FINAL REPORT

A RADAR STUDY OF MARBLED MURRELETS AT THE PROPOSED BEAR RIVER WINDPARK, CALIFORNIA, SUMMER 2006

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FOREST GROVE, OREGON

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EXECUTIVE SUMMARY

- This report presents the results of a radar and visual study of Marbled Murrelets conducted at the proposed Bear River Windpark (BRW), located in northern California. Radar observations were conducted for two days in June 2006 and two days in July 2006, at each of six sites. Radar sampling occurred during the morning activity period for Marbled Murrelets (i.e., from 75 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 BRW and then use those data to estimate an exposure index for Marbled Murrelets to the proposed wind energy facility.
- We observed ~0.3 landward targets/km/ morning in the BRW.
- There was some intersite variation in radar counts, but no obvious areas of high concentration or "bottlenecks" of murrelet use in the BRW.
- Our exposure indices suggest that 0.1–1.0 murrelets/morning would have passed within the airspace occupied by all proposed turbines at the BRW. Note that these exposure indices estimate how many times a murrelet(s) would be exposed to turbines, not the number of murrelets that would actually collide with turbines (because some unknown proportion of murrelets would detect and avoid turbines and some could pass through the blades without collision). Also, the exposure index calculates the number of exposure incidents, not the number of individual murrelets (i.e., the index takes into account that a single individual could be exposed to turbines multiple times).

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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, only limited information is available 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 and as threatened at the state level in Washington and Oregon. In addition, the species is listed as threatened in Canada. Comparison of historical and current data suggests that Marbled Murrelets have disappeared or become rare over much of their range south of Alaska (Nelson 1995). Current population trends of the species in the Pacific Northwest are unknown; however, demographic modeling suggests that the northern California population of Marbled Murrelets is declining at ~5% per year (Beissinger and Nur 1997, McShane et al. 2004).

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 the 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.

Several studies have shown that radar is an excellent tool for observing Marbled Murrelets (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. 2006a). 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 certain terrain types 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 "hot-spots" 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).

Avian collisions with tall, manmade structures have been recorded in North America since 1948 (Kerlinger 2000). Studies examining the impacts of windfarms on birds in the U.S. and Europe suggest that fatalities and behavioral modifications (e.g., avoidance of windfarms) occur in some, but not all, locations (Winkelman 1995, Anderson et al. 1999, Erickson et al. 2001). Documentation of bird fatalities at wind power facilities studied in the US (i.e., ~2 avian fatalities per turbine per year; Erickson et al. 2001) have generated interest in conducting preconstruction studies of bird activity at the many proposed wind power developments throughout the country to help identify important bird areas with high use and/or sensitive species.

Shell Wind Energy Inc. is proposing to develop a ~100 MW wind energy facility on the Bear River Ridge, near Ferndale, California (i.e., the Bear River Windpark [BRW]). Each of the 40–50 proposed wind turbines would have a generating capacity of ~2.0 MW. The currently proposed monopole towers would be ~80 m in height, and each turbine would have three rotor blades. The length of each rotor blade and hub would be ~44 m, thus, the total maximal height of a turbine would be ~124 m with a blade in the vertical position. To date, there are no known nesting locations of Marbled Murrelets in the BRW (Nielson and Leiston 1994). However, because the proposed turbine string would be located on a ridge that lies between the Pacific Ocean and nesting habitat of Marbled Murrelets in older redwood (*Sequoia sempervirens)*-dominated forests further to the east (e.g., Humboldt Redwoods State Park; Fig. 1) 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, a two-year study was undertaken to help determine if murrelets were crossing the proposed turbine facilities while flying between the ocean and their inland nest locations. This report presents the results of the first year of radar surveys for Marbled Murrelets in the proposed BRW.

OBJECTIVES

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 BRW, and use those data to estimate the amount of exposure of Marbled Murrelets to the proposed wind energy facility.

STUDY AREA

The proposed Bear River Windpark (BRW) is located on Bear River Ridge, an east-west ridge south of Ferndale, California (Fig. 1). The ridge forms the northern boundary of the Bear River watershed and the portion of the ridge containing the proposed string of wind turbines ranges in elevation from ~450 m above sea level (asl) on the western end to ~800 m asl in the highest areas of the eastern half. The ridge top is characterized by open grasslands interspersed with forested areas that extend upwards from the valleys. Virtually the entire BRW is currently grazed by cattle and much of the forested areas have been logged at least once. The predominant conifers in the forests are Douglas fir (*Psuedotsuga menzeisii*) and grand fir (*Abies grandis*) and the dominant hardwood species are red alder (*Alnus rubra*), big-leaf maple (*Acer macrophyllum*), California laurel (*Umbellularia californica*), and tan oak (*Lithocarpus densiflora*). There are no known stands of redwood in the area. The area is characterized by high winds and wide fluctuations in precipitation and temperature.

Radar observations were conducted from five locations (i.e., Sites 1–5) on the Bear River Ridge and from one location (Site 6) on Branstetter Ridge (Fig. 2, Table 1). The area was well-suited for radar observations, so all radar sites were in positions that provided maximal coverage of the surrounding area. In combination, the five sites on Bear River Ridge provided radar coverage of ~75% of the ~20 km-long proposed turbine string. While there are no current plans to develop Branstetter Ridge, the sixth site located there was added to provide some preliminary information on murrelet use over that area, in case of future interest. Data from Site 6 also provided further information on murrelet densities in the general area of the BRW.

METHODS

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). We conducted radar observations for two mornings in June and for two mornings in July at each of five locations spread along the proposed turbine string on Bear River Ridge and at one location on Branstetter Ridge (Fig. 2, Table 2). Each morning, a single observer set up a 12 kW, X-band marine radar and video recorder, and then attempted to get audio-visual verification of any murrelet-like targets detected by the radar.

Radar sampling occurred during the morning activity period for Marbled Murrelets, 75 min before sunrise to 75 min after sunrise (sunrise times for Ferndale, California were gathered from the U.S. Naval Observatory website [http://aa.usno.navy.mil]). This period encompasses the known peak of daily murrelet activity (Burger 1997; Cooper et al. 2001; Cooper and Hamer 2003; Cooper and Blaha 2002; Cooper et al. 2005). The audio-visual observations were transmitted via voice directly to the video recording of the radar screen. These audio-visual data were used to verify species identifications on the radar. After the morning observations were completed, the tape of the radar screen was analyzed and the data entered on a computer.

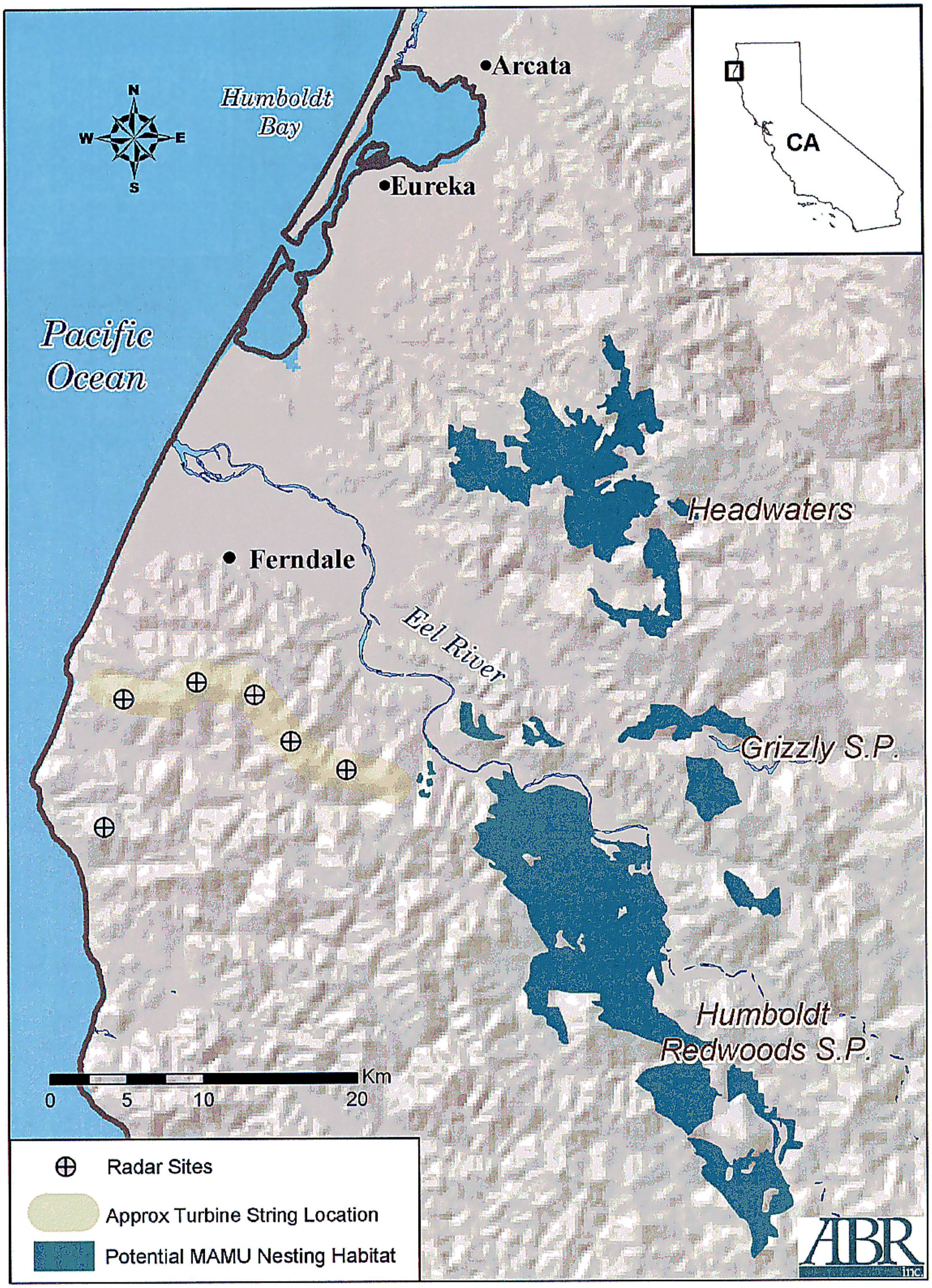

Figure 1. Location of the proposed turbine string and our summer 2006 radar sampling sites in the proposed Bear River Windpark, California, in relation to the location of potential murrelet nesting habitat. We used California Department of Forestry and Fire Protection [http://frap.cdf.ca.gov/data.html] maps to determine the location and amount of potential Marbled Murrelet nesting habitat inland from our study site, following Miller et al. (2002).

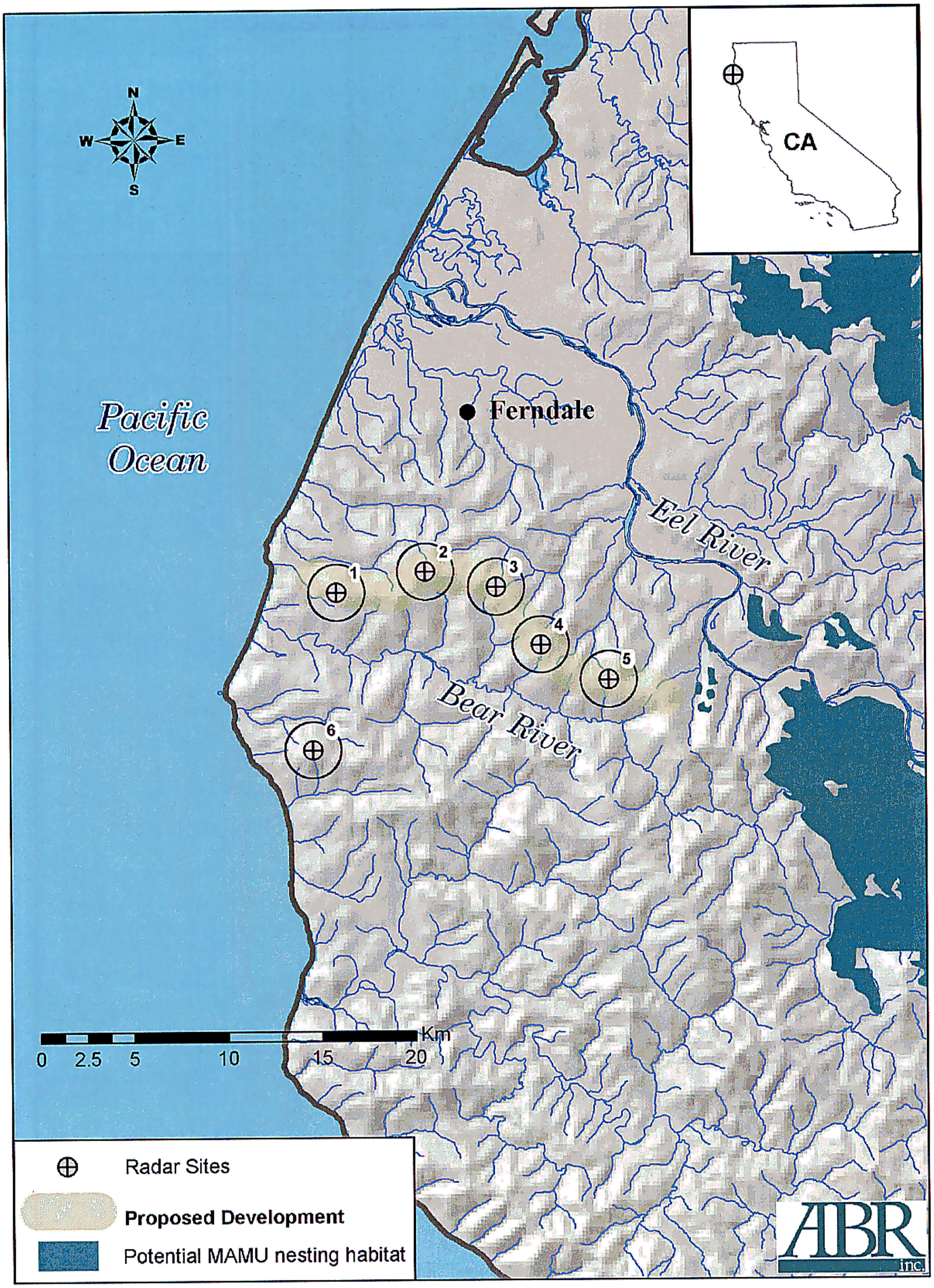

Figure 2. Location of our six radar sampling sites at the proposed Bear River Windpark, California, that were used for radar studies of Marbled Murrelets in summer 2006. The circle around each sampling site represents the approximate area of radar coverage.

Table 1. Location of radar sampling sites in the proposed Bear River Windpark (Sites 1–5) and at the Branstetter Site (Site 6), during summer 2006.

	UTM coordinates (NAD 83)		Elevation
Site	North	West	(m above sea level)
1	386286	4482852	470
2	390988	4484082	698
3	394780	4483362	608
4	397226	4480361	792
5	400891	4478607	723
6	385061	4474336	674

For each 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 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. We recorded the following weather information at the beginning of each 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 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 those of the targets of interest.

RADAR EQUIPMENT

Our mobile radar laboratory consisted of a marine surveillance radar mounted on a van. 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) and Cooper et al. (1991). The lab was powered by four 6-V batteries that were linked in series. The surveillance radar (Furuno Model FCR-1510; Furuno Electric Company, Nishinomiya, Japan) is a standard marine radar transmitting at 9,410 MHz (i.e., X-band) through a slotted wave guide (i.e., antenna) 2 m long tilted upward at 10–15° and with a peak power output of 12 kW. We operated the radar at a range of 1.5 km and set the pulse length at 0.07 µsec. Figure 3 shows the 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 (*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 elevating the forward edge of the antenna by ~15° and 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

Table 2. Sampling dates and summary of numbers of radar targets (observed before sunrise) and audio-visual detections (observed before or after sunrise) of Marbled Murrelets in the proposed Bear River Windpark (Sites 1–5) and at the Branstetter Site (Site 6), during summer 2006.

				Targets observed on radar			
Site	Date	Sampling Hours	Sunrise Time	# Landward targets	# Seaward targets	# Other targets	# Audio-visual detections
1	11 June	0431–0701	0546	0	1	2	0
	15 June	0431–0701	0546	0	3	1	0
	14 July	0443–0713	0558	0	3	136	0
	24 July	0451–0721	0606	0	7	8	0
2	10 June	0431–0701	0546	0	1	3	0
	14 June	0431–0701	0546	3	0	2	0
	11 July	0441–0711	0556	0	11	41	0
	21 July	0449–0719	0604	0	0	0	0
3	9 June	0431–0701	0546	2	0	1	0
	14 June	0431–0701	0546	2	0	2	0
	13 July	0443–0713	0558	0	0	1	0
	26 July	0453–0723	0608	0	2	3	0
4	11 June	0431–0701	0546	1	0	0	0
	15 June	0431–0701	0546	1	0	0	0
	15 July	0444–0714	0559	0	4	63	0
	23 July	0450–0720	0605	0	0	1	0
5	10 June	0431–0701	0546	0	0	7	0
	13 June	0431–0701	0546	4	0	0	0
	12 July	0442–0712	0557	2	1	0	0
	20 July	0448–0718	0603	1	2	20	0
Sites 1–5 Subtotal:				16	35	291	0
6	12 June	0431–0701	0546	0	2	0	0
	16 June	0431–0701	0546	0	2	4	0
	16 July	0445–0715	0600	2	11	24	0
	22 July	0449–0719	0604	0	1	3	0
Site 6 Subtotal:				2	16	31	0

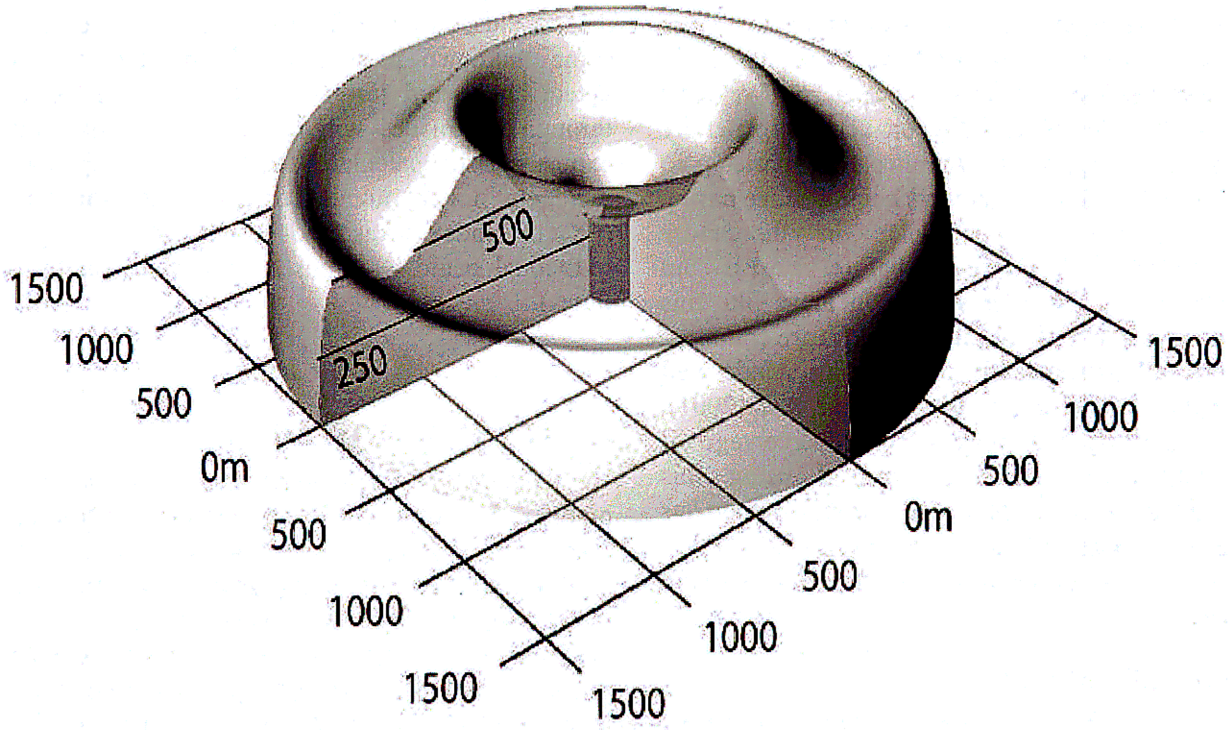

Figure 3. Approximate murrelet-sampling airspace for the Furuno FR–1510 marine radar at the 1.5-km range setting, as determined by field trials with Rock Pigeons, which are similar in size to Marbled Murrelets. Note that the configuration of the radar beam within 250 m of the origin (i.e., the darkened area) was not determined.

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 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 2005). For quality assurance, we cross-checked results of the SPSS analyses with hand-tabulations of small data subsets whenever possible. For all analyses, we classified targets as "landward" or "seaward" if they were flying within 60° of east (i.e., >30° and <150°) or west (i.e., >210° and <330°), respectively, and classified targets as "other" if they were not flying in a landward or seaward direction. Following Cooper et al. (2001, 2005, 2006), we used landward radar counts as our daily index of abundance at a site.

Marbled Murrelet targets detected on radar were distinguished from other species by their flight speed, timing, and target signature. We have determined that a >40-mi/h (64-km/h) speed cutoff minimizes the number of non-murrelet species and eliminates only a small percentage (~3%) of Marbled Murrelets (Cooper et al. 2001). Thus, all targets with a flight speed greater than 40 mi/h (64 km/h) were considered to be Marbled Murrelets, unless the target signature was typical of a flock of Band-tailed Pigeons, or the target was observed after sunrise. 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 targets are easily distinguished from a typical Marbled Murrelet target. In addition, we eliminated targets that were observed after sunrise, to help eliminate single Band-tailed Pigeons from the data set. We have found that Band-tailed Pigeon activity generally does not start until a few minutes after sunrise (i.e., 75 min after our radar surveys begin), so we have a great degree of confidence in the radar identification of murrelets before sunrise, but lower confidence after sunrise in areas like this study area where Band-tailed Pigeons are common. Nearly all 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 birds would be missed using this technique. Further, 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.

EXPOSURE INDEX

To describe passage rates within the potential turbine area we developed an exposure index (estimated number of times that murrelets would pass within the airspace occupied by the proposed turbines each morning). The exposure index is comprised of several components, including: (1) *number of target/km flying <125 m* agl each morning (calculated by multiplying passage rates from surveillance radar by the percentage of murrelets with flight altitudes <125 m agl; and (2) *turbine area* that murrelets would encounter when approaching turbines from the side (parallel to the plane of rotation) or from the front (perpendicular to the plane of rotation). These factors are combined as described in Table 3 to produce the exposure index.

We consider these estimates to be indices because they are based on several simplifying assumptions. The assumptions for this specific project include: (1) minimal (i.e., side profile) and maximal (i.e., front profile, including the entire rotor-swept area) areas occupied by the wind turbines relative to the flight directions of murrelets, and (2) a worst-case scenario of the rotor blades turning constantly (i.e., used the entire rotor swept area, not just the area of the blades themselves). Note that our exposure indices estimate how many times a murrelet(s) would be exposed to turbines, not the number of murrelets that would actually collide with turbines (because some unknown proportion of murrelets would detect and avoid turbines and some could pass through the blades without collision). Also, the exposure index calculates the number of exposure incidents, not the number of individual murrelets (i.e., the index takes into account that a single individual could be exposed to turbines multiple times).

RESULTS

PATTERNS OF MOVEMENT

Our radar observations suggested that the number of murrelets crossing the proposed turbine string (i.e., landward targets) was low in summer 2006 (Table 1). Specifically, number of landward targets observed prior to sunrise ranged from 0 to 4 per morning and the number of seaward targets ranged from 0 to 11 per morning. In addition to the landward/seaward targets, we observed 0–136 "other" targets per morning.

There was some among-site variation in the number of murrelet targets: we did not observe any landward targets during the four surveys at Site 1, but observed 7 targets on the four surveys at Site 5 (Table 1). While there was some of this among-site variation in the total number of landward targets observed, we did not see strong evidence of any "funnel points" or areas of high concentration in the vicinity of the proposed turbine string (Fig. 4).

We observed more landward targets in June (13 targets) than in July (5), but observed far fewer seaward and "other" targets in June (9 and 22, seaward and "other" targets, respectively) than July (42 and 300, respectively. Further, most (91%) of the "other" targets and 73% of the seaward targets were flying in a southerly direction (i.e., 180–230°) and were large, fast-flying targets. Because of the consistency of direction, target signature, flight speeds, and July timing of the majority of those southbound birds, we believe that many of these were migrating shorebirds, which are known to begin to pass over the area in July. No audio-visual verifications of radar targets (i.e., murrelets or other species) occurred at any of the sites during the pre-sunrise period, however.

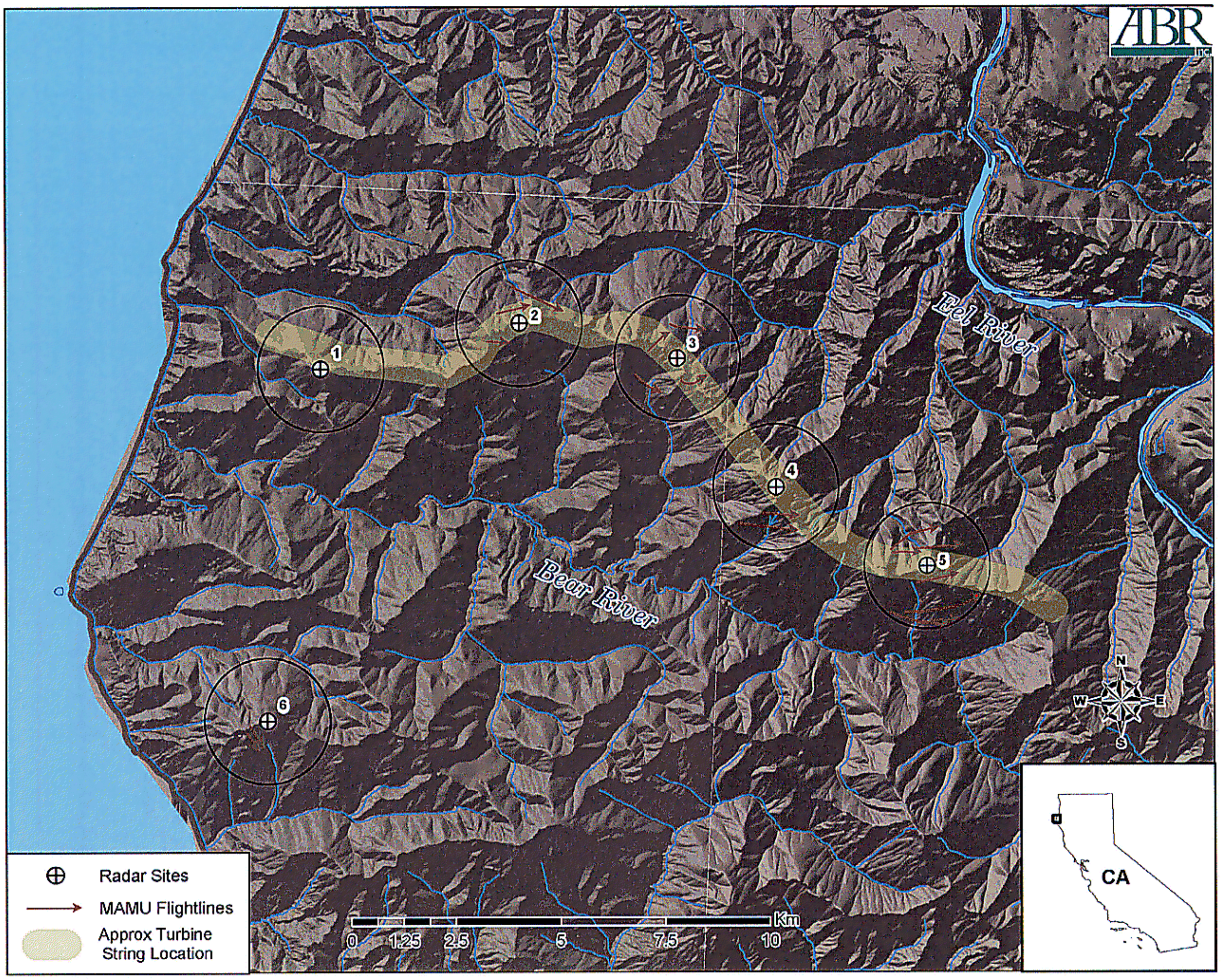

Figure 4. Map showing the flight paths of landward radar targets observed before sunrise on four mornings at each of five sites (1–5) in the Bear River Windpark and one site (# 6) on Branstetter Ridge, California, during summer 2006. The circle around each sampling site represents the approximate area of radar coverage.

EXPOSURE INDEX

Combining the data from landward targets at all five Bear River Ridge sites (i.e., 16 targets/20 mornings/3-km sampling range), we calculated a landward passage rate of 0.267 targets/km/morning. We made several assumptions to estimate an exposure index (i.e., the number of targets that would pass within the airspace occupied by the proposed turbines; Table 3): (1) the minimal area occupied by each wind turbine (i.e., side profile), (2) the maximal area occupied by each wind turbine (i.e., front profile, including the entire rotor-swept area), (3) a worst-case scenario of the rotor blades turning constantly, (4) that the number of murrelets that passed through the windpark on their way back to the ocean each day was the same as the number of landward targets (i.e., the daily passage rate = (landward rate × 2) = (0.267 × 2) = 0.533 targets/km/morning); (5) that the average number of birds in each target was 1.2 murrelets/target (*n* = 43 visually confirmed targets from Northern California during 2001–2004; Cooper, unpubl. data); and (6) a range of 40–50 turbines in the windpark. Further, we did

Table 3. Calculation of turbine exposure indices (estimated number of times that murrelets would pass within the area occupied by all proposed turbines each morning) during the 2006 breeding season at the proposed Bear River Windpark, California.

Calculation Parameter	40-turbine array	50-turbine array
TURBINE CHARACTERISTICS		
(A) Turbine height (m)	123.5	123.5
(B) Blade radius (m)	43.5	43.5
(C) Height below blade (m)	36.5	36.5
(D) Front to back width (m)	6	6
(E) Min side profile area of turbine (m^2) = (A x D)	741	741
(F) Max front profile area of turbine (m^2) = (C x D) + (π x B^2)	6164	6164
(G) # turbines	40	50
CROSS-SECTIONAL AREA OF WINDPARK		
(H) Min area of windpark (m^2) = (E x G)	29640	37050
(I) Max area of windpark (m^2) = (F x G)	246548	308185
PASSAGE RATE		
(J) Mean rate below 125 m agl (targets/morn/125000m^2)	0.338	0.338
(K) Area sampled below 125 m agl (m^2)	125000	125000
(L) Mean passage rate through exposure zone (targets/morn/m^2) = (J/K)	0.00000270	0.00000270
(M) Number of murrelets/target	1.2	1.2
(N) Mean number of murrelets/morn/m^2 in exposure zone = (M x N)	0.00000324	0.00000324
TOTAL NUMBER IN EXPOSURE ZONE EACH MORNING		
(O) Minimum number of murrelet flights/morn through exposure zone = (H x N)	0.096	0.120
(P) Maximum number of murrelet flights/morn through exposure zone = (I x N)	0.800	1.000

not have any altitude data for murrelets at Bear River Ridge but needed to correct our passage rates for the proportion of birds flying within turbine height, so we assumed that 63.2% of all murrelets that passed over the ridge were flying at or below turbine height (i.e., <125 m above ground level [agl]), based on percentages of murrelets observed crossing ridges at altitudes below 125 m agl on their way to/from inland breeding areas in southern Oregon (*n* = 19 flocks; Cooper and Augenfeld 2001). Thus, we reduced our passage rate by 36.8% for the calculation of the exposure index to account for the proportion of birds that would have flown above the turbine zone and not been exposed to the turbines.

If all murrelets approached the turbines from the side, an estimated 0.1–0.8 murrelets would have passed within the airspace occupied by the proposed turbines each morning (Table 2). If all murrelets approached the turbines from the front, an estimated 0.1–1.0 birds/morning would have passed within the airspace occupied by all proposed turbines. Note that all of these figures are exposure indices and thus include an unknown proportion of birds that would detect and avoid the turbines, plus a proportion of birds that would fly safely through turbine blades (spinning or non-spinning) without colliding. Thus, exposure indices estimate how many times a murrelet(s) would be exposed to turbines, not the number of murrelets that would actually collide with turbines. Also, the exposure index calculates the number of exposure incidents, not the number of individual murrelets (i.e., the index accounts for the fact that a single individual could be exposed to turbines multiple times).

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 currently is unknown. In this study, we addressed the first of these issues and documented some of the key movement patterns in order to describe some of the general properties of murrelet use of the proposed project site.

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 timing of movements unique to birds of that location. Fortunately, the Marbled Murrelet is one of the few rapid-flying species at inland sites near the Pacific coast that is active in the earliest part of the morning; hence, it has been successfully identified at many locations. Murrelets also usually produce a fairly distinctive radar echo that is larger and more directional than that of most other species. Accuracy rates for identification of landward- and seaward-flying Marbled Murrelets with radar during morning in Washington, Oregon, and California range from 69–98%, (Hamer et al. 1995; Cooper et al. 2000, 2001, 2005), with the identification rate of landward targets usually being better than seaward targets. Further, Burger (1997) reported that error rates in British Columbia were too low to have affected his radar counts significantly.

In the study at BRW, we did not have any visual observations of radar targets, so we were unable to calculate an accuracy rate for identification. Nevertheless, we felt that the majority of inbound, landward targets were Marbled Murrelets, because their timing, speed, direction, and target signature was consistent with known murrelet targets from other studies. Further, because we eliminated targets that were observed after sunrise, we probably eliminated most Band-tailed Pigeons from the data set. We have found that Band-tailed Pigeon activity generally does not start until a few minutes after sunrise. Since nearly all murrelets fly into nesting stands well before sunrise (Burger 1997, Cooper et al. 2001), it is likely that in using this strategy we eliminated band-tailed targets from our data while only missing a small percentage of landward murrelet targets.

In contrast to landward targets, it is highly likely that the seaward-bound and "other" targets were heavily contaminated by shorebird migrants during July. For example, we observed more landward targets in June than in July, but observed far fewer seaward and "other" targets in June than July. Further, most (91%) of the "other" targets and 73% of the seaward targets were flying in a southerly direction (i.e., 180–230°) and were large, fast-flying targets. Because of the consistent SSW flights, target signature, high flight speeds, and July timing of the majority of those birds, we believe that many of these were migrating shorebirds, which are known to begin to pass over the area beginning in late June or early July. For example, Dunlin (*Calidris alpina*) and Short-billed Dowitcher (*Limnodromus griseus*) are two common shorebird migrants that begin to pass through the area during this period (Paulson 1993, Harris 2005). Observations in the second year of this study may provide more information on species identification of these seaward and "other" targets, but because we wanted to avoid contaminating the murrelet dataset with these southbound shorebirds and because we have always used landward targets as our index of abundance for radar studies (e.g., Cooper et al. 2001, 2005, 2006), we feel that it was appropriate and necessary to use landward targets as the index of abundance for the present study at the BRW.

PATTERNS OF MOVEMENT

Our radar study found that murrelet use of the BRW was low (i.e., ~0.3 landward targets/km/morning), which was consistent with results of previous audio-visual studies of murrelets in the vicinity that found no evidence of nesting Marbled Murrelets in the BRW and little nesting habitat in the area (Nielson and Leiston 1994). Specifically, Nielson and Leiston (1994) did not record any detections of Marbled Murrelets on a total of 327 intensive survey visits and 102 survey visits to 51 transect stations. In addition to observing relatively low use of the area, we did not see any obvious areas of concentration or "bottlenecks" for murrelet targets. Since sample sizes were so low (*n* = 16 targets), however, the addition of a second year of data should provide more solid information on the existence of "bottleneck" areas along the proposed turbine string.

Landward passage rates of murrelets over the BRW were far lower than passage rates over many other sites in Northern California. For example, the average landward passage rates observed at a site along the Eel River approximately 10 km east of the BRW was ~53 targets (landward and seaward targets combined) per morning in 2006 (D. Bigger, pers. comm.), compared to <3 targets (landward and seaward) per morning at the BRW in 2006. Radar counts also were higher at other locations in the general area: landward counts at 10 sites in northern California averaged 42 targets/site/morning in 2003 and 54 targets/site/morning in 2004, with a range of 4–170 targets/site/morning (Cooper et al. 2005). Their highest radar counts were recorded at sites where large, contiguous blocks of suitable nesting habitat occurred near the ocean (e.g., Redwood National Park) and, not surprisingly, they found a strong correlation between radar counts and the amount of potential nesting habitat inland from the radar site.

Although the BRW study area also is located on a ridge that lies just west of a large, contiguous block of nesting habitat of Marbled Murrelets (e.g., Humboldt Redwoods State Park; Fig. 1), one reason for the low counts we observed may be that murrelets were foraging at points further north, rather than directly offshore from the nesting habitat. Results of boat counts support this notion: marine densities of Marbled Murrelets tend to be lower in the area offshore from, and south of, Cape Mendocino than in areas further north along the coast (i.e., from ~Trinidad, California, to the Oregon border; Ralph and Miller 1995, Miller et al. 2002). If most murrelets were foraging in these northern locations rather than directly offshore, it would make sense from an energetic standpoint for the birds to follow the Eel River into the nesting areas of Humboldt Redwoods State Park, rather than flying down the coast, then inland over the ~750-m-high ridgeline of the BRW on their way to the nesting habitat.

INTERANNUAL VARIATION IN RADAR COUNTS

Recent evidence suggests that 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) affect the distribution, abundance, and reproduction of seabirds (Ainley et al. 1994, Oedekoven et al. 2001). 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 fishes and zooplankton that are an important food source for seabirds. The oceanic variation associated with ENSO events has 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. in press) 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). 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. 2006a).

A strong ENSO event did not occur in 2006 which suggests that radar counts should have been somewhat average this year. Data from local radar studies (Bigger 2006b; D. Bigger, pers. comm.) are equivocal in their support of this contention, however: their average 2006 radar count fell within the range of counts observed during 2002–2005, but the 2006 count was the second lowest of those counts. These data suggest that our radar counts in the BRW in 2006 may have been slightly lower than average, but probably were not abnormally low. We plan to collect data in 2007 to help address this question of annual variation in radar counts at the BRW.

TARGETS WITHIN THE PROPOSED TURBINE AREA

We estimated an exposure rate 0.1–1.0 murrelets/morning passing within the airspace occupied by all proposed turbines during summer 2006. It is possible to use these estimated exposure rates as a starting point for developing a complete avian risk assessment; however, it currently is unknown whether bird use and fatality at wind power developments are strongly correlated. There are a variety of factors (e.g., weather) that could be more highly correlated with fatality rates than bird abundance. To determine which factors are most relevant, studies that collected concurrent bird use, weather, and fatality data would be needed to begin to determine whether bird use and/or weather conditions can be used to predict the likelihood of bird fatalities at wind power developments.

In addition to these questions about the unknown relationship between fatality, weather, and abundance, there also is very little data available on the proportion of murrelets that (1) do not collide with turbines because of their avoidance behavior (i.e., birds that alter either their flight paths or altitude to avoid colliding with turbines) and (2) safely pass through the turbine blades by chance alone—a proportion that will vary with the speed at which turbine blades are turning as well as the flight speeds of individual birds. The proportion of murrelets that detect and avoid turbines is currently unknown (but see Winkleman 1995, Desholm and Kahlert 2005, and Desholm et al. 2006 for studies of waterbirds in Europe). Clearly, detection of turbines could alter flight paths, passage rates, and flight altitudes of birds which in turn could reduce the likelihood of avian collisions. Although there are no empirical data that predict a species' ability to pass safely through the rotor-swept area of a turbine, there is a hypothetical model available (Tucker 1996). We speculate that the values are high for both the proportion of birds that avoid the turbines and the proportion that safely pass through turbines, considering the relatively low fatality rates (of other species) at wind power developments in the U.S. (Erickson et al. 2002). Again, our exposure indices estimate how many times a murrelet(s) would be exposed to turbines, not the number of murrelets that would actually collide with turbines. Also, the exposure index calculates the number of exposure incidents, not the number of individual murrelets (i.e., the index accounts for the fact that a single individual could be exposed to turbines multiple times).

There are additional factors that could affect our estimates of exposure, both in a positive and a negative direction. One factor that was not included in our morning exposure model was evening flights. Evening movements consist of a dusk visit by murrelets to inland locations. In general, fewer birds fly inland during the evening movement period: evening passage rates average 18–43% of morning rates (Burger 2001, Cooper and Augenfeld 2001, Cooper et al. 2003, Cooper et al. 2005; B Cooper, unpubl. data). Given the low morning passage rates at BRW (i.e., 0.1–1.0), the addition of evening rates still would not have raised the exposure index up to 2 birds per day. It is worth noting, however, that exclusion of a correction for evening movements would create a slight negative bias for a *daily* exposure index. Another factor that would create a negative bias in our index are those targets that were missed because they flew down in the trees or within other radar shadows and targets that flew inland after our sunrise cutoff. Because of the excellent nature of our sampling sites, we believe that the proportion of targets that were missed because they passed through the entire area of coverage within a radar shadow were minimal. We also believe that only a small proportion of landward targets flew in after our sunrise cutoff, because only 5% of the landward targets (n = 3,209 targets) at other sites in northern California flew in after sunrise (Cooper et al. 2005, B. Cooper, unpubl. data).

There are other factors that may have caused an upward bias in our exposure index. One of these was the assumption that the number of seaward-bound murrelets that passed through the windpark on their way back to the ocean each day was similar to the number of landward targets (i.e., that the daily passage rate = [landward rate × 2]). Most studies have found that landward counts are significantly higher than seaward counts (Cooper et al. 2001, 2005, 2006). A second factor that could have biased our exposure index upwards was the inclusion of non-murrelet targets. Our sunrise cut-off and use of only landward targets probably minimized the inclusion of non-murrelets, but it is certainly possible that some of our landward targets that met the criteria for murrelets were shorebirds, or some other fast-flying species that were active during the sampling period. Another factor that could contribute to a positive bias in the exposure index if it were extrapolated across the entire ~150-day breeding season would be that we collected data during what is thought to be the period of peak radar counts. Lower counts are expected to occur during May and August (Cooper et al. 2001, Evans Mack et al. 2003). Further, while it is known that some birds visit inland areas in California during the winter months (Naslund 1993, O'Donnell et al. 1995, Nelson 1997), the visitation rates then are likely to be lower than during June and July. Thus, it would be inappropriate to apply our exposure rates to the winter months. A final factor that could affect our exposure indices (either direction) is interannual variation in counts and, as we have already pointed out, counts in 2006 may have fallen in the low-to-mid range of counts that one might expect, based on other radar surveys in the area (Bigger 2006b, Bigger, pers. comm.) and on the lack of major ENSO events during 2006. We plan to collect another year of data at BRW in 2007 to help address annual variation in radar counts.

CONCLUSIONS

This study focused on the movement patterns and flight behavior of Marbled Murrelets during the peak period of inland activity within the murrelet breeding season. The key results of our study were: (1) murrelet use of the BRW was ~0.3 landward targets/km/morning; (2) there was some intersite variation in radar counts, but no obvious areas of concentration or "bottlenecks" for murrelet use; and (3) 0.1–1.0 murrelets/morning passed within the airspace occupied by all proposed turbines during summer 2006. Again, this exposure index probably would be far lower than 1 murrelet/morning if we were able to correct that number for the proportion of birds that detect and safely maneuver around or through the turbines. Also, the exposure index calculates the number of exposure incidents, not the number of individual murrelets (i.e., the index accounts for the fact that a single individual could be exposed to turbines multiple times), so if one murrelet was killed over the course of time, it could substantially reduce the exposure rate after that event. In summary, we believe the risk of murrelet collisions at BRW is very low relative to many other coastal locations, but over time it is possible that a low number of collisions with turbines could occur, given murrelet's lengthy breeding season, the possibility of inland flights during the nonbreeding season, and the low light conditions in which these birds commute between the ocean and nesting areas.

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