub. data; Stumpf *et al.* 2011).

We used marine radar to conduct a year-long study of Marbled Murrelet activity patterns and flight altitudes at three high-use, inland sites in northern California. Marine radar is an effective tool for quantifying the numbers and flight altitudes of murrelets at inland sites, without many of the biases associated with audiovisual surveys (Burger 1997, Cooper & Blaha 2002, Bigger *et al.* 2006, Stumpf *et al.* 2011). The specific objectives of our investigation were to 1) quantify and describe inland activity patterns (passage rates) and flight altitudes of murrelets across a complete annual cycle; and 2) examine among-site differences in the seasonal patterns of activity and in flight altitudes of murrelets.

METHODS

STUDY SITES

We conducted radar surveys at three sites in northern California located between the ocean and large stands of redwood *Sequoia sempervirens* habitat in national and state parks where murrelets nest (Fig. 1). Previous radar surveys identified moderate-to-high numbers of Marbled Murrelets transiting through each site during the breeding period (e.g. Cooper *et al.* 2005). The Crescent City (N 41.74764°, W 124.15906°) and Espa Lagoon (N 41.35706°, W 124.07413°)

sites were located in low-lying areas 1 km and 0.25 km from the coast, respectively. The Eel River site (N 40.44764°, W 124.04031°) was 90 m above sea level and 29 km from the coast.

Study design

Our survey effort was spread across nine sample periods from 12 February to 13 December 2012. Each sample period was nine to 10 days long, with up to three morning surveys per site. We grouped the sample periods into four major seasonal periods based primarily on radio-telemetry studies in northern California (Hebert & Golightly 2006): 1) winter nonbreeding (November–February); 2) spring transition (March–early April); 3) summer breeding (late April–July); and 4) fall transition (August–October). We conducted radar surveys from 90 min before sunrise to 75 min after sunrise, providing coverage of the peak period of morning inland activity of murrelets during the breeding period (Cooper *et al.* 2001, 2006; Cooper & Hamer 2003).

Radar equipment

We used a vehicle with two roof-top-mounted radars. One radar scanned horizontally to record passage rates, flight speeds and flight paths of murrelet targets. This radar was tilted upward at ~10° to increase detectability of murrelets (Harper *et al.* 2004). The other radar, used to measure murrelet flight altitudes, scanned a vertical plane oriented parallel with the coast and hence perpendicular to the flight path of murrelets. Our radar units were Furuno FR-1510 MKIIIs (X-band, 9.410 GHz, 2 m waveguide, 12 kW output) with the pulse length set at 0.07 microseconds.

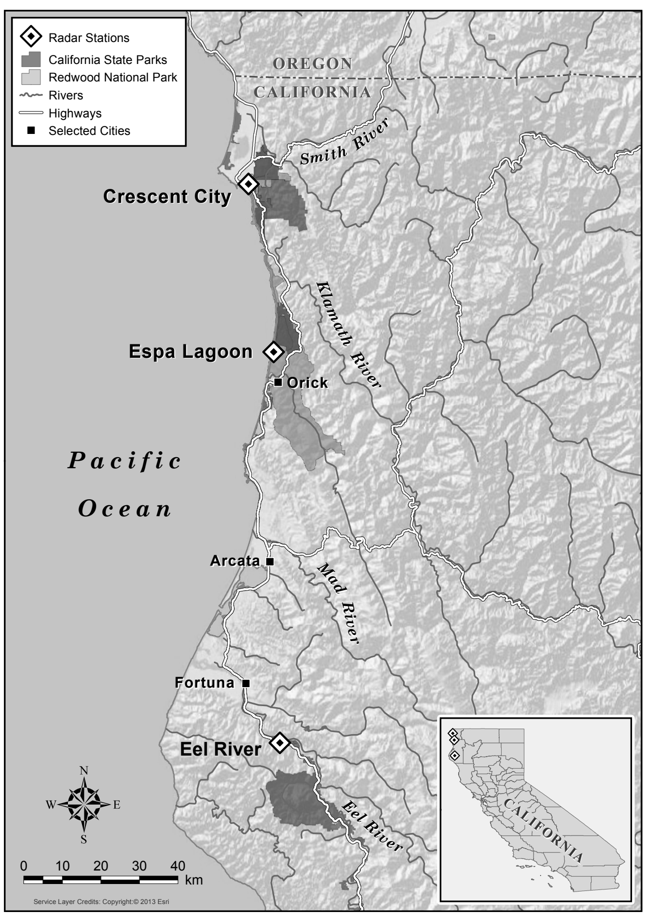

Fig. 1. Map of radar study sites in Del Norte and Humboldt Counties, California.

Data collection

During each survey morning, a single observer operated the radars and manually entered data into a computer database. The observer also attempted to obtain audiovisual identification of radar targets flying close to the radar vehicle. We recorded all radar images with frame-grabbers (Epiphan Systems Inc., Ottawa, ON) for review after each survey to detect any murrelets missed during the survey and to determine flight altitudes. Weather data collected during each survey included information on cloud cover, ceiling height, wind speed and direction at ground level, temperature and precipitation.

Target identification

We defined a "murrelet" as a radar echo that represented one or more birds meeting the criteria for a Marbled Murrelet. The use of "murrelet" as a metric is a minimum measure, because a small proportion of targets will represent two or more birds flying close to one another. Following previous studies (Hamer *et al.* 1995; Cooper *et al.* 2001, 2006; Cooper & Blaha 2002), we used the airspeed, signature (i.e. size and appearance) and flight direction of radar targets to distinguish murrelets from other species. The target airspeed cut-off for consideration as a Marbled Murrelet was >64 km/h, but at the Espa Lagoon site we used a >56 km/h cutoff for landward-heading targets. This lower cut-off was based on our observations of murrelets at that site flying at slower-than-average speeds while transitioning off the water and climbing over the coastal hills from sea level. We computed airspeeds (i.e. groundspeeds corrected for wind speed and relative direction) of surveillance radar targets with the formula used by Mabee *et al.* (2006). Finally, we classified flight directions of murrelets at the Espa Lagoon and Eel River sites as heading landward or seaward if they were flying within 60° of east (>30° and <150°) or west (>210° or <330°), respectively. At the Crescent City site, Cooper *et al.* (2005) found that murrelets approached land from the south and then turned northeast, toward nesting habitat at Jedediah Smith Redwoods State Park; therefore, at this site we classified murrelets as heading landward or seaward if they were flying 330°–090° or 150°–270°, respectively. Targets with flight directions outside these ranges were not considered murrelets.

Hamer *et al.* (1995) and Cooper *et al.* (2001) used methods similar to ours and reported accuracy rates of 87%–98% for identification of murrelets, based on visual confirmation of targets. Although we did not have a large enough sample of concurrent audiovisual and radar detections to calculate an identification accuracy rate, we did have auditory and visual confirmation of Marbled Murrelet radar targets at all three of our study sites. Additionally, the timing of landward- and seaward-flying murrelets recorded during this study closely matched the morning activity patterns of murrelets from other studies (Cooper *et al.* 2001, Cooper & Blaha 2002). Thus, we have a high degree of confidence in our identification of Marbled Murrelet radar targets. Therefore, we refer to them as "murrelets," acknowledging that, on occasion, more than one bird could be included.

Flight altitudes

Flight altitudes were determined from the vertical radar in areas with no obstruction from hills or trees, such that birds could be observed close to ground level. We used the timing, direction and radial distance of murrelets detected on surveillance radar to identify the appropriate targets on vertical radar images. We measured altitudes relative to the radar location and then used digital elevation models to adjust for differences in ground elevation between that radar location and the location of the bird.

Statistical analyses

We used daily counts of pre-sunrise, landward-flying murrelets as the metric of murrelet activity rates, as this provides the least variable measure of activity with the lowest rates of confusion with other species (Burger 2001, Cooper *et al.* 2001, Cooper *et al.* 2006). We summarized the intra-annual pattern in passage rates at each site by calculating the mean daily count of murrelets during each of the nine sample periods. We compared passage rates during summer (breeding) versus winter (nonbreeding) periods using a one-way analysis of variance (ANOVA) that treated passage rates (radar counts/morning) as the dependent variable, season as the within-subject factor and site as a covariate. We did not include the spring and fall transitional periods in this analysis because of the low sample sizes for passage rates during those seasons.

We summarized the intra-annual pattern of flight altitudes for pre-sunrise, landward-flying murrelets by calculating mean daily flight altitude by sample period. We used a one-way ANOVA with least-significant-differences multiple comparisons to determine whether flight altitudes differed among sites. Mean flight altitude (m agl) was the dependent variable, site was the within-subject factor and trip was a covariate. Precipitation is thought to influence the daily timing of murrelet activity (see Nelson 1997). However, potential effects on murrelet flight altitudes are not known and have obvious implications for collision risk assessments. We therefore used a one-way ANOVA that lumped flight altitudes across all trips for each site and used a categorical variable representing presence of precipitation (including both scattered rain and fog) as the within-subject factor and site as a covariate. We used SPSS statistical software (SPSS 2009) for all analyses, used a significance level of $P \leq 0.05$ for tests, and reported values as means ± standard error (SE) unless otherwise noted.

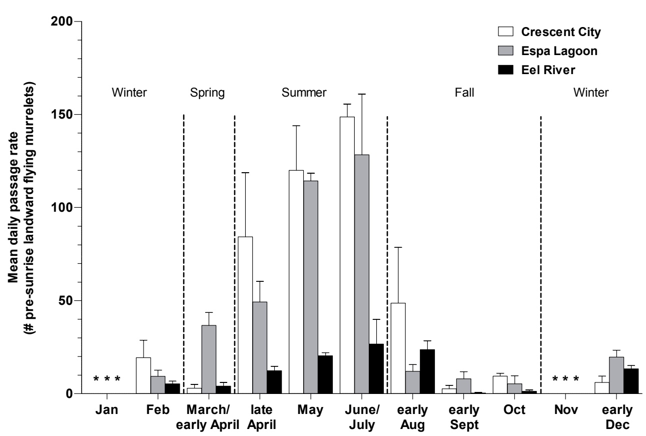

Fig. 2. Mean (± SE) daily passage rates per sample period of Marbled Murrelets detected on morning radar surveys at three sites in northern California, 2012. (*) indicates periods when no surveys were conducted.

RESULTS

Passage rates

Excluding radar surveys compromised by persistent or widespread rain, we analyzed 78 dawn surveys: 25 from Crescent City, 27 from Espa Lagoon and 26 from Eel River (Appendix 1, available on the website). We detected a total of 2780 pre-sunrise, landward-flying murrelets (Crescent City = 1314; Espa Lagoon = 1149; Eel River = 317). Mean daily passage rates varied among sites and sample periods (Fig. 2; Appendix 1) and ranged from 6.0–148.7 murrelets/d at Crescent City (mean = 52.7 ± 12.1 murrelets/d), 5.3–128.3 murrelets/d at Espa Lagoon (mean = 42.7 ± 9.3 murrelets/d) and 0.3–26.7 murrelets/d at Eel River (mean = 12.2 ± 2.3 murrelets/d). Passage rates exhibited a similar seasonal pattern across all sites, with highest mean rates recorded during June and July in the summer breeding period and lowest rates recorded during early September and October in the fall transition period (Fig. 2; Appendix 1).

Seasonal passage rates were higher during the summer than during the winter sample periods ($F_{1, 56} = 21.2$, $P < 0.001$; Appendix 1). Ratios of winter to summer rates were similar at Crescent City (0.11) and Espa Lagoon (0.15) but over three times higher at Eel River (0.47; Table 1).

Flight altitudes

We calculated flight altitudes for 891 pre-sunrise, landward-flying murrelets (Appendix 1) at Crescent City (n = 319), Espa Lagoon (n = 383) and Eel River (n = 189). Mean flight altitudes differed among sites ($F_{2, 880} = 535.3$, $P < 0.001$); with pairwise comparisons indicating that murrelets exhibited significantly lower flight altitudes at Crescent City and Espa Lagoon than at Eel River (Fig. 3). Sample sizes of flight altitudes varied by season, with less than five flight altitudes recorded at Eel River and Crescent City during some sample periods and no flight altitudes recorded at Eel River during the October (fall transition) sample period. Mean flight altitudes were generally

TABLE 1
Seasonal mean daily passage rates of Marbled Murrelets and ratios of winter-to-summer activity at three sites in northern California

Site	Mean ± SE daily passage rate (n = survey days)[a]		Winter:Summer ratio
	Winter	Summer	
Crescent City	12.7 ± 6.7 (6)	118.1 ± 19.0 (9)	0.11
Espa Lagoon	14.5 ± 5.2 (6)	97.8 ± 24.6 (9)	0.15
Eel River	9.3 ± 4.0 (6)	19.8 ± 4.1 (9)	0.47

[a] Passage rates expressed as mean number of pre-sunrise, landward-flying murrelets per day detected on radar. Winter months include November–February and summer months late April–July.

lowest during the summer sample periods at Crescent City and Espa Lagoon, but not at the Eel River (Fig. 3). Flight altitudes recorded during fog or scattered rain (mean = 122.7 ± 5.3 m agl, n = 187) did not differ from those recorded in the absence of precipitation (mean = 131.8 ± 2.7 m agl, n = 707; $F_{1, 891} = 2.3$, $P = 0.129$).

DISCUSSION

Seasonal activity patterns

Summer breeding period

We recorded the highest activity at all sites during June and July, a common finding from both audiovisual (O'Donnell *et al.* 1995, Jodice & Collopy 2000) and radar surveys (Cooper *et al.* 2001, Burger 2001). The high activity seems to reflect increased nest visitation by adults during the chick-rearing period and possibly increased flights of nonbreeding, nest-prospecting birds (Nelson 1997). Cooper *et al.* (2001) observed a similar pattern in the Olympic Peninsula, where peak passage rates in July were two to three times those in May. In contrast, Burger (2001) found that passage rates in British Columbia did not increase significantly from the mid-May to mid-July period.

Winter nonbreeding period

Why murrelets fly inland outside the breeding period is not known, but it has been speculated that these winter flights may be associated with nest site selection, nest territory defense and pair-bond formation (Naslund 1993, Nelson 1997). There are few comparative data on inland activity of murrelets during winter, in part because sampling opportunities during this season are hampered by extensive periods of rain throughout the breeding range. Determination of a predictable relationship between summer and winter passage rates of murrelets could therefore reduce future needs for winter surveys by providing a basis for extrapolating winter rates based on summer rates. In a comparison of five inland sites in central California, Naslund (1993) calculated a ratio of daily audiovisual detections in winter to summer ranging from 0.35 to 0.80 and an unweighted mean ratio at all sites combined of 0.51. We observed a similar ratio at the Eel River (0.47) but found much lower winter-to-summer ratios at Crescent City (0.11) and Espa Lagoon (0.15). The unweighted mean ratio across all our study sites (0.24) also was considerably lower than that of Naslund (1993).

Radar surveys avoid many of the inherent biases associated with audiovisual surveys (Cooper & Blaha 2002, Bigger *et al.* 2006). In particular, audiovisual survey data often contain an "auditory bias": they may be based on calls heard, but the relationship between the number of murrelet calls heard and the number of murrelets present is unknown. Additionally, seasonal differences in calling rates of individuals influence audiovisual survey results (Nelson 1997). Thus, we believe that passage rates derived from radar surveys provide a better basis for comparisons of seasonal activity. Our radar data provide a starting point for evaluating potential winter activity based on summer movement rates; however, the among-site variation indicates to us that seasonal patterns may be site-specific even within a small region.

Spring and fall transition periods

The transition periods between breeding and nonbreeding seasons are of particular interest to land managers and policy-makers for determining when murrelet activity at inland sites increases and decreases. Understanding transitional patterns facilitates scheduling of activities, such as road construction, to minimize disturbance and other impacts to murrelets. During our studies, murrelet passage rates increased by 75% between the February and March–early April sampling periods at Espa Lagoon, when rates declined at both Eel River and Crescent City (Fig. 2). Increases were then observed at Crescent City and Eel River between the March–early April and late April periods. Thus, our data indicate among-site variation in the timing of the spring increase in inland passage rates of murrelets.

The fall transition period and associated decrease in inland flights of murrelets marks the end of the summer breeding period and onset of the fall molting period. Marbled Murrelets undergo a nearly simultaneous prebasic molt of flight feathers and thus are flightless for several weeks following the breeding season (Carter & Stein 1995, Peery *et al.* 2008). The absence of murrelets at inland sites during audiovisual surveys from September to October has been attributed to this fall flightless period (Naslund 1993, O'Donnell *et al.* 1995). Similarly, we detected the lowest seasonal movement rates at most sites during fall surveys coinciding with the molt period, although we had no sample periods with a complete absence of murrelets. We detected decreases in passage rates from July to August of 67% and 91% at Crescent City and Espa Lagoon, respectively, but large decreases in activity (99%) at Eel River were not observed until early September (Fig. 2; Appendix 1). Peery *et al.* (2008) found that in central California individuals took an average of 37 days to complete their primary molt and that the population-level molt extended 120 days from 2 August to 29 November. Thus, asynchrony in the timing of molt among individuals may contribute to the among-site differences we observed in the onset of decreased activity in the fall and may explain the extended fall period of low activity observed at all three study sites.

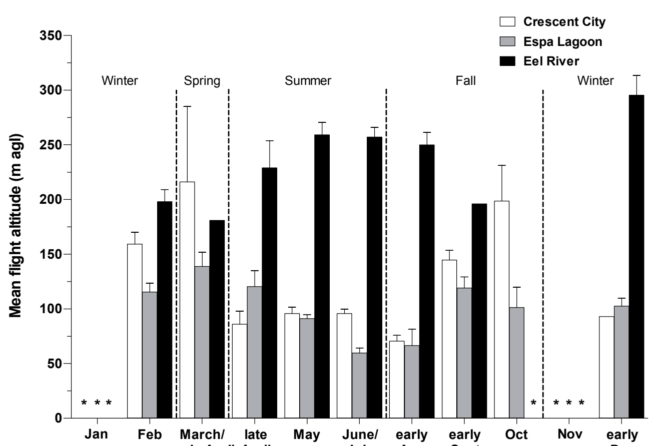

Fig. 3. Mean (± SE) daily flight altitudes per sample period of Marbled Murrelets detected on morning radar surveys at three sites in northern California, 2012. (*) indicates periods when no surveys were conducted or no flight altitudes recorded. agl = above ground level.

Flight altitudes

Among-site differences

We observed significant differences in flight altitudes between two sites near the coast (Espa Lagoon and Crescent City) and a single site further inland (Eel River). Among-site differences in flight altitudes of murrelets have also been observed at two valleys in the Olympic Peninsula: the mean flight altitude of murrelets was 246 ± 4.7 m agl (n = 282 murrelets in three mornings) at a location approximately 6 km up the Queets Valley (Stumpf *et al.* 2011), compared with 142 ± 6 m agl (n = 309 murrelets in eight mornings) at a location approximately 1.5 km up the Duckabush Valley (Cooper 2010). Results of these two studies and the current study indicate substantial among-site variation in flight altitudes of murrelets and show that murrelets may fly at higher altitudes over sites located farther inland than at sites closer to the coast.

Weather effects

Information on influences of weather on flight altitudes of murrelets is lacking (Nelson 1997, Stumpf *et al.* 2011); however, weather conditions are known to affect flight altitudes of other birds (Blockpoel & Burton 1975, Alerstam 1990, Shamoun-Baranes *et al.* 2006, Kemp *et al.* 2013). For example, Gauthreaux (1978) found that daytime passerine migrants flew lower when visibility was poor and during periods of dense cloud cover and drizzle. X-band marine radar does not function well during continuous and widespread rain; however, we were able to sample during periods of fog and scattered rain and did not observe any differences in murrelet flight altitudes between survey times with and without these conditions While there are obvious seasonal differences in average precipitation in northern California (i.e. dry summers versus rainy winters), our finding that there was no influence of precipitation on flight altitudes does not support the hypothesis that precipitation contributes to seasonal differences in flight altitudes.

Conservation implications

This study provides information that can be used in the assessment and mitigation of potential impacts to murrelets from activities associated with timber operations (e.g. road construction), wind energy projects and other human activities in northern California. For example, our findings indicate that murrelets in this region occur at inland sites during all periods of the annual cycle. Thus, risk assessments should consider potential impacts throughout the entire year and not just during the breeding season.

In the context of collision risk, we found that 75.2% and 80.2% of murrelets flew below the maximal height of most modern wind turbines (i.e. <130 m agl) at the Espa Lagoon and Crescent City sites, respectively. In contrast, only 2.6% of birds flew within the zone of risk at the Eel River site, indicating substantial among-site variation in exposure to collision risk that should be considered when modeling fatality risk for proposed wind energy facilities. For comparison, Cooper (2010) found that 52.8% of murrelets flew <130 m agl whereas Stumpf *et al.* (2011) found that 8.4% of murrelets flew <130 m agl. The altitude data provided by the current study and others (Cooper 2010, Stumpf *et al.* 2011) indicate that murrelets may fly lower at sites closer to the coast than at sites located further inland. More studies would be required to validate this pattern, but these data indicate the possibility that tall structures may pose a greater collision risk to murrelets at coastal sites than at sites located further inland.

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