CHARACTERISTICS OF MARBLED MURRELET (*BRACHYRAMPHUS MARMORATUS*) HABITAT IN NORTHERN CALIFORNIA

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ABSTRACT/SUMMARY

The Marbled Murrelet (*Brachyramphus marmoratus*) is a federally threatened seabird and little is known about the species' nesting ecology, especially in the redwood forests of northern California. Redwood National and State Parks represents a major component of the remaining stands of old-growth redwood forest where Marbled Murrelets nest. We built habitat models to examine differences between used Marbled Murrelet nest sites and random sites and between successful and failed nests in Redwood National and State Parks at three spatial scales: stand, tree, and nest site. The probability of nest-site use increased with distance to the nearest paved road and nests were more likely to be successful in stands with a greater number of downed logs. Nest trees were larger than the average tree size in the stand, but not always the largest tree in the stand. We also measured sound levels at roads and park facilities and estimated the distances from these sites at which anthropogenic noises could no longer be detected. Using a Geographic Information System, we then mapped potential Marbled Murrelet habitat in Redwood National and State Parks, and excluded areas around roads and park facilities that were likely impacted by anthropogenic noise disturbances. Management actions could include protection of these habitat characteristics within old-growth redwood forest, particularly where it occurs far from roads, and minimization of human activities and disturbance within potential Marbled Murrelet habitat in Redwood National and State Parks.

INTRODUCTION

The Marbled Murrelet (*Brachyramphus marmoratus*) is a seabird in the Alcid family whose populations have declined over the last 30-50 years because of anthropogenic activities including oil spills, gill net fishing, and particularly the loss and fragmentation of nesting habitat resulting from the harvest of old-growth coniferous forests in the northwestern United States (McShane et al. 2004). Populations in Washington, Oregon, and California were federally-listed as threatened in 1992 (USFWS 1992). The species was also state-listed as endangered in California in 1992 (California Fish and Game Commission 1992). Marbled Murrelets in California nest in old-growth redwood (*Sequoia sempervirens*) forests. Timber harvest on the northern coast of California began in the mid-1800s and currently only 4% of old-growth redwoods remain (USFWS 1997).

Egg and chick mortality from predation, frequently by corvid species such as ravens (*Corvus corax*) and Steller's jays (*Cyanocitta stelleri*), has also contributed to Marbled Murrelet population declines (Nelson and Hamer 1995a, Hébert and Golightly 2006, 2007, Golightly et al. 2009). Habitat fragmentation increases forest edges around nesting habitat which results in greater concentrations of these predators near nest sites (Hamer and Nelson 1995, Vigallon and Marzluff 2005, Marzluff and Neatherlin 2006, Hébert and Golightly 2006, 2007).

In Washington, Oregon, and California, Marbled Murrelets nest on high branches of large old-growth conifers, within 80 km of the coastline, and forage in near-shore marine habitats (Golightly et al. 2004, Meyer et al. 2004, McShane et al. 2004). Females usually lay a single-egg clutch, and although replacement of a failed clutch early in the breeding season has been documented (Hébert et al. 2003, McFarlane-Tranquilla et al. 2004), it is uncommon.

Terrestrial habitat characteristics associated with nest sites have been measured at a variety of scales, including the nest site, nest tree, stand, and landscape scale, in several areas throughout their range (e.g., Grenier and Nelson 1995, Hamer and Nelson 1995, Naslund et al. 1995, Singer et al. 1995, Becker and Beissinger 2003, Ripple et al. 2003, Burger and Bahn 2004, Meyer et al. 2004, Baker et al. 2006). However, most of the focus has been on coarser scales of analysis because fine-scale analyses require knowledge of exact nest locations, which has been difficult to determine due to their secretive nesting behavior (Hamer and Nelson 1995, Hébert and Golightly 2006). Further, little is known about nesting habitat characteristics specifically in the redwoods of northern California; only Baker et al. (2006) have examined tree-level nesting habitat characteristics in redwood stands. Recently, the use of radio-transmitters has allowed researchers to track the movements of individual murrelets and accurately locate nest trees and nest sites (Perry et al. 2004, Hébert and Golightly 2006, Zharivok et al. 2007).

We quantified habitat characteristics at murrelet nest sites and at random locations as part of a radio-telemetry-based investigation in Redwood National and State Parks (RNSP), California (Hébert and Golightly 2006). RNSP contains much of the remaining old-growth habitat for Marbled Murrelets in northern California (Ralph and Miller 1995). We characterized habitat at the stand, nest tree, and nest site scales by determining if habitat differed between nest sites and random sites and between successful and failed nests.

Noise has been considered by some to be a source of disturbance and a potential deterrent to nesting murrelets, thus affecting the quality of remaining habitat (see Hébert and Golightly 2006). Areas with intense sound levels may be an important factor in the selection of nesting habitat (Hébert and Golightly 2006). In RNSP, noise generated by vehicular traffic and visitor use may also be influencing the presence of corvids which prey on murrelet eggs. Therefore, we quantified sound around roads and park facilities with the logic that sound may attract corvids or damage nesting habitat (see Hébert and Golightly 2006), and identified areas of old-growth forest in RNSP that were not affected by anthropogenic noise.

STUDY AREA

Redwood National and State Parks are located on the coast of northern California in Humboldt and Del Norte Counties (Figure 1), and include Redwood National Park, managed by the National Park Service, and Del Norte Coast Redwoods State Park, Jedediah Smith Redwoods State Park, and Prairie Creek Redwoods State Park, managed by the California Department of Parks and Recreation (NPS 2000). The first of the state parks was created in 1923. The national park was established in 1968 and expanded in 1978 in order to protect some of the last remaining old-growth redwoods (NPS 2000). All nest sites and random plots were within old-growth, although a few sites were near forest patches that were harvested in the 1950-70s (NPS 2000).

Elevations in RNSP range from sea level to 975 m, and the old-growth forests in RNSP are dominated by redwood, Douglas-fir (*Pseudotsuga menziesii*), and Sitka spruce (*Picea sitchensis*) (NPS 2000). Other common tree species include tanoak (*Lithocarpus densiflorus*), madrone (*Arbutus menziesii*), big-leaf maple (*Acer macrophyllum),* California bay laurel (*Umbellularia californica),* and red alder (*Alnus rubra*). Three distinct watersheds are found within the parks: Redwood Creek, the Smith River, and the Klamath River, as well as a few small watersheds with streams flowing directly to the Pacific Ocean (NPS 2000). Maritime climate conditions result in cool, dry summers (13-18°C) and wet, mild winters (7-13°C). RNSP contains approximately 264 km of trails and receives about 400,000 annual visitors (NPS 2000).

METHODS

LOCATING NEST SITES AND AVAILABLE SITES

Marbled Murrelet (hereafter “murrelet”) nest site locations were estimated using aircraft to detect murrelets with radio transmitters, which were attached to murrelets as part of a concurrent study of disturbance to nesting murrelets in RNSP in 2001, 2002, and 2003 (see Hébert and Golightly 2006). Handheld telemetry was then used by ground crews to more accurately locate nest sites. Once nest trees were located, murrelet use was confirmed by audio/visual surveys (see Hébert and Golightly 2006). Nest sites were verified by visual observation or by location of a fecal ring (see Nelson and Hamer 1995b). Of the 102 murrelets tracked by Hébert and Golightly (2006) in 2001, 2002, and 2003, we utilized 10 accurately located nests for our study.

We generated 11 random locations to compare against the 10 nest sites. To determine random locations, we first calculated an 85% fixed kernel estimate (Stubblefield et al. 2006) of the nesting home ranges around the 10 nest sites in ArcView (v. 9.1, Environmental Research Systems Institute, Inc., Redlands, California). Then, we generated the random locations that were within the individual nesting ranges but at least 500 m from a nest tree, and within old-growth habitat (using topographic maps provided by RNSP). Random locations were tree-centered and experienced observers verified each location. Those occurring in incorrectly classified habitat (not old-growth) were regenerated. All nest sites and random locations were in the southern portion of RNSP (Figure 2), within 6.7 km of the Pacific Ocean and adjacent to the ocean waters where the birds were initially captured.

MEASUREMENT OF HABITAT CHARACTERISTICS

For comparative purposes, we examined habitat variables that were used for other murrelet studies (Grenier and Nelson 1995, Hamer and Nelson 1995, Manley and Nelson 1999, Burger and Bahn 2004, Baker et al. 2006) and measured habitat characteristics at the stand scale for each nest site and random location, and at the tree scale and nest site scale for each nest site. To measure the stand scale around each nest tree and random location, we selected a random direction for an initial transect line and established five 56-m long, radial transect lines around each location. Along each transect line, we measured the mean diameter at breast height (dbh; cm) of all trees, tree density (sum of basal area for all trees >10 cm dbh in plot; m^2/ha), number of downed logs (diameter >50 cm), tree species composition (%), canopy closure (%), canopy height (m), number of canopy layers, number of canopy gaps, and distance to nearest canopy gap (straight-line distance from nest tree to nearest gap used by murrelets; m). Finally, we measured the distance from the nest tree or random location to the nearest paved road (m), trail (m), campground (m), streambed (m), and coastline (km), and the slope (%), aspect (°), and elevation (m) in ArcView.

At the tree scale, we measured height (m), dbh (cm), number of small platforms (limbs 10-19.9 cm in diameter) and large platforms (limbs >20 cm in diameter), vertical extent of the crown (m) of the nest tree, and ambient sound (dB).

At the nest site scale, for nest trees only, we measured the epiphytic cover of nest branch (%), vertical cover above nest branch (%), horizontal cover from nest branch (%), nest height (m), diameter of nest branch at trunk and at nest (cm), length (cm) and width (cm) of the nest branch, cardinal direction from trunk to nest (°), and distance from trunk to nest (cm). The condition of the nest branch was noted as healthy or alive/broken.

Hébert and Golightly (2006) determined nest success at each nest using automated telemetry receiving stations (Advanced Telemetry Systems, Bethel, Minnesota), tree-climbing observations, and video recordings. In order to predict the probability of murrelet nest site use and the probability of nest success, we built habitat models using a Resource Selection Function (Manly et al. 2002).

For the 10 nest sites and 11 random locations, we compared habitat variables at the stand scale. For the 10 nest sites at the tree scale, we compared the dbh between the nest tree and the other trees in the plot, and we compared habitat variables at the nest scale, nest tree scale, and stand scale between unsuccessful and successful nests. To reduce the number of variables used for model selection (Miller 1990), prior to model building, we eliminated variables with $P > 0.20$ based on the results of the Mann-Whitney U signed-rank tests (sample variances were unequal). Also prior to model building, we used Pearson coefficients to determine if any of the habitat variables were correlated ($P < 0.05$), and if any were correlated, we eliminated one of the two variables. We used information-theoretic models with Akaike's Information Criterion, corrected for small sample size (AICc; Akaike 1973, Burnham and Anderson 2002) to assess the overall strength of each model. We ranked all candidate models according to their AICc values, and the best model was the one with the smallest AICc value (ΔAICc = 0) (Burnham and Anderson 2002). We also calculated Akaike weights (w_i) to determine the weight of evidence in favor of each model (Burnham and Anderson 2002).

ESTIMATING ANTHROPOGENIC SOUND DISTURBANCE

We measured ambient sound in different areas of RNSP to determine the distance at which sound levels from anthropogenic disturbances reached background levels (no greater than normal environmental noise in habitat-type that was not near anthropogenic disturbances). Sound measurements were made using a digital Type 1 sound level meter (Model 407750, Extech, Waltham, Massachusetts) on a tripod ~1 m from the ground (configured for 'A' weighting, slow response). Locations for sound equipment were chosen for an absence of obstructions near the measuring device, (> 3 m from reflective surfaces and an avoidance of open fields). To minimize noise contamination, the observer was 7-15 m from the microphone during all measurements. At each location, meteorological information (wind speed, wind direction, temperature, humidity, and sky conditions), and a general description of the area was recorded.

We measured sound at two types of locations: at roads and at park facilities (i.e., visitor centers, picnic areas, campgrounds, parking lots). The duration of each session was 15 min, with the minimum and maximum sound sampled every 2 min during the 15-min session. Measurements occurred on days without precipitation with wind speeds of <3.5 mph. When measuring at a road, sound meters were placed ~400 m from intersections with the nearest connecting road and 10 m from the edge of any road. At park facilities, sound meters were placed ~100 m from center of activity area (measured from the north side of the center).

Before conducting sound measurements at the roads, we first conducted a pilot study to determine the time of day with the highest level of activity at three kinds of roads: along the main paved highway through the park (Highway 101), at a frequently used secondary park road, and at a common day-use trail. At each location, we measured sound during one 15-min session in the morning (0700-1000 h), afternoon (1100-1400 h), and evening (1500-1800 h). We also recorded the number of people and vehicles that passed through the area during each 15-min session. Each session was repeated 3 times on 3 different days. Afternoon and evening had the highest levels of activity and greatest number of people and vehicles; therefore, for the sound study at roads, we collected all sound measurements between 1000-1600 h.

We measured sound at 9 road locations (Appendix A); 3 at unpaved roads; 3 at paved, heavily used roads (highways or major parkways); and 3 at paved, lightly used roads. At each location, we conducted one 15-min session at three different distances from the road. These distances were at the road (hereafter "source"), at a distance at which we reached background noise (≤ 42 db; Hébert and Golightly 2006; hereafter "background"), and then at the midpoint, which was halfway between the two locations (hereafter "midpoint"). If the source was ≤ 42 dB during the initial set of sound measurements, then all three sessions were conducted at the source. If slope at the source was >1%, we conducted one 15-min session pointing the sound meter upslope and one 15-min session pointing the meter downslope. To determine anthropogenic activity levels, during each 15-min session, we recorded the number of cars, trucks, tractor-trailer vehicles, people, dogs, and other (i.e., motorcycles) that produced sound or passed through the source.

We measured sound at 15 park facilities (Appendix A); 3 at large campgrounds (>70 campsites), 1 at a small campground (26 campsites), 2 at large parking areas (>25 parking spaces), 3 at small parking areas (<15 parking spaces), 3 at campground/picnic areas, and 3 at other types of facilities (1 at a youth hostel and 2 at visitor centers). At each facility, we measured sound during three 15-min sessions, one at the source, one at background, and one at the midpoint. Again, if the source was ≤ 42 dB during the initial set of sound measurements, then all three sessions were conducted at the source.

For each session, we compared the minimum and maximum sound measurements between the source, midpoint, and background and calculated the coefficient of variation (CV) of sound measurements using the ratio between minimum and maximum sound measurements. We estimated the distance from roads and facilities at which the maximum sound levels could no longer be heard by determining at which location and distance from the source the mean maximum sound measurement (+1 SE) was less than background sound. If the mean maximum sound (+1 SE) at background was still greater than background sound, we estimated the distance that sound levels reached background levels by regressing all mean maximum sound measurements with distance from the source. We then determined where mean maximum sound measurements intercepted background sound (42 dB), and used this to predict the distance from the source that mean maximum sounds would be less than or equal to background sound.

For roads and park facilities where all three sessions were conducted at the source (because initial sound measurements were ≤ 42 dB), we calculated the mean sound, range, standard error (SE), and coefficient of variation (CV) for minimum and maximum sound measurements. We classified each road and park facility as “quiet” (mean maximum: ≤ 42 dB), “medium” (mean maximum: 43-50 dB), or “loud” (mean maximum: > 50 dB).

Using digital maps of vegetation type obtained from RNSP, we mapped old-growth redwood/Douglas fir forest within RNSP, excluding areas that were > 300 m from streams, and areas > 50% slope (Meyer et al. 2004). Then, we mapped all roads (paved and unpaved), and park facilities within RNSP. We estimated the distance from roads and park facilities where background noise would be the only noise detected. We then buffered all roads and park facilities by this distance and excluded these areas from old-growth redwood/Douglas fir forest in RNSP. The remaining area was classified as potential Marbled Murrelet habitat that was not affected by anthropogenic noise.

RESULTS

NEST SITE USE AT THE STAND SCALE

We measured 16 habitat characteristics at the stand scale for 10 Marbled Murrelet nest sites and 11 random sites (Table 1). Six habitat variables were highly correlated at the stand scale (Appendix B); all were excluded from the model because they did not differ between nests and random sites (Mann-Whitney U tests, $P > 0.20$). Two of the 16 variables, distance to nearest paved road and canopy height, differed between nests and random sites and were used for model selection (Mann-Whitney U tests, $P < 0.20$). Nest sites were farther from paved roads and were in stands with lower canopy heights than random sites (Table 1).

From the two variables selected, there were 3 candidate models. The model that included distance to nearest paved road provided the best discrimination between nests and random sites at the stand scale (Table 2). This model received > 70% of the Akaike weight and was 3 times more likely than the second-ranking model (which included canopy height), and 10 times more likely than the third-ranking model (which included distance to nearest paved road and canopy height), to be the best explanation for nest site use.

NEST SITE SELECTION AT THE TREE SCALE

For the 10 Marbled Murrelet nests at the tree scale, the mean dbh of all nest trees (266 ± 30 cm; $\bar{x}$ ± SE) was greater than the mean dbh (122 ± 8 cm) of all other trees in the plot (t = -4.64; df = 19; $P = 0.001$). However, nest trees were not always the largest trees in the plot; the mean dbh of the three largest trees (382 ± 14 cm) was greater than the mean dbh of the nest trees (266 ± 30 cm; t = -3.98; df = 38; $P > 0.001$).

NEST SUCCESS AT THE NEST SITE, NEST TREE, AND STAND SCALE

Of the 10 nests located by Hebert and Golightly (2006), 6 nests successfully fledged chicks, 3 nests failed to fledge chicks, and 1 nest failed to fledge a chick in 2002 but fledged a chick in 2003. We measured 33 habitat characteristics at the nest site, nest tree, and stand scale. Four habitat variables were highly correlated at the nest site scale, and one habitat variable was highly correlated at the tree scale (Appendix C); one of each correlated pair was excluded from the model because they did not differ between nests and random sites (Mann-Whitney U tests, $P > 0.20$). At the nest site scale, cardinal direction (included in the model) was negatively correlated with distance from nest to trunk (excluded from the model); nests on the west side of the nest tree were closer to the trunk than those on the east side of the tree (Appendix D).

Six of the 33 habitat characteristics at the nest site and stand scale (cardinal direction of nest branch, horizontal nest cover, number of small platforms, number of downed logs, distance to nearest campground, and tree density) differed between successful and unsuccessful nests (Mann-Whitney U tests, $P < 0.20$; Table 3), and were used for model selection. From the six variables selected, there were 8 candidate models. The model that included number of downed logs provided the best discrimination between nest success and failure (Table 4). This model received 45% of the Akaike weight and was 3 times more likely than the second-ranking model (which included horizontal nest cover), and 4 times more likely than the third-ranking model (which included number of small platforms), to be the best explanation for nest site success.

ANTHROPOGENIC SOUND DISTURBANCE

Activity at roads.-- Activity levels were greatest at the three paved, heavily used roads, with > 20 counts of cars, trucks, and tractor-trailer trucks per session at Drury Parkway, and > 40 counts of cars truck, and tractor-trailer trucks per session at Highway 101 and Highway 199

(Figure 3). The other two types of roads (paved, lightly used roads and unpaved roads) had lower activity levels, with < 20 counts per session (Figure 4).

Road-associated noise.-- Sound levels were greater than background noise at four roads; one was a paved, lightly used road (Bald Hills Road) and three were paved, heavily used roads (Highway 101, Highway 199, and Drury Parkway). At these four roads, the distance from the source to background locations were 10-119 m, and midpoints were 5-31 m from the source (Figure 5). Although midpoints and background locations were generally quieter than the source, all of them had mean maximum sound levels greater than background noise. Using linear regression, we estimated that background noise would be the only sound detected (i.e., no road-associated noises) at a minimum distance of 135 m from roads (Figure 6).

Park facility-associated noise.-- Sound levels were greater than background noise at three park facilities; one at a small parking lot (Lady Bird Johnson picnic area), one at a large parking lot (Kuchel Visitor Center parking lot), and one at a large facility (Prairie Creek Visitor Center) (Figure 5). At these three sites, background locations were at distances of 20-50 m from the source, and midpoints were at distances of 10-20 m. The background location for Prairie Creek Visitor Center, at 50 m from the source, was the only location that had a mean maximum sound level (+1 SE) of less than background noise (Figure 7). Therefore, we estimated that background noise would be the only sound detected (i.e., no facility-associated noise) at a minimum distance of 50 m from park facilities.

Sound buffers.-- We estimated that RNSP has a total of 16,023 ha (39,593 ac) of old-growth redwood/Douglas fir forest habitat which would be potentially suitable for Marbled Murrelets. We placed a buffer of 135 m around all roads (paved and unpaved), and 50 m around all park facilities and excluded these areas from old-growth redwood/Douglas fir forest in RNSP, for a total of 1298 ha (3207 ac) (8% of total) excluded (Figure 8). The amount of old-growth redwood/Douglas fir suitable for Marbled Murrelet habitat was estimated at 14,725 ha (36,386 ac) in RNSP that was not affected by anthropogenic noise disturbance associated with roads and park facilities.

DISCUSSION

Consistent with other studies on Marbled Murrelet nesting habitat in northern California and southern Oregon (Miller and Ralph 1996, Meyer et al. 2004), we found that murrelets in northern California nested predominately in redwood trees, although Douglas-fir has also been a common nest tree species in the Pacific Northwest and in central California (Hamer and Nelson 1995, Baker et al. 2006). Nest trees were large (mean dbh: 266 cm), tall (mean height: 60 m), and probably contained numerous large branches with suitable and well-concealed nest platforms (Meyer et al. 2004, Perry et al. 2004, McShane et al. 2004). Nest trees were larger, on average, than the other trees in the plot but they were not the largest trees in the plot; the mean dbh of the three largest trees measured in plots with a nest tree was larger than the nest tree dbh. This is similar to a study that found that nest tree diameters were within the upper 25th percentile compared to other trees around the nest, but most nest trees were 5-10 m shorter than the surrounding canopy (Naslund et al. 1995). Hamer (1995) found that suitable platforms for nesting increased rapidly with an increase in tree diameter from 50 to 200 cm, but then there was no increase in the mean number of platforms for larger trees that ranged from 220 to 300 cm in diameter. This suggests that murrelets require large trees for nesting because suitable nesting platforms are found in larger trees, but they may not need to select the largest trees in the stand.

Other nest tree characteristics, such as nest height, distance from nest to trunk, nest branch diameter, nest cover, and number of small and large platforms, were similar to nest sites in other geographic areas or different forest types (i.e., predominately Douglas-fir instead of redwood) in British Columbia (Burger and Bahn 2004), Washington (Hamer and Meekins 1999), Oregon (Nelson and Wilson 2002), and California (Hamer and Nelson 1995, Baker et al. 2006; see McShane et al. 2004).

Distance to nearest paved road was the best habitat correlate of nest site use at the stand scale. Murrelets were more likely to nest farther away from paved roads, consistent with findings from other studies (Manley and Nelson 1999, Meyer et al. 2004). They may have nested farther from roads to avoid anthropogenic disturbance and nest predators such as Steller's Jays, which tend to be more abundant along forest edges (Marzluff et al. 2004), and near human settlements (Marzluff and Neatherlin 2006); roads create forest edge and human settlements and campgrounds often occur along roads.

Number of downed logs was the best habitat correlate of Marbled Murrelet nest success (Table 4), and nests were more likely to be successful in stands with a greater number of downed logs (Table 6). It is possible that a greater number of downed logs indicates openings in the canopy (created by fallen trees), where murrelets could access nest sites. Nests were also more likely to be successful at sites with less horizontal nest cover and reduced tree density, suggesting that murrelets utilize openings in the stand, and at the nest, to access nest sites. Nest success may increase with greater access to nests because they are able to fly directly into nest sites and reduce the chance of detection by predators. Several studies (e.g., Hamer and Meekins 1999, Bradley 2002, Nelson and Wilson 2002) have found that murrelets tended to select nest sites that were close to natural openings, as it may improve access. Nest success may have also been greater in habitats with more downed logs, less horizontal cover and tree density because these habitats may contain fewer corvids. Steller's Jays have been associated with fragmented habitat and forest edges and use young-seral forests, barren areas, agriculture, and settled areas more than late-seral forests (Marzluff et al. 2004). Habitats that contain downed logs, little horizontal cover and low tree density tend to occur in late-seral, unharvested, and unfragmented forests. Corvids have been associated with more "complex" and structured landscapes because these areas are likely to contain a wider range of food sources (Marzluff et al. 1999, Raphael et al. 2002); little horizontal cover and low tree density indicate a simple forest structure with fewer food sources, and may not be optimal corvid habitat.

The third-best model indicated that nest success was more likely with a greater number of small platforms. Several studies have indicated that nest trees with numerous platforms were important nesting habitat characteristics for Marbled Murrelets (Hamer et al. 2008, McShane et al. 2004).

ANTHROPOGENIC SOUND DISTURBANCE

Hébert and Golightly (2006) found that Murrelet nest sites tended to be slightly louder (47 ± 2 dB) than background sound (42 ± 1 dB; measured at 11 random sites;), although this difference was not significant. Higher sound levels have been associated with human activity which is known to attract nest predators such as corvids (Marzluff and Neatherlin 2006), although it could also be caused by a close proximity to a stream, singing birds, or other natural sounds. Disturbance at nest sites (indicated by sound) has been suggested to cause secretive adults to abandon eggs or feeding attempts, which would reduce reproductive success (Long and Ralph 1998, Hébert and Golightly 2006). There was no difference in the sound levels between failed and successful nests. Murrelets may not use sound levels as a cue when selecting nesting habitat; in evolutionary time, the introduction of significant anthropogenic sound has been a recent event facilitated by the automobile. Thus, given existing placement of nests at a distance further from roads, sound itself is not a daily contributor to risk of nest failure. Conversely, unusual or rare sounds could attract predators and then reduce reproductive success. Given that murrelets were more likely to nest in areas farther from paved roads, it is possible that paved roads are a better indicator of disturbance or predator activity than other measures, regardless of sound levels.

We estimated that anthropogenic noise became negligible at a distance of 135 m from roads and 50 m from park facilities, and suggest considering these areas as unavailable for murrelet habitat in old-growth forest in RNSP. Although activity and sound levels varied at different types of roads (Appendices E and F), we excluded a 135 m area around all types of roads in RNSP because we assumed that travel-associated sounds (i.e., cars, trucks) would be similar, although the amount of activity and frequency of these sound occurrences differed. Sound levels at park facilities differed by location; however, this study was a small snapshot in time and we assumed that all facilities intermittently received greater sound levels. Therefore, we also excluded a 50 m area around all park facilities that occurred within old-growth forest, and considered these areas as unavailable in the assessment of total habitat for murrelets in the parks. Roads and facilities that received more intermittent sound levels could be at a greater risk of disturbing murrelets than those that received more constant noise (i.e., from paved, heavily used roads), because murrelets in habitats with constant noise may habituate to the noise while those in quieter habitats may become disturbed by unexpected intermittent noises (Long and Ralph 1998). The exclusion of these areas affected by sound as potential murrelet habitat resulted in a relatively small loss of approximately 8%, or 1298 ha (3207 ac), of the total old-growth forest in RNSP.

The fact that murrelets were more likely to nest farther from paved roads suggested that murrelets were already selecting nesting habitat away from roads or that nests closer to roads had already resulted in consistently failed reproduction. Therefore, the 135 m buffer around roads was not likely high quality or highly used murrelet habitat. In this study, the nearest nest to a paved road was 200 m, and anecdotally, this nest failed. For murrelets that nest near anthropogenic disturbance areas, noise-related stress can result in reduced nest attendance and/or nest abandonment. In addition, human activity is known to attract corvids and increase corvid densities, which can ultimately result in increased nest predation by corvids (Marzluff and Neatherlin 2006). Thus, the effects of road and park facility-associated anthropogenic disturbances on murrelets may include poor nest success.

MANAGEMENT IMPLICATIONS

Our ability to predict nest site use and nest success was limited by the small sample size of nests (n = 10), and there may be other habitat characteristics that are important for nest site use and nest success in Redwood National and State Parks. However, these results suggest that management for Marbled Murrelet nesting habitat within the parks should include protecting stands of old-growth redwoods that are away from roads and other potential sources of anthropogenic disturbances. It is also important to protect stands of old-growth redwoods that contain natural openings in the stand and at individual trees, characteristics that are likely naturally present in areas of undisturbed and unmanaged old-growth forest. Park facilities that occur within old-growth forest, especially those that had a sound rating of “loud” or “medium”, and/or a high coefficient of variation (i.e., CV > 15 %; indicates intermittent loud noises; Appendix F) could be at risk of disturbing nesting murrelets because they probably do not habituate to intermittent loud noises. Therefore, picnic areas, campgrounds, and other park facilities that occur in old-growth forest should not be considered murrelet habitat. Restoration actions that include road removal and limiting traffic in old-growth forest would be expected to increase and improve murrelet nesting habitat. Habitat quality around park facilities and roads that do occur in old-growth forest could be improved by managing food and garbage to avoid attracting known murrelet predators such as jays and ravens.

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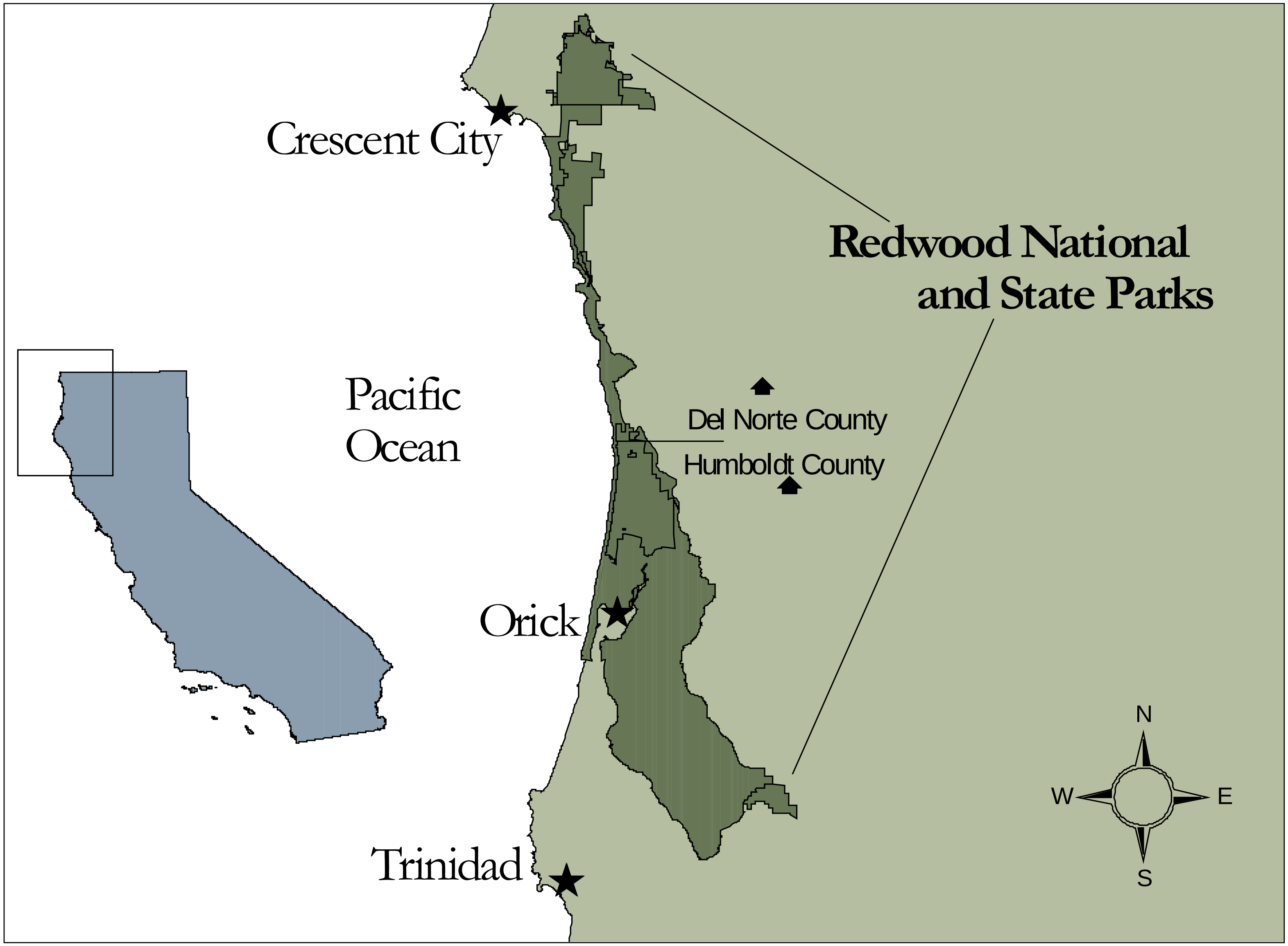


FIGURE 1. Redwood National and State Parks in northwest California.

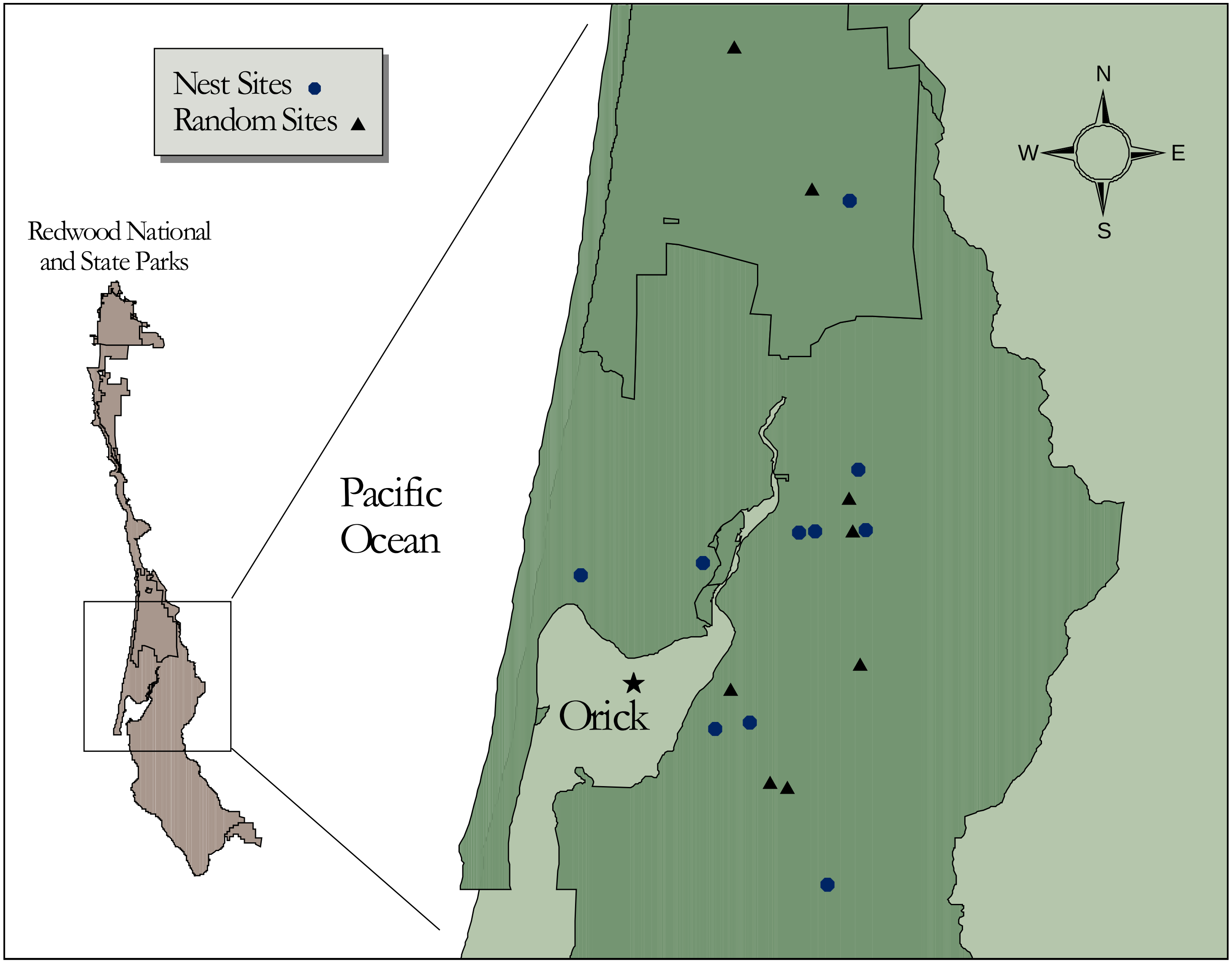


FIGURE 2. General locations for Marbled Murrelet nest sites (2001-2003) and random sites used to sample habitat in Redwood National and State Parks, California.

TABLE 1. Habitat characteristics at the stand scale for 10 Marbled Murrelet nest sites and 11 random sites in Redwood National and State Parks, California, 2001-2003.

Variable	Nest sites	Random sites	Mann-Whitney U	*P* (2-tailed)
	$\bar{x} \pm$ SE	$\bar{x} \pm$ SE		
Tree density (m^2/ha)	208.0 ± 18.6	180.8 ± 11.4	41	0.32
Mean dbh (cm)	122.5 ± 8.3	115.7 ± 8.2	44	0.44
Canopy height (m)	62 ± 5	66 ± 2	37	0.20
Canopy closure (%)	56 ± 4	60 ± 3	53	0.89
Distance to nearest canopy gap (m)	6 ± 3	7 ± 3	47	0.51
Number of canopy gaps	6 ± 1	7 ± 1	49	0.66
Number of canopy layers	2 ± 0.2	2 ± 0.1	48	0.55
Number of downed logs	34 ± 3	38 ± 3	45	0.46
Distance to nearest streambed (m)	132.2 ± 28.8	114.3 ± 26.4	48	0.62
Distance to nearest campground (km)	3.2 ± 0.4	3.3 ± 0.3	44	0.44
Distance to coast (km)	4.7 ± 0.5	4.5 ± 0.5	52	0.83

Distance to nearest paved road (m)	1333 ± 234	825 ± 187	30	0.08
Distance to nearest trail (m)	339.4 ± 99.1	292.4 ± 68.6	51	0.78
Slope (%)	25 ± 4	31 ± 7	54	0.94
Aspect (°)	161 ± 36	161 ± 37	51	0.78
Elevation (m)	128.2 ± 21.6	151.5 ± 33.1	52	0.83
Tree species composition (%)				
Redwood	83 ± 2	77 ± 1	42	0.36
Douglas-fir	7 ± 1	7 ± 1	55	1.00
Hemlock	7 ± 1	4 ± 0.3	54	0.92
Spruce	3 ± 1	5 ± 1	54	0.93

TABLE 2. Akaike's Information Criteria scores, corrected for small sample size (AIC_c), for 3 *a priori* candidate models predicting whether a site was a Marbled Murrelet nest site or a random site at the stand scale at Redwood National and State Parks, California, 2001-2003. A (-) or (+) indicates whether the habitat variable had a positive or negative effect on nest site use.

Model	K[1]	AIC_c	Δ_i [2]	w_i [3]
Distance to nearest paved road (+)	2	32.134	0	0.701
Canopy height (-)	2	34.389	2.26	0.227
Distance to nearest paved road (+) + Canopy height (-)	3	36.704	4.57	0.071

[1] Number of parameters.
[2]The difference in AICc scores between the best model and the model in question
[3]Akaike weights

TABLE 3. Habitat characteristics for 10 Marbled Murrelet nests[1] and a comparison between 6 successful and 3 failed nests in Redwood National and State Parks, California, 2001-2003.

	All nests (n = 10)	Successful Nests (n = 6)	Failed Nests (n = 3)	Mann-Whitney	P
	$\bar{x}$ ± SE	$\bar{x}$ ± SE	$\bar{x}$ ± SE	U	(2-tailed)[2]
Nest site characteristics					
Nest height (m)	48.4 ± 3.9	45.4 ± 4.3	46.3 ± 4.7	8	0.80
Distance from nest to trunk (cm)	102.0 ± 33.0	113.0 ± 46.3	93.3 ± 72.2	8	0.80
Diameter of nest branch at nest (cm)	29.2 ± 3.1	28.6 ± 3.7	25.5 ± 5.7	7	0.61
Diameter of nest branch at trunk (cm)	35.6 ± 4.4	36.8 ± 6.2	30.1 ± 7.9	6	0.44
Length of nest branch (cm)	584.5 ± 60.9	548.0 ± 51.9	561.7 ± 163.9	7	0.61
Trunk width at nest branch (cm)	116.5 ± 24.4	109.8 ± 28.5	134.5 ± 67.9	7	0.61
Epiphytic cover (%)	65 ± 13	60 ± 17	64 ± 29	N/A	N/A
Vertical nest cover (%)	73 ± 6	63 ± 7	85 ± 6	6	0.44
Horizontal nest cover (%)	83 ± 3	79 ± 4	90 ± 5	3	0.12
Cardinal direction of nest branch	179 ± 34	147 ± 47	261 ± 34	3	0.12

Nest branch condition:					
Healthy	8	5	2	7.5	0.59
Alive/broken	2	1	1	7.5	0.59
<u>Tree characteristics</u>					
Tree height (m)	59.7 ± 5.0	58.6 ± 6.3	52.8 ± 5.7	7	0.61
dbh (cm)	266 ± 30	249 ± 39	295 ± 70	7	0.61
Number of small platforms	18 ± 5	22 ± 7	9 ± 3	4	0.20
Number of large platforms	18 ± 5	19 ± 8	9 ± 2	9	1.0
Nest tree species:					
Redwood	8	5	2	7	0.48
Douglas-fir	1	1	0	7	0.48
Western hemlock	1	0	1	7	0.48
<u>Stand characteristics</u>					
Tree density (m^2/ha)	208.0 ± 18.6	190.8 ± 25.7	256.1 ± 11.5	3	0.12
Mean dbh (cm)	122.5 ± 8.3	111.5 ± 11.2	138.1 ± 10.3	6	0.44
Canopy height (m)	62 ± 5	59 ± 6	59 ± 1	9	1.0

Canopy closure (%)	56 ± 4	54 ± 6	60 ± 5	5	0.29
Distance to nearest canopy gap (m)	6 ± 3	5 ± 3	10 ± 10	8	0.76
Number of canopy gaps	6 ± 1	6 ± 1	7 ± 2	8	0.69
Number of canopy layers	2 ± 0.2	3 ± 0.2	2 ± 0.3	8	0.66
Number of downed logs	34 ± 3	39 ± 3	26 ± 4	2	0.07
Ambient sound (dB)	46.6 ± 2.4	44.8 ± 2.2	46.0 ± 5.6	8	0.80
Distance to nearest streambed (m)	132.2 ± 28.8	121.4 ± 41.6	108.7 ± 19.7	8	0.80
Distance to nearest campground (km)	3.2 ± 0.4	3.2 ± 0.5	2.7 ± 0.3	4	0.20
Distance to coast (km)	4.7 ± 0.5	4.7 ± 0.9	5.1 ± 0.4	8	0.80
Distance to nearest paved road (m)	1333 ± 234	1560 ± 290	1150 ± 475	6	0.44
Distance to nearest trail (m)	339 ± 99	437 ± 130	250 ± 181	5	0.30
Slope (%)	25 ± 4	24 ± 6	27 ± 7	8	0.80
Aspect (°)	161 ± 36	156 ± 55	163 ± 61	7	0.61
Elevation (m)	128.2 ± 21.6	136.7 ± 36.0	117.3 ± 17.8	8	0.80

[1]one of the 10 Marbled Murrelet nests was unsuccessful in 2002 and successful in 2003 and not included in the comparison

[2]df = 7

TABLE 4. Akaike's Information Criteria scores, corrected for small sample size (AIC_c), for 8 *a priori* candidate models predicting Marbled Murrelet nest success at the stand, nest tree, and nest site scale at Redwood National and State Parks, California, 2001-2003. A (-) or (+) indicates whether the habitat variable had a positive or negative effect on nest site success.

Model Structure	K[1]	AIC_c	Δ_i [2]	w_i [3]
Number of downed logs (+)	2	11.068	0	0.447
Horizontal nest cover (-)	2	13.179	2.111	0.156
Number of small platforms (+)	2	13.736	2.668	0.118
Tree density (-)	2	14.513	3.445	0.080
Cardinal direction of nest branch (-)	2	14.562	3.494	0.078
Number of downed logs (+) + Horizontal nest cover (-)	3	15.344	4.276	0.053
Horizontal nest cover (-) + Tree density (-)	3	15.645	4.577	0.045
Distance to nearest campground (+)	2	16.910	5.842	0.024

[1] Number of parameters.
[2]The difference in AICc scores between the best model and the model in question
[3]Akaike weights

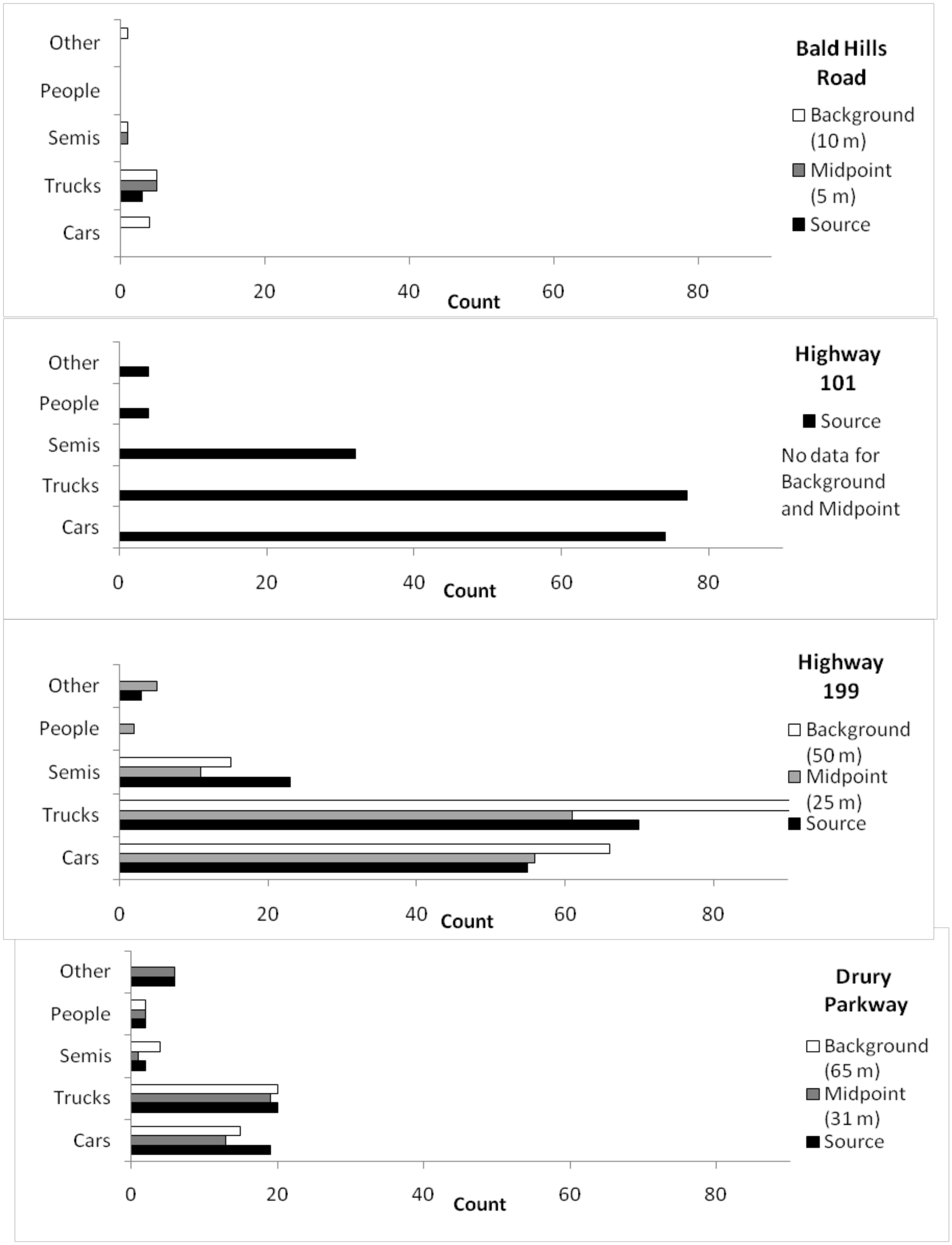


FIGURE 3. Activity levels at the source, where background (≤ 42 dB) was the only sound detected, and at the midpoint between source and background at 4 roads in Redwood National and State Parks, California in 2007

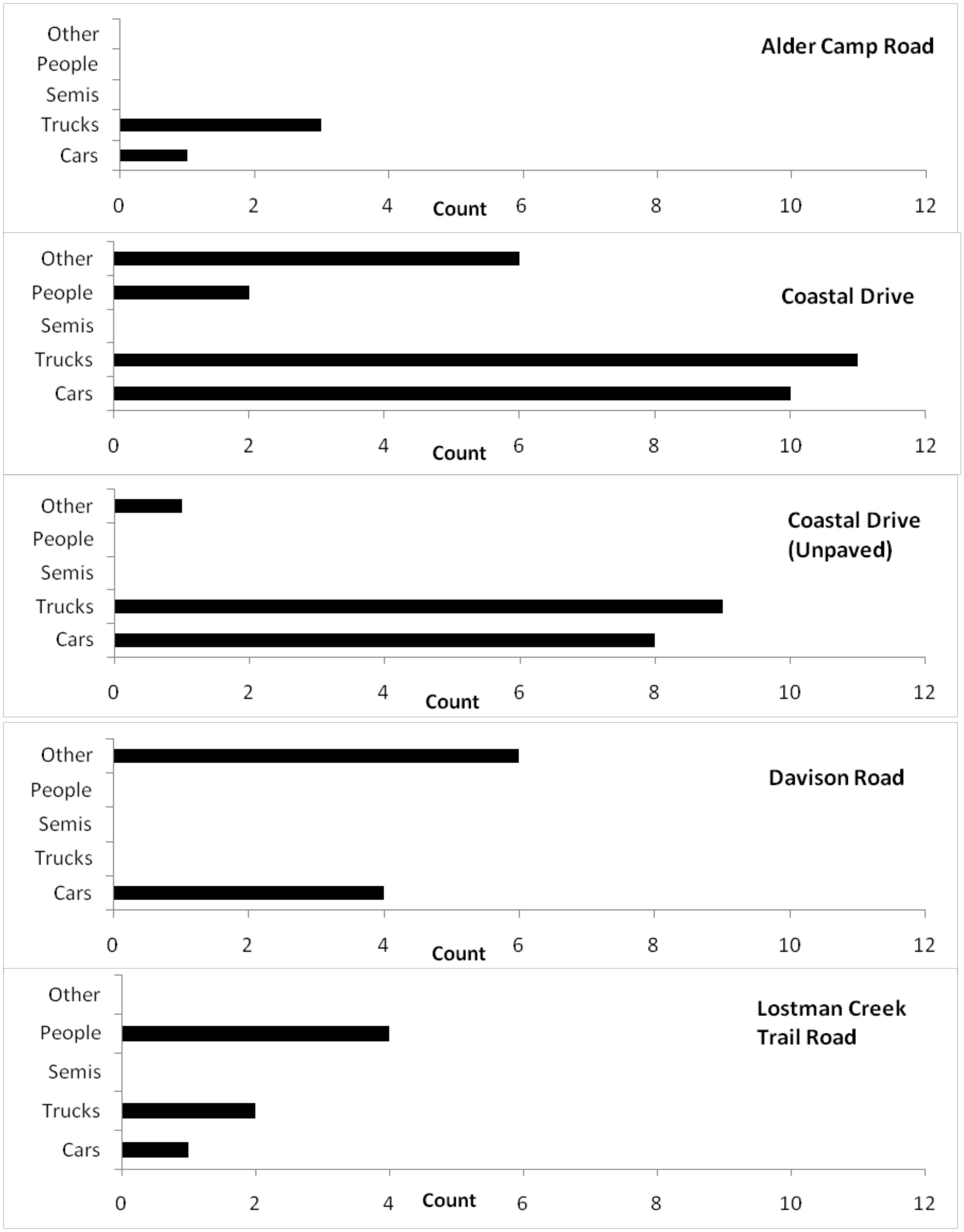


FIGURE 4. Activity levels at 5 roads in Redwood National and State Parks, California in 2007.

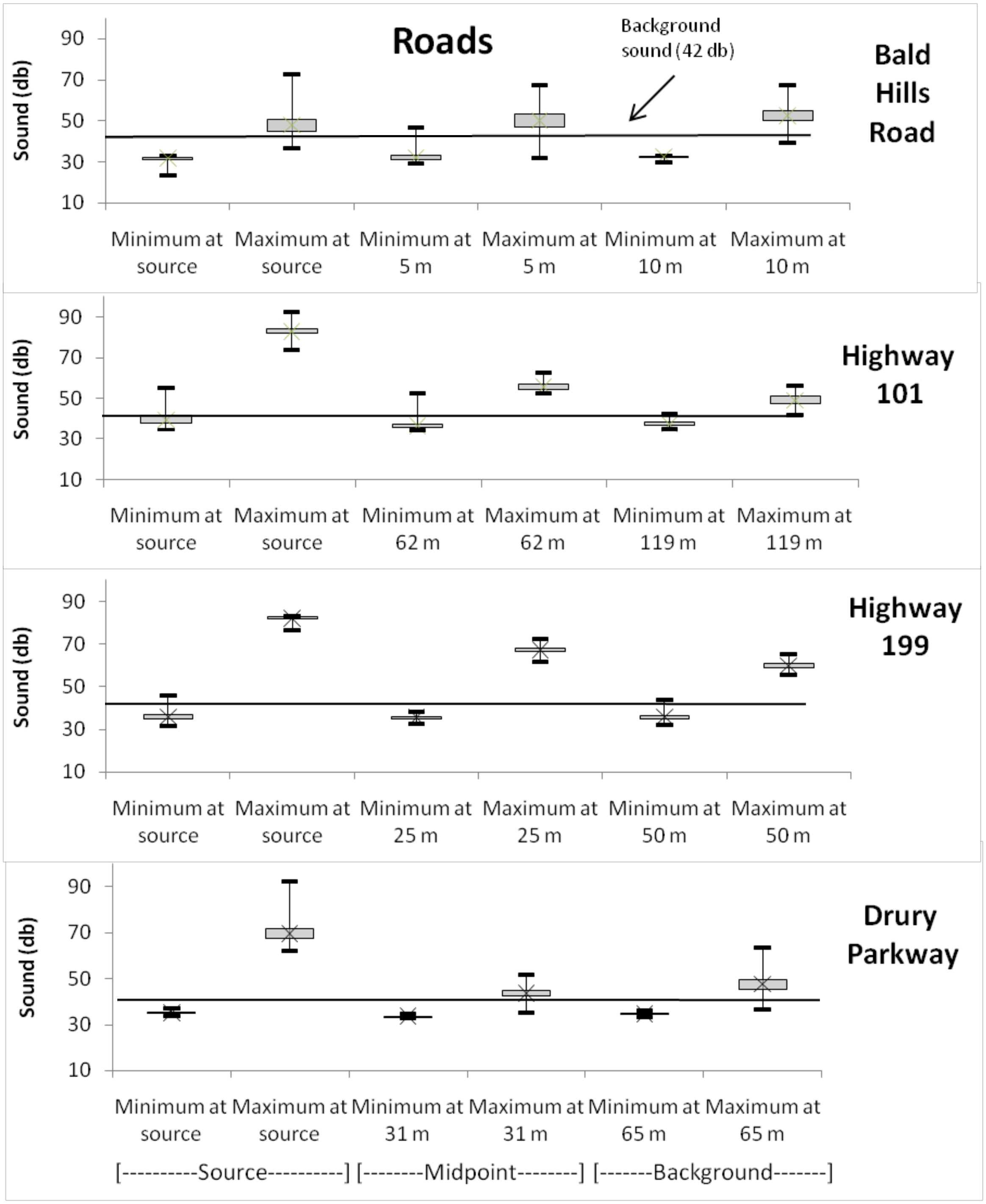


FIGURE 5. Mean ±1 SE (grey box) and range (black bars) of minimum and maximum sound levels at the source, at where only background noise (≤ 42 db) was detected, and at the midpoint between the source and background at 4 road sites in Redwood National and State Parks, California in 2007.

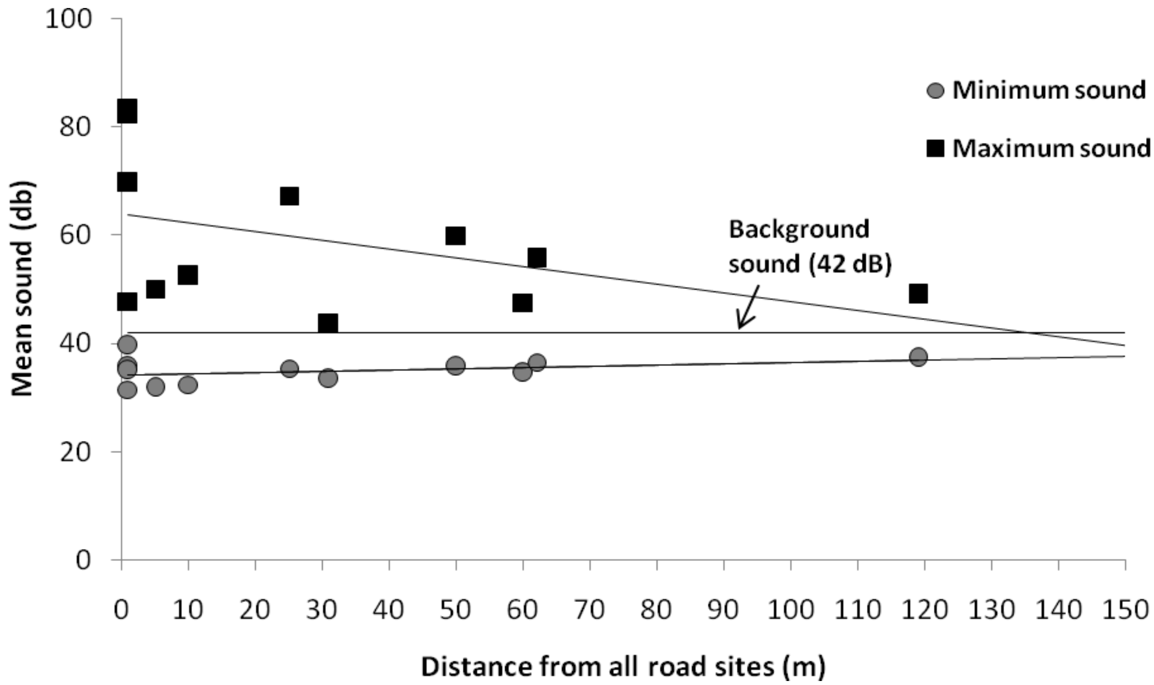


FIGURE 6. Linear regression of mean minimum and maximum sound levels at various distances from 4 roads (Bald Hills Road, Highway 101, Highway 199, and Drury Parkway), in Redwood National and State Parks, California in 2007. Maximum sound levels are predicted to reach background sound at approximately 135 m from roads.

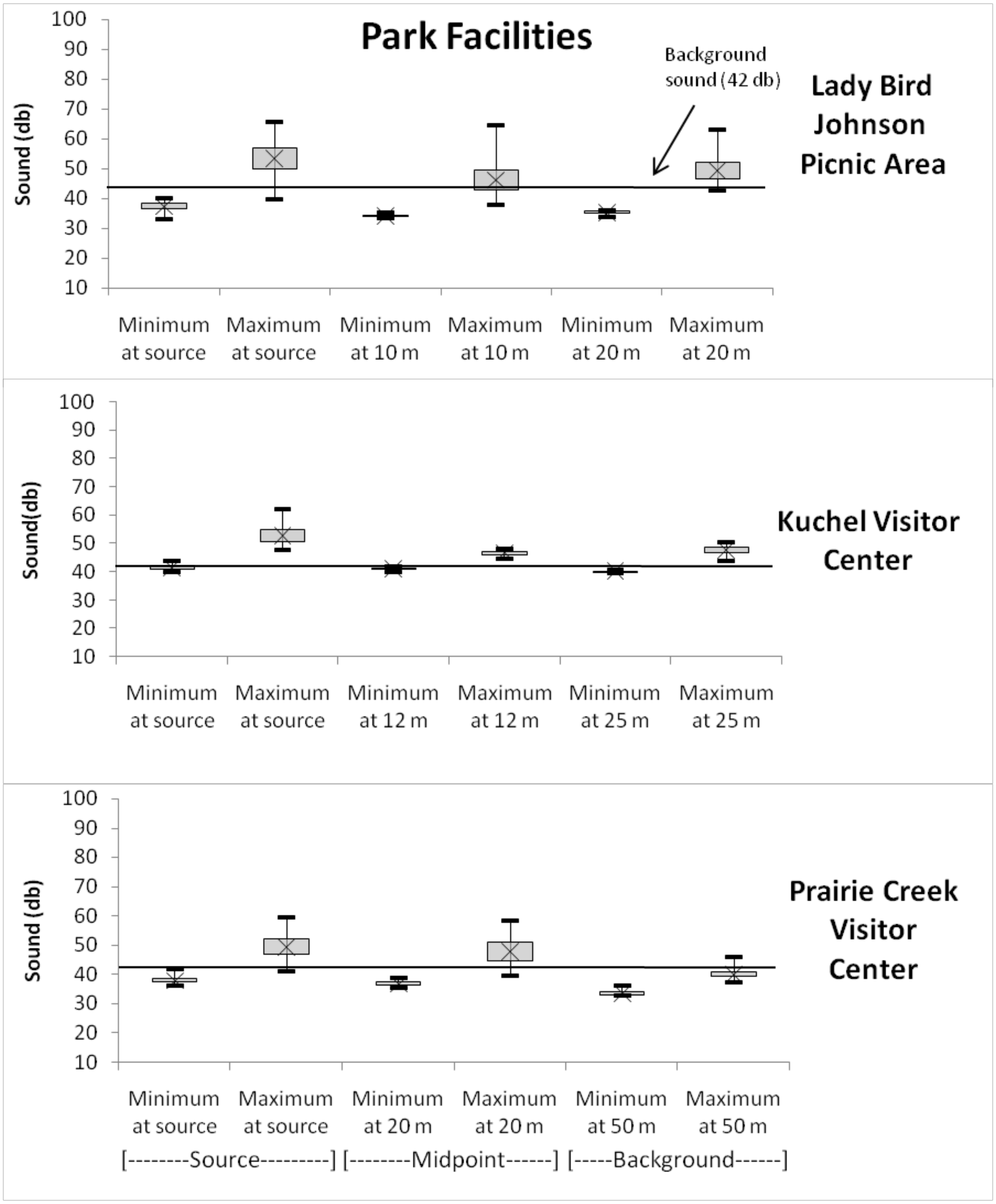


FIGURE 7. Mean ±1 SE (grey box) and range (black bars) of minimum and maximum sound levels at the source, at where only background noise (≤ 42 db) was detected, and at the midpoint between the source and background at 3 park facilities in Redwood National and State Parks, California in 2007.

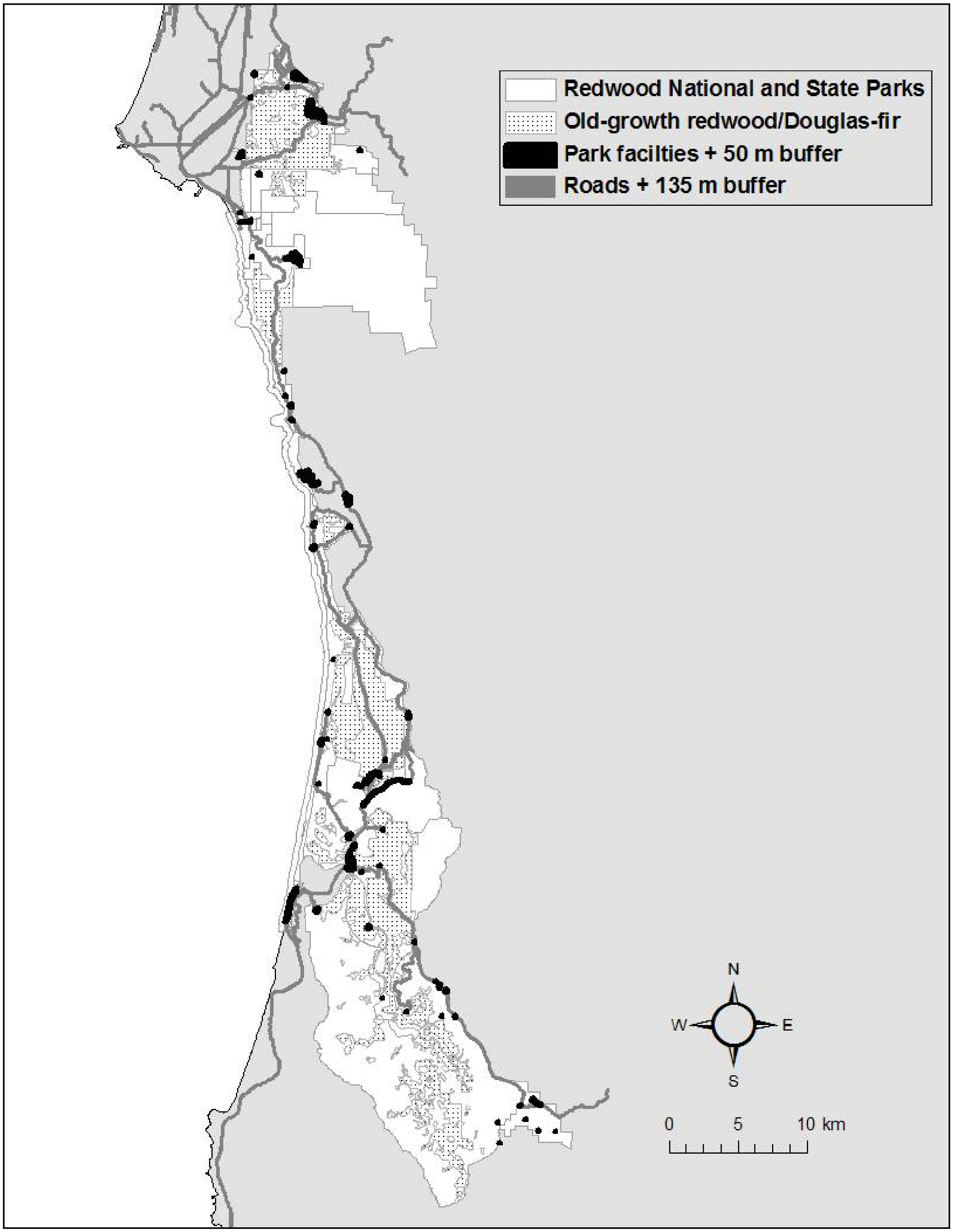


FIGURE 8. Extent of old-growth redwood/ Douglas-fir forest with roads (grey lines) and park facilities (black) buffered and excluded, in Redwood National and State Parks, California.

APPENDIX A. Roads and park facilities used in sound study of Marbled Murrelet habitat in Redwood National and State Parks, California, 2007.

Location	Location type	Description
Alder Camp Road	paved, lightly used road	
Bald Hills Road	paved, lightly used road	
Coastal Drive	paved, lightly used road	
Highway 101	paved, heavily used road	
Highway 199	paved, heavily used road	
Drury Parkway	paved, heavily used road	
Coastal Drive (unpaved)	unpaved road	
Davison Road	unpaved road	
Lostman Creek Trail Road	unpaved road	
Davison Road parking lot	large parking lot	>25 spaces, 3 tables, bathrooms
Kuchel Visitor Center	large parking lot	>50 spaces, no tables
High Bluff Overlook	small parking lot	<10 spaces, 2 tables, 1 bathroom
Lady Bird Johnson picnic area	small parking lot	<15 spaces, 1 table, 1 bathroom
Wilson Creek parking lot	small parking lot	<15 spaces, 3 tables

Jedidiah Smith Visitor Center	facilities	within campground area
Prairie Creek Visitor Center	facilities	small parking lot and kiosk
Redwood Youth Hostel	facilities	small parking lot below hostel
Mill Creek Campground	large campground	145 sites, very forested
Elk Prairie Campground	large campground	75 sites, open & less forested
Jedidiah Smith Campground	large campground	90 sites, forested
Gold Bluffs Beach Campground	small campground	26 sites, open beach area
Lostman Creek picnic area	campground/picnic area	small parking lot, row of tables, 1 bathroom
Redwood Creek Overlook picnic area	campground/picnic area	small parking lot, few tables, 1 bathroom
Redwood Creek Trail picnic area	campground/picnic area	mostly parking lot, 2 tables, 1 bathroom

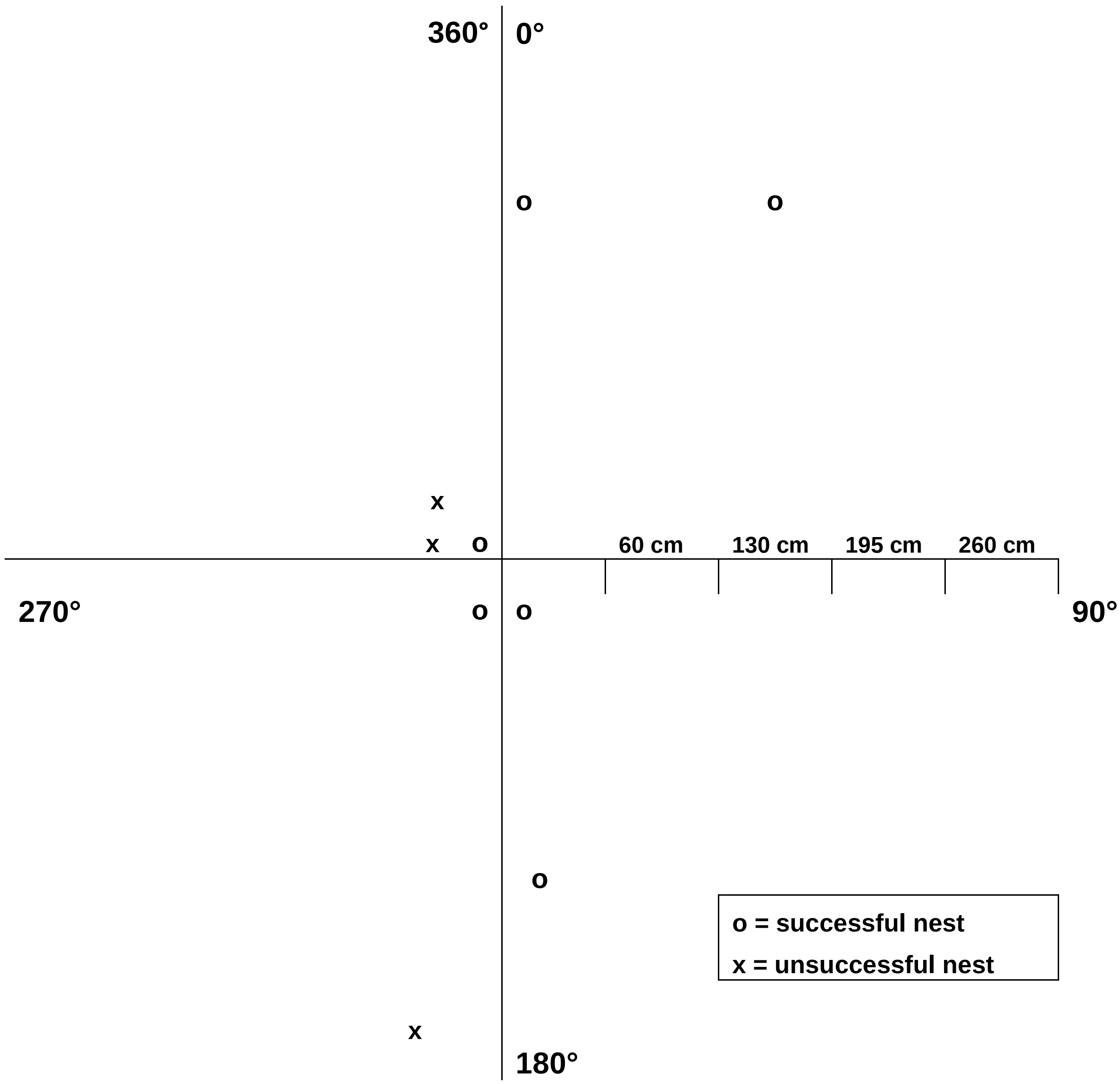
APPENDIX B. Highly correlated habitat variables at the stand scale for Marbled Murrelet nest sites and random sites at Redwood National and State Parks, California, 2001-2003.

	Pearson Correlation	*P* (2-tailed)
Distance to nearest campground, Number of canopy gaps	0.47	0.03
Distance to nearest campground, Tree density	-0.62	0.003
Elevation, Tree density	-0.52	0.02
Distance to nearest campground, Mean dbh	-0.45	0.04
Mean dbh, Tree density	0.55	0.01
Distance to nearest trail, Mean dbh	-0.47	0.03
Distance to nearest paved road, Number of canopy layers	0.49	0.03

APPENDIX C. Highly correlated habitat variables at the nest scale and tree scale for Marbled Murrelet nest sites at Redwood National and State Parks, California, 2001-2003.

	Pearson Correlation	*P* (2-tailed)
Nest scale		
Trunk width at nest branch, Diameter of nest branch at trunk	0.75	0.02
Trunk width at nest branch, Length of nest branch	0.69	0.04
Distance from nest to trunk, Cardinal direction of nest branch	-0.68	0.04
Tree scale		
Number of small platforms, Number of large platforms	0.87	0.003

APPENDIX D. Cardinal direction of nest branch and distance from nest to trunk of successful nests and unsuccessful Marbled Murrelet nests at Redwood National and State Parks, California, 2001-2002.



APPENDIX E. Minimum and maximum sound levels and coefficient of variation (CV) at source, where background (≤ 42 dB) was the only sound detected, and at the midpoint between source and background at 7 locations in Redwood National and State Parks, California in 2007.

	Sound (dB) at source			Sound (dB) at midpoint				Sound (dB) at background			
Location	Minimum ($\bar{x}$ ± SE)	Maximum ($\bar{x}$ ± SE)	CV (%)	Distance (m) from location	Minimum ($\bar{x}$ ± SE)	Maximum ($\bar{x}$ ± SE)	CV (%)	Distance (m) from location	Minimum ($\bar{x}$ ± SE)	Maximum ($\bar{x}$ ± SE)	CV (%)
Bald Hills Road	31.5 ± 0.7	47.8 ± 2.8	20	5	31.9 ± 1.1	50.1 ± 3.3	27	10	32.4 ± 0.2	52.5 ± 2.6	21
Highway 101	39.6 ± 2.0	83.2 ± 1.3	21	62	36.5 ± 0.6	55.7 ± 1.3	8	113	37.4 ± 0.8	49.1 ± 1.9	13
Highway 199	35.8 ± 1.1	82.3 ± 0.5	16	25	35.4 ± 0.5	67.3 ± 0.7	6	50	35.8 ± 0.8	59.9 ± 0.9	9
Drury Parkway	35.0 ± 0.2	69.6 ± 2.0	9	31	33.5 ± 0.1	43.6 ± 1.2	12	60	34.6 ± 0.2	47.5 ± 2.2	17
Kuchel Visitor's Center	41.4 ± 0.5	52.7 ± 2.2	9	12	41.1 ± 0.3	46.6 ± 0.5	3	25	40.2 ± 0.1	47.6 ± 1.0	6
Lady Bird Johnson picnic area	37.4 ± 0.9	53.5 ± 3.5	14	10	34.2 ± 0.2	46.2 ± 3.2	14	20	35.4 ± 0.3	49.4 ± 2.7	12
Prairie Creek Visitor's Center	38.0 ± 0.7	49.5 ± 2.6	14	20	36.9 ± 0.5	47.9 ± 3.2	14	50	33.6 ± 0.6	40.1 ± 0.7	6

APPENDIX F. Minimum and maximum sound levels, sound rating, and coefficient of variation (CV) at 16 locations in Redwood National and State Parks, California in 2007.

		Sound (dB)			
Location	In old-growth?	Minimum ($\bar{x} \pm$ SE)	Maximum ($\bar{x} \pm$ SE)	Sound rating[1]	CV (%)
Alder Camp Road	Partial	31.3 ± 0.1	38.2 ± 1.4	Quiet	16
Coastal Drive	Partial	32.2 ± 0.2	48.1 ± 2.7	Medium	29
Coastal Drive (unpaved)	No	35.8 ± 0.3	46.6 ± 1.7	Medium	21
Davison Road	No	36.7 ± 0.3	46.4 ± 0.5	Medium	8
Lostman Creek Trail Road	Yes	33.1 ± 0.1	37.0 ± 0.9	Quiet	12
Davison Road parking lot	No	35.6 ± 0.3	45.6 ± 0.6	Medium	6
High Bluff Overlook	No	34.7 ± 0.4	47.4 ± 3.0	Medium	24
Wilson Creek parking lot	No	46.1 ± 0.3	65.9 ± 1.3	Loud	9
Jedidiah Smith Visitor Center	Yes	35.6 ± 0.3	44.5 ± 0.8	Medium	7
Redwood Youth Hostel	No	38.5 ± 0.3	56.9 ± 1.0	Loud	9
Mill Creek Campground	No	34.6 ± 0.2	39.3 ± 0.6	Quiet	6
Elk Prairie Campground	Yes	32.5 ± 0.4	40.9 ± 1.2	Quiet	11
Jedidiah Smith Campground	Yes	33.8 ± 0.2	48.7 ± 2.7	Medium	22
Gold Bluffs Beach Campground	No	40.4 ± 0.2	48.6 ± 0.9	Medium	8
Lostman Creek picnic area	Yes	33.2 ± 0.0	35.3 ± 0.5	Quiet	6
Redwood Creek Overlook picnic area	No	31.7 ± 0.2	40.6 ± 1.8	Quiet	15
Redwood Creek Trail picnic area	No	33.1 ± 0.2	35.6 ± 0.4	Quiet	3

[1]Maximum mean < 42 dB = “Quiet”; 42-50 dB = “Medium”; > 50 dB = “Loud”