

Chapter 34

Offshore Occurrence Patterns of Marbled Murrelets in Central California

David G. Ainley¹

Sarah G. Allen²

Larry B. Spear³

Abstract: We assessed the occurrence patterns of Marbled Murrelets (*Brachyramphus marmoratus*) offshore of Waddell Creek, in central California. Data were derived primarily from cruises during the height of the murrelet breeding season, in June, between 1986 and 1994, as well as some cruises during the pre-breeding period, February to early April. The large majority of sightings occurred within 10 km of Point Año Nuevo, directly offshore the species' breeding area. Only three sightings occurred farther offshore (12-24 km). The physical factors that explained a small but significant portion of variability in murrelet occurrence were: (1) inverse relationships related to distance to breeding area (including ocean depth); and (2) relationships to recently up-welled water. Murrelets were least abundant during periods of El Niño-Southern Oscillation. An analysis of the availability of potential prey species indicated that murrelets were most abundant when more euphausiids were found from the coast to well offshore. Murrelets were absent in years when a large prey concentration occurred only close to shore, indicating that the birds were too close to shore for us to census. We suggest that the critical habitat of this population should include the nearshore marine waters within 10 km of Año Nuevo Island.

The Marbled Murrelet (*Brachyramphus marmoratus*) nests in old-growth forests along the Pacific Coast of North America from central California to southern Alaska and the Aleutian Islands. In this region, the birds are unevenly distributed at sea, occurring in distinct clumps, often in bays at the mouths of coastal rivers (Carter and Erickson 1992, Nelson and others 1992, Rodway and others 1992, Speich and others 1992, Strong and others 1993). These concentrations may be associated with the river valleys in which the birds nest, or they may represent areas of good foraging. Both staging and foraging areas comprise "critical habitat," the designation of which is defined and required under the Endangered Species Act (U.S. Fish and Wildlife Service, 1993b).

Other than surveys to estimate abundance, little work at sea on the biology of Marbled Murrelets has been undertaken since the studies of Sealy (1972, 1975c), Carter (1984), and Carter and Sealy (1990), who investigated the species in the inside passage waters of British Columbia. Information on factors affecting distribution or clumping remains largely at the broadest scales (Briggs and others 1987, Piatt and Ford 1993). Repetitive at-sea surveys designed to understand at-

sea biology and marine factors as they affect murrelet distribution from a mesoscale perspective, i.e. 30-50 km, remain non-existent. The smaller scale surveys would be more pertinent to localized populations.

The most disjunct population of Marbled Murrelets is in central California, the southern limit of the species' breeding range. Murrelets aggregate along the coast of northern Santa Cruz and southern San Mateo counties, in the vicinity of Point Año Nuevo and Año Nuevo Island (hereafter referred to collectively as Año Nuevo), about 350 km south of the next closest murrelet nesting area; see figure 1A (Briggs and others 1987). This aggregation is associated with Waddell Creek, the last remaining near-to-pristine coastal watershed in the lower two-thirds of California (see, for example, Shapovalov and Taft 1954, an analysis still pertinent to recent times). The watershed drains Big Basin Redwoods State Park and adjacent, private, forested lands. About 250 birds are thought to breed here (Carter and Erickson 1992).

We collected information on Marbled Murrelets in the vicinity of Año Nuevo on ship-based surveys designed to elucidate the physical and biological factors that organize seabird communities off central California during the years 1986-1994. Overall our work was not directed specifically at Marbled Murrelets. Moreover, our large vessel was usually not able to cruise in waters shallower than 20 m, where Marbled Murrelets often occur (Ralph and others 1990, Sealy and Carter 1984, Strong and others 1993). We were able to direct the ship's course at times, however, and whenever in the vicinity of Año Nuevo, we pointedly surveyed for murrelets. We collected data on sea-surface temperature and salinity, thermocline depth, bottom depth, distance-to-shelf break, distance-to-shore, and distance-to-nesting area, which we recorded at frequent, regular intervals while we surveyed continuously for birds. We also obtained information on availability of potential prey in the study area.

Methods

Our research extended from Bodega Bay to Carmel, California, in waters from 20 to 2,000 m deep. For purposes of this report, our study area includes the middle third of this region, specifically, from Half Moon Bay to Santa Cruz (fig. 1). We censused seabirds from the flying bridge of the NOAA Ship David Starr Jordan during the 9 cruises in the first two weeks of June 1986-1994 (referred to hereafter as late spring), and in 5 cruises during 7-27 April 1987, 16-22 April 1988, 21 February-6 March 1992, 2-15 March 1993, and 1-14 March 1994 (early spring). Two observers simultaneously counted

¹ Marine Program Director, Point Reyes Bird Observatory, 4990 Shoreline Highway, Stinson Beach, CA 94970

² Ecologist, Western Regional Office, National Park Service, U.S. Department of the Interior, San Francisco, CA 94107

³ Research Biologist, Point Reyes Bird Observatory, 4990 Shoreline Highway, Stinson Beach, CA 94970

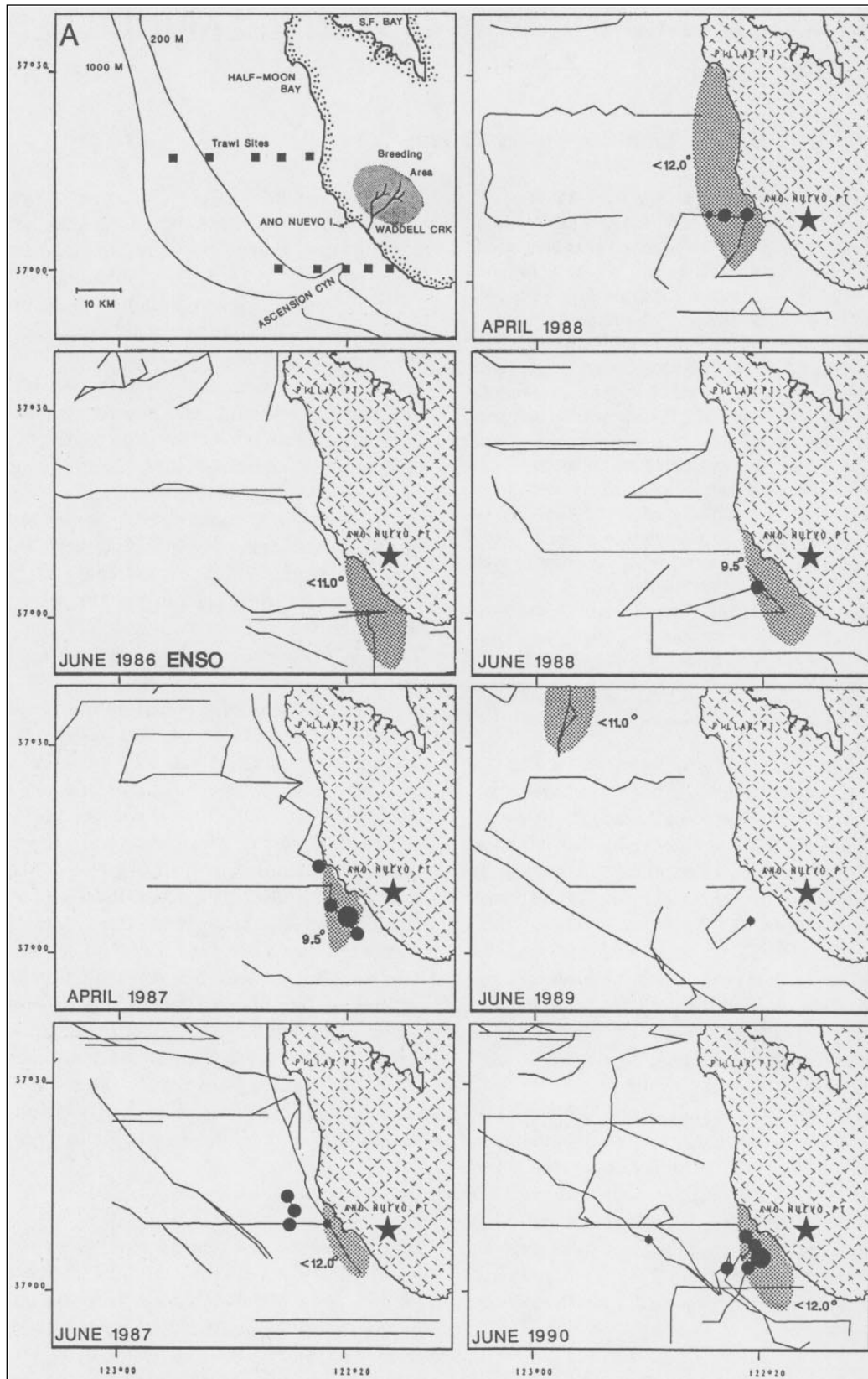
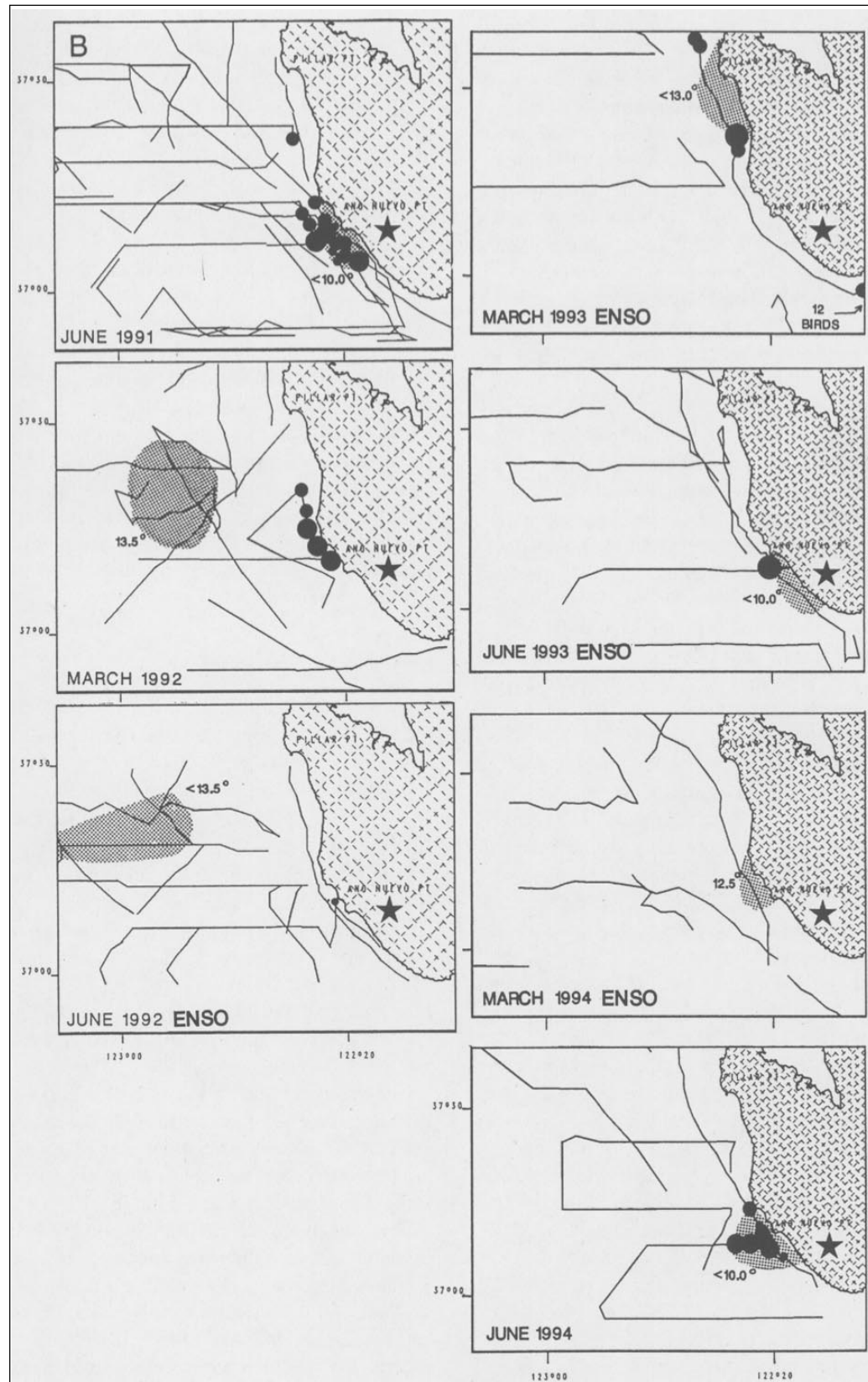


Figure 1A and B—The coast of San Mateo and Santa Cruz counties showing transect lines and number of murrelets seen within 300 m of the vessel during surveys, 1986-1994. A small circle = 1 bird, medium circle = 2-5 birds, and large circle = >5 birds; the star designates the breeding area. The upper panel of 1A gives localities mentioned in the text; shaded ocean areas in other panels indicate where sea-surface temperature is the lowest in the region as indicated in degrees centigrade. ENSO indicates an El Niño-Southern Oscillation condition.



all birds within 300 m of one fore-quarter, i.e., that side of the bow on which glare was least, but did not include birds following or attracted to the ship (see Tasker and others 1984; not a problem in the case of murrelets). Almost all murrelets were detected on the water, thus, we did not correct for bird flight speed or direction (Spear and others 1992). We looked forward of the 300-m transect boundary to ensure that murrelets were detected before the ship caused them to dive or take flight. Our counts were not affected by ocean turbulence, as wind speeds were generally less than 15 knots and the 10-m above water vantage point of the flying bridge precluded birds from being obscured by waves. The average ($\pm$ s.d.) wind speed was 9.0 ± 6 knots. Similarly, counts were not affected by poor visibility as we experienced no fog.

Two observers censused the 300-m band continuously whenever the ship was under way (cruising speed 14-15 km/h). We divided censuses into 15-minute (ca. 3.5 km) segments; at the start of each segment, we recorded position, distance-to-shore, water depth, weather (wind speed and direction, cloud cover) and, using the ship's electronic systems, sea-surface temperature, and salinity. We determined thermocline depth and slope from "CTD"'s conducted by ship's personnel at 8-km intervals along our cruise track (CTD is "conductivity and temperature with depth" and refers to the probe used to measure these factors.) Within the region bounded by the coast, 26 km offshore and at latitudes $37^{\circ} 02' N$ and $37^{\circ} 20' N$ (fig. 1), we logged 1863 15-min transects.

National Marine Fisheries Service personnel conducted trawls at night to estimate the concentrations of micronektonic (i.e., ones <10 cm in length) crustaceans and fish. The trawl surveys, done in the May-June period, were designed to assess prevalence of juvenile rockfish (*Sebastes* spp.). These and similar sized organisms, all of which the nets targeted, all would include suitable murrelet prey. One track of five trawl stations at increasing bottom depth (25 - 480 m) occurred in the southern part of the study area, off Davenport, and another occurred in the northern part, off Pescadero (see fig. 1A). In most years, two sweeps of the trawl stations were made during the murrelet census period, but in a few years only one was made. For a given year, we averaged trawl results combining all sweeps and both station lines by depth stratum in 5 intervals. Herein, we present average percent composition of the 5 trawl intervals among the four most prevalent species groups: euphausiids (mostly *Thysanoessa spinifera*), anchovies (*Engraulis mordax*), juvenile rockfish, and myctophiids (mostly *Tarletonbaena crenularis*).

We mapped murrelet sightings using an Arc-Info Geographic Information System (ESRI, Inc., Redlands, California). We analyzed the physical habitat features listed above in an attempt to explain murrelet occurrence patterns by both multiple regression on murrelet density and logistic regression on presence/absence of murrelets on census segments. Data were log-transformed before analysis. Our initial model also included the following interaction terms as independent variables: distance-to-shore $\times$ distance-to-nesting-

area; distance-to-shore $\times$ depth; and distance-to-shore $\times$ distance-to-shelf-break. Besides the physical habitat features, we calculated distance-to-nesting-area for each transect segment using the southern boundary of the region where most nests or grounded fledglings have been found (see fig. 1A; see Carter and Erickson 1992). We conducted the backwards stepwise analysis first for all years and all seasons, and then for early and late spring separately. We considered results to be significant at $P < 0.05$.

We could not use prey abundance as a factor in the regressions owing to the statistically inappropriate spacing of the trawl stations relative to the bird censuses. We made qualitative comparisons between murrelet and prey distributions, considering both the species composition of trawls and the number of organisms caught per trawl by depth stratum.

Finally, we investigated the distribution of murrelets relative to distance-to-shore, as this parameter is integral to assessment of murrelet numbers by other researchers in many regions to the north. Besides determining the proportion of murrelets seen at 1000-m intervals from shore, we also normalized the data by using search effort (number of murrelets seen divided by the number of transects at each distance interval $\times 100$).

Results

Although our June surveys were conducted in the middle of the murrelet nesting season (Carter and Erickson 1992), we saw no fledglings. Our surveys earlier in the spring coincided with the early courtship period.

Most murrelet sightings were within 7 km of shore (fig. 2) (median <5 km, $\bar{x} \pm$ s.d. 5.5 ± 5.4 km). The largest number of sightings occurred 3-5 km offshore; normalizing the data by search effort revealed no change in this pattern. We saw one Marbled Murrelet 24 km offshore, the farthest from shore that one was seen. This was near to the edge of the continental shelf break.

In spite of the wide area of our search, almost all murrelet sightings were within 10 km of Año Nuevo. Only once did we see Marbled Murrelets anywhere else in the region, Bodega Bay to Carmel, in any of the years (see below). On a smaller scale—within 10 km of Año Nuevo—substantial annual variation was apparent (compare cells of fig. 1). On some cruises, we saw few murrelets: during early spring, only 5 in April 1988 and none in March 1994; and during late spring, none in June 1986, two in 1989, and one in 1992, even though sampling was adequate. In spite of even more sampling tracks, we saw only 5 murrelets in June 1988 and 6 in June 1993. Murrelets were much more numerous during other cruises: 18 in April 1987; 19 in March 1992; and 16 in March 1993. Highest numbers occurred in late spring (June): 27 in 1987, 16 in 1990, 45 in 1991, and 28 in 1994. The March 1993 census was the only one in which we saw substantial numbers of murrelets farther than 10 km from Año Nuevo; 12 more were recorded off Santa Cruz, a point located just to the right of the margin in figure 1.

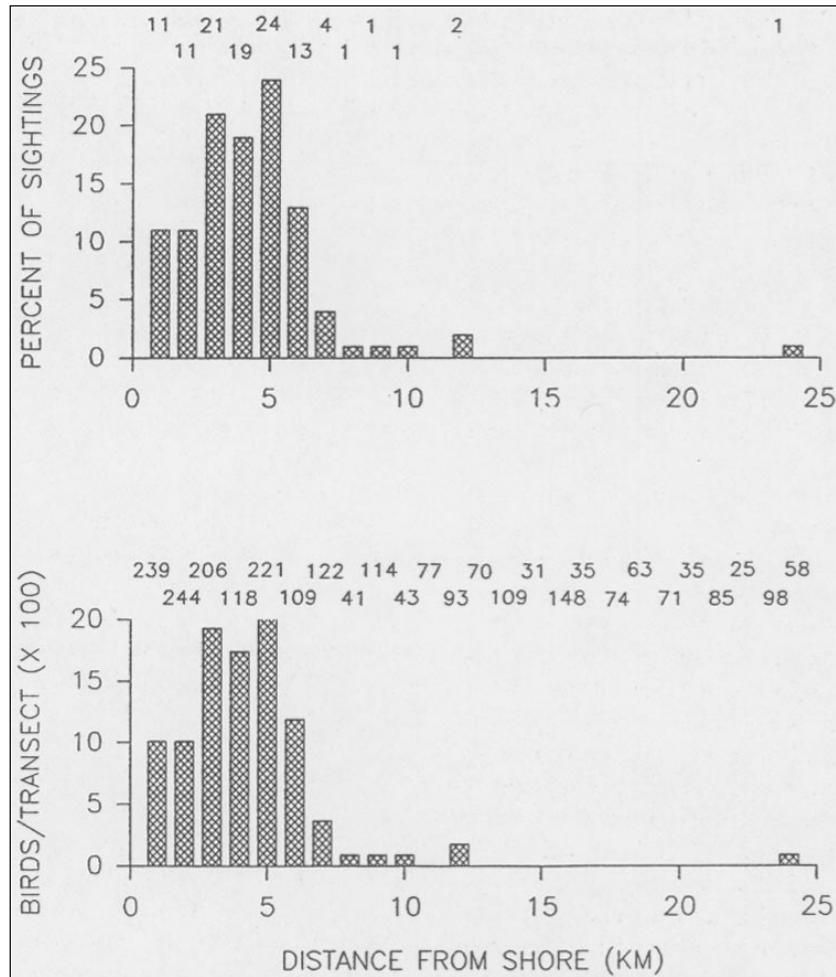


Figure 2—Frequency distribution of murrelet sightings by distance to shore by 1000-m (1-km) intervals: (A) percent of sightings in the raw data (number of murrelet sightings along the top); and (B) sightings normalized by search effort (sightings divided by number of 15-min transects in the distance intervals and the number of transects along the top).

Results of multiple regression analyses, using data from all seasons and only census segments on which murrelets were seen (hence, sample size is low), show distance-to-land to be the most important explanatory physical factor, in this case a negative one (higher densities occur closer to land; *table 1*). Using data from early spring, distance-to-land remains important (and becomes statistically significant), but depth and distance-to-nesting-area are important as well. This is logical: a correlation analysis (*table 2*) shows that distance-to-land, distance-to-nest, and depth are all closely correlated: a point moving closer to land also moves closer to nesting sites (to some degree) and to shallower water. Analyses using only late spring data show that densities are affected most strongly by waters influenced directly by upwelling, i.e. those of low temperature and high salinity (see below; *table 1*).

In the logistic analysis, which considers only presence-absence on each 15-minute transect and therefore uses all

transects, the same factors, but more of them together, explained murrelet distribution (*table 3*). In addition, more of the variance was explained. Considering both seasons, temperature, salinity, distance-to-land, distance-to-nesting-area, and distance-to-shelf-break were all important (and statistically significant). These distance parameters were related to one another as was temperature to salinity (*table 2*). Murrelets were found in waters of low salinity during early spring. At this time, freshwater runoff is at maximum extent and enters the study area from the fresh water plume that passes south from the Golden Gate (just to the north of *figure 1* boundaries), as well as from Pescadero and Waddell creeks. Thus, lowest salinities at this time of year occur close to shore but in a broad band. During early spring, distance-to-shelf-break was not a significant variable. Considering only late spring data, depth, distance-to-shelf-break and -to-nesting-area, as well as salinity, became the explanatory variables. The role of salinity was reversed from

Table 1—Results of multiple regression analysis to explain variation in murrelet density: dependent variable = murrelet density; independent variables = water depth, sea-surface temperature and salinity, wind speed, distance-to-land, distance-to-shelf-break, and distance-to-nesting-area, as well as interaction terms presented in the Methods

Variable	Coefficient	Standard error	T	P (2-Tail)
All seasons ($r^2 = 0.056$, $n = 53$)				
Constant	1.318	0.106	12.463	<0.001
Land	-0.033	0.019	-1.735	0.089
Early spring ($r^2 = 0.381$, $n = 20$)				
Constant	1.684	0.346	4.870	<0.001
Depth	0.011	0.005	2.088	0.053
Land	-0.154	0.058	-2.670	0.017
Nest	-0.014	0.008	-1.783	0.094
Late spring ($r^2 = 0.124$, $n = 33$)				
Constant	8.159	2.795	2.920	0.006
Sea-surface temperature	-0.481	0.230	-2.093	0.045

Table 2—A matrix showing correlation coefficients among independent variables used in the regression analyses

Variable	Depth	Land	Nest	Shelf	Sea-surface temperature
Early spring ($n = 496$ transects)					
Distance to:					
Land	0.717				
Nest	0.641	0.638			
Shelf	0.613	0.465	0.482		
Sea-surface temperature	0.229	0.279	-0.023	-0.040	
Sea-surface salinity	0.006	-0.048	0.176	-0.149	-0.415
Late spring ($n = 1367$)					
Distance to:					
Land	0.696				
Nest	0.468	0.651			
Shelf	0.520	0.431	0.364		
Sea-surface temperature	-0.124	-0.217	-0.149	-0.193	
Sea-surface salinity	0.153	0.179	-0.025	0.175	-0.755

the early spring, however; murrelets were found where salinity was highest, which at this time also happened to be close to shore. This was consistent with the onset of coastal upwelling, which reaches maximum in May and June and which brings cold, high salinity water to the surface adjacent to the beach especially to the south of Point Año Nuevo (*fig. 1*).

The relationship of murrelet occurrence to prey availability during late spring (*fig. 3*) could be analyzed only qualitatively because of an inconsistency of scale between the trawls and the censuses. Patterns were apparent, however, and high inshore prey abundance appeared to

result in fewer birds offshore. When murrelets were scarce in June surveys (1986, 1988, 1989, 1992, and 1993), prey abundance was disproportionately high (>1000 prey per trawl) on the shallowest (and next shallowest in the case of 1993) trawl station, as compared to the adjacent trawls in deeper waters out to the shelf break (i.e., waters <280 m). In contrast, during cruises when murrelets were abundant, particularly 1990, 1991, and 1994, potential prey were also abundant, and equally so among all or almost all the trawls throughout the shelf waters. The exception was 1987, when trawl catches were low, but murrelets were abundant. In

Table 3—Results of logistic analysis to explain presence and absence of Marbled Murrelets on transect segments

Variable	Coefficient	Standard error	T	P (2-Tail)
All seasons (McFadden's $\rho^2 = 0.529$, $n = 1863$)				
Constant	22.949	5.966	3.847	0.001
Land	-0.145	0.071	-2.032	0.042
Nest	-0.060	0.013	-4.563	<0.001
Shelf	-0.058	0.027	-2.184	0.029
Sea-surface temperature	-0.422	0.172	-2.459	0.014
Sea-surface salinity	-0.460	0.143	-3.219	0.001
Early spring (McFadden's $\rho^2 = 0.569$, $n = 496$)				
Constant	36.752	13.542	2.714	0.007
Land	-0.154	0.058	-2.670	0.017
Nest	-0.014	0.008	-1.783	0.094
Sea-surface temperature	-0.966	0.386	-2.501	0.012
Sea-surface salinity	-0.671	0.268	-2.502	0.012
Late spring (McFadden's $\rho^2 = 0.553$, $n = 1367$)				
Constant	-75.56	41.000	-1.843	0.065
Depth	-0.026	0.010	-2.501	0.012
Nest	-0.088	0.026	-3.372	0.001
Shelf	-0.092	0.036	-2.584	0.010
Sea-surface salinity	2.342	1.213	1.930	0.054

most years of high prey abundance, euphausiids dominated most of the trawl catches.

Discussion

Our results indicate that in the designation of “critical habitat,” at least for Marbled Murrelets of the Waddell Creek nesting population, the coastal waters within 10 km of Point Año Nuevo should be included. It is not surprising to us that during the nesting season, murrelets in this population do not travel far from the nesting area because, as explained below, food availability is predictably high. The juxtaposition of nesting and feeding areas should also be studied among vulnerable, i.e. isolated, murrelet populations to the north.

The small percentage of variation in murrelet distribution explained by physical habitat variables is partly due to the small regional scale of our study and the fact that certain oceanographic features are quite ephemeral (see below). Within the mesoscale perspective that our study area provided, the availability of prey was likely the factor that best explains murrelet occurrence (see below).

The specific prey of this population are unknown, but the three most likely candidates are euphausiids, juvenile rockfish, and young-of-the-year anchovies, the three most important prey to all other coastal seabirds in the vicinity (Ainley and Boekelheide 1990). Euphausiids, shown to be important to murrelets in British Columbia (Sealy 1972, 1975c), probably also comprise a significant proportion of the diet among adults in the Waddell Creek population. The

effect of euphausiid abundance on murrelet distribution, as indicated in the analysis above, is circumstantial evidence for this. Euphausiids are especially abundant in this region (see below) and are easily caught by diving seabirds.

Similar to many other alcids (see Bradstreet and Brown 1985), while the adults eat euphausiids, only fish are fed to the nestlings. It is much more efficient for the parents to carry fish to their young, because a single fish represents much more food value than a single euphausiid. In this region, juvenile rockfish and anchovies are likely candidates as dominant species in the chick diet. The undersea Ascension Canyon, extending out from Waddell Creek (see *fig. 1*), is an area where the high prevalence of juvenile rockfish, specifically *Sebastes jordani*, is more consistent than anywhere else along this coast (Woodbury, pers. comm.). The principal prey species of central California's seabirds during the nesting season is *S. jordani* (Ainley and Boekelheide 1990). Anchovies are also consistently abundant in the Año Nuevo area and northern Monterey Bay during late spring and summer (Woodbury, pers. comm.). Euphausiids, too, are consistently abundant in the Ascension Canyon region at this time of year and more so than in adjacent ocean areas.

When euphausiids are abundant throughout shelf waters in the vicinity of Año Nuevo, adult murrelets need not forage far from Waddell Creek, but can remain within 3-5 km of the nesting area throughout the day. This was the pattern revealed in our analysis. Not inconsistent with this pattern is the fact that we saw few murrelets when potential prey were only abundant at the shallowest trawl station and sparse farther

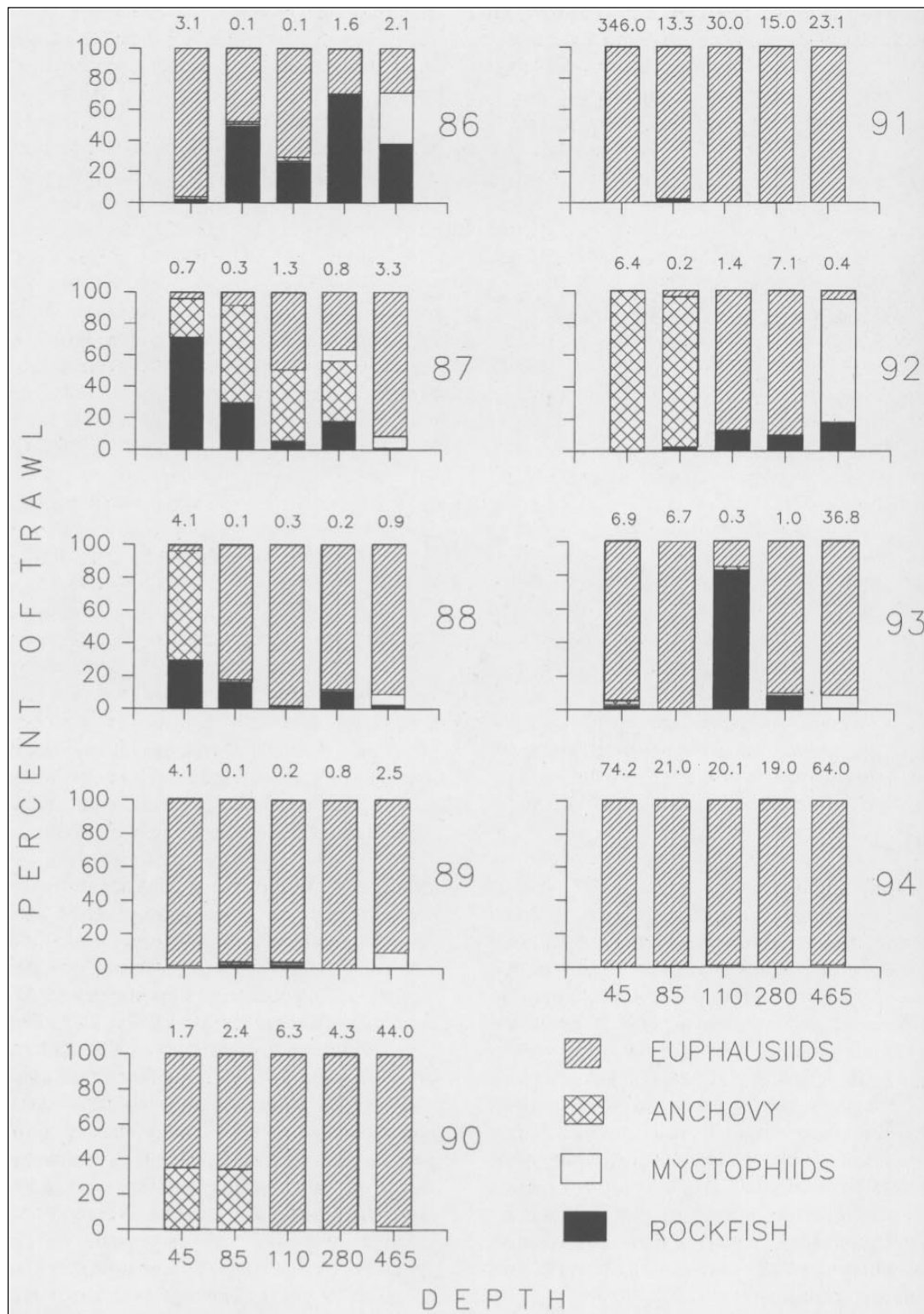


Figure 3—The percent composition among potential prey species collected in trawls off Pescadero (10 km north of Point Año Nuevo) and Davenport (10 km south) during early June 1986-1994 (see *fig. 1A* for locations of trawl sites); results of the two trawl lines were averaged by depth stratum in meters. Average number of prey items (x 1,000) per trawl is listed above each depth bar.

offshore. We believe that under these conditions, the murrelets were distributed linearly along the shore within a few hundred meters of the beach, a pattern often displayed by murrelets in some regions to the north (Briggs and others 1987; Strong and others, this volume). We would have been unable to detect these birds because the ship could not venture close enough to shore. Under these conditions, in a distributional pattern likely similar to that of March 1993, some parents would have to fly farther than others to bring food to their chicks. This explanation for the variation in murrelet numbers and distribution is hypothetical, of course. An adequately designed regional study could easily test its validity.

Among years when we saw few murrelets, ocean anomalies may have limited food supply. In particular, El Niño-Southern Oscillation conditions (deep thermocline, warm water, low ocean productivity; see review in Ainley and Boekelheide 1990) occurred during 1986 and from late spring 1992 to early spring 1994 (see *fig. 1*). The response of other coastal alcid species to these conditions, and to winter conditions when food is also sparse, is to spread out linearly along shore where feeding opportunities are more diverse than in the open ocean (Ainley and Boekelheide 1990; Ainley, unpubl. data). At the least, the frequency of ocean anomaly in the California Current region dictates that any investigation of seabird natural history in this region should span at least a 5-year period (Ainley and others, in press).

The negative effect of cooler sea-surface temperature (or a positive one of salinity) on murrelet distribution during late spring is consistent with the oceanography of this area and the high availability of prey. A plume of cool, salty water frequently upwells southward from Point Año Nuevo (see *fig. 1*), moves offshore and then curls back to the north in an anti-cyclonic eddy (Schwing and others 1991). Besides providing nutrients to this region centered on Ascension Canyon, the eddy may concentrate and maintain prey in place as alluded to above. The plume was often indicated by surface measurements of temperature, salinity, and thermocline characteristics revealed by the CTD ("conductivity and temperature with depth" probe). However, as shown by Schwing and others (1991), surface manifestations of this plume and eddy disappear rapidly, i.e. within a day, following cessation of upwelling-favorable winds. Such a rapid change in ocean characteristics in this region precludes further analysis in our study; a more directed investigation including oceanographic measurements is required.

It is possible that other murrelet populations along the West Coast also occupy small at-sea ranges in proximity to nesting areas during spring and summer. Repetitive, regional surveys are needed to identify these habitats. On the other hand, some populations apparently vary much more in the choice of waters to frequent, as indicated by temporal variation in numbers within Puget Sound (Speich and others 1992). Strong and others (1993) noted late spring and summer shifts off Oregon in murrelet clumping and hypothesized that it may be a response to the appearance of *Ammodytes hexapterus*, an important prey species there but rarely found in central

California. In these broader scale investigations in regions of more closely spaced nesting populations, the movements of non-breeders and adjacent breeding populations may confuse interpretation of factors affecting distribution patterns.

Many studies have found that Marbled Murrelets occur very close to shore, usually within a few hundred meters and in depths <15 m. Our results indirectly confirm this pattern, but also indicate that under certain circumstances, the species can occur much farther offshore. Analysis of the along-beach surveys of the USDA Forest Service in the Año Nuevo area during the past few years (Ralph and Miller, this volume) will be helpful in further interpretation of our results. The timing of our surveys and those of the Forest Service, however, did not correspond closely (their surveys were later in the summer). On the other hand, consistent with the finding of Strachan and others (this volume), we too detected highest numbers in the vicinity of Año Nuevo during the late spring, as compared to earlier in the year.

The fact that we did see significant numbers of murrelets well offshore in some years indicates that surveys near the coast to estimate murrelet populations (Carter and others 1990a), especially in the Año Nuevo region, need to account for the possibility that significant numbers of birds may be far offshore. Either the surveys, as recommended above, need to be repeated for several years to assess spatial variability (and then choose the survey in which the murrelets are distributed most linearly alongshore), or the surveys need to include closely spaced, inshore-offshore segments that extend well off the coast (at least to 12 km).

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