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PANA/IKEv2: An Internet authentication protocol for heterogeneous access

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Chapter 33

Offshore Population Estimates of Marbled Murrelets in California

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Abstract: We devised a method of estimating population size of Marbled Murrelets (*Brachyramphus marmoratus*) found in California's offshore waters. The method involves determining the distribution of birds from the shore outward to 6,000 m offshore. Applying this distribution to data from boat surveys, we derived population estimates and estimates of sampling error. We estimate a total California population of approximately 6,500 birds (+ 450). Lower previous estimates of the Marbled Murrelet population in California were derived from surveys conducted for different purposes. Possible sources of error in our estimates are birds occurring farther offshore than our surveys, incubating birds missed while on nests, birds foraging underwater when the boat passed, double counting flushed birds, and observer error in estimating distance to birds. We feel that these sources of error compensated each other or were minimal.

The widespread Marbled Murrelet (*Brachyramphus marmoratus*) breeds inland along coasts of the North Pacific and is fairly abundant in many portions of its range. In California, the murrelet forages for small fish and invertebrates (Burkett, this volume) in nearshore waters, primarily within five km of the coast.

Because of the murrelets' secretive nesting habits at inland conifer forests, and the unknown relationship between the number of detections at inland sites and the number of birds present, population estimates must be based on censuses of birds at sea. Previous estimates of the population in California have been derived from incidental data collected during surveys of seabird colonies. Sowls and others (1980) recorded observations of murrelets opportunistically while travelling by boat between colonies. Birds were counted in narrow strips at variable distances, within 1 km of shore. They speculated that the breeding population in California could be about 2,000 birds. In 1989, Carter and others (1990b) systematically recorded murrelets along certain coastal sections. Boat transects were parallel to and between 200 m and 600 m out from shore. They estimated a population of 1,821 breeding birds. Few birds were seen south of Humboldt Bay and only 5 birds between Cape Mendocino (just south of Eureka) and Half Moon Bay, in Central California.

To effectively use offshore survey data to estimate a population of murrelets, we first needed to determine how the birds are distributed in relation to the shoreline. Are they found in pelagic or nearshore waters, and at what depth or distance from the shoreline do they most often forage? From this information, appropriate survey techniques can be developed which optimally survey murrelet populations in the marine environment.

The objectives of our work were to (1) determine the distribution of murrelets from the shore outward in these waters; (2) determine the distribution of birds in the varied marine habitat along the coastline of the state; and (3) from these data, estimate the population for California.

Methods

For each bird(s) detected during the surveys described below, we recorded the number of individuals, their perpendicular distance from the transect line, and characteristics of plumage or behavior. A 40-cm fishing buoy attached to a 100-m line was towed behind the boat and used by observers as a reference for distance estimates. All birds detected by the observer were recorded, including flying birds. The crew of observers changed from year to year, but some observers surveyed in all years. During each season observers usually participated in surveys in all areas, thereby reducing the bias of observer variability.

Detection Distance

We assumed that all birds on the transect line were detected, but that some birds were missed as the distance from the transect increased (Dixon 1977, Gould and Forsell 1989, Weins and others 1978). We calculated the "effective area surveyed" (EAS), which allows an unbiased estimate from all detected birds. Using this distance and transect width, it is then possible to calculate the density of birds on the water. The EAS of murrelets varied little from about 100 m, probably because of the limited range of sea conditions under which surveys were conducted. We discontinued surveys when seas reached 25 - 35 cm and frequent whitecaps appeared (Beaufort scale 3 or 4). The transect width also appeared to remain relatively constant regardless of the observer platform heights on boats we used: 7 m and 1-2 m. A 100-m transect width was used for calculations below. The area surveyed on each 2-km survey segment described below is therefore 200 m wide by 2,000 m long or 0.4 km^2 (*fig. 1*).

Intensive Surveys

In order to determine the distribution of birds outward from the shoreline, we conducted intensive surveys from

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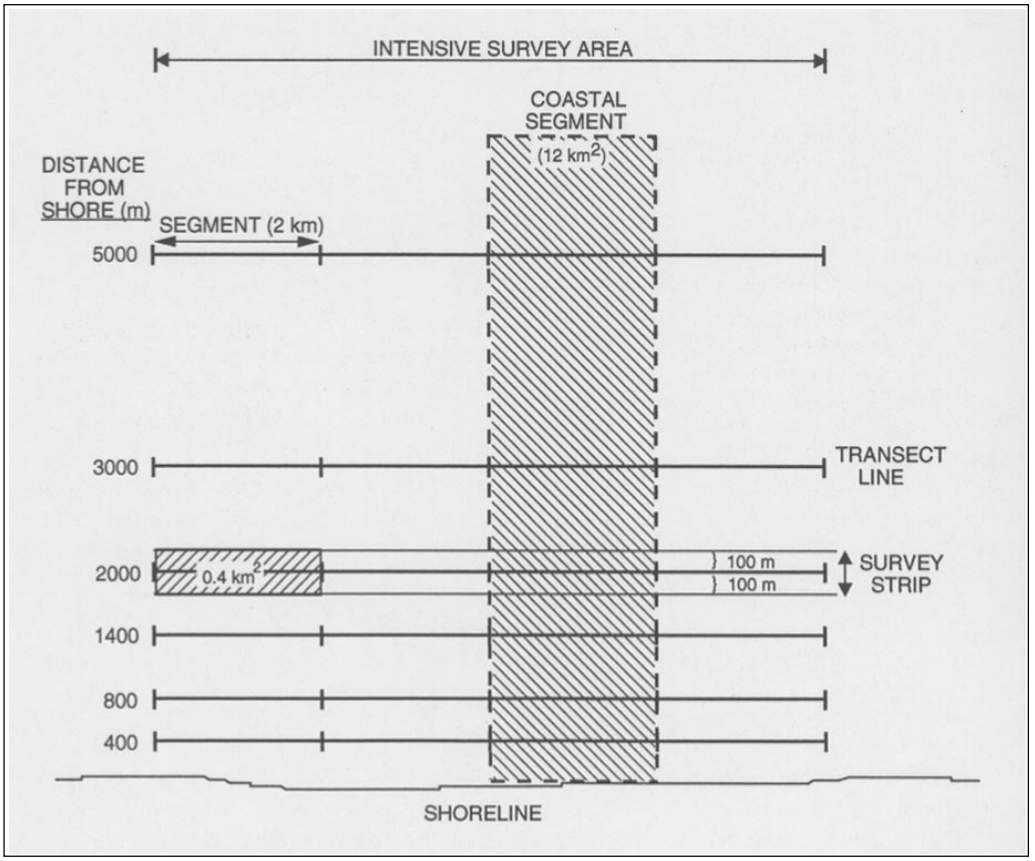

Figure 1—Diagram of intensive survey areas used to determine distribution of Marbled Murrelets from the shoreline outward to 6,000 m.

1989 through 1993 at three survey areas: two in Del Norte County (Pebble Beach and Crescent Beach) and one in Humboldt County (South Jetty) (*fig. 2*). We chose areas that were accessible from nearby harbors and based on previous Marbled Murrelet sightings consistently had murrelets present. We used two open-decked boats with center consoles and without visual obstructions (Boston Whalers, 5.5 m and 7 m lengths). Boat speeds ranged from 8 to 12 knots, depending upon sea conditions, with slower speeds in higher seas. Surveys began in the morning, as soon after sunrise as sea and fog conditions allowed. Surveys ended usually by mid-day, as sea conditions deteriorated.

Surveys consisted of travelling along a series of 6-8 km long transect lines parallel to shore and, in general, following the depth contours of the ocean floor. The transect lines were positioned offshore from the shoreline at 400 m, 800 m, 1400 m, 2000 m, 3000 m, and 5000 m (*fig. 1*). Due to inshore rocks or surf, the 400 m distance was only possible at the protected Crescent Beach site.

Each year we completed one to four surveys per month at each intensive survey area, as weather and sea conditions permitted. On each survey day we attempted to complete all transects; however, a change in conditions sometimes resulted in partial surveys. Subsequent surveys would begin with those transects not completed on the previous survey.

Extensive Surveys

We surveyed the coastline of northern and central California from the Oregon border to Point Lobos, south of Monterey Bay (*fig. 2*). The sampled area was divided into 26 coastal sections with varying numbers of 2-km segments, totalling 393 segments or 786 km (*table 1*, *fig. 2*). The length of each coastal section, and therefore the number of 2-km segments, was determined by topography and access from harbors. Depending on availability of boats and harbors, the different sections of coast were sampled with different intensity. Areas with easy access to harbors were sampled most frequently.

Each coastal section was surveyed at two distances from the shoreline, 800 m and 1,400 m. The transects were parallel to the shoreline and observations were recorded in 2-km segments. As with the intensive surveys, the area surveyed by each 2-km segment was 200 m wide by 2,000 m long, or 0.4 km^2.

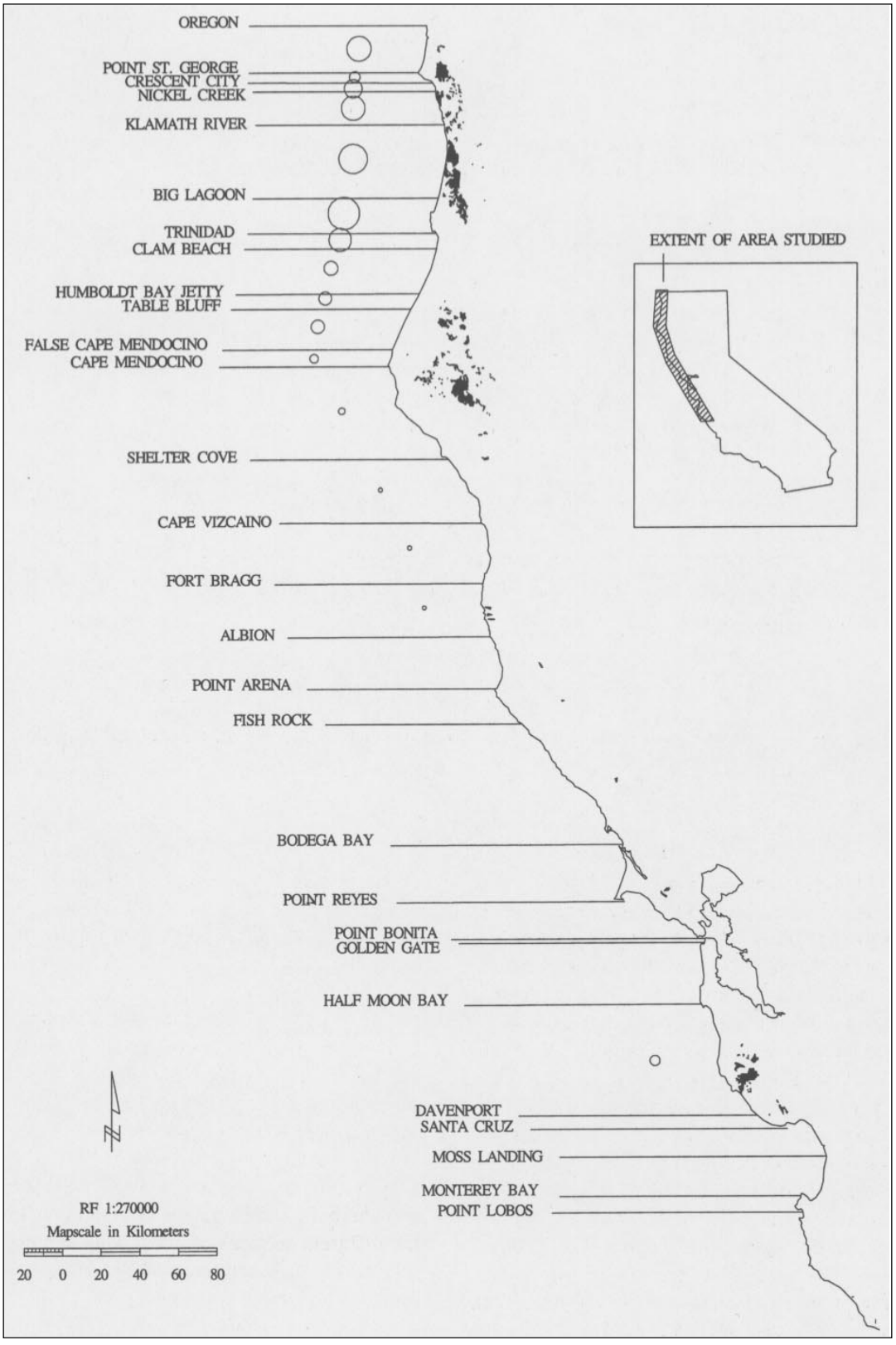

Figure 2—Densities of Marbled Murrelets along California coast by coastal sections. Proportional circles indicate densities per 2-km coastal segment (12 km^2). The largest circle (Big Lagoon to Trinidad) equals a density of 8.81 birds/km^2 (see *table 1*). Areas of old-growth forests are shown inland as shaded areas, from several sources.

Table 1—Survey effort, densities, and numbers of Marbled Murrelets in coastal waters of California , 1989-1993

Northern boundary of coastal section (see *fig. 2*)	No. 2-km coastal segments	1400 m		800 m		No. birds per km^2	No. birds per segment (12 km^2)	Total birds (estimate)	*s.e.*	*s.e.* (pct. total)
		No. segments surveyed	No. survey days	No. segments surveyed	No. survey days					
Oregon	12	48	5	48	5	4.47	53.67	644	192.5	29.9
Point St. George	4	156	42	172	46	1.98	23.75	95	12.7	13.3
Crescent Beach	2	110	55	164	57	3.71	44.50	89	9.3	10.5
Nickel Creek	9	210	24	227	23	4.60	55.22	497	39.9	8.0
Klamath River	20	159	12	108	11	5.43	65.15	1303	132.0	10.1
Big Lagoon	9	92	13	97	14	8.81	105.67	951	159.7	16.8
Trinidad	8	30	10	29	10	4.35	52.25	418	72.8	17.4
Mad River	13	265	26	272	28	2.17	26.07	339	19.3	5.7
Humboldt Bay	4	177	46	170	47	2.48	29.75	119	14.9	12.5
Table Bluff	11	275	16	282	15	2.59	31.09	342	21.9	6.4
False Cape Mendocino	4	12	4	12	4	1.50	18.00	72	16.2	22.6
Cape Mendocino	29	197	7	90	6	1.16	13.93	404	50.4	12.5
Shelter Cove	20	36	5	50	5	0.72	8.60	172	15.7	9.2
Cape Vizcaino	16	17	2	30	2	0.72	8.69	139	16.6	11.9
Fort Bragg	15	18	2	22	2	0.67	8.00	120	13.8	11.5
Albion	14	13	2	3	1	0	0	0	0	0
Point Arena	10	10	1	0	0	0	0	0	0	0
Fish Rock	41	33	2	42	2	0	0	0	0	0
Bodega Bay	20	9	1	11	1	0	0	0	0	0
Point Reyes	29	17	1	8	1	0	0	0	0	0
Golden Gate[1]	17	9	1	14	1	0	0	0	0	0
Half Moon Bay	35	57	3	33	3	1.82	21.80	763	125.5	16.5
Davenport	11	11	1	5	2	0	0	0	0	0
Santa Cruz	17	14	2	18	2	0	0	0	0	0
Moss Landing	11	11	1	11	1	0	0	0	0	0
Monterey Bay	12	12	1	12	1	0	0	0	0	0
Totals for California	393	1998	285	1930	290			6467	452.3	5.1

[1]No surveys were conducted from Point Bonita to Golden Gate.

Analyses

Murrelet Distribution From the Shoreline

We used the following method to determine the relationship between the number of birds at varying distances from shore and the total number of birds at the three intensive survey areas. We assumed the relationship was similar for the three areas. Differences in coastal habitat types (sandy beach, rocky shoreline, and offshore rocks) and relative numbers of birds (low, medium, and high densities) at the three areas did not affect the distribution of birds out from the shoreline, as determined by plots of the residuals from a regression analysis.

The following four steps were used to establish the relationship between the distribution of murrelets from shore and the total population in an area.

Monthly Mean Counts

The datum used for analyses was derived from the total number of birds detected in each 2-km segment on each survey day at each distance from shore. Surveys from April through October for all years were included in the data set. Monthly mean counts were calculated for each transect distance (400, 800, 1400, 2000, 3000, and 5000 m). An example would be the following: during April, at Crescent Beach in the two 1400-m 2-km segments combined, a total of 235 birds were seen over all years. We surveyed a total of 133 of the 2-km segments at that distance during April. The average was then 235 birds/133 2-km segments or 1.77 birds per 2-km segment for all years.

Not all distances were sampled in all years during each month at each survey area. For example, surveys were not conducted at 400 m at Pebble Beach because of the unsafe rocky shoreline, nor at 5,000 m at any survey area prior to 1990.

Where possible, the missing monthly mean counts were estimated with regression equations constructed with the non-missing monthly mean counts. We assumed that nearby distances would provide the best predictive ability for missing mean counts, and only those models were examined for each distance. For example, when estimating the 400-m count, we looked only at two models: one with the 800 m monthly mean and another with both the 800 m and the 1,400 m monthly means. The mean monthly count from October 1990 at 800 m offshore did not fit the distinct pattern found with all other sample points and was excluded from the analysis. The regression equations were chosen to have up to two independent variables and the results were as follows:

$$\bar{x}_{400} = 0.228 + 0.6824 \cdot \bar{x}_{800}$$

std. err. of estimate = 2.775

$r^2 = 0.414$; $n = 20$

$$\bar{x}_{2000} = 0.2605 + 0.23003 \cdot \bar{x}_{1400} + 1.6631 \cdot \bar{x}_{3000}$$

std. err. of estimate = 1.205

$r^2 = 0.738$; $n = 36$

$$\bar{x}_{3000} = 0.1205 + 0.20603 \cdot \bar{x}_{2000}$$

std. err. of estimate = .5375

$r^2 = 0.441$; $n = 36$

$$\bar{x}_{5000} = 0.009026 + 0.942065 \cdot \bar{x}_{3000} - 0.121016 \cdot \bar{x}_{2000}$$

std. err. of estimate = 0.2290

$r^2 = 0.668$; $n = 12$

The missing values were estimated with the regression equations, and any negative estimates were replaced with zero. Because some counts could not be predicted because not all of the independent variables were available, repeated use of the equations was performed until no more missing values could be estimated. Months with remaining missing values were excluded from the next step of the analysis.

Murrelets Per 2-km Intensive Coastal Segment

The total mean numbers of murrelets per 2-km coastal segment (*fig. 1*) of intensive survey area were then calculated from the actual and estimated mean monthly counts for all survey distances (400, 800, 1400, 2000, 3000, and 5000 m). Counts associated with 200-m wide and 2-km long survey strips (*fig. 1*) starting (and centered) at 200 m from shore, and ending with a 200-m wide strip centered at 6,000 m from shore, were interpolated or extrapolated using the surrounding or closest observed counts. For example, the 200-m estimate was found with a linear extrapolation of the 400-m and the 800-m count (*fig. 3*). This extrapolated distribution closely resembled results of surveys conducted from shore-based stations (Ralph and others 1990), where we found the peak numbers of birds occurred beyond 400 m from the shoreline. The 3,200-m strip count was estimated with linear interpolation of the 3,000-m and 5,000-m count. If any linear interpolation resulted in a negative number, then zero was used instead. The total number of murrelets between 100 m from shore and 6,100 m from shore was then found by summing the contribution of the 200-, 400-, 600-,..., 6000-m strips (*fig. 3*).

The Total Birds From 800- and 1,400-m Counts

The total number of murrelets from the intensive surveys was then regressed against the mean counts at 800 m and 1,400 m. The resulting equation:

$$\textit{Coastal segment total} = 6.758 + 4.6102 \cdot \bar{x}_{800} + 4.6241 \cdot \bar{x}_{1400}$$

represents the relationship between the counts at these two distances and the total number of birds in a 2-km coastal segment of coastline, from 100 m to 6100 m offshore.

Estimates of Murrelet Numbers for Each Coastal Section

The extrapolated distribution of birds, from 100 m to 6,100 m out from the shoreline at our intensively surveyed areas, was used to estimate the numbers of birds in the

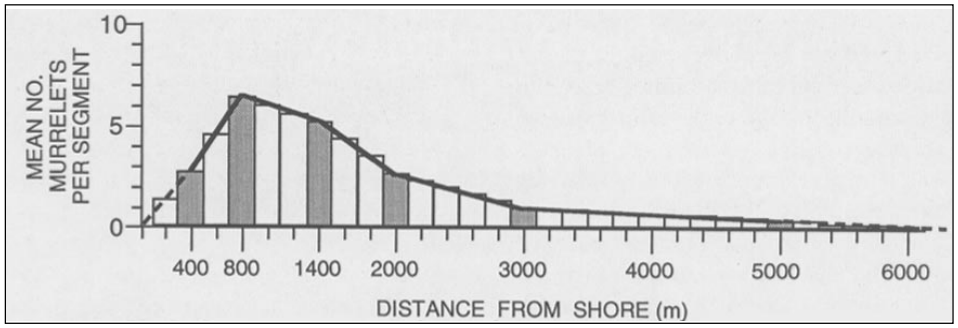

Figure 3—Distribution of Marbled Murrelets at distances from 100 m to 6,000 m from the shoreline. Extrapolation and interpolation of population estimates for survey strips based on known counts (shaded bars) of the 400-, 800-, 1400-, 2000-, 3000-, and 5000-m transect distances.

extensive survey of coastal sections where only two offshore distances (800 m and 1,400 m) were surveyed.

For the 800 m and 1,400 m distances of each coastal section (*fig. 2*), we calculated the mean count, the standard deviation of the count, and the correlation coefficient of the two distances for all paired counts (2-km segments with counts at both distances on the same day). These summary statistics were used with the regression equation from the intensive distribution to estimate the total number of murrelets in each section (*table 1*) and the standard error of that estimate.

Summary Statistics:

n_{800} = number of counts in a section at 800 m

$\bar{x}_{800}$ = mean count at 800 m

s_{800} = standard deviation of counts at 800 m

n_{1400} = number of counts in a section at 1400 m

$\bar{x}_{1400}$ = mean count at 1400 m

s_{1400} = standard deviation of counts at 1400 m

r = correlation coefficient for pairs of 800-m and 1400-m counts

n = number of pairs of counts at 800 m and 1400 m

L = number of 2-km coastal segments

The total numbers for all the sections are then summed to obtain an estimate of murrelets in California and the standard error of the total estimated.

Section total =

$$L \cdot (6.758 + 4.610 \cdot \bar{x}_{800} + 4.624 \cdot \bar{x}_{1400})$$

Std. err. =

$$L \sqrt{4.610^2 \cdot \frac{s_{800}^2}{n_{800}} + 4.624^2 \cdot \frac{s_{1400}^2}{n_{1400}} + 2 \cdot \frac{21.318 \cdot r \cdot s_{800} \cdot s_{1400}}{n}}$$

Results

Coastal Distribution

We estimate the total state population to be approximately 6,500 birds (*table 1*). The distribution of birds in the north and central parts of the state were disjunct *(fig. 2)*. The highest densities of birds were found in the northernmost part of the state, from the Oregon border to Trinidad in Humboldt County. In most of this area, there was a density of more than 4 birds/km^2 (48 birds per 2-km coastal segment, 12 km^2). This population includes approximately 4,000 birds. Most of these birds were adjacent to, and contiguous with, the old-growth forests in Del Norte and northern Humboldt counties. These forests are largely on state and federal parks, and composed primarily of coast redwood (*Sequoia sempervirens*). From Trinidad south to False Cape Mendocino, murrelet densities were generally less than 2.5 birds/km^2. This population was adjacent to the old-growth forests of Humboldt Redwoods State Park and the private lands of Pacific Lumber Company, all in Humboldt County. South of False Cape Mendocino, the densities of birds again declined from 1.5 to 0.67 birds/km^2 in the area of Fort Bragg and Albion. No birds were observed during surveys between Albion and Half Moon Bay, several hundred kilometers to the south.

The central California population, comprising about 12 percent of the state's population, was estimated at 763 individuals and was located between Half Moon Bay in San Mateo County and Davenport in Santa Cruz County. This population was found primarily between Pigeon Point and the mouth of Waddell Creek and was also offshore of old-growth redwood forests, mainly in state parks.

Discussion

Censusing murrelets from boats is preferable to censusing from the shoreline. During 2 years of surveys conducted from observation points on the shoreline with 30 x telescopes,

we found the highest numbers of birds were seen between 400 m and 800 m from shore, depending on the height of the observer above the water. On surveys conducted from boats at the same locations, we found that most birds were 800 m or farther from shore, apparently beyond the effective range of the shore-based observers.

Factors Which Might Affect the Estimate

There are five factors which might cause over- or under-estimate of the population: (1) a small number of birds occur at distances greater than 6,000 m from shore, beyond our surveys; (2) during incubation a portion of the birds are on nests and, therefore, not counted at sea; (3) a fraction of the birds are foraging underwater when the boat passes and are, therefore, missed by observers, (4) some birds would be flushed and fly ahead of the boat and be repeatedly counted, thus resulting in an overestimate, and (5) observer error in estimating distances to the birds. We feel that these sources of error, detailed below, in part compensate for each other, and would account for only perhaps as much as 10 percent error.

Birds Outside Our Sampled Area

The density of birds declined rapidly beyond 2,000 m (*fig. 3*), but even at 5,000 m, the density of birds is appreciable. About 10 percent of the total are estimated to occur between 3,500-6,000 m from shore. In extensive surveys off the central California coast murrelets have only very rarely been detected beyond 7,000 m (Ainley and others, this volume). If we extrapolate our distribution to 7,000 m, approximately 4 percent of the population might occur beyond our sampled area. A log-log plot of the data shows that birds could theoretically be detected out to 20 km from shore, albeit in extremely low densities. While birds regularly occur out to 60 km from shore off British Columbia and Alaska, there is no evidence of this in California.

Birds Missed During Incubation

During the approximately 90-day breeding season (Hamer and Nelson, this volume a), incubation extends over about 30 days for each breeding pair. As the sexes alternate incubation duties, half of the breeding population would be on the nest during the incubation period. Estimates of the proportion of the population breeding in any one year range between 30 and 85 percent (Carter and Sealy 1987b; Beissinger, this volume). Thus, at-sea censuses during incubation would result in an underestimate of 5 to 14 percent of the population. This is calculated by determining the percent of birds that would be on the nest at any one time during the breeding season:

0.85 breeding x 0.33 breeding season x 0.50 birds = 14 percent underestimate.
0.30 breeding x 0.33 breeding season x 0.50 birds = 5 percent underestimate.

Since the potential incubation period represents 43 percent of our survey period from April through November, the error estimates of 5 to 14 percent should be multiplied by 0.43, suggesting an underestimate of approximately 2 to 6 percent. Based on the proportion of young birds observed offshore in recent years (see Beissinger, this volume; Ralph and Long, this volume), the proportion actually breeding could be substantially lower than 30 percent.

Birds Missed While Diving

We assume in this study that no birds were missed by being underwater as the observers passed. Our data show that the average dive time of murrelets is less than 17 seconds (Strachan and others, this volume), and the distance traveled in that time at 12 knots is less than 100 m. Since we can detect birds out to 100 m in front of the boat, most birds that dive while foraging would resurface before the boat passed. While we are certain that some birds are missed due to this factor, we feel that the effect is minimal, and probably much less than 5 percent of the total population.

Repeated Counting of the Same Individuals

Double counting by more than one observer might result in an overestimate with some survey methods, but we used only a single observer, aided by the driver. It is possible that some birds would fly ahead of the boat and be repeatedly counted, thus also resulting in an overestimate. Strong and others (this volume), however, discount this, and present data indicating a relatively small number of birds fly out ahead of the boat.

Distance Estimates

One factor which could affect population estimates using EAS for calculations is observer variation, or error in distance estimates. Underestimation of the distance to birds would reduce the transect width and would result in an overestimate of the total population. Overestimating the distance would have the opposite effect and the population would be underestimated. Our use of a reference buoy towed at a known distance from the boat helped decrease the variation and error in distance estimates.

Comparison with Previous Population Estimates

The numbers of birds derived from the pioneering work of Sowls and others (1980) and Carter and others (1990b) were based on more limited data. Sowls and others (1980) speculated that the population was about 2,000 birds, but their murrelet data was collected opportunistically and did not provide sufficient data for a population estimate. Carter and others (1990b) assumed that birds could be detected out to 250 m, and conducted a limited number of surveys during one breeding season. Furthermore, they often surveyed inshore of the area where we found the highest numbers of murrelets (Carter, pers. comm.). Our surveys were more extensive, sampled most of the offshore areas used by murrelets, and

were repeated over several years, under usually optimal conditions. Thus, we are confident that our population estimates are more accurate than those derived from past, preliminary survey work.

Comparison of Coastal and Inland Habitat Distribution

Murrelets are found at sea in California offshore of old-growth redwood forests. The only minor exception is the population in the vicinity of Trinidad. This population is about 30 km to the south and west of the major concentration of old-growth in Redwood National Park. The waters in this area are felt to be unusually productive by knowledgeable fisheries biologists (Roelofs, pers. comm.), perhaps explaining the abundance of murrelets in the area. A 20- to 30-km flight from nesting to foraging areas is well within the capabilities of murrelets. In British Columbia murrelets with radio transmitters were regularly tracked 40 to 60 km on daily flights from feeding areas to presumed inland nesting sites (Varoujean, pers. comm.).

The coincidence of the fragmentation of the offshore population and the fragmentation of the remaining large stands of old-growth forests adds weight to the argument that the species is dependent for nesting habitat on these stands.

Risk Factors

Our documentation of two population centers in the state with a decline of numbers from north to south, make it important to ensure that offshore populations are protected from mortality from oil spills and gill nets. Both these risks are present today, and the concentration of birds in local areas, especially the southern population, make them especially vulnerable to extirpation.

Recommendations

The data on the offshore populations of the murrelet we have gathered over the past five years can provide a basis for determining future population changes. We suggest that these surveys continue annually to monitor this threatened species, as well as the other species frequenting the nearshore waters. Any monitoring program should also include collection of data on the production of young by determining the presence of newly-fledged birds while they are distinguishable from winter-plumaged adults. With such a plan and a regular monitoring program in place, we can determine the health and trend of the population of this unique species.

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