Chapter 20

Relationship of Marbled Murrelets with Habitat Characteristics at Inland Sites in California

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Abstract: We examined the range and the relationships of Marbled Murrelet (*Brachyramphus marmoratus*) behavior with habitat and landscape characteristics in isolated old-growth and residual forest stands from 2 to 400 ha in California. In large contiguous stands of old-growth forest in parks, we examined relationships of murrelet detections with elevation and topography. In isolated stands we found higher murrelet detection levels in stands with higher dominant and codominant crown cover and >50 percent coast redwood (*Sequoia sempervirens*). Surveys also were more likely to detect occupied behaviors at stands with higher crown cover and a greater proportion of redwoods. Density of old-growth cover and species composition may be the strongest predictors of murrelet presence and occupancy in California. Contrary to previous studies, we did not find that larger stands were more likely to have murrelets present. In the large park stands, we found that mean detection levels and the number of occupied stations were highest in the major drainages and at lower elevations. Major ridges tended to have lower detection levels and fewer occupied behavior stations.

In recent years, much has been learned about the occurrence of Marbled Murrelets (*Brachyramphus marmoratus*) at inland forest sites. Throughout most of its range, the murrelet nests in old-growth forests within 50-75 miles of the coast (Carter and Morrison 1992). In California, Paton and Ralph (1990) conducted general surveys (Paton, this volume) to determine the distribution of murrelets in coastal old-growth and mature second-growth forests. Concentrations were found in regions containing large, contiguous, unharvested stands of old-growth redwood, mostly within state and federal parks, with the highest detection numbers in stands >250 ha. In excess of 200 detections for single-survey mornings have been recorded at some survey stations in remaining unharvested stands within parks in California, including Redwood National Park and Prairie Creek State Park in Humboldt County (Ralph and others 1990); and Big Basin State Park in San Mateo County (Suddjian, pers. comm.).

Federal listing of the Marbled Murrelet as threatened (U.S. Fish and Wildlife Service 1992) has created a need for information about the role of habitat and landscape features for the murrelet.

We conducted two studies to examine the relationships of the murrelet to habitat and landscape characteristics within old-growth forests, as defined by Franklin and others (1986). In isolated stands in fragmented landscapes (the Stand Study), we compared murrelet detections with stand size, structure, and landscape characteristics. In large contiguous stands of old-growth in state and federal parks (the Park Study), we examined murrelet detections with landscape features, such as elevation and topography. We confined our study to old-growth forests, because previous studies indicate murrelets nest only in forests with these characteristics.

Methods

The survey methods followed the intensive survey protocol of Ralph and others (1993). To maximize the number of visual detections, we selected station positions at the edges of the isolated stands or at interior locations with openings in the canopy whenever possible. Observers could move within a 50-m radius of the station.

We estimate that, for an individual forest stand, four surveys are needed to determine with a 95 percent probability that murrelets are present (*appendix A*). If below canopy behaviors were observed, we categorized the stand as Occupied (see below) for analyses. During 1992 and 1993 for the Stand Study, we attempted to survey each isolated stand at least four times between 15 April and 7 August. Surveys at each stand were distributed throughout the survey period whenever possible. However, due to difficult access for some stands, surveys in some areas were temporally aggregated. To eliminate potential effects from aggregated surveys, detection levels were standardized for seasonal variation (see Analyses below).

For the 1993 Park Study, within the boundaries of the large stands of old-growth forests in national and state parks (*fig. 1*), stations were placed in a matrix over the landscape, as illustrated in *figure 2*. We surveyed all sections of park stands with adequate accessibility. We placed stations 400 meters apart on roads and trails, and 400 meters out perpendicular to trails, creating a matrix. Ralph and others (1993) found that observers detect few birds at distances >200 m, therefore, we assumed each station covered a 200-m radius circle, approximately 12.5 ha. Due to safety considerations for observers hiking to stations in pre-dawn hours, we limited stations to within 400 meters of a trail or road. Stations were surveyed once during the survey season. We attempted to avoid surveys at adjacent stations on the same morning.

The species' range in northern California was determined by examining the results of inland surveys conducted from 1988 through 1992 by government agencies and private landowners. Murrelet use for each stand or station was determined by the number and type of detections. All survey stations were digitized into a Geographic Information System

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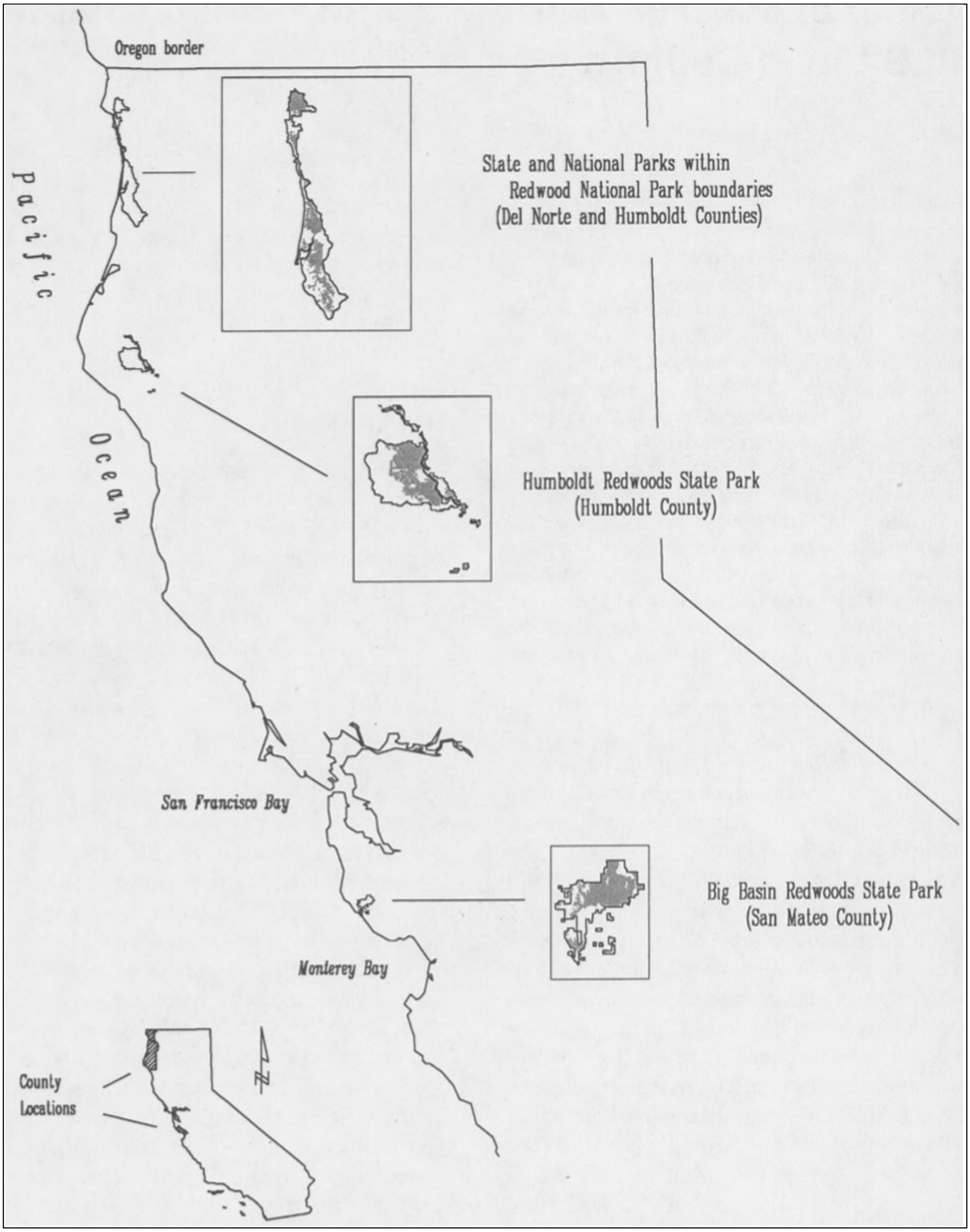

Figure 1—Location of state and national parks surveyed during the summer of 1993. Shaded areas represent distribution of old-growth forests within the parks.

(GIS) database (ARC/INFO 6.1.1) and grouped by distances from the ocean by 10-km bands from 0 to 60 km (*fig. 3*).

Definition and Selection of Isolated Study Stands

Isolated stands were located by examining habitat maps of private lands, state and federal parks, and national forests. The maps were drawn from interpretation of aerial photographs. For the stand selection process, stand size was estimated from measurements on the maps. Stands were randomly selected from size categories of 2 to 20 ha, 21 to 40 ha, 41 to 100 ha, and greater than 100 ha. If the stand was accessible, it was visited and visually inspected. If the stand was old-growth or residual forest, the stand was surveyed, if not, then another stand was selected. Upon completion of field work, station locations and stand perimeters were adjusted on maps according to ground-truthing, then digitized into a GIS database.

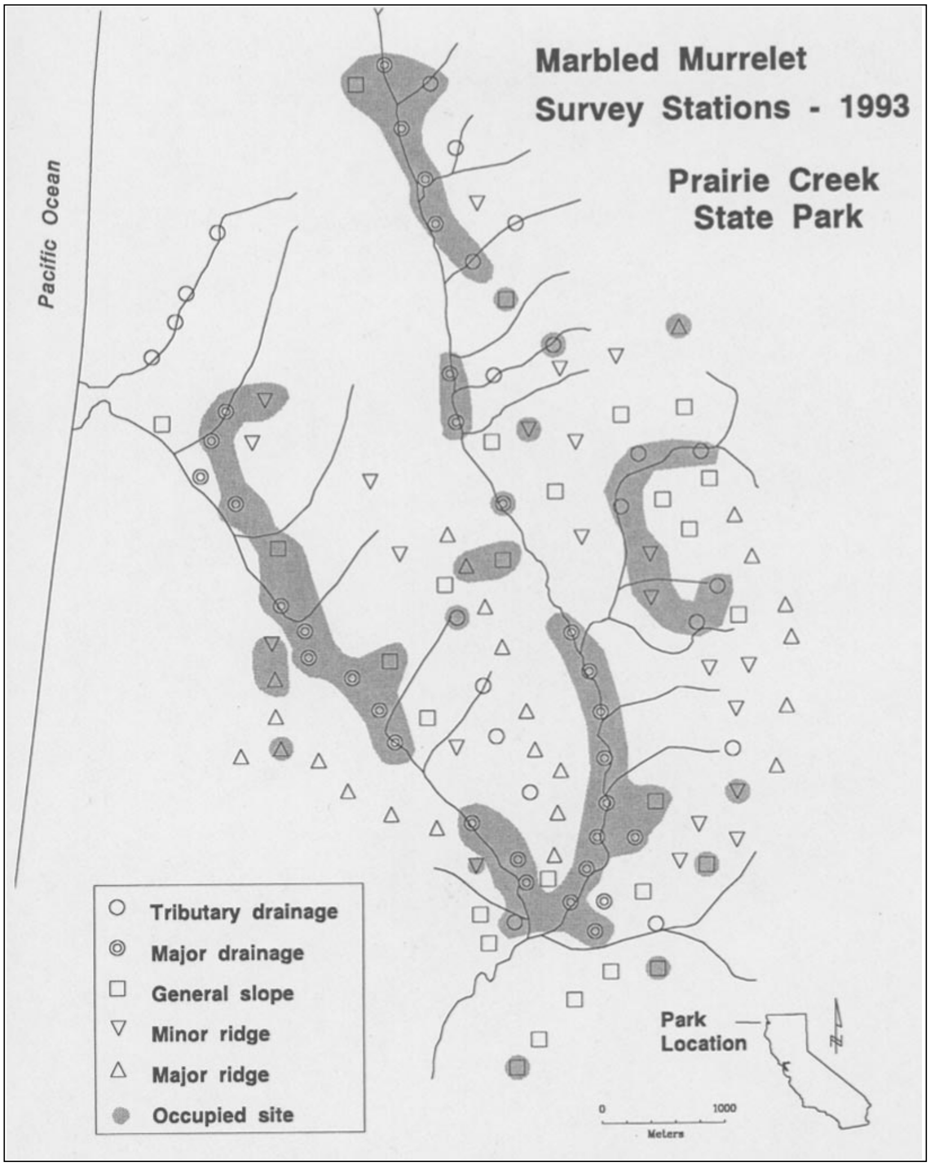

Figure 2—Spatial and topographical distribution of a subset of Marbled Murrelet stations surveyed at Prairie Creek Redwoods State Park during the summer of 1993. Occupied sites are shaded in groups to illustrate possible associations with topographical features.

Stand area, perimeter length, and distance from salt water were derived from the GIS database. For stands with inclusions of non-forested area within the stand, we added the length of the lines around the stand and around the inclusions for the total perimeter measurements. Perimeter, therefore, is a measure of the amount of forest edge in and around the stand.

Stand type was characterized as residual or old-growth. This variable is a measure of harvest history for the stand, but is not a direct measure of years since the last disturbance. Old-growth stands contained trees greater than 90 cm diameter at breast height (d.b.h.) with no history of timber harvest and some evidence of decadence in the canopy. Residual stands had some history of partial removal of large trees with the remaining dominant trees greater than 90 cm d.b.h.. Some stands with contiguous areas of old-growth and residual were classified as mixed.

Stands also were classified by density as determined by interpretation of aerial photographs. Density was defined as the percent of the old-growth canopy cover (dominant and codominant trees): sparse, <25 percent; low, 25-50 percent; moderate, 51-75 percent; and dense, >75 percent. Species of dominant trees (>50 percent) was determined from aerial photography and verified by vegetation information after visiting the stand. For the purpose of this study, a stand was a single, isolated group of old-growth trees surrounded by

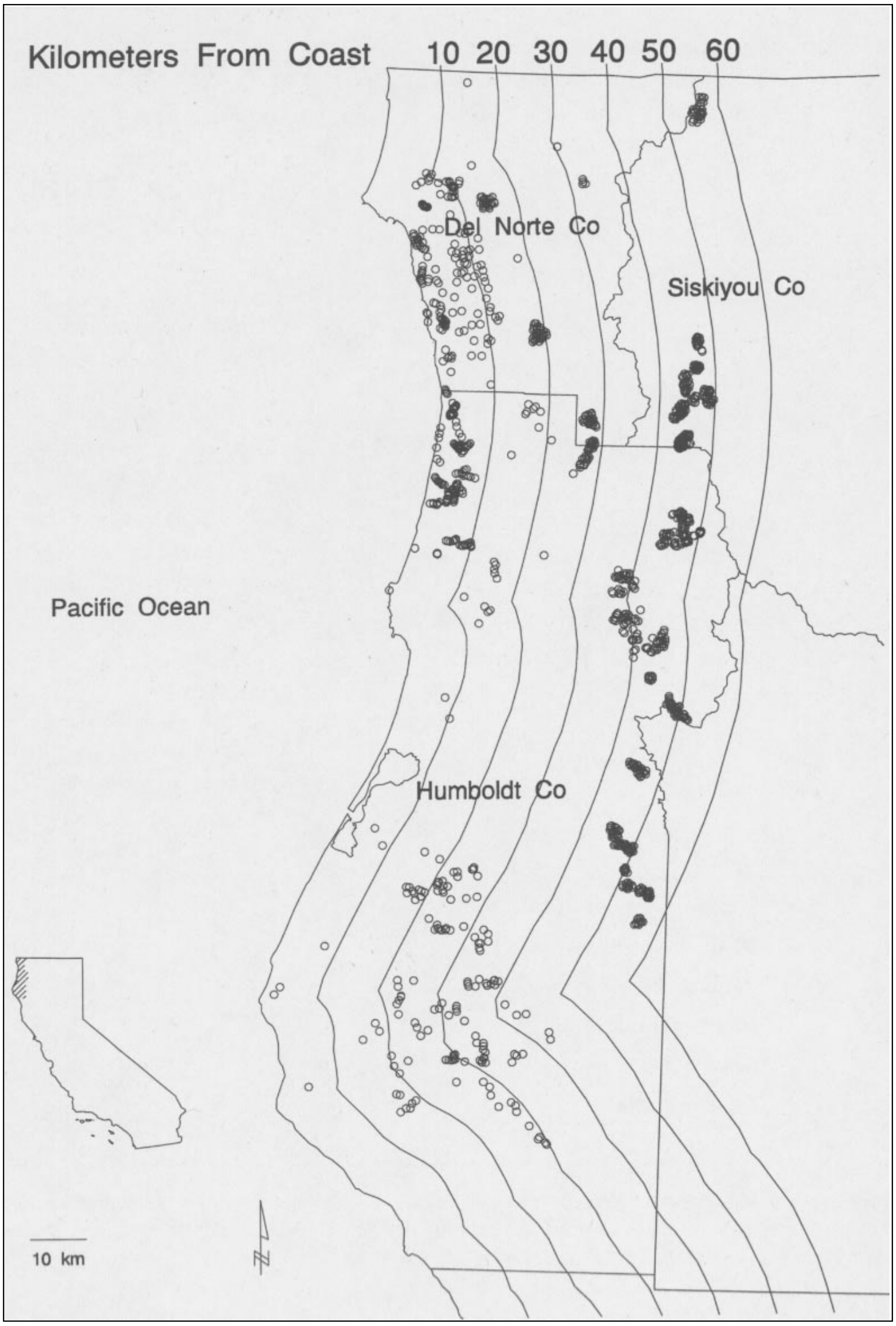

Figure 3—Distribution of Marbled Murrelet survey stations in northern California. Stations are located on private and public lands and surveys were conducted one or more seasons from 1988 to 1994. Open circles represent one survey station or a group of stations in one isolated stand. In areas with high concentrations of stations, open circles appear filled in or shaded.

non-forested or harvested habitat. If groups of trees were less than 160 meters apart they were considered one stand.

Stands that met all of the following criteria were included in the group of potential survey sites: old-growth or residual stands with dominant and codominant trees that comprised at least 20 percent canopy cover; size between 2 ha and 400 ha; distance from coast less than 40 km (25 miles); dominant vegetation type of coast redwood (*Sequoia sempervirens*) or Douglas-fir (*Pseudotsuga menziesii*) at elevations of less than 1,000 m; and safely accessible by road or well-defined trail.

Analyses

Standardization for Seasonal Variation

Various factors may influence the numbers of detections of murrelets at inland locations, including environmental conditions, time of year (O'Donnell and Naslund, this volume), and observer (O'Donnell, this volume). To help eliminate the effects of observer bias, all stands were surveyed by two or more observers. The influence of weather on numbers of detections appears to be highly variable (Naslund and O'Donnell, this volume). The effect of weather is probably stochastic with respect to survey days, and we assumed it did not have an overall impact at a site because surveys were distributed throughout the breeding season. The seasonal variation in detection levels, however, has been well documented and quantified at several sites in California (O'Donnell and Naslund, this volume). To identify differences in murrelet use (detection levels) of stands in our study, we first accounted for the effect of season on detection levels.

Morning surveys were conducted throughout the breeding season in multiple years at three sites in Humboldt County. The sites at Lost Man Creek (Redwood National Park) and James Irvine Trail (Prairie Creek Redwoods State Park) were surveyed from 1989-1993. The Experimental Forest site was surveyed in 1989, 1990, 1992, and 1993. We attempted to monitor each site weekly. Data from these three sites was used to calculate standardization factors.

Standardization

The following method was used to calculate a factor to standardize the number of detections for seasonal differences.

1. We examined the distribution of detections (*fig. 4*) over all years for the three sites and used a Kruskal-Wallis test to determine that the distributions by season were similar for the three sites ($P < 0.0001$). Surveys from all sites and years then were pooled.
2. We calculated the mean number of detections per survey for the period 15 April to 12 August, that we refer to as the summer mean.
3. We then calculated the mean numbers of detections per survey for each 10-day interval, the interval mean. Detection levels for periods longer than 10 days began to show the effects of seasonal variation.
4. The ratio of each of the 12 interval means and the summer mean was calculated (interval mean/summer mean = standardization factor).

The 10-day intervals and corresponding standardization factors calculated for the data from the three sites are presented in *table 1*.

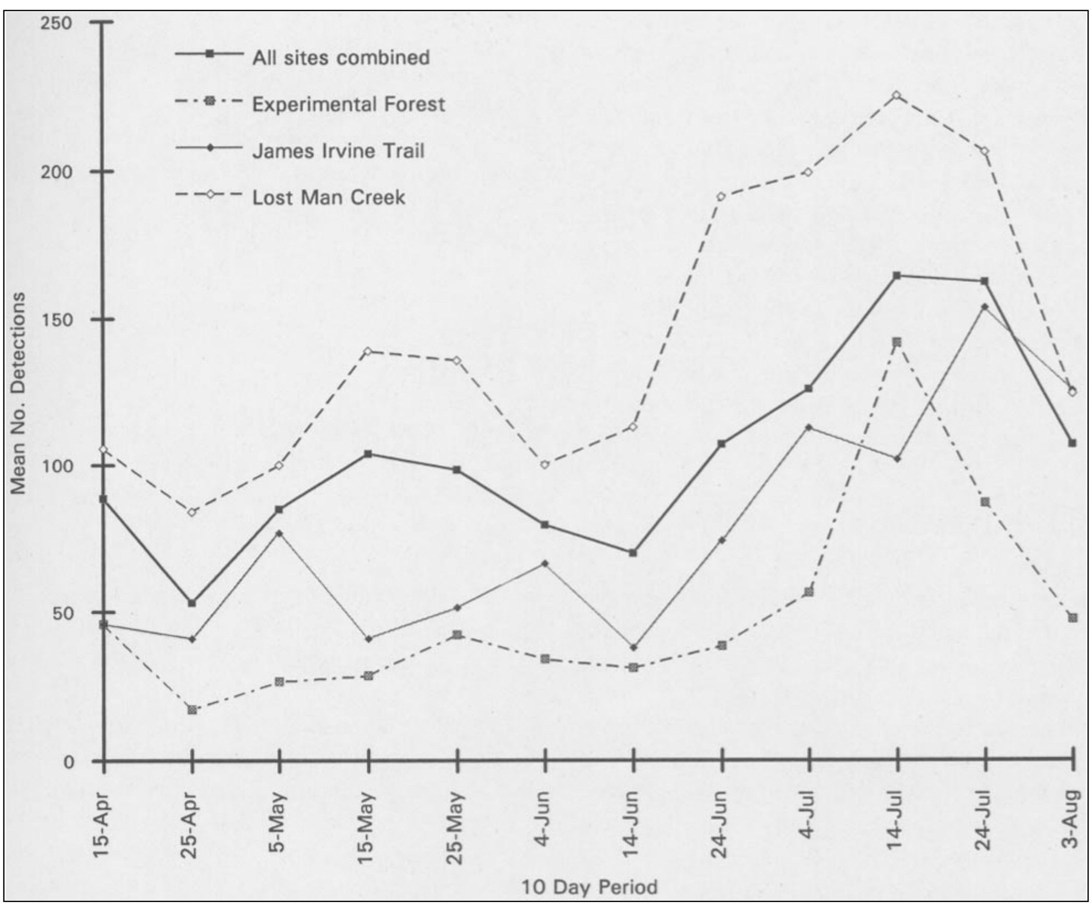

Figure 4—Mean Marbled Murrelet detections from forest surveys at three sites in northern California: James Irvine Trail, Prairie Creek Redwoods State Park; Lost Man Creek, Redwood National Park; and the USDA Forest Service Experimental Forest, Klamath. Means for the three sites combined by 10 day intervals also are presented. Surveys were conducted 3–4 times per month most years from 1989–1993 and points represent the means for 10-day intervals.

Table 1—Ten-day intervals and corresponding standardization factors for seasonal variation of mean Marbled Murrelet levels at three sites in northern California

Interval	Standardization factor
April 15 to April 24	0.86
April 25 to May 4	0.51
May 5 to May 14	0.82
May 15 to May 24	1.01
May 25 to June 3	0.95
June 4 to June 13	0.77
June 14 to June 23	0.68
June 24 to July 3	1.04
July 4 to July 13	1.22
July 14 to July 23	1.59
July 24 to August 2	1.04
August 3 to August 12	1.03

Thus for surveys conducted at the three sites from 14 July to 23 July, numbers of detections per survey were on average 1.59 times greater than the summer mean; surveys conducted from 15 May through 24 May had numbers of detections which were about equivalent to the summer mean; and numbers of detections for surveys from 25 April to 4 May averaged about half of the summer mean.

In applying the standardization, we made the assumption that the relationship between detections at any site on a given day and the mean detection levels for the summer period at that site would be the same as the relationship we found at the three test sites. We have compared data with one site with very low activity and found the seasonal curves were similar. Standardized mean detection levels were calculated for all stands and stations and this measure used for all analyses.

Stand Study: Isolated Stands

Multiple Regression

We examined the relationship between standardized mean detection levels for the stand, referred to as the dependent variable, and the following independent variables: stand size, Patton's index of perimeter to area (Patton 1975) which was used as a measure of the edge or shape, distance from salt water, density of old-growth trees, type of stand, and dominant tree species. As a transformation of the standardized mean detection level, we used the square root of the mean for the multiple regression.

Logistic Regression

For each stand we summarized the detections and behaviors for all surveys conducted during the study to determine the status of the stand. If no murrelets were detected during any of the surveys, then the status was "Undetected." Stands with murrelet detections were assigned a status of "Present" or, if occupied behaviors (Paton, this volume; Ralph and others 1993) were observed, a status of "Occupied."

Using logistic regression (SAS Institute, Inc. 1991) with maximum likelihood analysis of variance, we examined the relationship between a selection of independent variables, and status. We compared response variables Present (including Occupied stands) and Undetected, and response variables Occupied and Unoccupied (all stands with a status of Undetected or Present). For the stands with murrelets present we compared Occupied stands, with stands with a status of Present.

Park Study: Large Contiguous Stands

Elevation and position on the landscape were estimated from topographic maps to give a measure of topography for each station. Landscape position was described as one of five categories: (1) in the bottom of a major drainage, a drainage covering a large length of the landscape and isolated by parallel ridges; (2) in the bottom of a tributary (or minor) drainage, a drainage flowing into a major drainage, or a short, steep drainage flowing directly into the ocean; (3) on top of a major ridge, a ridge running parallel to a major drainage; (4) on top of a minor ridge, a ridge line that originated from the major ridge and was generally perpendicular to a major drainage; and (5) on a general slope, a station not on a ridge nor in a drainage.

When stations were located on slopes or ridges, it was possible to detect murrelets calling in the drainages. The topography within 100 m of the stations was similar to the topography at the station itself. To help isolate the effects of topography, we included only detections within 100 m of the observer.

Results

Stand Study: Isolated Stands

We identified 286 potential study stands in Del Norte, Humboldt, Trinity, San Mateo, and Santa Cruz counties meeting the criteria in the four size categories 2 to 20 ha (n = 184); 21 to 40 ha (n = 39); 41 to 100 ha (n = 35); >100 ha (n = 28). We located few stands >21 ha, therefore, we surveyed all accessible stands in those categories. From these potential study stands we selected and surveyed 152 stands as follows: 2 to 20 ha (n = 86); 21 to 40 ha (n = 22); 41 to 100 ha (n = 23); >100 ha (n = 21). Due to weather conditions, three stands were surveyed only three times.

Density of the combined dominant and codominant tree cover and presence of redwood trees were positively and significantly ($F_{0.05} = 2.428$, $df_{model} = 10$, $P = 0.0105$, $R^2 = 0.1625$) related to mean murrelet detection levels in the multiple regression model. Because only 16 percent of the variation in the system was explained by the model, the predictive ability was limited. Other variables examined were not related to mean detection levels.

The logistic regression model included density of old-growth (dominant and co-dominant) tree cover, tree species, and stand size as variables explaining the differences between sites with no detections and those with murrelets present (*table 2*). Stands with higher density classifications, and with redwood as the dominant tree species, were more likely to have murrelets present. Results also indicated a very minor effect of smaller stands increasing the likelihood of murrelet presence. We found, however, no significant effect of stand size on the status of murrelets in the stands (Undetected, Present, or Occupied), when tested by Chi-square contingency table ($df = 6$, $\chi^2 = 3.294$, $P = 0.7721$) (*table 4*). Using these variables accounts for virtually all of the variability in the model.

For stands with a status of Occupied ($n = 37$), compared with all Unoccupied stands ($n = 115$), old-growth tree density and tree species were significant variables (*table 3*) for predicting observations of occupied behaviors. Stands in higher density classes with redwood as the dominant species were more likely to be classified as Occupied.

Among stands with murrelet detections ($n = 62$), we found no differences in habitat variables between stands with a status of Occupied ($n = 37$) and Present ($n = 25$).

Park Study: Large Contiguous Stands

Central California

Big Basin Redwoods State Park was surveyed in a matrix of 37 survey stations. The elevation ranged from 240-500 m and we divided stations into four equal categories (*table 5*). We found the mean detection levels and the number of Occupied stations higher for stations in lower elevation categories. The proportion of Occupied stations was not significantly different ($P > 0.05$) among topography categories (*table 5*). Occupied behaviors were observed in all topography categories, and the only station with a status of Undetected was on a major ridge.

Table 2—Results of logistic regression analysis for stands in California (n = 152) with a status of murrelets Present (Present and Occupied) (n = 62) and Undetected (n = 90). Only variables with significant contribution to the model are presented

Variable	Regression coefficient	Chi-square	Chi-square probability
Tree species[1]	1.8101	9.43	0.0021
Cover density[2]	0.8755	5.76	0.0164
Stand size	-0.0206	5.45	0.0195

[1]Coast redwood (*Sequoia sempervirens*) or Douglas-fir (*Pseudotsuga menziesii*) >50 percent of stand.
[2]Percent dominant and codominant tree cover.

Table 3—Results of logistic regression analysis for stands in California (n = 152) with status of Occupied (n = 37) and stands with murrelets Present or Undetected (Unoccupied)(n = 115). Only variables with significant contribution to the model are presented

Variable	Regression coefficient	Chi-square	Chi-square probability
Tree species[1]	1.9243	5.86	0.0155
Cover density[2]	1.0831	6.64	0.0100

[1]Coast redwood (*Sequoia sempervirens*) or Douglas-fir (*Psuedotsuga menziesii*) >50% of stand.
[2]Percent dominant and codominant tree cover.

Northern California

We surveyed 352 stations in the 8 stands within northern California parks. We found that topography had a major influence on murrelet use ($P < 0.0001$). The mean detection levels were three times higher in major drainages (*table 6*) than on the major ridges.

Table 4—Percent of stands by murrelet use or status in each size category of stands surveyed in California for the Stand Study. Stands with a designation of Present had murrelet detections, but no observations of below canopy, or Occupied behaviors

		Percent of stands by murrelet use (status)					
		Not detected		Present		Occupied	
Stand size (ha)	*n*	*n*	Percent	*n*	Percent	*n*	Percent
2- 20	86	55	63.9	14	16.3	17	19.8
21- 40	22	12	54.6	3	13.6	7	19.8
41-100	23	12	52.2	5	21.7	6	26.1
>100	21	11	52.4	3	14.3	7	33.3
Totals	152	90	59.2	25	16.4	37	24.3

Table 5—For central California: Summary of detections[1] and status for Marbled Murrelet stations surveyed in old-growth forests within state and national parks during the summer, 1993

Landscape variable	Mean number of detections[2]	*s.d.*	Range	Number of stations (*n*)			
				Occupied	Present	Absent	Total
Topography							
Tributary drainage	55	42	30-104	3	0	0	3
Major drainage	74	53	1-177	10	3	0	13
General slope	58	31	1- 97	7	1	0	8
Minor ridge	34	31	1- 83	5	2	0	7
Major ridge	11	14	0- 37	3	2	1	6
Elevation							
240-305 m	70	53	1-177	10	2	0	12
306-360 m	64	36	13-122	10	1	0	11
361-420 m	35	31	1-946	4	0	10	10
421-500 m	4	6	0-122	1	1	4	4

[1]Includes only detections within 100 meters of observer
[2]Standardized detections

Table 6—For northern California: Summary of detections[1] and status of Marbled Murrelet stations surveyed in old-growth forests within the state and national parks during the summer, 1993

Landscape variable	Mean number of detections[2]	*s.d.*	Range	Number of stations (*n*)			
				Occupied	Present	Absent	Total
Topography							
Tributary drainage	22	33	0-134	18	19	54	91
Major drainage	30	28	0-160	67	25	17	109
General slope	14	17	0- 83	40	67	22	129
Minor ridge	16	19	0-107	19	29	18	66
Major ridge	10	13	0- 51	14	27	6	47
Elevation							
21-100 m	28	30	0-160	83	53	27	163
101-200 m	16	18	0- 83	46	66	36	148
201-300 m	12	13	0- 56	19	37	19	75
301-500 m	4	6	0- 22	10	11	18	39

[1]Includes only detections within 100 meters of observer
[2]Standardized detections

The proportion of Occupied stations was significantly higher at stations of less than 100-m elevation than at stations >200 m ($P < 0.0001$) (*table 6*). The proportion of stations with no detections was significantly higher in the >300 m category and significantly lower in the <100 m category.

Inland Range

We found highest frequencies of presence (89.05 percent) and occupancy (21.91 percent) at stands and stations within 10 km of the coast (*table 7*). The proportion of Occupied sites decreased in the 10- to 20-km band. The number of stations with detections declined by more than 99 percent from the 30- to 40-km to the 40- to 50-km band, although four times the number of stations were surveyed in the 40- to 50-km band. The proportion of Occupied stations declined rapidly beyond 30 km from the coast.

Discussion

Stand Study

The most important factor in indicating Occupied stands was density of the old-growth cover, that is, the percent of the area covered by the crowns of old-growth trees. Occupied stands had a higher percentage of old-growth cover than stands with murrelets only present, or in stands with no detections. These relationships are consistent with those

Table 7—Marbled Murrelet use of forest stands in northern California. Numbers represent individual stands for isolated stands surveyed surveyed four times during the Stand Study or stations for surveys conducted in each 12.5 ha of a large contiguous stand for the Park Study or in preparation for timber harvest

Distance band km from coast	Number of stations surveyed	Number of stations by use			
		Detected[1]	Percent	Occupied	Percent
0-10	283	252	89.05	62	21.91
10-20	133	38	28.57	6	4.51
20-30	144	52	36.11	24	16.67
30-40	100	36	36.00	6	6.00
40-50	428	1	0.23	1	0.23
50-60	95	2	2.11	0	0.00
Totals	1183	379	32.04	98	8.28

[1]All stations or stands with murrelet detections, including occupied behaviors

found in Oregon (Grenier and Nelson, this volume) and Washington (Hamer, this volume).

We found the presence of redwood as the dominant tree species to be a factor for predicting higher mean detection levels and stand occupancy. In Washington, Hamer and others (1993) also found tree species composition to be an important factor for murrelet occupancy. Within the range of our study, stands dominated by Douglas-fir often were in drier areas with higher summer temperatures. Sites very close to the coast are usually dominated by Douglas-fir and Sitka spruce (*Picea sitchensis*) and, for unknown reasons, also lack murrelets.

Contrary to previous studies we did not find larger stands more likely to have murrelets present or to be occupied. Other factors, such as, stand history and juxtaposition to other old-growth stands may mask the effects, if any, of stand size on murrelet presence and use.

Although in the Stand Study we did not find a significant relationship between distance from the ocean and murrelet detections or behaviors, this possibly was related to the limited range of distances for stands surveyed. Our examination of all surveys from 1988 through 1992, however, indicates a strong pattern of declining murrelet presence with distance from the coast (*table 7*). The number of stations more than 40 km inland with murrelet detections was only about 2 percent. One factor which may have biased the bands >40 km inland was the selection of the survey sites. Many of these sites were located in forest habitat selected for timber planning and not considered optimal for murrelets. A lack of murrelet detections would then allow timber harvesting on some of these lands. Further studies inland in California at sites selected by unbiased methods would provide needed information on the murrelet's distribution in these areas.

It is unlikely that one factor alone will best describe murrelet habitat. Density of old-growth cover and species composition are included as important factors in more than one analysis. These variables may be the strongest predictors of murrelet presence in California.

Large Contiguous Stands

Within the large stands of old-growth in the parks, most stations with observations of occupied behaviors occurred in the major drainages and, correspondingly, at low elevations. Occupied behaviors were observed at 69 (73 percent) of the 95 stations in the major drainages. Trees in these drainages tend to be larger, and experience less limb breakage from wind (Tangen, pers. comm.). Both of these factors could contribute to larger diameter branches and more potential nest platforms.

Acknowledgments

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Appendix A

Designing a study to examine the relationship of Marbled Murrelets with forest habitats requires first determining if the birds are present or absent from individual forest stands. Here, we outline the methods used to determine the appropriate number of surveys required when the objective is to determine murrelet presence or absence.

For our study, we wished to know how many survey mornings were necessary to determine presence in a stand of murrelets with a 95 percent probability of being correct. We, therefore, set the level of probability of a false negative at 5 percent. That is, murrelets are present, but we accept a 5 percent probability that they are not detected. Data from previous surveys have been used in the discussion below (*table 1*). From the data provided by Rob Hewlett, Steve Kerns, Kim Nelson, and our studies, we determined the number of survey mornings needed to meet this level of confidence at sites having various levels of detection rates.

In the following example, we assumed murrelets are present in the relatively homogeneous stand of old-growth timber to be surveyed. Each survey consists of one person observing from a station for one morning.

The method for examining our data was:

$$P = 1 - (1 - p)^n$$

where—

P is the probability of at least one detection,

p is the proportion of surveys with at least one detection, that is, the number of surveys with at least one detection, divided by the number of surveys, and

n is the number of surveys required to detect at least one bird.

To determine the number of surveys needed if we want to be 95 percent certain (P = 0.95) we are not missing birds which are present, we solve for n:

$$n \geq \frac{\ln(1-P)}{\ln(1-p)}$$

where—

ln is the natural log.

We tested our survey sample size from 19 sites (*table 1*) with relatively low average detection rates and a minimum of seven survey mornings. The mean detection rate per morning was divided into four categories, 0.4 to 2.5, 2.6 to 5.0, 5.1 to 7.5, and 9.4 to 16.6 detections. We used the average percent of surveys with detections within each category to estimate p.

In the 0.4 to 2.5 category, the percent of survey mornings with detections varied from 13 percent to 75 percent, with an average of 48 percent of the mornings with detections. The calculation is as follows:

$$n \geq \frac{\ln(1-0.95)}{\ln(1-0.48)} = 4.58, \text{ or 5 surveys.}$$

In the 2.6 to 5.0 detection range, the percent of surveys with detections varied over a smaller range, from 63 percent to 91 percent, an average of 81 percent. Using the average number, the calculation is:

$$n \geq \frac{\ln(1-0.95)}{\ln(1-0.81)} = 1.80, \text{ or 2 surveys.}$$

In the 5.1 to 7.5 detection range, the percent of surveys with detections varied from 65 percent to 88 percent, an average of 78 percent. The calculation as above was 1.98 or a minimum of 2 surveys.

The highest detection range used for this calculation was 9.4 to 16.6 birds per morning, an average of 85 percent of survey mornings with at least 1 detection. The calculation resulted in 1.75, or 2 surveys.

From these data we can conclude that in areas with mean detection rates as low as 0.4 to 2.5 per survey (and presumably low occupancy rates as well), a minimum of five survey mornings will detect birds if they are present, with a 95 percent probability. In areas of detection rates from 9.4 to 16.6, the number of surveys necessary to prevent a false negative is about two. Using this formula, 4 surveys would be required to detect birds in areas with a mean of 1.0 to 2.5 detections per survey. We can then conclude that a suggested survey rate of four surveys per stand, will detect birds in excess of 95 percent of the time, and will likely detect all but the smallest populations 99 percent of the time.

***Table 1**—Detection rate at stations with low rates, and the percent of surveys with detections*

Station name	Number of surveys	Mean detection rate	Percent of surveys with detections
Site F	8	0.4	13
ALCR 6	8	1.0	75
FRNO	7	1.3	57
Site E	8	2.1	25
ALCR 3	8	2.5	75
ALCR 9	8	2.6	63
ALCR 4	8	3.0	88
ALCR 1	8	3.1	75
FRSO	11	4.7	91
PATM	8	5.0	88
ALCR 10	8	5.1	75
ALCR 12	8	5.1	88
ALCR 13	8	5.6	88
KLMO	11	6.2	65
SFYA	13	6.5	77
EHSP 10	8	7.5	75
ALCR 11	8	9.4	75
ALCR 8	8	13.0	88
CUPE	13	16.6	92

Assumptions

There are several assumptions we have made in using these methods. We list them below and discuss each.

*We assume that the amount of canopy cover at a station will have no effect on detection probability (*P*).*

In most forests, the majority of detections are audio and are not affected by canopy cover. Though the number of visual detections decreases with increased canopy cover, there should be a compensating effect as we have found higher numbers of total detections (e.g., Paton and Ralph 1990) as forest age and canopy cover increase.

In calculating P*, the probability of at least one detection in a stand, we assume that murrelets are present in the stand when the survey is conducted.*

The effects of this assumption are discussed in detail in Azuma and others (1990), and the situation with the murrelet is similar. Since there is some probability that murrelets will be present in a stand and not be detected, the result would be an underestimate of the number of stands with murrelets present. Following data collection, bias adjustments presented in Azuma and others (1990) could be used to estimate the number of stands with murrelets in each stand category.

We assume that P *is constant and independent of stand size and habitat type.*

It is possible that as stand size increases and habitat matures, the number of birds in a stand will increase. Increased numbers will likely increase *P* as individuals may call in response to other birds as a result of social facilitation. Therefore, stands with few birds will have fewer detections than stands with many birds. We will be examining this assumption, and it forms the basis of the null hypothesis that stand size and habitat type have no effect on detection rate.

Frequency of surveys

If the habitat is homogeneous and we assume that the birds are distributed essentially evenly throughout the stand, the stations can be positioned throughout the stand and all stands, regardless of size, would be surveyed four survey mornings.

PART IV

The Marine Environment