APPENDIX H

RADAR STUDY OF MARBLED MURRELETS SUMMER 2008 AND 2009

FINAL REPORT

A RADAR STUDY OF MARBLED MURRELETS AT THE PROPOSED COYOTE CREST WIND POWER PROJECT, SUMMER 2008 AND 2009

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EXECUTIVE SUMMARY

- This report presents the results of a radar and visual study of Marbled Murrelets conducted at the proposed Coyote Crest Wind Power Project (CCWPP), located in southwestern Washington. The wind project would consist of ~47 wind turbines, each with a generating capacity of ~2.0 MW. Radar observations were conducted for two days in both June and July 2008–2009 at each of five sites. Radar sampling occurred during the morning activity period for Marbled Murrelets (i.e., from 105 min before sunrise to 75 min after sunrise).
- The primary goal of this study was to collect information on the number and flight paths of Marbled Murrelets flying in the vicinity of the proposed CCWPP in the summer of 2008 and summer 2009 and then use those data plus a series of assumptions based upon the best available data to estimate an exposure rate and the potential number of collision fatalities of murrelets with the proposed wind turbines.
- The average murrelet count (i.e., number of presunrise landward or seaward targets) was 0.78 targets/day (i.e., ~0.26 targets/km/day) at the proposed CCWPP during June-July 2008 and 2009.
- During July 2009 we used vertical radar to measure flight altitudes of the three targets that were concurrently detected on surveillance radar. The flight altitudes of those targets (corrected to the altitude where they crossed over proposed turbine strings) were 154 m, 353 m, and 364 m above ground level (agl).
- We estimated an average exposure rate of 0.00046682–0.00644850 murrelet passes/ turbine/ day at the CCWPP during the June/ July peak activity period.
- Our estimates for collision fatality for the entire year (breeding + nonbreeding seasons) ranged from 0.03–0.05 murrelets/year under an assumption of 99% avoidance, 0.14–0.27 murrelets/year assuming 95% avoidance, and 0.29–0.54 murrelets/year assuming 90% avoidance. Currently, no empirically derived estimates of avoidance rates are available for Marbled Murrelets, because there has been no opportunity to study their flight behavior near operational wind turbines. However, a review of the published data on other nocturnally-active seabird species suggests that avoidance rates may be greater than 90%. Thus, we took the approach of assuming a range of avoidance rates (90%, 95%, and 99%) that have been observed for other nocturnally-active species for our fatality model. These assumptions can be modified as data on murrelet flight behavior at wind farms become available.
- We also investigated the potential effect of a two-month and three-month curtailment (i.e., operational shutdown) of turbines on fatality estimates and found that a two-month curtailment of all turbines during the morning activity period in June and July could reduce the number of annual fatalities by 37.1% to a range of 0.02–0.03 fatalities/year under an assumption of 99% avoidance, 0.09–0.17 fatalities/year assuming 95% avoidance, and 0.18–0.34 fatalities/year assuming 90% avoidance. A three-month curtailment of all turbines during the morning activity period in May, June, and July could reduce the number of annual fatalities by 44.8% to a range of 0.02–0.03 fatalities/year under an assumption of 99% avoidance, 0.08–0.15 fatalities/year assuming 95% avoidance, and 0.16–0.30 fatalities/year assuming 90% avoidance.

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INTRODUCTION

The Marbled Murrelet (*Brachyramphus marmoratus*) is a seabird that nests in large trees in old-growth coastal forests throughout most of its range in North America (Nelson 1997). Marbled Murrelets fly at high speeds, visit their nests primarily during periods of low ambient light, and nest up to ~80 km inland. Because of their secretive behaviors, their semicolonial nesting behavior, and the difficulty of locating their nests in large trees, it has been difficult to collect information on their nesting behavior, habitat associations, population size in specific areas, and demography. The Washington, Oregon, and California population of the Marbled Murrelet was federally listed as a Threatened Species in 1992 because of excessive loss and fragmentation of nesting habitat and mortality associated with oil spills and gill-net fishing (USFWS 1992, 1997). The species also is classified as endangered at the state level in California (CDFG 2007), threatened at the state level in Washington and Oregon (ODFW 2007, WDFW 2007) and threatened in Canada (COSEWIC 2007). Comparison of historical and current data suggests that Marbled Murrelets have disappeared or become rare over much of their range south of Alaska (Nelson 1997). Further, demographic modeling suggests that the Washington population of Marbled Murrelets is declining at ~3% per year (Beissinger and Nur 1997, McShane et al. 2004).

Several methods have been developed to study this secretive species. The current ground-based Inland Forest Survey Protocol (IFSP) for Marbled Murrelets depends on the use of audio-visual cues to detect birds in flight (Evans Mack et al. 2003). Collecting information on murrelets this way is difficult, because of the low light conditions during their dawn and dusk peaks in inland activity and their small size, cryptic coloration, rapid flight speed, and habitat preference for old-growth, closed canopy forests. Further, because 85% of murrelet detections are auditory (Paton et al. 1990), it is difficult to determine with accuracy the number of birds that actually are flying over a particular survey area. In contrast, several studies have shown that radar is an excellent tool for observing Marbled Murrelets and does not have these biases (Cooper 1993; Hamer et al. 1995; Burger 1997, 2001; Cooper et al. 2001, 2006; Cooper and Blaha 2002; Raphael et al. 2002; Cooper and Hamer 2003; Burger et al. 2004; Bigger et al. 2006). The main advantages of using radar for inventorying murrelets are that it works under all light conditions, does not have the auditory bias of audio-visual surveys, and can sample a large area. Although radar cannot be used at all stands because terrain and/or lack of a good vantage point can preclude its use, it can be used in appropriate locations to determine quickly and accurately whether murrelets are present in a forest stand. Radar is particularly useful for detecting birds at low-use sites, where murrelets often are missed completely by audio-visual observers (Cooper and Blaha 2002). Radar data also can be used to focus ground observers' efforts toward specific areas of murrelet activity. Finally, radar can improve survey efficiency because it samples a much larger area (up to a 1,500-m radius) than audio-visual observers (up to a 200-m radius). Along with the benefits of the radar technique, there are some limitations. The major limitations of the technique as it applies to the current study are 1) species identification errors are possible (but below we list methods used to minimize this problem), and 2) X-band radar cannot be used during rain conditions (but can be used during drizzle or fog conditions).

Everpower Wind Holdings Inc. and Pe Ell North LLC propose to develop the Coyote Crest Wind Power Project (CCWPP), a ~110 MW wind power development in Lewis and Pacific Counties in southwestern Washington (Fig. 1). The development would consist of ~47 Gamesa G90 wind turbines, each with a generating capacity of up to 2.0 MW. Characteristics of the proposed wind turbines include a monopole tower ~80–100 m in height and three rotor blades each extending 44 m from a central hub, equating to a rotor area 90 m in diameter (including the hub width). Thus, the total maximal height of each turbine will be 125–145 m with a blade in the vertical position. To date, there are no known nesting locations of Marbled Murrelets in the proposed CCWPP (Washington Department of Fish and Wildlife, unpubl. data). However, there still is some collision potential because the proposed turbine string would be located on a ridge that lies between the Pacific Ocean and occupied Marbled Murrelet

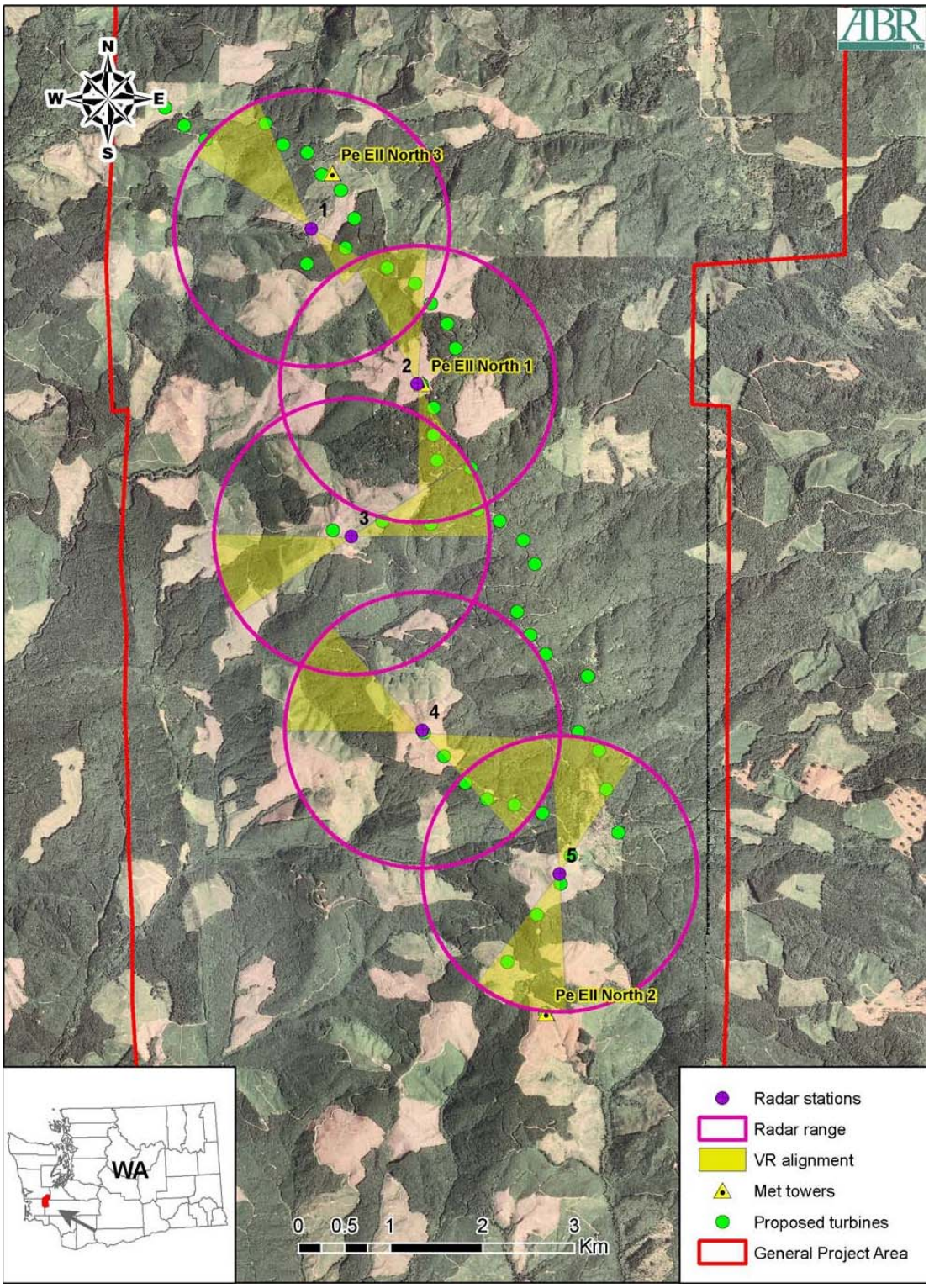

Figure 1. Location of radar-sampling sites, meteorological (met) towers, and proposed wind turbines and the Coyote Crest Wind Power Project (CCWPP) area, Washington, summer 2008 and 2009. The circle around each sampling site represents the approximate area of surveillance radar coverage and the shaded yellow wedges represent the approximate area of vertical radar coverage.

nesting sites in older forests ~60 km farther to the east and because murrelets typically fly at high speeds during periods of low light (Nelson 1997, Cooper et al. 2001) when they could be at risk of colliding with turbines. For this reason, a two-year study was undertaken to help determine if murrelets occur in the area of the proposed turbine facilities while flying between the ocean and their inland nest locations. This report presents results from summer 2008 and summer 2009.

OBJECTIVES

The primary goal of this study was to collect information on the number and flight paths of Marbled Murrelets flying over the proposed CCWPP during the summers of 2008–2009, and use those data to (1) calculate an exposure rate estimating the frequency that murrelets would pass within the airspace occupied by the proposed turbines each morning and (2) estimate the annual number of potential collision fatalities based on a series of assumptions.

STUDY AREA

The proposed Coyote Crest Wind Power Project consists of ~ 31,700 acres of mountainous terrain located in the Oregon Coast Range physiographic region (USGS 2003) of Lewis and Pacific Counties in southwestern Washington. The proposed development is located ~30 km east of the town of Raymond, Washington and ~30 km west of Chehalis, Washington (Fig. 1). Thus, the CCWPP is an inland site, and the closest salt water habitat (i.e., Willapa Bay) is ~40 km to the west of the CCWPP. The property is owned by Weyerhaeuser and managed as an industrial forest. The proposed turbine locations would occur along a ridgeline consisting of a patchwork of managed (second or third growth) coniferous forest ranging from 1 to 78 years of age. The proposed turbine strings are located along a non-linear ridge system that generally runs northwest to southeast, with elevations ranging from ~500–725 m asl. The topography of the project area is a convoluted ridge system that is not linear and is somewhat similar to other “ridges” in the area. Murrelets are not known to nest on the Weyerhaeuser lands within the CCWPP (M. Rochelle, Weyerhaeuser, pers.comm.; Washington Department of Fish and Wildlife, unpubl. database) or in the Washington DNR’s Lincoln Forest Block (located just east of CCWPP, with 320 acres that are part of the CCWPP. The science team that reviewed habitat areas for the DNR’s Long Term Marbled Murrelet Conservation Strategy for southwest Washington ranked the Lincoln Forest Block as a low priority conservation area in terms of overall value to marbled murrelet conservation and did not recommend it for conservation emphasis (Raphael et al. 2008).

The nearest known occupied marbled murrelet stand on the inland (i.e., eastern) side of CCWPP is ~60 km from the proposed site (Washington Department of Fish and Wildlife, unpubl. database). There are private timber stands within 10 km to the east of CCWPP, that based on stand inventory information may potentially contain murrelet nesting platforms. However, field inspections have not been conducted to confirm the presence of murrelet stand characteristics and the presence of nesting platforms. Additionally, no murrelets have been detected or observed in these stands (Weyerhaeuser, unpubl. data).

We conducted radar observations at five locations (i.e., Stations 1–5) in the study area (Fig. 1, Table 1). The area generally was well-suited for radar observations and all radar stations were in locations that provided maximal coverage of the surrounding area. In combination, the five stations provided north-to-south radar coverage of nearly the entire ~10 km-long ridge system where the turbines are proposed.

METHODS

RADAR EQUIPMENT

Our mobile radar laboratory consisted of a marine surveillance radar mounted on a van (Fig. 2). The radar scanned the entire area around the lab and was used to obtain information on flight paths, movement rates, and ground speeds of murrelets. A similar radar laboratory is described in Gauthreaux (1985a, 1985b), Cooper et al. (1991), and Mabee et al. (2006). During July 2009, we used a similar surveillance radar system that also included a second, vertical radar system (Fig. 3), so that we could collect simultaneous data on flight altitudes of the surveillance radar targets. The labs were

Table 1. Location of radar sampling stations in the proposed Coyote Crest Wind Power Project, Washington, during summer 2008 and 2009.

Station	UTM coordinates (NAD 83, zone 10)		Elevation (m above sea level)
	Easting	Northing	
1	472231	5177832	520
2	473384	5176142	626
3	472668	5174485	615
4	473437	5172382	609
5	474932	5170821	711

powered by four 6-V batteries that were linked in series. The surveillance and vertical radars (Furuno Model FCR-1510; Furuno Electric Company, Nishinomiya, Japan) are standard marine radars transmitting at 9,410 MHz (i.e., X-band) through a slotted wave guide (i.e., antenna) 2 m long, with a peak power output of 12 kW. The surveillance radar antenna was tilted upward at ~10° so that the bottom edge of the main beam was just below horizontal. We operated both radars at a range of 1.5 km and set the pulse length at 0.07 µsec. Figure 4 shows the approximate murrelet-sampling airspace for the Furuno FR-1510 marine surveillance radar at the 1.5-km range setting, as determined by field trials with Rock Pigeons (*Columba livia*), which are similar in size to Marbled Murrelets (Cooper et al. 2006).

Energy reflected from the ground, surrounding vegetation, and other solid objects that surround the radar unit causes a ground-clutter echo to appear on the display screen. Because ground-clutter echoes can obscure targets, we minimized their occurrence by parking the mobile radar laboratory in locations that were surrounded by low trees or low hills, whenever possible. These objects act as a radar fence that shields the radar from low-lying objects farther away from the lab and that produces only a small amount of ground clutter in the center of the display screen. For further discussion of radar fences, see Eastwood (1967), Williams et al. (1972), Skolnik (1980), and Cooper et al. (1991).

DATA COLLECTION

Radar observations followed protocols we developed in previous studies (Cooper et al. 2001, 2005, 2006; Cooper and Blaha 2002; Raphael et al. 2002). In both 2008 and in 2009, we conducted radar observations for two mornings in June and for two mornings in July at each of five stations distributed along the proposed turbine strings (Fig. 1, Tables 2 and 3). Each morning, a single observer set up a 12 kW, X-band marine radar and video/image recorder, and then attempted to get audio-visual verification of any targets detected by the radar by standing outside of the radar lab and then looking and listening for a bird in the vicinity of the radar target location. During July 2009, we added vertical radar sampling with a second radar, in an attempt to obtain additional flight altitude information for the surveillance radar targets.

Radar sampling occurred during the morning activity period for Marbled Murrelets, 105 min before sunrise to 75 min after sunrise. Sunrise times were gathered from the U.S. Naval Observatory website (http://aa.usno.navy.mil). This sampling period encompasses the known peak of daily murrelet activity (Burger 1997; Cooper et al. 2001, 2006; Cooper and Hamer 2003; Cooper and Blaha 2002). After the morning observations were completed, the recording of the radar screen was analyzed and the data entered on a computer.

For each surveillance radar target, we recorded date, time, flight direction (to the nearest 1°), transect quadrant, closest distance to radar lab, groundspeed, flight behavior, overlap category (recorded only on radar, recorded only by audio-visual observer, recorded by both radar and audio-visual observer), species (if known), number

Figure 2. Surveillance radar lab used for studies of Marbled Murrelets at the proposed Coyote Crest Wind Power Project, Washington, during June 2008 through June 2009.

Figure 3. Vertical and surveillance radar lab used for studies of Marbled Murrelets at the proposed Coyote Crest Wind Power Project, Washington, during July 2009.

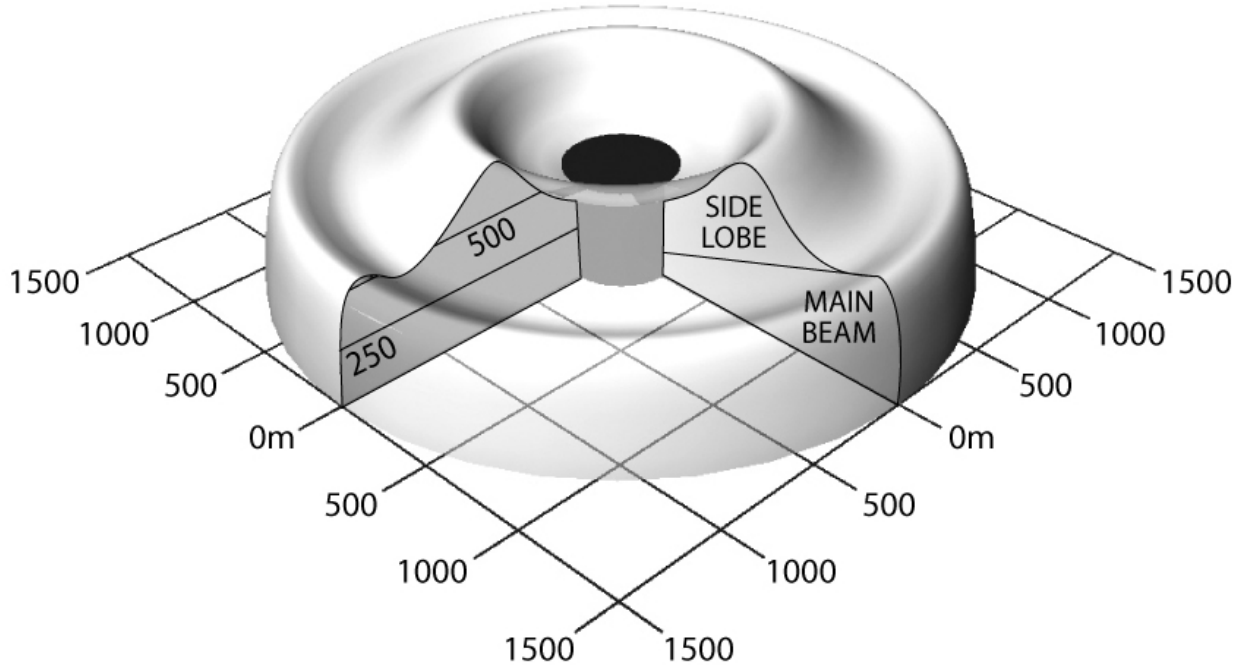

Figure 4. Approximate murrelet-sampling airspace for the Furuno FR–1510 marine radar at the 1.5-km range setting, as determined by field trials with Rock Pigeons, which are similar in size to Marbled Murrelets. Note that the configuration of the radar beam within 250 m of the origin (i.e., the darkened area) was not determined.

of birds represented by that radar echo (if known), flight altitude (if known), and audio-visual detection category (not detected by audio-visual observer, heard only, seen only, both seen and heard). We also plotted the flight path of each murrelet target on a transparency overlay of the radar screen for later transfer to a map of the study area.

During July 2009, we also used vertical radar to try to obtain altitude information for each concurrent vertical radar target that was confirmed as murrelet-like on the surveillance radar. We used target distance and timing to match up the vertical radar target with the surveillance target of interest. For each concurrent vertical radar target, we recorded date, time, flight altitude (to the nearest 1m, relative to the altitude of the radar location), transect quadrant, closest distance to radar lab, overlap category (recorded only on radar, recorded only by audio-visual observer, recorded by both radar and audio-visual observer), species (if known), number of birds represented by that radar echo (if known), and audio-visual detection category (not detected by audio-visual observer, heard only, seen only, both seen and heard).

We recorded the following weather information at the beginning of each sampling session or when conditions changed during a session: wind speed (average wind speed in mph, collected with a "Kestrel" anemometer); average wind direction (to the nearest 5°); cloud cover (to the nearest 5%); ceiling height (m above ground level [agl]; minimal visibility in a cardinal direction (in m; 0–50, 51–100, 101–500, 501–1,000, 1,001–2,500, 2,501–5,000, >5,000); precipitation level (no precipitation, fog, drizzle, light rain, heavy rain, snow flurries, light snowfall, heavy snowfall, sleet, hail); and air temperature (measured with a thermometer to the nearest 1°C). We could not collect radar data during rain because the electronic filtering required to remove the echoes of the precipitation from the display screen also removed the bird targets of interest.

Table 2. Sampling dates and summary of numbers of murrelet-like landward and seaward targets and "other" targets observed before sunrise, and number of audio-visual detections of Marbled Murrelets (observed before or after sunrise) in the proposed Coyote Crest Wind Power Project, Washington, during summer 2008.

				Targets observed on radar before sunrise			
Station	Date	Sampling hours	Sunrise time	Landward targets[1]	Seaward targets[1]	Other targets[1]	Audio-visual detections
1	6/18/2008	0335–0635	0520	0	0	0	0
	6/22/2008	0335–0635	0520	0	0	0	0
	7/11/2008	0347–0647	0532	0	2	1	0
	7/18/2008	0354–0654	0539	1	0	2	0
	Subtotal:			*1*	*2*	*3*	*0*
2	6/12/2008	0335–0635	0520	0	0	3	0
	6/23/2008	0336–0636	0521	1	0	4	0
	7/8/2008	0344–0644	0529	0	2	0	0
	7/15/2008	0351–0651	0536	0	0	2	0
	Subtotal:			*1*	*2*	*9*	*0*
3	6/13/2008	0334–0634	0519	1	2	0	0
	6/19/2008	0335–0635	0520	1	2	1	0
	7/9/2008	0345–0645	0530	3	0	3	0
	7/16/2008	0352–0652	0537	1	2	8	0
	Subtotal:			*6*	*6*	*12*	*0*
4	6/14/2008	0334–0634	0519	1	0	1	0
	6/20/2008	0335–0635	0520	0	1	2	0
	7/10/2008	0346–0646	0531	0	0	4	0
	7/17/2008	0353–0653	0538	1	1	16	0
	Subtotal:			*2*	*2*	*23*	*0*
5	6/16/2008	0334-635	0519	0	1	5	0
	6/21/2008	0335-636	0520	0	0	5	0
	7/12/2008	0348-649	0533	0	1	3	0
	7/19/2008	0355-655	0540	1	1	1	0
	Subtotal:			*1*	*3*	*14*	*0*
Total Targets:				**11**	**15**	**61**	**0**

[1] We classified targets as "landward" or "seaward" if they were flying within 40° of east (i.e., ≥50° and <130°) or west (i.e.,≥230 and <310°), respectively, and classified targets as "other" (i.e., not murrelets) if they were not flying in a landward or seaward direction.

Table 3. Sampling dates and summary of numbers of murrelet-like landward and seaward targets and "other" targets observed before sunrise, and number of audio-visual detections of Marbled Murrelets (observed before or after sunrise) in the proposed Coyote Crest Wind Power Project, Washington, during summer 2009.

				Targets observed on radar before sunrise			
Station	Date	Sampling hours	Sunrise time	Landward targets[1]	Seaward targets[1]	Other targets[1]	Audio-visual detections
1	6/23/2009	0334–0634	0521	0	0	1	0
	6/29/2009	0338–0638	0523	0	1	2	0
	7/15/2009	0350–0650	0535	0	1	2	0
	7/20/2009	0356–0656	0541	0	1	6	0
	Subtotal:			*0*	*3*	*11*	*0*
2	6/18/2009	0335–0635	0520	0	0	0	0
	6/28/2009	0338–0638	0523	0	0	0	0
	7/17/2009	0352–0652	0537	0	1	0	0
	7/22/2009	0358–0658	0543	0	0	5	0
	Subtotal:			*0*	*1*	*5*	*0*
3	6/22/2009	0335–0635	0520	0	0	0	0
	6/28/2009	0338–0638	0523	0	0	0	0
	7/18/2009	0353–0653	0538	0	0	2	0
	7/23/2009[2]	0359–0659	0544	0 (6)[2]	0	16	0
	Subtotal:			*0 (6)*[2]	*0*	*18*	*0*
4	6/26/2009	0336–0636	0522	0	0	0	0
	6/29/2009	0338–0638	0523	1	0	1	0
	7/16/2009	0351–0651	0536	0	0	0	0
	7/21/2009	0357–0657	0542	0	0	6	0
	Subtotal:			*1*	*0*	*7*	*0*
5	6/18/2009	0335-0635	0520	0	0	0	0
	6/26/2009	0336-0636	0522	0	0	0	0
	7/14/2009	0349-0649	0534	0	0	3	0
	7/19/2009	0354-0654	0539	0	0	1	0
	Subtotal:			*0*	*0*	*4*	*0*
Total Targets:				**1 (7)**[2]	**4**	**45**	**0**

[1] We classified targets as "landward" or "seaward" if they were flying within 40° of east (i.e., ≥50° and <130°) or west (i.e.,≥230 and <310°), respectively, and classified targets as "other" (i.e., not murrelets) if they were not flying in a landward or seaward direction.

[2] The six landward targets from 23 July were highly likely to be non-murrelet migrants based on their timing and flight direction, so those data were not included as landward murrelet targets for calculations of average movement rates.

DATA ANALYSES

IDENTIFYING RADAR TARGETS

We used flight speed (airspeed), target signature, timing of movements, and flight directions to help distinguish Marbled Murrelet targets from other species. *Airspeeds* (i.e., groundspeed corrected for wind speed and relative direction) of surveillance-radar targets were computed with the formula used by Mabee et al. (2006) and from wind velocity as measured at the ~55-m level of the nearest met tower. We have determined that a >64-km/h (40-mi/h) speed cutoff minimizes the number of non-murrelet species and eliminates only a small percentage (~3%) of Marbled Murrelets at sites within ~10 km of the coast (Cooper et al. 2001). Thus, corrected airspeed had to be greater than 64 km/h for a target to be considered to be a Marbled Murrelet. *Target signature* was also used to distinguish Marbled Murrelets from other species such as flocks of Band-tailed Pigeons (*Patagioenas fasciata*). Band-tailed Pigeon flocks frequently exhibit a characteristic signature that is large and composed of multiple targets that repeatedly break apart, and then coalesce. These distinct targets are easily distinguished from a typical Marbled Murrelet target and we eliminated them from our data set.

Timing of movements, also provides insight into a species identity, and we eliminated targets that were observed after sunrise, to help eliminate single Band-tailed Pigeons, Common Ravens (*Corvus corax*), and other diurnal, non-murrelet species from the data set. In particular, we have found that Band-tailed Pigeon activity generally does not start until a few minutes after sunrise (i.e., 105 min after our radar surveys begin). In contrast, nearly all Marbled Murrelets fly into nesting stands well before sunrise (Burger 1997, Cooper et al. 2001), so it is likely that only a small percentage of inbound murrelets would be missed using this technique. A precedent for this method has been set by Burger (2001) and Burger et al. (2004), who used sunrise for their cut-off period to count murrelets.

Flight directions, especially when considered in conjunction with time of year, are useful to differentiate migratory birds from Marbled Murrelets. All radar targets were classified as "landward" or "seaward" if they were flying within 40° of east (i.e., ≥50° and <130°) or west (i.e., ≥230° and <310°), respectively, and classified as "other" if they were not flying in either a landward or seaward direction. We then assumed that all murrelets flying over CCWPP between the ocean and breeding areas (closest known one 60 km to the east) would have been flying in a roughly easterly or westerly direction and therefore used our presunrise observations of only landward + seaward radar counts to compute the daily movement rates of Marbled Murrelets at the site.

This categorization based on flight direction was particularly important in the CCWPP study area because it is likely that most if not all of the "other" targets observed there were migrating birds or other species, and not murrelets. The characteristics of these "other" targets, including the large increase in numbers in July (Tables 2 and 3), their rapid (~40–55 mph) flight speeds, and their consistent flight direction in a seasonally appropriate migratory direction (Figure 5) rather than flying east/west between the coast and inland nesting areas, supports the idea that these are migratory birds. Figure 5 illustrates the dramatic increase between June and July in both the proportion and numbers of southeast-bound "other" targets. For example, 82% and 78% of the presunrise "other" targets (n = 81) were headed toward 130–180° in July 2008 and 2009, respectively, compared to only 18% and 25% of targets (n = 25) flying in those directions during June 2008 and 2009, respectively. Further, we recorded a large percentage of all "other" targets on our final round of sampling after the middle of July: 40% of all "other" targets in 2008 were observed during 16–17 July 2008 and ~65% of all "other" targets in 2009 were observed during 20–23 July 2009. Because we observed this large pulse of birds headed toward the southeast at ~40–55 mph during mid-July of both years, when fall shorebird migration is known to begin, we believe that it is highly likely that most of these targets were shorebird migrants heading SE away from coastal areas like Gray's Harbor, an important stopover habitat for large numbers of shorebirds and migratory waterfowl (Page et al. 1999). Given their SE heading, we also speculate that many of these targets could have been migrating toward the

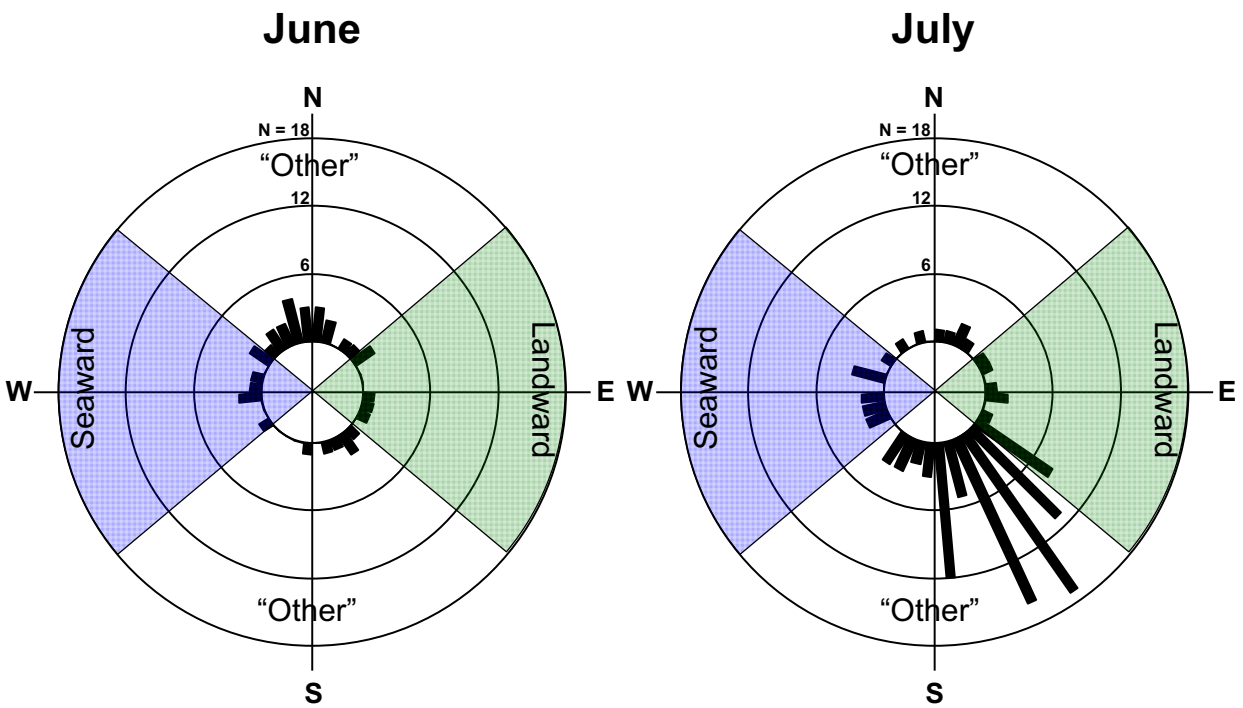

Figure 5. Flight directions of all presunrise radar targets (landward, seaward and "other") observed at the Coyote Crest Wind Power Project (CCWPP) area, Washington, during June and July in 2008–2009. The length of each spoke is proportional to the number of targets observed flying in that direction.

Great Basin. Western Sandpipers (*Calidris mauri*), Red-necked Phalaropes (*Phalaropus lobatus*) and Long-billed Dowitchers (*Limnodromus scolopaceus*) are common shorebird migrants that begin to show up at both coastal and Great Basin locations during July (Reed et al. 1997, Page et al. 1999, Marshall et al. 2003).

The combination of flight direction and timing of movements also led us to believe that on our final day of sampling in 2009 (23 July) that all targets were migratory birds and not murrelets. We came to this conclusion because of the sudden increase in the number of landward targets and because the flight direction and timing of movements was consistent with migratory bird movements (see previous discussion). The sudden increase in the number of landward targets on 23 July 2009 is clearly an outlier (see Tables 2 and 3) and inconsistent with the normal variability in Marbled Murrelet counts. For example, radar counts of murrelets tend to have low day-to-day variation (Cooper et al. 2001, 2006), so the daily count of 6 landward targets on 23 July was highly unusual given that only one other landward target was observed at CCWPP in the entire summer. Furthermore, the flight direction and timing of movements of all the 23 July landward targets were very similar to "other" targets seen that day: all six of the 23 July 2009 landward targets were headed 122–129° while all but one of the 16 "other" targets were flying 131–156° on that day (Figure 5) suggesting that all targets observed on this particular day were from similar species. Because it is highly likely that the six "landward" targets observed on 23 July 2009 were migrating birds, not murrelets, we excluded those data from all analyses.

RADAR DATA

We entered all radar data into a Microsoft Excel database. Data files were checked visually for errors after each morning and then were checked again electronically for irregularities at the end of the field season, prior to data analyses. All data summaries and analyses were conducted with SPSS statistical software (SPSS 2007). For quality

assurance, we cross-checked results of the SPSS analyses with hand-tabulations of small data subsets whenever possible.

A correction in movement rates was necessary to account for the percent of landward and seaward targets that occurred after sunrise. Radar studies in Washington, Oregon, and California (B. Cooper, unpubl. data; n = 17,750 landward targets and n = 12,863 seaward targets) found that on average, 92.4% of morning landward movements of murrelets occur prior to sunrise (i.e., 7.6% occur after sunrise) and 38.0% of seaward movements occur prior to sunrise (i.e., 62.0% occur after sunrise). Thus, to correct our presunrise movement rates to account for postsunrise movements, we calculated the sum of the presunrise landward rate divided by 0.924, plus the presunrise seaward rate divided by 0.380. That postsunrise sum plus the number of presunrise targets then equaled the total number of targets for the morning.

We collected flight altitude data for all vertical radar targets that were concurrently confirmed to murrelet-like targets on surveillance radar (because of their flight speed and direction). The heights of those vertical radar targets were measured relative to the height of the radar sampling location, and then corrected for the height of the ridgeline where the target was expected to cross (based on the flight path observed concurrently on the surveillance radar). This was necessary because the vertical radar did not always detect targets when they were directly over the proposed turbine string locations. Thus, if the altitude of the vertical radar target was measured somewhere other than over a potential turbine string location, we adjusted that flight altitude to estimate the altitude where the target would have crossed the proposed turbine string. For that correction, it was necessary to assume that the flight altitude of the target did not change between the location where altitude was measured on vertical radar and the point when it crossed the ridge.

MODELING FATALITY RATES

The risk-assessment technique that we have developed uses the radar data on movement rates of murrelets during their morning activity period to estimate numbers of birds flying over the area of interest (sampling stations) across the 150-d breeding season (Nelson 1997). This simplistic model then uses information on the physical characteristics of the turbines themselves to estimate horizontal and vertical interaction probabilities and combines these interaction probabilities with the movement rates to generate exposure rates (Figure 6). These rates represent the estimated numbers of murrelets that pass within the airspace occupied by each proposed wind turbine each day. We then combine this exposure rate with (1) the probability that an interaction results in fatality, and (2) the probability that birds detect structures and avoid interactions, to estimate fatality rates.

To calculate the exposure rate we combined daily movement rates with a number of assumptions (Table 4). Specifically, we used the radar-based movement rate data collected at sampling stations 1–5 in the proposed CCWPP during summer 2008 and summer 2009 to determine average daily movement rates (targets/morning) of murrelets in the proposed development area and assumed that this rate represents the average peak-season daily rate in an average year. Because movement rates of murrelets are lower in April, May and August than during the June-July peak in activity (Cooper et al. 2001), we adjusted our movement rates to calculate an average rate across the entire 150-day breeding season. To calculate this seasonal adjustment factor, we used data from Cooper et al. (2001) showing morning landward murrelet passage rates in two large drainages in the Olympic Peninsula during May vs. June and July in 1996–1998 and landward rates in June and July vs. August in 1997. We calculated that May counts at the two sites were on average 41% as high as June-July counts in 1996–1998 and calculated that August counts at the two sites were 15% as high as June-July counts in 1997. We then applied these correction factors to the movement rates in our model, to account for lower rates in April, May, and August, than during June and July when our movement rate data were collected. Assuming that rates in April and May were similar, we used an average correction factor of 0.41 for April, 0.41 for May, 1.0 for June, 1.0 for July, and 0.15 for August.

In addition to correcting our peak season movement rates for April, May, and August rates,

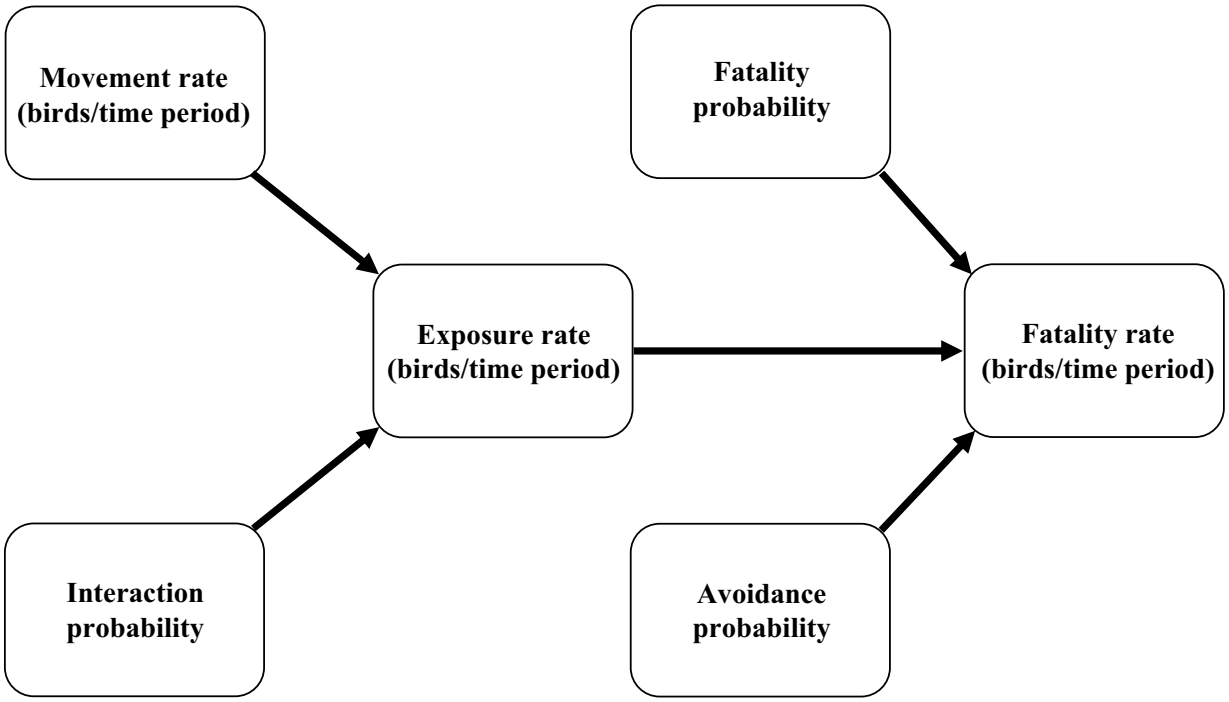

Figure 6. Major variables used in estimating possible fatality of Marbled Murrelets at wind turbines in the proposed Coyote Crest Wind Project, Washington, during summer 2008 and 2009. See Tables 5 and 6 for details on calculations.

it also was necessary to account for inland flights of murrelets at other times of day, but primarily during the evening, when breeding birds are making provisioning trips to their nests. A murrelet telemetry study in Northern California (R. Golightly, Humboldt State University, pers. comm.) found that during the 28-day period when a breeding pair provisioned young, evening flights averaged 39% as high as morning flights. Radar studies found that evening rates averaged 33% of morning flights in British Columbia, (Burger 2001) 18–25% in the Olympic Peninsula (Cooper, unpubl. data), 19% in Oregon (Cooper et al. 2000), and 31–43% in California (Cooper and Blaha 2004, Cooper et al. 2005). The overall average for all these studies was that evening rates were 28% of morning rates. Thus we used the approach of applying this adjustment factor (0.28) to a single month (July) in our model (Table 4) to represent the chick provisioning period with no adjustment to other months. Even though nesting may be asynchronous, by using the proportion of total flights it is most appropriate and efficacious to apply the correction to a single month's adjustment factor.

In addition to our peak season and evening correction factors, it also was necessary to account for inland flights of murrelets during the nonbreeding season (Table 4). Murrelets sometimes visit inland areas in California during the winter months (Naslund 1993, O'Donnell et al. 1995, Nelson 1997) and Washington (Hamer Environmental 2009), For instance, Naslund 1993 found the mean winter/summer ratio in number of audio-visual detections of murrelets was 0.51 (range = 0.345–0.799; n = 5 sites), suggesting that winter activity levels were roughly half of summer levels.. O'Donnell (1993, in O'Donnell et al. 1995), found that mean number of detections during November through February averaged 9–24% of mean levels in July (n = 3 sites). Because audio-visual counts are at best a rough index of abundance, however, radar counts are a better metric for a winter-to-summer comparison in

Table 4. Individual model adjustment factors and the cumulative adjustment factor (calculated as the product of all individual factors) that was applied to unadjusted daily fatality estimates for modeling of murrelet fatalities at the proposed Coyote Crest Wind Power Project, Washington.

Adjustment factors	April	May	June	July	August	Nonbreeding
Number of turbines	47	47	47	47	47	47
Number of days per period	27	31	30	31	31	215
Evening flight exposure proportion[1]	1.00	1.00	1.00	1.28	1.00	1.00
Proportion of flights outside peak of breeding season	0.41	0.41	1.00	1.00	0.15	0.594
Proportion of nonbreeding season flights	1.00	1.00	1.00	1.00	1.00	0.52
Cumulative adjustment factor	**520.290**	**597.370**	**1410.000**	**1864.960**	**218.550**	**3121.232**

[1] Adjustment factor applied to a single month (July) in the model to represent the chick provisioning period when evening inland flights occur.

activity levels. The only currently available radar information on how winter movement rates compare to summer movement rates comes from a radar study conducted at a ridgeline in southwestern Washington (Hamer Environmental 2009). Those studies found that the average winter (nonbreeding season) movement rates were 52% of average summer rates. Thus, we used a correction factor of 0.52 to account for the average additional movement rates during the winter nonbreeding activity at the CCWPP (Table 4).

It also was necessary to correct the number of targets for flock size (Tables 5 and 6). The average flock size of murrelet targets is 1.5 individuals/target (n = 370 visually confirmed targets from Northern California, Oregon and Washington during 1996–2004; B. Cooper, unpubl. data).

INTERACTION PROBABILITIES

HORIZONTAL

Interaction probabilities consist of horizontal and vertical components. The horizontal-interaction probability is the probability that a bird seen on radar will pass through the airspace occupied by a turbine located somewhere on the radar screen. This probability is calculated from information on the two-dimensional area (side view) of the turbine and the two-dimensional area sampled by the radar screen (Tables 5 and 6). Thus, we assumed that the probability of exposure was equal to the fraction of sampled air space that was occupied by the turbines and also assumed that there was a uniform distribution of murrelets in the sampled airspace. The proposed wind turbines have 80-m or 100-m monopole towers and a rotor-swept area 45 m in radius. Two calculations of turbine area were made because of the large differences in area of the structure that depended on the orientation of the blades relative to the flight path of an approaching bird: the area occupied by each proposed turbine if a bird approaches it from the side (i.e., side profile) and the area occupied by each turbine if a bird approaches it from the front (i.e., front profile; the "lollipop"-shaped area that includes a rotor-swept area above the base of the tower). The ensuing ratio of approximate cross-sectional area of the proposed turbine to the cross-sectional area sampled by the radar at or below turbine height (i.e., 3 km × 125 or 145 m) indicates the probability of interacting with (i.e., flying through the airspace occupied by) the proposed 125- or 145-m-tall turbine.

VERTICAL

The vertical-interaction probability is the probability that a bird seen on radar will be flying at an altitude low enough that it might pass through the airspace occupied by a proposed turbine located somewhere on the radar screen. Again, the implicit assumption here is that the probability of exposure was equal to the fraction of sampled air space that was occupied by the turbines and also that there was a uniform distribution of murrelets in the sampled airspace. This probability is calculated from a combined data set of the three vertical radar targets observed in this study and the 38 vertical radar targets observed at the nearby Radar Ridge Wind Resource area using similar study methods (Hamer Environmental 2009). A combined 9.8% (i.e., 4/41 vertical radar targets) flew at or below 125 m agl. A combined 17.6% (i.e., 6/34) vertical radar targets flew at or below 145 m agl (note that the denominator is reduced to 34 for the 145-m calculation because only a subset of the 38 altitude values in the Hamer 2009 report [in Figures 6 and 7] were listed in an individual manner that allowed calculation of the percent of targets ≤145 m). We would have preferred only to use flight-altitude data from the proposed CCWPP turbine locations for the flight-altitude computations, but adequate sample sizes from the CCWPP turbine string areas do not currently exist and would be difficult to obtain given the low number of murrelets flying over the site.

FATALITY RATES

The estimated fatality rate is calculated as the product of: (1) the exposure rate (i.e., the number of birds that might fly within the airspace occupied by a turbine); (2) the fatality probability (i.e., the probability of a fatal collision with a portion of the structure while in the airspace occupied by a turbine); and (3) the avoidance probability (i.e., the probability that a bird will detect and avoid entering the airspace containing the turbine; Figure 6).

Table 5. Estimated average daily exposure rates and daily fatality rates of Marbled Murrelets at Gamesa G90 wind turbines (with 80-m hub heights) at the proposed Coyote Crest Wind Power Project, Washington, based on radar data collected in summer 2008 and summer 2009. Values of particular importance are in boxes.

Variable/parameter For G90 TURBINE with **80-m hub height**	Side Approach	Frontal Approach
MOVEMENT RATE (MVR)		
A) Mean presunrise movement rate in peak June-July period (targets/day)		
A1) Mean presunrise landward targets/d	0.30	0.30
A2) Mean presunrise seaward targets/d	0.48	0.48
B) Correction for postsunrise targets (targets/day) = ((A1/0.924) +(A2/0.380))	1.59	1.59
C) Mean number of birds/target	1.5	1.5
D) Daily movement rate (bird passes/day =B*C)	2.38	2.38
E) Fatality domain (days)	1	1
HORIZONTAL INTERACTION PROBABILITY (IPH)		
F) Turbine height (m)	125	125
G) Blade radius (m)	45	45
H) Height below blade (m)	35	35
I) Width of base of turbine (m)	6	6
J) Min side profile area (m^2) = (F * I)	750	
K) Max front profile area (m^2) = (H * I) + (π x G^2)		6572
L) Cross-sectional sampling area of radar at or below 125 m turbine height (= 3000 m * 125 m = 375,000 m^2)	375000.000	375000.000
M) Minimal horizontal interaction probability (= J/L)	0.00200000	
N) Maximal horizontal interaction probability (= K/L)		0.01752464
VERTICAL INTERACTION PROBABILITY (IPV)		
O) Proportion of murrelets flying ≤ turbine height)	0.098	0.098
EXPOSURE RATE (ER = MVR*IPH*IPV)		
P) Daily exposure rate (bird passes/turbine/day = D*(M or N)*O, rounded to 8 decimal places)	0.00046682	0.00409045
FATALITY PROBABILITY (MP)		
Q) Proportion of time turbines expected to operate during the morning activity period (0300-0800 h)	0.839	0.839
R) Probability of striking turbine if in airspace on a side approach	1.00	
S) Probability of striking turbine if in airspace on frontal approach		0.108
T) Probability of fatality if striking turbine	1.00	1.00
U) Probability of fatality if an interaction on side approach (= Q*R*T)	0.83900	
V) Probability of fatality if an interaction on frontal approach (= Q*S*T)		0.09061
FATALITY RATE (= ER*MP)		
Daily fatality rate with 90% exhibiting collision avoidance (birds/turbine/day = P*(U or V)*0.1)	0.0000392	0.0000371
Daily fatality rate with 95% exhibiting collision avoidance (birds/turbine/day = P*(U or V)*0.05)	0.0000196	0.0000185
Daily fatality rate with 99% exhibiting collision avoidance (birds/turbine/day = P*(U or V)*0.01)	0.0000039	0.0000037

Table 6. Estimated average daily exposure rates and daily fatality rates of Marbled Murrelets at Gamesa G90 wind turbines (with 100-m hub heights) at the proposed Coyote Crest Wind Power Project, Washington, based on radar data collected in summer 2008 and summer 2009. Values of particular importance are in boxes.

Variable/parameter For G90 TURBINE with **100-m hub height**	Side Approach	Frontal Approach
MOVEMENT RATE (MVR)		
A) Mean presunrise movement rate in peak June-July period (targets/day)		
A1) Mean presunrise landward targets/d	0.30	0.30
A2) Mean presunrise seaward targets/d	0.48	0.48
B) Correction for postsunrise targets (targets/day) = ((A1/0.924) +(A2/0.380))	1.59	1.59
C) Mean number of birds/target	1.5	1.5
D) Daily movement rate (bird passes/day =B*C)	2.38	2.38
E) Fatality domain (days)	1	1
HORIZONTAL INTERACTION PROBABILITY (IPH)		
F) Turbine height (m)	145	145
G) Blade radius (m)	45	45
H) Height below blade (m)	55	55
I) Width of base of turbine (m)	6	6
J) Min side profile area (m^2) = (F * I)	870	
K) Max front profile area (m^2) = (H * I) + (π x G^2)		6692
L) Cross-sectional sampling area of radar at or below 145 m turbine height (= 3000 m * 145 m = 435,000 m^2)	435000.000	435000.000
M) Minimal horizontal interaction probability (= J/L)	0.00200000	
N) Maximal horizontal interaction probability (= K/L)		0.01538331
VERTICAL INTERACTION PROBABILITY (IPV)		
O) Proportion of murrelets flying ≤ turbine height)	0.176	0.176
EXPOSURE RATE (ER = MVR*IPH*IPV)		
P) Daily exposure rate (bird passes/turbine/day = D*(M or N)*O, rounded to 8 decimal places)	0.00083838	0.00644850
FATALITY PROBABILITY (MP)		
Q) Proportion of time turbines expected to operate during the morning activity period (0300-0800 h)	0.839	0.839
R) Probability of striking turbine if in airspace on a side approach	1.00	
S) Probability of striking turbine if in airspace on frontal approach		0.108
T) Probability of fatality if striking turbine	1.00	1.00
U) Probability of fatality if an interaction on side approach (= Q*R*T)	0.83900	
V) Probability of fatality if an interaction on frontal approach (= Q*S*T)		0.09061
FATALITY RATE (= ER*MP)		
Daily fatality rate with 90% exhibiting collision avoidance (birds/turbine/day = P*(U or V)*0.1)	0.0000703	0.0000584
Daily fatality rate with 95% exhibiting collision avoidance (birds/turbine/day = P*(U or V)*0.05)	0.0000352	0.0000292
Daily fatality rate with 99% exhibiting collision avoidance (birds/turbine/day = P*(U or V)*0.01)	0.0000070	0.0000058

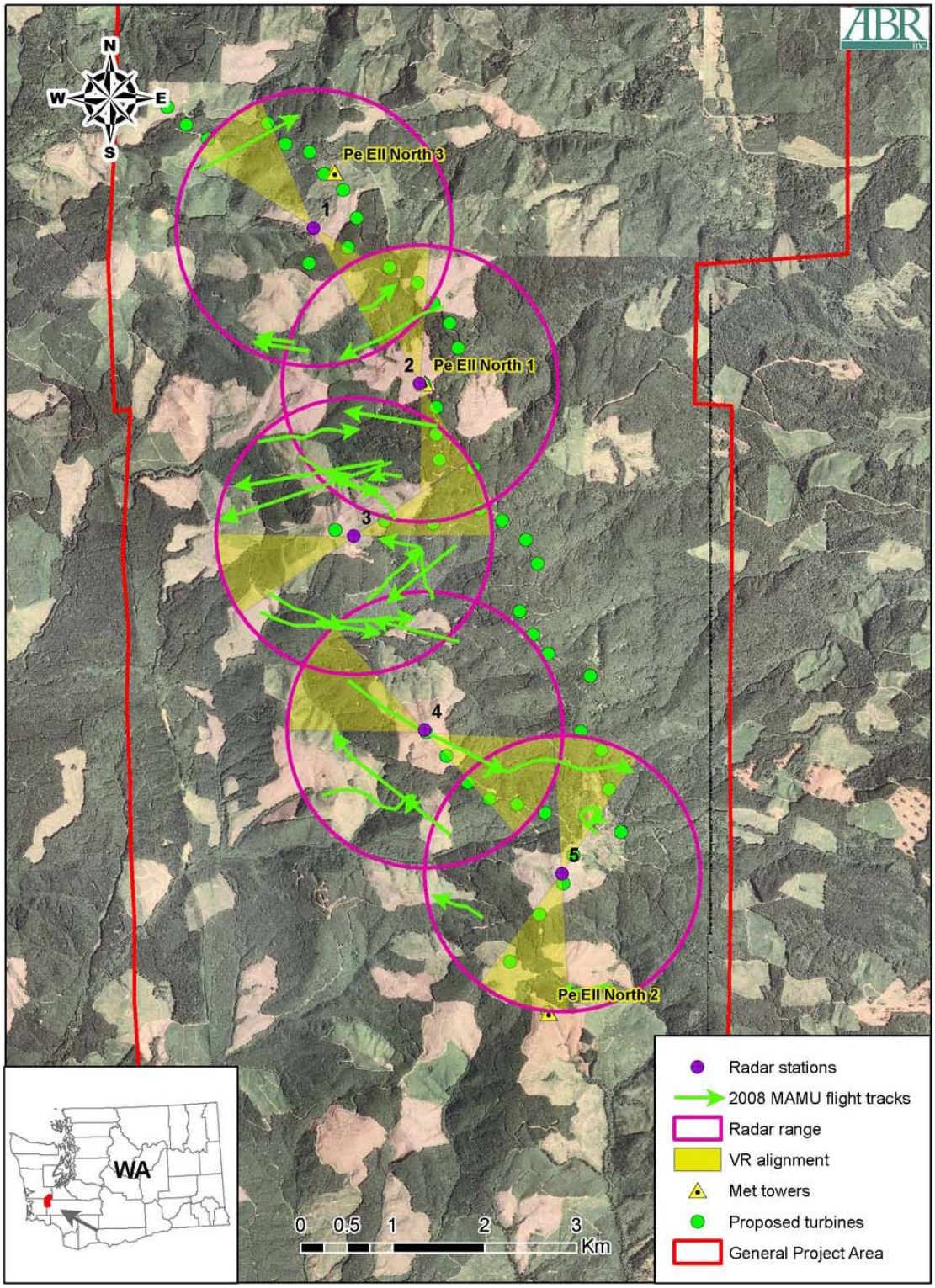

Figure 7. Map showing the flight paths of landward and seaward Marbled Murrelet radar targets observed before sunrise at each of five sites in the proposed Coyote Crest Wind Project, Washington, during summer 2008.

FATALITY PROBABILITY

The estimate of the fatality-probability portion of the fatality rate formula is derived as the product of: (1) the probability of encountering an active (i.e., operating) turbine); 2) the probability of dying if it collides with the turbine; and (3) the probability of colliding with the turbine if the bird enters the airspace occupied by either of these structures (i.e., are there gaps big enough for birds to fly through the structure without hitting any part of it). To calculate the first probability, we used data on average wind speeds collected during 1 April through 31 August 2008 and 2009 at the ~55-m level from the two meteorological towers within the proposed turbine area (i.e., meteorological towers North1 and North2). Those wind speed data were used to estimate the average proportion of time (83.9%) and the average rotational speed (13.6 rpm) that the turbines would be spinning from 0300 h to 0800 h during April through August, the approximate peak daily movement period and dates of murrelet inland breeding activity (Nelson 1997). We used specifications for the Gamesa G90 2.0 MW turbines to determine turbine dimensions, rotor swept area, rotational speed (9–19 rpm), cut-in speed (3 m/s), and cut-out speed (21 m/s). Because a murrelet hitting the proposed turbines will have a very high probability of actually dying, we used an estimate of 100% for the second fatality-probability parameter (i.e., the probability of a bird dying if it collides with a turbine). The third probability (i.e., striking the structure) needed to be calculated in two ways for turbines, because a bird approaching a wind turbine from the side has essentially a 100% probability of collision, while a bird approaching from the back or front of a turbine may pass through the rotor-swept area without colliding with a blade. Tucker (1996) provides a hypothetical model and estimated that a bird with a 1-m wingspan flying 5 m/s through the rotor-swept area of a turbine with three 10-m blades had a mean probability of a collision on 22–40% of all passes. Because, however, the collision probability varies with bird species, turbine type, and turbine dimensions, we recalculated the collision probability for a smaller, faster murrelet flying through the larger, slower-moving blades of the modern turbines planned for the CCWPP project. We estimated that a murrelet approaching from the back or front of a turbine has only a 10.8% chance of hitting a blade (Tables 5 and 6). This calculation for the "frontal" bird approach was based on the length of a murrelet (25 cm; Nelson 1997); the average flight speed of murrelets (mean ± SE velocity = 53 ± 0.1 mph, n = 42,832 murrelet targets; B. Cooper, unpubl. data); and the time that it took a 25-cm-long murrelet to travel completely past a 2-m-wide turbine blade spinning at the average estimated rotor speed (13.6 rpm). Thus, these calculations indicated that 10.8% of the disk of the rotor-swept area was occupied by a blade sometime during the length of time (i.e., 0.0016 min) that it would take a murrelet to fly completely past a rotor blade (i.e., to fly 2.25 m).

AVOIDANCE PROBABILITY

The final parameter is the avoidance probability, which is the probability that a bird will see the turbine and change flight direction, flight altitude, or both so that it completely avoids flying through the space occupied by it. Currently, no empirically derived estimates of avoidance rates are available for Marbled Murrelets, because there has been no opportunity to study their flight behavior near operational wind turbines. However, a review of the published data on other nocturnally-active seabird species (see Discussion) suggests that avoidance rates may be greater than 90% (Winkelman 1995, Dirksen 1998, Desholm and Kahlert 2005, Desholm et al. 2006, Chamberlain et al. 2006, Day et al. *In prep*). Thus, we took the approach of assuming a range of avoidance rates (90%, 95%, and 99%) that have been observed for other nocturnally-active species for our fatality model. These assumptions can be modified as data on murrelet flight behavior at wind farms become available.

RESULTS

MOVEMENT PATTERNS

In total, we observed 26 murrelet-like (i.e., presunrise landward and seaward) targets in 2008 (Table 2) and 5 in 2009 (Table 3). The number of landward targets ranged from 0–3 per day in 2008 and from 0–1 per day in 2009. The number of

seaward targets ranged from 0–2 per day in 2008 and from 0–1 per day in 2009. The number of "other" targets was widely variable and ranged from 0–16 per day in 2008 and from 0–16 per day in 2009. Each year, the highest counts of "other" targets occurred on the last round of July surveys. We did not detect any audio-visual observations of murrelets in 2008 or in 2009.

On average, we observed 0.55 presunrise, landward targets/day in 2008 (11 targets/20 days) and 0.05 landward targets/day in 2009 (1 target/19 days) for an overall average of 0.30 landward targets/day. We also observed an average of 0.75 seaward targets/day in 2008 (15 targets/20 days) and 0.21 seaward targets/day in 2009 (4 targets/19 days) for an overall average over the two years of 0.48 seaward targets/day. Combining the landward and seaward data gives us an average number of 0.78 presunrise targets/day within the 1.5-km radar sampling radius. We then corrected that number for the expected post-sunrise movement of murrelets and calculated a total morning movement rate of 1.59 murrelet targets/day within a 1.5-km radius of the radar (Tables 5 and 6). Thus, our data suggest that low numbers of murrelets flew over CCWPP during the summers of 2008 and 2009.

We saw at least one pre-sunrise landward or seaward target at each of the five sampling stations at CCWPP during summer 2008 (Table 2) and observed at least one target at all stations except Station 3 and Station 5 in 2009 (Table 3). Figures showing flight paths of presunrise landward and seaward targets suggest that there were not any predictable movement corridors or zones of concentration over the CCWPP in 2008 (Figure 7) or 2009 (Figure 8).

FLIGHT ALTITUDE

All three of the presunrise landward or seaward targets we observed on surveillance radar during July 2009 also were detected on vertical radar. The flight altitudes of those targets (corrected to the altitude where they crossed over proposed turbine strings) were 154 m, 353 m, and 364 m above ground level (agl). Thus, all three targets would have flown above the proposed 125–145 m turbine heights. All three were seaward targets heading in a westerly (seaward) direction.

EXPOSURE RATES

The exposure rate represents the number of times that murrelets fly through the airspace occupied by a turbine over a given time period. To calculate the exposure rate we combined information on the movement rate of murrelets in the project area with the horizontal and vertical probabilities of interaction with a turbine. The average of the combined 2008 and 2009 radar movement data collected at the CCWPP was 0.30 landward murrelet targets/morning and 0.48 seaward targets/morning (Tables 5 and 6). Using correction factors (described in methods) for the number of expected post-sunrise targets each morning and also flock size represented by each radar target we calculated a daily movement rate during the peak June/July sampling period of 2.38 bird passes/morning (Tables 5 and 6). Based on the physical characteristics of the proposed turbines and the radar sampling area we calculated an interaction probability for turbines with an 80-m hub height of 0.00200000 for a side approach and 0.01752464 for a frontal approach (Table 5). For turbines with a 100-m hub height, we calculated an interaction probability of 0.00200000 for a side approach and 0.01538331 for a frontal approach (Table 6). Using radar data on flight altitudes of murrelets at the CCWPP and a nearby location, we determined that the probability of vertical interaction was 0.098 for a turbine with an 80-m hub height and 0.176 for a turbine with a 100-m hub height. The product of the movement rate and the interaction probabilities results in an exposure rate for turbines with an 80-m hub height of 0.00046682 murrelet passes/turbine/day for a side approach and an exposure rate of 0.00409045 murrelet passes/turbine/day for a frontal approach (Table 5). The exposure rate for turbines with a 100-m hub height was 0.00083838 murrelet passes/turbine/day for a side approach and 0.00644850 murrelet passes/turbine/day for a frontal approach (Table 6**).**

FATALITY ESTIMATES

The estimated number of collision fatalities is calculated as the product of: (1) the exposure rate (i.e., the number of times that birds might fly within the airspace occupied by turbines); (2) the

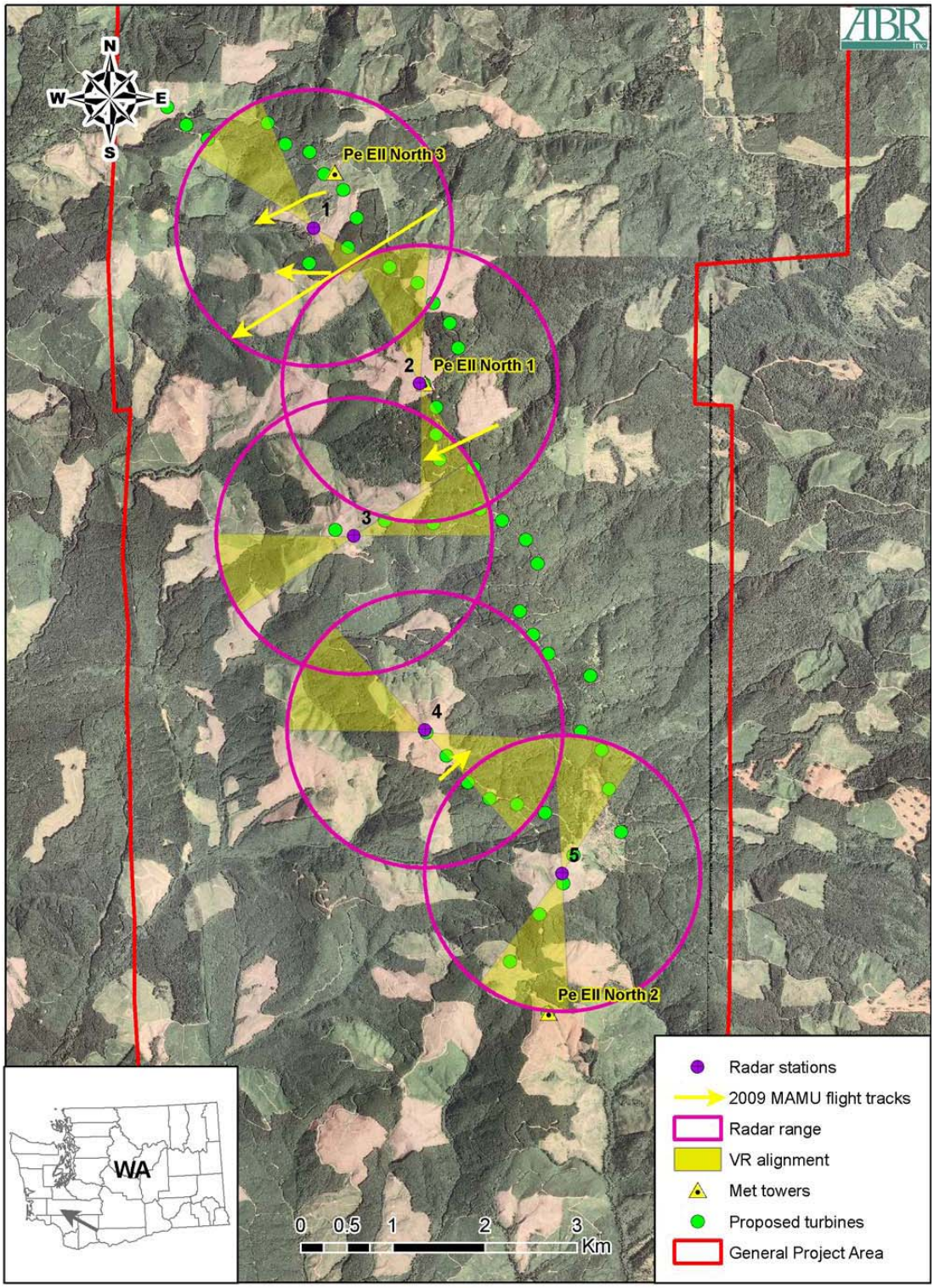

Figure 8. Map showing the flight paths of landward and seaward Marbled Murrelet radar targets observed before sunrise at each of five sites in the proposed Coyote Crest Wind Project, Washington, during summer 2009.

avoidance probability (i.e., the probability that a bird will detect and avoid entering the airspace containing the turbine); and (3) the fatality probability (i.e., the probability of a fatal collision with a portion of the structure once a bird is in the airspace occupied by a turbine). The output from these calculations is the unadjusted number of daily fatalities during the breeding period (Tables 5 and 6). The final step is to multiply these unadjusted fatalities by the product of the combined adjustment factors (Table 4) that represent an effort to account for influential factors (e.g., total number of turbines, number of days within each period, seasonal variation in movement rates, and evening movements) not included in the original model structure and thus provide a more realistic estimate of fatalities during the breeding period and nonbreeding period (Tables 7 and 8).

DAILY AND MONTHLY FATALITY ESTIMATES

The unadjusted daily fatality estimates based on a range of avoidance factors (90–99% avoidance) and both maximum and minimum exposure was 0.0000037–0.0000392 murrelets/turbine/day for turbines with an 80-m hub height (Table 5) and 0.0000058–0.0000703 murrelets/turbine/day for turbines with a 100-m hub height (Table 6). The product of the unadjusted daily fatality estimates and the monthly adjustment factors resulted in a final adjusted monthly fatality (across all 47 turbines) of 0.001–0.073 murrelets/month at the entire proposed CCWPP during the breeding period and 0.012–0.122 murrelets during the entire nonbreeding period, based on a range of avoidance factors (90–99%) for turbines with an 80-m hub height (Table 7). The final adjusted monthly fatality estimate for turbines with a 100-m-hub height was 0.001–0.131 murrelets/month at the entire proposed CCWPP during the breeding period and 0.018–0.220 murrelets during the entire nonbreeding period (Table 7).

CUMULATIVE ANNUAL FATALITY ESTIMATES

The maximum fatality estimate (adjusted) across the entire proposed 47-turbine CCWPP during the entire year (breeding + nonbreeding seasons) for the 80-m hub height ranged from 0.03–0.30 murrelets/year for the 80-m hub height and from 0.05–0.54 murrelets/year for the 100-m hub height (Table 8).

EFFECT OF TURBINE CURTAILMENTS ON FATALITY ESTIMATES

Two options under consideration to reduce the number of potential murrelet collision fatalities are a June-July and a May-June-July curtailment in the morning operation of turbines. In these scenarios turbines would be shut down during the three-hour-long morning peak of murrelet inland flight activity for a two- or three-month period and an assumption is made that no murrelets would collide with turbines once they were shut down. The fatality model estimates that a two-month curtailment (i.e., operational shutdown) of all turbines during the morning activity period in June and July could reduce the total number of annual fatalities by 37.1%, to a range of 0.02–0.19 murrelets/year for the 80-m hub height and 0.03–0.34 murrelets/year for the 100-m hub height (Table 8). A three-month curtailment of all turbines during the morning activity period in May, June, and July could reduce the total number of annual fatalities by 44.8%, to a range of 0.02–0.17 murrelets/year for the 80-m hub height and 0.02–0.30 murrelets/year for the 100-m hub height. Again, note that the range of assumed avoidance rates of murrelets at wind turbines (90–99%) is not supported by empirical data at this time, other than a weight of evidence suggesting that a large proportion of many species (including several nocturnally-active seabird species) are able to detect and avoid structures more than 90% of the time (see Discussion).

DISCUSSION

Predictions of the effects of wind power development on birds are hampered by both a lack of detailed knowledge about patterns of movement and behavior of birds around wind turbines and by the fact that the precise relationship between bird abundance and bird fatalities at wind turbines is unknown. In this study, we documented morning movement rates of Marbled Murrelets at the proposed Coyote Crest Wind Power Project in order to describe some of the general properties of murrelet use of the CCWPP site. Additionally,

Table 7. Monthly adjusted total fatality estimates of murrelets for each month in the breeding period (April–August) and for the entire nonbreeding period (September–March) across the entire (47-turbine) proposed Coyote Crest Wind Power Project, Washington, based on two different turbine hub heights and a range of avoidance factors. Results are calculated using model adjustment factors (Table 4) applied to unadjusted daily fatality estimates (Tables 5 and 6).

Turbine Height/ Avoidance Factor	April		May		June		July		August		Nonbreeding	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
80-m Hub:												
0.90	0.019	0.020	0.022	0.023	0.052	0.055	0.069	0.073	0.008	0.009	0.116	0.122
0.95	0.010	0.010	0.011	0.012	0.026	0.028	0.035	0.037	0.004	0.004	0.058	0.061
0.99	0.002	0.002	0.002	0.002	0.005	0.006	0.007	0.007	0.001	0.001	0.012	0.012
100-m Hub:												
0.90	0.030	0.037	0.035	0.042	0.082	0.099	0.109	0.131	0.013	0.015	0.182	0.220
0.95	0.015	0.018	0.017	0.021	0.041	0.050	0.054	0.066	0.006	0.008	0.091	0.110
0.99	0.003	0.004	0.003	0.004	0.008	0.010	0.011	0.013	0.001	0.002	0.018	0.022

Table 8. Summary of the estimated number of murrelet fatalities per year across all 47 turbines at the proposed Coyote Crest Wind Power Project, Washington, with no turbine curtailment and with two-month and three-month turbine curtailments for three hours each morning.

			Estimated Number of Murrelet Fatalities					
			No Curtailment		JN-JL Curtailment		MY-JL Curtailment	
Hub Height	Avoidance Factor		Breeding Season	Annual	Breeding Season	Annual	Breeding Season	Annual
80 m	90%	Min	0.17	0.29	0.06	0.18	0.04	0.16
		Max	0.18	0.30	0.07	0.19	0.04	0.17
	95%	Min	0.09	0.14	0.03	0.09	0.02	0.08
		Max	0.09	0.15	0.03	0.10	0.02	0.08
	99%	Min	0.02	0.03	0.01	0.02	<0.01	0.02
		Max	0.02	0.03	0.01	0.02	<0.01	0.02
100 m	90%	Min	0.27	0.45	0.10	0.28	0.07	0.25
		Max	0.32	0.54	0.12	0.34	0.08	0.30
	95%	Min	0.13	0.23	0.05	0.14	0.03	0.12
		Max	0.16	0.27	0.06	0.17	0.04	0.15
	99%	Min	0.03	0.05	0.01	0.03	0.01	0.02
		Max	0.03	0.05	0.01	0.03	0.01	0.03

based on a range of biologically-based assumptions, we calculated estimates of the number of times murrelets would be exposed to turbines during the breeding period and the potential number of collision fatalities in an average year.

TARGET IDENTIFICATION

One of the limitations of ornithological radar is that it usually is difficult to identify radar targets to species solely by flight characteristics. Identification to the species level is possible only if that species has flight characteristics and/or a unique timing of movements for a particular location. The Marbled Murrelet is one of the few rapid-flying species present at many sites near the Pacific coast that is active in the earliest part of the morning and thus has been successfully identified on radar at those locations (Hamer et al. 1995; Burger 1997; Cooper et al. 2000, 2001, 2005). In the study at CCWPP in 2008–2009, we did not have any visual verification of the few landward and seaward targets that were detected and thus were unable to calculate an accuracy rate for radar identification of murrelets. We acknowledge that our CCWPP radar data are likely to include contamination from non-murrelet targets; however, for the purposes of this study we assumed that all presunrise landward and seaward targets meeting all of our criteria were Marbled Murrelets because their timing, speed, direction, and target signature were consistent with known murrelet targets from other studies.

PATTERNS OF MOVEMENT

The mean landward movement rates of murrelets over the CCWPP during the June-July 2008 and 2009 (mean = 0.30 landward targets/morning) was low, far lower than movement rates measured using similar radar methods over sites generally located closer to the coast. For example, the average movement rate observed at similar radar studies at 12 valleys in the Olympic Peninsula ranged from ~30–150 landward targets/morning during 1996–2004 (Cooper et al. 2001, 2006). Of 30 sites in Oregon, most had counts of ~10–50 landward targets/site/morning (range of all sites = 2–80

landward targets/morning; Cooper et al. 2000, Cooper and Augenfeld 2001). Landward counts at 10 sites in northern California averaged 42 targets/ morning in 2003 and 54 targets/morning in 2004, with a range of 4–170 targets/morning (Cooper et al. 2005).

The low movement rates of murrelets over the CCWPP study area was not unexpected, since murrelets are not known to nest within the CCWPP (Weyerhaeuser, unpublished data) and the nearest occupied marbled murrelet stand on the inland (i.e., eastern) side of CCWPP is ~60 km away (WDFW, unpubl. database of murrelet detections). There are timber stands within ~10 km to the east of CCWPP (and beyond), however, that contain potential habitat with murrelet nesting platforms but where murrelets have not yet been detected.

FLIGHT ALTITUDES

The limited vertical radar data suggested that a large proportion of murrelet targets may have flown above the proposed turbine heights at CCWPP (i.e., >125–145 m agl), although our sample size was so small (n = 3) that no definitive statements on altitude at the site can be made. What can be said, however, is that the average altitude at the nearby Radar Ridge Wind Resource area (i.e., average height = 308 m agl [n = 38 targets]; Hamer Environmental 2009) was similar to the average altitude at CCWPP (290 m agl), suggesting that a large proportion of murrelets may have flown above proposed turbine height. Because of the close proximity, similar topography, and similar altitude data at the two sites, we combined the altitude data from the two areas to determine that a combined 9.8% of targets flew at or below 125 m agl and a combined 17.6% flew at or below 145 m agl. Those altitude data were then used for our fatality models, however, we would have preferred only to use site-specific flight-altitude data. Unfortunately, adequate sample sizes from the CCWPP turbine string areas do not currently exist.

In contrast to the data above, visually-estimated flight altitude data from throughout the Pacific Northwest (n = 357 murrelet flocks; Cooper, unpubl. data) suggested that ~80% of murrelets fly ≤ 125 m agl. Most of these data were collected in valley locations between the ocean and inland nesting locations rather than on ridges, so perhaps the large difference between these data and the CCWPP and Radar Ridge flight altitude data is partially related to distance from ocean or breeding location and/or related to topography. Visual flight altitude also may have more of a low-altitude bias than the radar data (which can have a high-altitude bias in some locations); however, it is highly unlikely that such a bias would fully account for the large differences in flight altitudes between the two data sets. Hamer Environmental (2009) also collected data for three mornings in the Queets River valley (n = 282 targets) in the Olympic Peninsula for comparison with Radar Ridge and found that a similar proportion of targets occurred within 130 m at the Queets (8.4%) as at Radar Ridge (10.5%), but that the overall distribution of Radar Ridge altitudes was wider. They concluded that the different shape of the two distributions suggested that there may have been some non-murrelet targets (i.e., nocturnal migrants) included in the Radar Ridge radar data that may have affected the mean height (but perhaps not the percent of targets at or below turbine height). Clearly, more radar and visual flight altitude information from a variety of sites, topography, and conditions is needed to determine how much among-site and among-day variation in flight altitudes exists and to compare the visual and radar data for biases.

INTERANNUAL VARIATION IN RADAR COUNTS

Multiyear studies of avian activity provide important insight on interannual variation in activity levels. In this study, for instance, the average presunrise movement rate of landward and seaward targets was 1.3 targets/day in 2008 versus 0.3 targets/day in 2009. Factors known to affect murrelet activity during the breeding period include human activities (e.g., recreation and timber harvesting; Carter and Erickson 1992, Hebert and Golightly 2006), oceanic conditions (Ainley et al. 1994, Oedekoven et al. 2001), and predator activity (Hebert and Golightly 2007). In particular, changes in ocean conditions, such as those that occur as the result of the El Niño–Southern Oscillation (ENSO) and the Pacific Decadal Oscillation, (PDO) have been linked to

changes in diet, productivity, survival, and distribution of Marbled Murrelets along the Pacific coast (Ainley et al. 1995, Becker 2001, Becker and Beissinger 2003, Peery et al. 2006, Becker et al. 2007) and has been associated with widespread reproductive failure in several species of seabirds in the northeastern Pacific (Hodder and Graybill 1985, Ainley and Boekelheide 1990, Wilson 1991).

Strong ENSO events (such as the 1998 event) result in a reversal of the flow of the California Current System, the presence of a surface layer of warm, nutrient-depleted water, and the replacement of coastal upwelling with downwelling (Hunt 1995). A consequence of these events is a marked reduction in primary production, followed by a reduction in the abundance of some food sources important for murrelets and other seabirds. It is possible that fewer Marbled Murrelets fly inland when there is widespread nesting failure in a particular year, especially if the failure occurs before the nestling period in July. Further, there is evidence indicating that nonbreeding murrelets in central California rarely fly inland during the breeding season, which suggests that lower radar-based counts should occur during years of poor breeding effort and that they are essentially indices of the potential breeding effort in that area (Peery et al. 2004, Bigger et al. 2006).

An ENSO event did not occur during our studies in 2008, but a moderate ENSO event began in April 2009 and was still developing when our study occurred in June-July 2009 (NOAA 2009). We speculate that it is unlikely that ENSO-related oceanographic effects were large enough by June-July 2009 to have significantly reduced Marbled Murrelet movements over CCWPP during our 2009 study period, even though the average movement rate was lower in 2009 than in 2008. Variation in mean summer movement rates at the nearby Radar Ridge site was 1.3 and 2.7 targets/3 km/morning in 2007 and 2008, vs.1.8 targets/3 km/morning in 2009, which also suggests that the 2009 ENSO event did not have a large effect on murrelet movement rates in the local area.

Another factor that could cause interannual variation in counts in either direction is overall population increases or declines. Current population trends of the murrelet population in the Pacific Northwest are unknown; however, demographic modeling suggests that the Washington population of Marbled Murrelets is declining at ~3% per year (Beissinger and Nur 1997, McShane et al. 2004). While a continuing decline could explain a small part of the lower counts we observed in 2009 than in 2008, this factor does not fully explain the differences. Thus, we cannot fully explain the ~1 target/morning difference in radar counts between the two years of the study.

EXPOSURE RATES AND FATALITY ESTIMATES

We estimated an average exposure rate of 0.00046682–0.00644850 murrelet passes/turbine/day at the CCWPP based on data collected during the June/July peak activity period (Tables 5 and 6). We used these estimated exposure rates as a starting point for developing a complete avian risk assessment; however, we emphasize that it currently is unknown whether bird use (i.e., exposure) and fatality at windfarms are strongly correlated. For example, Cooper and Day (1998) found no relationship between movement rates and fatality rates of Hawaiian Petrel (*Pterodroma sandwichensis*) and Newell's Shearwater (*Puffinus auricularis newelli*) at powerlines on Kaua'i, indicating that other factors had a much greater effect on causing fatality than movement rates did. Other factors such as poor weather could be more highly correlated with fatality rates than is bird abundance. As an example, collisions of Laysan Albatross (*Diomedea immutabilis*) with a large array of communication-tower antenna wires and guy wires at a breeding colony on Midway Atoll occurred at a far higher rate during periods of high winds, rain, and poor visibility: 838 (>25%) of the 2,901 birds killed during the 1.5-yr-long study were killed during two storms (Fisher 1966). To determine which factors are most relevant, future studies that collect concurrent data on movement rates, weather, and fatality rates would be useful to begin to determine whether movement rates and/or weather conditions can be used to predict the likelihood of murrelet fatalities at wind turbines.

In addition to these questions about the unknown relationships among abundance, weather, and fatality, no murrelet-specific data are available on the proportion of flights that do not result in

collisions with wind turbines because of collision-avoidance behavior (i.e., flights when birds completely alter their flight paths horizontally and/or vertically to avoid flying through the space occupied by a turbine). Clearly, research is needed to address this important topic for murrelets, especially given the powerful influence that the avoidance factor has on both fatalities and fatality estimates.

There is evidence that many species of birds detect and avoid human-made structures in low-light conditions (Winkelman 1995, Dirksen 1998, Desholm and Kahlert 2005, and Desholm et al. 2006). For seabirds, there are data available that suggest that the behavioral-avoidance rate of Hawaiian Petrels and Newell's Shearwaters near powerlines at night is high (Cooper and Day 1998; Day et al. *In prep*) For example, across all 207 Hawaiian Petrels observed flying within 150 m of transmission lines on Kauai, 40 exhibited behavioral responses; of those 40 birds that exhibited collision-avoidance responses, none (0%) collided with a transmission line. Thus, the collision-avoidance rate for Hawaiian Petrels was 100% (i.e., 40 of 40 interactions resulted in collision avoidance). Across all 392 Newell's Shearwaters observed flying within 150 m of transmission lines, 29 exhibited behavioral responses; of those 29 birds that exhibited collision-avoidance responses, none (0%) collided with a transmission line. However, one Newell's Shearwater that did not exhibit a collision-avoidance response hit a transmission line. Thus, the collision-avoidance rate for Newell's Shearwaters was 97% (i.e., 29 of 30 interactions resulted in successful collision avoidance). There also is some information available on collision-avoidance of petrels on Lanai, where the behavior of petrels was studied as they approached large communication towers near their breeding colony (TetraTech 2008). In that study, all 20 (100%) of the Hawaiian Petrels seen on a collision-course toward communication towers at night exhibited avoidance behavior and avoided collision.

Additional data that provides some insight on collision-avoidance behavior of petrels and shearwaters at windfarm structures (e.g., wind turbines and met towers) are available from other studies associated with the operational KWP I windpark on Maui (Day et al., *In prep*). There was 1 Hawaiian Petrel fatality and 0 Newell's Shearwater fatalities observed at the 20 turbines and three met towers in the first 3.5 years of operation (G. Spencer, FirstWind, pers. comm.). Calculations using data for scavenging bias and searcher efficiency collected at the KWP I wind facility indicate that the one observed fatality equates to a corrected direct take of 0.5 Hawaiian Petrels/yr and 0 Newell's Shearwaters/yr (Kaheawa Wind Power LLC 2009, *In prep*). Cooper and Day (2004b) modeled seabird fatality for the KWP I wind turbines, based on movement rates from radar studies at the site (Day and Cooper 1999; Cooper and Day 2004a, 2004b), and estimated that the combined annual fatality of Hawaiian Petrels and Newell's Shearwaters at the KWP I turbines would be ~3–18 birds/yr with a 50% avoidance rate, ~1–2 birds/yr with a 95% avoidance rate, and <1 bird/yr with a 99% avoidance rate. Thus, the fatality model that used a 99% avoidance value was the closest fit with the measured fatality rates at the windpark.

A further example of avoidance behavior in seabirds comes from studies of seaducks in Europe, where those birds were found to detect and avoid turbines >95% of the time (Desholm et al. 2006). Further, natural anti-collision behavior (especially alteration of flight directions) is seen in migrating Common and King eiders (*Somateria mollissima* and *S. fischeri*) approaching human-made structures in the Beaufort Sea off of Alaska (Day et al. 2005) and in diving ducks approaching offshore wind parks in Europe (Dirksen et al. 1998). Collision-avoidance rates around wind turbines are high for Common Eiders in the daytime (Desholm and Kahlert 2005),Common Terns (*Sterna hirundo*) and Sandwich Terns (*Sterna sandvicensis*) during the daytime (>99%, Everaert and Stienen 2007), gulls (*Larus* spp.) in the daytime (>99%; Painter et al. 1999, cited in Chamberlain et al. 2006), Golden Eagles (*Aquila chrysaetos*) in the daytime (>99%; Madders 2004, cited in Chamberlain et al. 2006), American Kestrels (*Falco sparverius*) in the daytime (87%, Whitfield and Band [in prep.], cited in Chamberlain et al. 2006), and passerines during both the day and night (>99%; Winkelman 1992, cited in Chamberlain et al. 2006). Further, the proportion of nocturnal migrants that detect and

avoid turbines must be very high because the average annual fatality rates of nocturnal migrants of a few birds per MW generally are far lower than average annual exposure rates of nocturnally migrating birds (as measured by radar; B. Cooper, unpubl. data).

We agree with others (Chamberlain et al. 2006, Fox et al. 2006) that species-specific, weather-specific, and site-specific avoidance data are needed in models to estimate murrelet fatality rates accurately. However, the currently available avoidance data from a variety of seabirds and other species, while incomplete, is consistent with the notion that substantial proportions of many species detect and avoid large, human-made structures. The ability to detect and avoid objects under low-light conditions also makes sense for a species like the Marbled Murrelet, which are adept at navigating through forests near their nests during low light conditions and have good enough visual acuity to capture prey underwater at night (Nelson 1997). Clearly, there is a compelling need to conduct studies to collect murrelet-specific data on avoidance behavior at wind turbines, so that fatality rates can be estimated more precisely based on empirical evidence. However, until murrelet-specific data on the relationship between exposure and fatality rates are available for wind turbines, we continue to use a range of avoidance rates in our fatality models (i.e., 90%, 95%, and 99% avoidance) under the assumption that avoidance rates for murrelets may be similarly high to what the weight-of-evidence suggests for other seabird species noted above (i.e., >90%). Our annual fatality estimates for the entire proposed 47-turbine CCWPP ranged from 0.03–0.27 murrelets/year under an assumption of 95–99% avoidance.

There are additional factors besides avoidance rates that could affect our exposure model and collision estimates, both in a positive and a negative direction. One negative factor that was not included in our fatality calculations was a correction for the number of targets that were missed because they flew down in the trees or within other radar shadows. Because our sampling stations provided excellent radar coverage over the ridge and valleys (up to several hundred meters below the sampling station), we believe that the proportion of targets that were missed because they passed through the entire area of coverage within a radar shadow was minimal.

There are other factors that caused a positive (upward) bias in our exposure rate and fatality estimates. A factor we already have discussed that could have biased our exposure rate upwards was the inclusion of non-murrelet targets. Our sunrise cut-off probably helped minimize the inclusion of non-murrelets; however in this location it is very possible that some of our presunrise targets that met the criteria for murrelets were shorebirds, or some other species capable of high flight speeds and that were active during the presunrise period.

A second positive bias is that our model assumed that movement rates of murrelets over the CCWPP would not decline, even after a bird was killed (i.e., we assumed sampling with replacement). Clearly, there appears to be a limited (but unknown) number of murrelets that regularly traverse the area of the proposed CCWPP and the sampling-with-replacement factor creates a positive bias in our estimate of fatality for the entire breeding season, with the bias being inversely related to the size of the local population traversing the area. For example, if we multiply our overall movement rates in the CCWPP (2.38 bird passes per morning/3 km = 0.8 bird passes/km/morning) by the maximal north-to-south width of the CCWPP turbine string for inbound/outbound murrelets (~10 km), it suggests that ~4 (or 8, if an incubation exchange occurs) individual murrelets per morning cross the CCWPP. There may be different additional individual birds flying over the area on different days (e.g., the occasional nonbreeding individuals, or breeders that do not normally fly over CCWPP), but assuming that there is some flyway fidelity, then it appears that there are relatively few murrelets that fly over the proposed CCWPP on a regular basis and that the loss of even a single bird would substantially reduce the average daily movement rate. Thus, it even is possible that our model could produce a fatality rate that was higher than the size of the local population of murrelets traversing the area. However, without knowing how many individual murrelets fly over the project area during the average year, or how many of our observations were of the same bird making a different trip, there is no way to know what the upper limit of the fatality estimates is for the study

site, nor are we able to calculate the bias created by sampling with replacement.

Factors that could affect the predictive value of our fatality estimates in either direction are uncertainties in the proportion of murrelets flying at or below turbine height, our assumption regarding how winter movement rates compare to summer rates, and interannual variation in the number of birds visiting nesting areas. More data from a variety of sites (especially those where murrelets are present in high numbers) would be valuable to help address the uncertainties in assumptions regarding winter passage rates and flight altitudes. Reasons for interannual variation already have been discussed above and include oceanographic factors (e.g., El Niño–Southern Oscillation events) and overall population increases or decreases. Again, we do not have an explanation for why our counts of murrelets were ~1 target/day higher in 2008 than in 2009, but think it is unlikely that they are related to changes in either oceanographic conditions or population changes. Thus, we expect that the passage rate data that were collected during 2008–2009 are somewhat average for the site, but acknowledge that future variation in passage rates could affect future fatality rates at the proposed CCWPP in either direction.

CONCLUSIONS

This study focused on the movement patterns and flight behavior of Marbled Murrelets at the proposed Coyote Crest Wind Power Project during the peak period of inland activity within the murrelet breeding season during summer 2008 and 2009. The key results of our study were: (1) the average murrelet count (i.e., number of presunrise landward or seaward targets) at the CCWPP was 0.78 targets/day (i.e., ~0.26 targets/km/day); (2) the flight altitudes of the three vertical radar targets we observed in 2009 all were above the proposed 125–145 m turbine heights; (3) there was an average exposure rate of 0.00046682–0.00644850 murrelet passes/turbine/day at the CCWPP during the June/July peak activity period; and (4) fatality estimates for the entire year (breeding + nonbreeding seasons) ranged from 0.03–0.05 murrelets/year under an assumption of 99% avoidance, 0.14–0.27 murrelets/year assuming 95% avoidance, and 0.29–0.54 murrelets/year assuming 90% avoidance. Currently, no empirically derived estimates of avoidance rates are available for Marbled Murrelets, because there has been no opportunity to study their flight behavior near operational wind turbines. However, a review of the published data on other nocturnally-active seabird species suggests that avoidance rates may be greater than 90%. Thus, we took the approach of assuming a range of avoidance rates (90%, 95%, and 99%) that have been observed for other nocturnally-active species for our fatality model. These assumptions can be modified as data on murrelet flight behavior at wind farms become available.

We also investigated the potential effect of a two-month and three-month curtailment (i.e., operational shutdown) of turbines on fatality estimates and found that a two-month curtailment of all turbines during the morning activity period in June and July could reduce the number of annual fatalities by 37.1%, to a range of 0.02–0.19 murrelets/year for the 80-m hub height and 0.03–0.34 murrelets/year for the 100-m hub height. A three-month curtailment of all turbines during the morning activity period in May, June, and July could reduce the total number of annual fatalities by 44.8%, to a range of 0.02–0.17 murrelets/year for the 80-m hub height and 0.02–0.30 murrelets/year for the 100-m hub height.

LITERATURE CITED

Ainley, D.G., S.G. Allen, and L.B. Spear. 1995. Offshore occurrence patterns of Marbled Murrelets in central California. Pages 361–369, *in* C.J. Ralph, G.L. Hunt Jr., M.G. Raphael, and J. F. Piatt [eds.], Ecology and conservation of the Marbled Murrelet. USDA Forest Service General Technical Report PSW-GTR-152.

Ainley, D.G., and R.J. Boekelheide. 1990. Seabirds of the Farallon Islands: ecology, dynamics, and structure of an upwelling-system community. Stanford University Press, Stanford, CA.

Ainley, D.G., W.J. Sydeman, S.A. Hatch, and U.W. Wilson. 1994. Seabird population trends along the west coast of North America: causes and extent of regional concordance. Studies in Avian Biology 15:119–133.

Becker, B.H. 2001. Effects of oceanographic variation on Marbled Murrelet diet and habitat selection. Ph.D. dissertation, University of California, Berkeley, CA.

Becker, B.H., and S.R. Beissinger. 2003. Scale-dependent habitat selection by a nearshore seabird, the Marbled Murrelet, in a highly dynamic upwelling system. Marine Ecology Progress Series 256:243–255.

Becker, B.H., Z.M. Peery, and S.R. Beissinger. 2007. Ocean climate and prey availability affect the trophic level and reproductive success of the Marbled Murrelet, an endangered seabird. Marine Ecology Progress Series 329: 267–279.

Beissinger, S.R., and N. Nur. 1997. Population trends of the Marbled Murrelet projected from demographic analysis, Appendix B. *In* G.S. Miller, S.R. Beissinger, H.R. Carter, B. Csuti, T.E. Hamer, and D.A. Perry [eds.], Recovery plan for the Marbled Murrelet (Washington, Oregon, and California population). U.S. Fish and Wildlife Service, Portland, OR.

Bigger, D., M.Z. Peery, J. Baldwin, S. Chinnici, and S.P. Courtney. 2006. Power to detect trends in Marbled Murrelet breeding populations using audiovisual and radar surveys. Journal of Wildlife Management 70: 493–504.

Burger, A.E. 1997. Behavior and numbers of Marbled Murrelets measured with radar. Journal of Field Ornithology 68: 208–223.

Burger, A.E. 2001. Using radar to estimate populations and assess habitat associations of Marbled Murrelets. Journal of Wildlife Management 65: 696–715.

Burger, A.E., T.A. Chatwin,, S.A. Culler, N.P. Holmes, I.A. Manley, M.H. Mather, B.K. Schroeder, J.D. Steventon, J.E. Duncan, P. Arcese, and E. Selak. 2004. Application of radar surveys in the management of nesting habitat of Marbled Murrelets *Brachyrhamphus marmoratus*. Marine Ornithology 32: 1–11.

Carter, H.R., and R.A. Erickson. 1992. Status and conservation of the Marbled Murrelet in California, 1892–1987. Pages 92–108 *in* H.R. Carter and M.L. Morrison (eds). Status and conservation of Marbled Murrelets in North America. Proceedings of the Western Foundation of Vertebrate Zoology. Volume 5.

CDFG (California Department of Fish and Game). 2007. State and federally listed endangered and threatened animals of California. Available at www.dfg.ca.gov/biogeodata/cnddb/pdfs/TEAnimals.pdf (Viewed October 2007).

Chamberlain, D.E., M.R. Rehfisch, A.D. Fox, M. Desholm, and S.J. Anthony. 2006. The effect of avoidance rates on bird mortality predictions made by wind turbine collision risk models. Ibis 148:198–202.

Cooper, B.A. 1993. Feasibility of using boat-based marine radar to study Marbled Murrelets in Kenai Fjords National Park, Alaska, 1993. Unpublished report prepared for U.S. Fish and Wildlife Service, Anchorage, AK, by Alaska Biological Research, Inc., Fairbanks, AK. 19 pp.

Cooper, B.A., and K.H. Augenfeld. 2001. Radar surveys for Marbled Murrelets in the Elliott State Forest, Oregon, 2001. Unpublished report prepared for Oregon Department of Forestry, Salem, OR, by ABR, Inc., Forest Grove, OR. 24 pp.

Cooper, B.A., and R.J. Blaha. 2002. Comparison of radar and audio-visual counts of Marbled Murrelets during inland forest surveys. Wildlife Society Bulletin 30: 1182–1194.

Cooper, B. A., and R. J. Blaha. 2004. Determining population trends of Marbled Murrelets in the portion of Conservation Zone 4 north of the PALCO HCP Area. Unpublished report prepared for Scotia Pacific Company LLC, Scotia, CA, U.S. Fish and Wildlife, Arcata, CA, and California Department of Fish and Game, Arcata, CA, by ABR, Inc., Forest Grove, OR. 22 pp.

Cooper, B.A., R.J. Blaha, and J.H. Plissner. 2005. Determining local population trends of Marbled Murrelets in that portion of Conservation Zone Four North of the Palco HCP Area. 2004. Unpublished. report prepared for Pacific Lumber Company (Palco), U.S. Fish and Wildlife Service, and California Department of Fish and Game, Scotia, CA, by ABR, Inc., Forest Grove, OR. 26 pp.

Cooper, B. A., and R. H. Day. 1998. Summer behavior and mortality of Dark-rumped Petrels and Newell's Shearwaters at power lines on Kauai. Colonial Waterbirds 21: 11–19.

Cooper, B. A., and R. H. Day. 2004a. Results of endangered bird and bat surveys at the proposed Kaheawa Pastures Wind Energy Facility, Maui Island, Hawaii, fall 2004. Unpublished report prepared for Kaheawa Windpower LLC, Makawao, HI, and UPC Wind Management LLC, Newton, MA, by ABR, Inc., Forest Grove, OR, and Fairbanks, AK. 16 pp.

Cooper, B. A., and R. H. Day. 2004b. Modeling annual seabird use and fatality at the proposed Kaheawa Pastures Wind Energy Facility, Maui Island, Hawaii, fall 2004. Unpublished report prepared for Kaheawa Windpower LLC, Makawao, HI, and UPC Wind Management LLC, Newton, MA, by ABR, Inc., Forest Grove, OR, and Fairbanks, AK. 7 pp.

Cooper, B.A., R.H. Day, R.J. Ritchie, and C.L. Cranor. 1991. An improved marine radar system for studies of bird migration. Journal of Field Ornithology 62: 367–377.

Cooper, B.A., and T.E. Hamer. 2003. Use of radar for Marbled Murrelet Surveys, Appendix G. *In* Evans, D.R., W.P. Ritchie, S.K. Nelson, E. Kuo-Harrison, P. Harrison, and T.E. Hamer (eds.). Methods for surveying marbled murrelets in forests: an update to the protocol for land management and research. Published by the Pacific Seabird Group. 64 pp.

Cooper, B.A., M.G. Raphael, and D.M. Evans. 2001. Radar-based monitoring of marbled murrelets. Condor 103: 219–229.

Cooper, B.A., M.G. Raphael, and M.Z. Peery. 2006. Trends in radar-based counts of Marbled Murrelets on the Olympic Peninsula, Washington, 1996–2004. Condor 108: 936–947.

Cooper, B.A., and P.M. Sanzenbacher. 2006. A radar study of Marbled Murrelets at the proposed Bear River Windpark, California, summer 2006. Unpublished report prepared for Shell Wind Energy Inc., Houston, TX, by ABR Inc., Forest Grove, OR. 18 pp.

Cooper, B.A., C. Strong, and L. Folliard. 2000. Radar-based monitoring of Marbled Murrelets in Oregon, 1996–1999. Unpublished report prepared for U.S. Fish and Wildlife Service, Portland, OR, by ABR, Inc., Forest Grove, OR. 46 pp.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2007. Listing of the conservation status of species at risk in Canada. Available at www.cosewic.gc.ca/eng/sct5/index_e.cfm (Viewed October 2007).

Day, R. H., and B. A. Cooper. 1999. Results of endangered bird and bat surveys at the proposed Kaheawa Pastures Windfarm on Maui Island, Hawaii, summer 1999. Unpublished report prepared for Zond Pacific, Wailuku, HI, by ABR, Inc., Fairbanks, AK, and Forest Grove, OR. 26 pp.

Day, R. H., B. A. Cooper, T. J. Mabee, J. H. Plissner, P. M. Sanzenbacher, and A. Oller. *In prep*. Collision-avoidance behavior of Hawaiian Petrels and Newell's Shearwaters in the Hawaiian Islands.

Day, R. H., A. K. Prichard, and J. R. Rose. 2005. Migration and collision avoidance of eiders and other birds at Northstar Island, Alaska, 2001–2004. Unpublished final report prepared for BP Exploration (Alaska), Inc., Anchorage, AK, by ABR, Inc.—Environmental Research and Services, Fairbanks, AK. 142 pp.

Desholm, M., A.D. Fox, P.D.L. Beasley, and J. Kahlert. 2006. Remote techniques for counting and estimating the number of bird-wind turbine collisions at sea: a review. Ibis: 148: 76–89.

Desholm, M. and J. Kahlert. 2005. Avian collision risk at an offshore windfarm. Biology Letters 1: 296–298.

Dirksen, S.E., A.L. Spaans, and J. Winden. 1998. Nocturnal collision risks with wind turbines in tidal and semi-offshore areas. Pages. 99–108 *in* Proceedings of International Workshop on Wind Energy and Landscape, Genua, 26–27 July 1997. Balkema, Rotterdam.

Eastwood, E. 1967. Radar ornithology. Methuen and Co., Ltd., London, United Kingdom. 278 pp.

Erickson, W.P., G.D. Johnson, M.D. Strickland, D.P. Young, Jr., K.J. Sernka, and R.E. Good. 2001. Avian collisions with wind turbines: a summary of existing studies and comparisons to other sources of avian collision mortality in the United States. National Wind Coordinating Committee, Washington, DC. 62 pp. Available at www.nationalwind.org/publications/wildlife/avian_collisions.pdf (Viewed October 2007).

Evans Mack, D.M., W.P. Ritchie, S.K. Nelson, E. Kuo-Harrison, P. Harrison, and T.E. Hamer. 2003. Methods for surveying Marbled Murrelets in forests: a revised protocol for land management and research. Pacific Seabird Group unpublished document. Available at www.pacificseabirdgroup.org/publications/PSG_TechPub2_MAMU_ISP.pdf (Viewed October 2007).

Everaert, M. and E. W. M. Stienen. 2007. Impact of wind turbines on birds in Zeebrugge (Belgium). Biodivers. Conserv. 16: 3345–2259.

Fisher, H. I. 1966. Midway's deadly antennas. Audubon Magazine, July-August 1966. Pp. 220–223.

FAA (Federal Aviation Administration). 2007. Obstruction marking and lighting. Advisory circular of U.S. Department of Transportation, Federal Aviation Administration. AC 70/7460-1K. Available at www.oeaaa.faa.gov/oeaaa/external/content/AC70_7460_1K.pdf (Viewed October 2007).

Fox, A. D., M. Desholm, J. Kahlert, T. K. Christensen, and I. K. Petersen. 2006. Information needs to support environmental impact assessment of the effects of European marine offshore wind farms on birds. Ibis 148: 129–144.

Gauthreaux, S.A., Jr. 1985a. Radar, electro-optical, and visual methods of studying bird flight near transmission lines. Unpublished Final Report prepared for Electric Power Research Institute, Palo Alto, CA, by Clemson University, Clemson, SC. 76 pp.

Gauthreaux, S.A., Jr. 1985b. An avian mobile research laboratory: hawk migration studies. Pages 339–346 *in* M. Harwood, ed. Proceedings of Hawk Migration Conference IV. Hawk Migration Association of North America, Washington, CT.

Hamer Environmental. 2009. Use of radar to determine passage rates and height distribution of Marbled Murrelets at the proposed Radar Ridge Wind Resource Area,

Pacific County, Washington. Unpublished Final Report prepared for Energy Northwest, Richland, WA, by Hamer Environmental L.P., Mount Vernon, WA. 54 pp.

Hamer, T.E., B.A. Cooper, and C.J. Ralph. 1995. Use of radar to study the movements of Marbled Murrelets at inland sites. Northwestern Naturalist 76: 73–78.

Hebert, P.N., and R.T. Golightly. 2006. Movements, nesting, and response to anthropogenic disturbance of marbled murrelets (*Brachyramphus marmoratus*) in Redwood National and State Parks, California. Unpublished report, Department of Wildlife, Humboldt State University, Arcata, CA and California Department of Fish and Game report 2006-02, Sacramento, CA.

Hebert, P.N., and R.T. Golightly. 2007. Observations of predation by corvids at a Marbled Murrelet nest. Journal of Field Ornithology 78: 221–224.

Hodder, J., and M.R. Graybill. 1985. Reproduction and survival of seabirds in Oregon during the 1982–1983 El Niño. Condor 87: 535–541.

Hunt, G.L., Jr. 1995. Oceanographic processes and marine productivity in waters offshore of Marbled Murrelet breeding habitat. Pages 219–222 *in* C.J. Ralph, G.L. Hunt Jr., M.G. Raphael, and J.F. Piatt [eds.], Ecology and conservation of the Marbled Murrelet. USDA Forest Service General Technical Report PSW-GTR-152.

Kaheawa Wind Power, LLC. 2009 (I*n prep*). Kaheawa Pastures Wind Energy Generation Facility, Habitat Conservation Plan: Year 3 Annual Report. First Wind Energy, LLC, Environmental Affairs, Newton, MA.

Mabee, T. J., J. H. Plissner, B. A. Cooper, and D. P. Young. 2006. Nocturnal bird migration over an Appalachian Ridge at a proposed wind power project. Wildlife Society Bulletin 34: 682–690.

Madders, M. 2004. Proposed wind farms at Ben Aketil Edinbane, a Quantitative Collision Risk Model for Golden Eagle. Unpublished report by Natural Research Ltd., Isle of Islay, UK.

Marshall, D.B., M.G. Hunter, and A. L. Contreras (eds.). 2003. Birds of Oregon: a general reference. Oregon State University Press, Corvallis, OR. 768 pp.

McShane, C., T.E. Hamer, H. Carter, G. Schwartzman, V. Friesen, D. Ainley, R. Tressler, K. Nelson, A. Burger, L. Spear, T. Mohagen, R. Martin, L. Henkel, K. Prindle, C. Strong, and J. Keany. 2004. Evaluation report for the 5-year status review of the Marbled Murrelet in Washington, Oregon, and California. EDAW, Inc., Seattle, WA. Available at www.hamerenvironmental.com/pdf/Mamu%20full%20final.pdf (Viewed October 2007).

Naslund, N.L. 1993. Why do Marbled Murrelets attend old-growth forest nesting areas year-round? Auk 110: 594–602.

National Research Council (NRC). 2007. Environmental impacts of wind-energy projects. The National Academies Press, Washington, D.C. USA.

Nelson, S.K. 1997. Marbled Murrelet (*Brachyramphus marmoratus*). *In* A. Poole and F. Gill, eds. The Birds of North America, No. 276. Academy of Natural Sciences, Philadelphia, PA, and American Ornithologists' Union, Washington, DC. 32 pp.

Nelson, K., M. G. Raphael, and P Harrison. 2009. Independent Science Panel Review of potential impacts to Marbled Murrelets relating to the Radar Ridge Wind Resource Area. Unpublished report to Washinton Commissioner of Public Lands Peter Goldmark, Olympia, WA. 9 pp. + attachment.

NOAA 2009. National Climatic Data Center El Niño and La Niña website. [http://www.ncdc.noaa.gov/oa/climate/elnino/elnino.html]

ODFW (Oregon Department of Fish and Wildlife). 2007. Oregon list of threatened and endangered fish and wildlife species. Available at www.dfw.state.or.us/threatened_endangered/t_e.html#or (Viewed October 2007).

O'Donnell, B.P., N.L. Naslund, and C.J. Ralph. 1995. Patterns of seasonal variation of activity of Marbled Murrelets in forested stands. Pages 117–128 *in* C.J. Ralph, G.L. Hunt Jr., M.G. Raphael, and J.F. Piatt [eds.], Ecology and conservation of the Marbled Murrelet. USDA Forest Service General Technical Report PSW-GTR-152.

Oedekoven, C.S., D.G. Ainley, and L.B. Spear. 2001. Variable responses of seabirds to change in marine climate: California Current, 1985–1994. Marine Ecology Progress Series 212: 265–281.

Page, G. W., L. E. Stenzel, and J. E. Kjelmyr. Overview of shorebird abundance and distribution in wetlands of the Pacific coast of the contiguous United States. Condor: 101 461–471.

Paton, P.W., C.J. Ralph, H.R. Carter, and S.K. Nelson. 1990. Surveying Marbled Murrelets at inland forest sites: a guide. USDA Forest Service, Pacific Southwest Research Laboratory, Arcata, CA. Gen. Tech. Rep. PSW-120. 9 pp.

Peery, M.Z., S.R. Beissinger, B.H. Becker, E. Burkett, and S.H. Newman. 2004. Inland flight behavior of Marbled Murrelets: implications for population monitoring with radar. Condor 106: 344–353.

Peery, M.Z., S.R. Beissinger, E. Burkett, and S.H. Newman. 2006. Local survival rates of Marbled Murrelets: roles of oceanographic conditions, sex, and radio-tagging. Journal of Wildlife Management 70: 78–88.

Raphael, M. G., S. K. Nelson, P. Swedeen, M. Ostwald, K. Flotlin, S. Desimone, S. Horton, P. Harrison, D. Prenzlow Escene, and W. Jaross. 2008. Recommendations and supporting analysis of conservation opportunities for Marbled Murrelet long-term conservation strategy. Washington State Dept. Natural Resources, Olympia, WA. 337 pp.

Raphael, M.G. D. Evans Mack, and B.A. Cooper. 2002. Use of radar to investigate landscape-scale relationships between abundance of Marbled Murrelets and nesting habitat. Condor 104: 331–342.

Reed, J.M., N. Warnock, and L.W. Oring (eds.) 1997. Conservation and management fo shorebirds in the western Great Basin of North America. International Wader Studies 9. 81 pp.

SPSS. 2007. SPSS for Windows, version 16.0. SPSS, Inc., Chicago, IL.

Skolnik, M.I. 1980. Introduction to radar systems. McGraw-Hill, New York, NY. 581 pp.

TetraTech EC. 2008. DRAFT Habitat Conservation Plan for the construction and operation of Lanai met towers, Lanai, Hawaii (Revised February 8, 2008, TTEC-PTLD-2008-080). Unpubl. report by Tetratech EC, Honolulu, HI for Castle and Cooke LLC, Lanai City, HI. 52 pp. + appendices. Available at: http://www.state.hi.us/dlnr/dofaw/pubs/Lana'i_Met_Towers_HCP.pdf

Trapp, J.L. 1998. Bird kills at towers and other human-made structures: an annotated partial bibliography (1960–1998). Unpublished report by U.S. Fish and Wildlife Service, Office of Migratory Bird Management, Arlington, VA. Available at http://www.fws.gov/migratorybirds/issues/tower.html (Viewed October 2007).

Tucker, V.A. 1996.A mathematical model of bird collisions with wind turbine rotors. ASME Journal of Solar Energy Engineering 118: 253–262.

USFWS (U.S. Fish and Wildlife Service). 1992. Endangered and threatened wildlife and plants: determination of threatened status for the Washington, Oregon, and California population of the Marbled Murrelet. Federal Register 61: 26,256–26,320.

USFWS (U.S. Fish and Wildlife Service). 1997. Recovery plan for the Marbled Murrelet (Washington, Oregon, and California population). U.S. Fish and Wildlife Service, Portland, OR. 203 pp.

USGS (U.S. Geological Survey). 2003. Physiographic regions of the US. Available at http://tapestry.usgs.gov/physiogr/physio.html.

WDFW (Washington Department of Fish and Wildlife). 2007. State threatened species. Available at wdfw.wa.gov/wlm/diversity/soc/threaten.htm (Viewed October 2007).

Williams, T.C., J. Settel, P.O'Mahoney, and J.M. Williams. 1972. An ornithological radar. American Birds 26: 555–557.

Wilson, U.W. 1991. Responses of three seabird species to El Niño events and other warm episodes on the Washington coast, 1979–1990. Condor 93: 853–858.

Winkelman, J.E. 1995. Bird/wind turbine investigations in Europe. Pages 43–47 and 110–140 *in* LGL Ltd. ed. Proceedings of National Avian-Wind Power Planning Meeting I, Lakewood, CO.