Chapter 32

Distribution and Population Estimates of Marbled Murrelets at Sea in Oregon During the Summers of 1992 and 1993

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Abstract: We used standardized transect techniques to count Marbled Murrelets and other seabird species at sea from a boat and from a low-flying light aircraft along the length of the Oregon coast. The focus of effort was on vessel surveys of the central Oregon coast. In both years, Marbled Murrelets were most abundant in central Oregon, between Cascade Head and Cape Arago. They were concentrated much closer to shore in 1992 than in 1993. Different distribution patterns in the two years was likely a consequence of El Niño oceanographic conditions which severely impacted Oregon's seabirds in 1993. New population estimates for the state ranged from 2,500 (shore-based) to 22,250 birds (boat). Estimates generated from vessel surveys were considered far more reliable than estimates from air or from shore counts due to more thorough coverage, proximity to birds, more observers, and longer scanning time. Vessel estimates using both strip and line transect analyses for two years with very different distribution characteristics each produced state population totals between 15,000 and 20,000 birds, after accounting for some assumptions. There is a strong possibility that a large proportion of these birds may not be nesting successfully due to limitations of nesting habitat and other factors.

In the past 6 years, research effort on the Marbled Murrelet (*Brachyramphus marmoratus*) has increased in response to an apparent dramatic decline in their numbers on the west coast south of British Columbia (Carter and Erickson 1992; Marshall 1988; Nelson and others 1992; Ralph, this volume). Their recent listing as a federally threatened species (U.S. Fish and Wildlife Service, 1992) adds a further imperative to learn more of this bird's nesting and at-sea biology, population size, and reproductive parameters so that meaningful management and recovery plans may be developed.

Historically, Marbled Murrelets were described as 'common' and 'abundant' in the vicinity of the Columbia River and in Tillamook county, and near the Yaquina River mouth in central Oregon (Gabielson and Jewett 1940, Taylor 1921). Currently, sightings from shore are infrequent in these areas (Nelson and others 1992, Strong and others 1993), indicating a decline in the northern half of the state. Presently Marbled Murrelets are seen regularly from shore only between Seal Rock, Lincoln County, and Cape Arago, Coos County (Strong, unpubl. data). Unfortunately, there are no quantified historical data to compare with recent shore counts or vessel surveys in order to determine to what extent the population has declined in central Oregon. There are no records to indicate the historic abundance of murrelets south of Cape Arago. Even current shore observations are few and inconclusive (Nelson and others 1992, Strong and others 1993).

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This project was initiated to fill a gap in knowledge about the abundance, distribution, and at-sea biology of Marbled Murrelets along the Oregon coast. Previous murrelet research at sea in Oregon consisted of observations from shore and limited vessel surveys, summarized in Nelson and others (1992), though more recently aerial surveys have been undertaken (Burkett, pers. comm.; Varoujean and Williams, this volume).

We surveyed Marbled Murrelets and other seabird species in the Oregon coastal waters from Washington to California during the summers of 1992 and 1993 to address the following objectives of this report:

(1) Compare behavior, distribution, and abundance patterns of murrelets between the two years in each of four regions.

(2) Compare and evaluate population estimates between the three survey methods (aerial, vessel, and shore-based) and between line and strip transects.

(3) Qualitatively assess the feasibility and reliability of the three methods for monitoring distribution and abundance of murrelets.

Methods

The Oregon coast was divided into three regions with distinctly different characteristics of murrelet abundance (Nelson and others 1992, Strong and others 1993). The northern region extended from the Columbia River to the north end of Cascade Head (155 km of coastline). The central region extended from Cascade Head to Coos Bay (209 km), though the southern 75 km of this region, from Florence to Coos Bay, was analyzed separately as a fourth region because of ambiguity of survey results. The southern region went from Coos Bay, south to the California border (195 km).

Vessel Surveys

A 20 foot Boston Whaler powered by two 70 hp outboard motors was used for all surveys. It was operated from a console in the middle of the boat. A driver and two observers manned the boat. Each observer scanned a 90º arc between the bow and the beam continuously, only using binoculars to confirm identification or to observe plumage or behavior of murrelets. All species of birds within 50 m of the boat and on the water were recorded, and plunge divers (terns, pelicans) were also recorded when flying. Marbled Murrelets sighted at any distance were recorded along with the time of sighting, distance from the vessel, group size (defined as birds within 2 m of each other), side of vessel, behavior and plumage notes. Distance was not reported until murrelets had either responded to the boat by flying or diving, or had been passed by the boat. A bright float was deployed periodically at 50 m behind the vessel to aid in distance estimation.

Location was determined by distance travelled through the water between known landmarks on shore, using the speedometer and trip log functions on a sonar fish finder. Speed was maintained at approximately 8 knots at all times. Other variables monitored included water temperature and depth, presence of sonar scattering layers, rip currents, type of shoreline (rocky, sandy beach, adjacent to river mouths, or a combination of the above), association of murrelets with other species, and weather conditions. Observation conditions, as they affected the detectability of murrelets, were categorized as excellent, very good, good, fair, and poor. Observation conditions were classified based on Beaufort sea state, swell, reflections, and fog. Surveys were not initiated at Beaufort state 3 (fair observing conditions), and surveys were terminated at Beaufort state 4 (poor observing conditions). The driver alternated with observers periodically to reduce observer fatigue, and a rest stop was taken at least every 3 hours.

To quantify distribution along the length of the Oregon coast ("coastline transects"), transect lines parallel to the shore between 250 and 500 m from shore were run, typically covering from 25 to 100 km in a day.

To quantify distribution in relation to distance from shore ("offshore transects"), repeated transect lines along the same 4 km section of coast were run, each one 300 m to 600 m farther out to sea than the previous one (all 1993 increments were of 300 m; in 1992 the distance increment was variable). Transects lines were repeated progressively farther offshore until no murrelets were seen on the water for a full 4 km line. In 1992 the outer limit of surveys was 2.5 km offshore, in 1993 the outer limit was 6 km. offshore. The sample 4 km coastal sections were selected at various locations between Gleneden Beach and Seal Rocks (except for one survey south of Heceta Head in 1992) in central Oregon. The sample locations were all off sand or mixed sandy and rocky shorelines where murrelets were consistently present.

All information was spoken into a tape recorder via an external microphone, held by one of the observers.

Aerial Surveys

A single engine high-wing Cessna 187 or 206 aircraft was used for aerial surveys. An observer on each side of the plane used a tape recorder with remote microphone to record observations.

In 1993, the inboard observer (nearest the shoreline) noted when landmark locations were passed. In 1992, a third person recorded time and location on maps. The pilot maintained an altitude of approximately 60 m and a speed of 90 knots. Distance from shore was held at between 300 and 500 m (the same as for coastline vessel transects), except when passing seabird nesting islands, where a wide berth was given (>800 m) to avoid disturbance. Each observer continuously scanned a 50 m wide corridor of ocean surface which was calculated as an angle between 32° and 57° off horizontal, as measured with a clinometer. While maintaining their scan of the water surface, observers recited the number and species of birds seen and time to the nearest 10 seconds, and reported on observing conditions. We found that at the altitude we flew, we were able to identify most birds to species. The 60 m level was recommended in Briggs and others (1985) and by Varoujean and Williams (this volume) as optimal for surveys of small marine birds. Since our aircraft had only a pressure altimeter, our recorded altitude was only approximated.

Shore-Based Observations

Additional shore observations were made opportunistically. A 20-45 power telescope was used to carefully scan the sea beyond the surf line to a distance of approximately 1.2 km (using marks on topographic maps a known distance offshore for reference). Information recorded included location, time of beginning and end of survey, weather and observation conditions, number of all seabird species (except in a few instances when time limitations allowed only Marbled Murrelets to be counted), group size of murrelets, and other notes on murrelet behavior or distribution (e.g. fish holding, concentrated in surf line, etc.).

Data Management and Analyses

To describe distribution along the Oregon coast, Marbled Murrelets counted from coastline vessel transects were summed in 10 km blocks as measured by landmarks on shore and time elapsed when traveling at known speed (8 knots). Currents and variation in speed resulted in location errors of up to 3 km on some long transects without landmarks, but error was usually less than 1 km. The 10 km sums were averaged where counts were repeated on the same section of coast.

Population Estimates

We used both line and strip transect analyses to develop population estimates from the vessel coastline transects. This allowed for a more robust conclusion and assessment of the different assumptions underlying each method. For both analyses, the complete transect of each day was treated as a sampling unit, which avoided statistical dependence of adjacent transect legs. Birds flying through the transect area were not included in any calculations.

Line Transects

Because distance from the vessel to each murrelet sighting were recorded, these data were amenable to line transect analyses. Data were processed by the program DISTANCE (Laake and others, 1993) which fits a model to the distances at which birds were detected (a detection probability curve) and then includes data on encounter rate (number of detections/length of transect) and average group size to derive a density of birds per km^2. This is then multiplied by the length of the region to achieve an abundance estimate for a given area. The resulting models (half-normal or cosine, with polynomial adjustments to the fit) all had their peak detection probability on the transect line, whereas, due to avoidance behavior, peak reported detection distance was typically 20-40 m from the line. To resolve this, we divided the reported distance by 2 or 3 for birds seen on the forward quarters and divided by 4 for birds sighted off the bow. We also truncated observations to within 160 m from the vessel, which eliminated very few observations and improved modeling capability

This approximated the undisturbed distribution of birds and allowed satisfactory fit of the models. Transect data for each day were fitted to a model and an independent population estimate was derived for each day. Daily estimates were averaged within a region for population estimates in each year, and variance of daily estimates was used to construct confidence intervals using a normal approximation (Zar 1984: 103). Where lower confidence intervals approached zero (due to few sample days), the lower limit was taken as the actual count times 2.

Strip Transects

For strip transects, we summed all Marbled Murrelets occurring within the designated strip (excluding flying birds) for each day's transect, and divided that sum by the length of the transect (in km) for a density within the strip. This was multiplied by the appropriate factor to obtain a density measure in km^2 and by the length of the region to obtain a population estimate for the day. These estimates were averaged the same way as for line transects to obtain regional population estimates and confidence intervals. Strip width was selected at 50 m out from the vessel (100 m total) after study of frequency histograms of reported distances and iterations of density calculations at different strip widths (*figs. 1* and *2*).

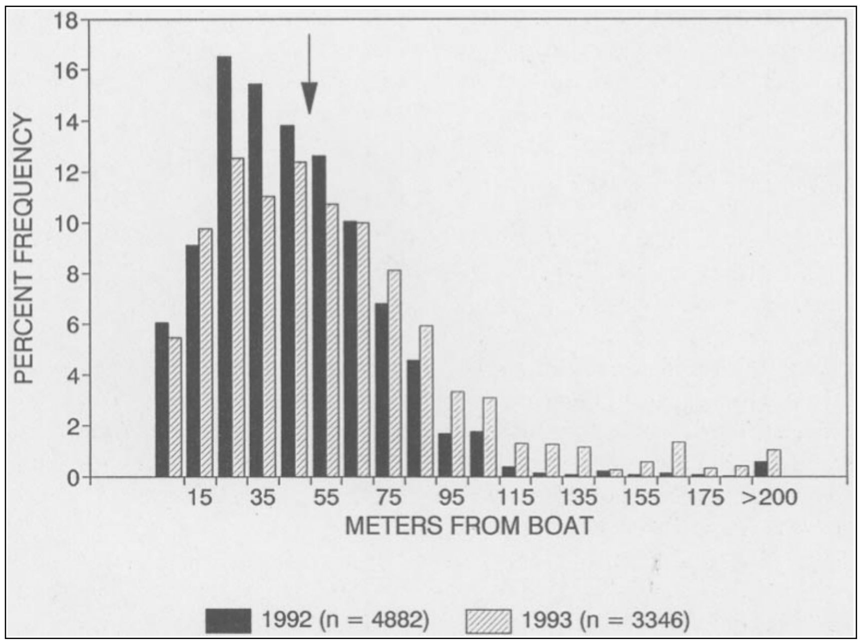

Figure 1—Distances at which murrelets were reported from observing vessel. Arrow at 50 m indicates distance from vessel within which all birds were assumed to be detected for strip transects.

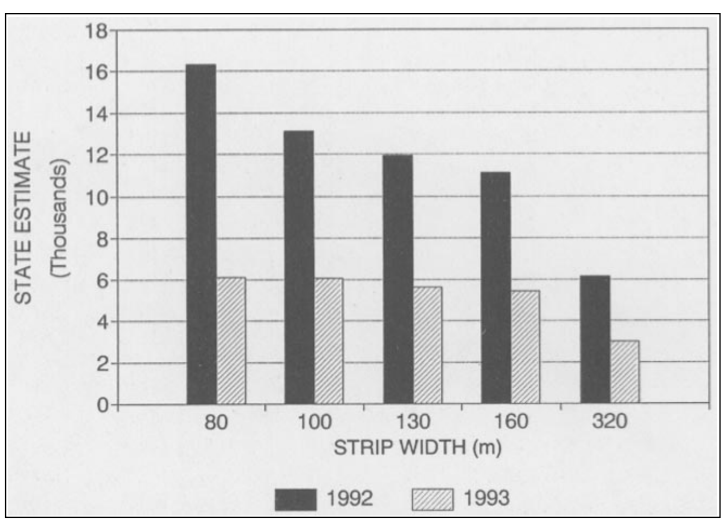

Figure 2—Abundance estimates for the state extrapolating for five different strip widths, without addition of birds > 500 m offshore (central region) or birds 1000 m offshore (north and south regions, see text).

Table 1—Marbled Murrelet unweighted population estimates, estimates weighted by km of transect/day (number of observation points for shore surveys), and 95 percent confidence intervals (CI) around unweighted estimates for Marbled Murrelets in Oregon using four methods of estimation

Method	Year	Region	Unweighted Estimate	Weighted Estimate	Lower CI	Upper CI
Vessel Line	1992	North	1,115	1,090	557	1,671
		Central	6,928	7,092	4,936	8,920
		Central offshore	4,056	4,056	1,865	6,273
		Center-south	4,898	4,898	1,71	4,898
		South	5,255	6,137	1,912	9,784
		State total	22,252	23,273	10,980	31,546
	1993	North	915	827	184	2,360
		Central	2,277	2,427	1,404	3,150
		Central offshore	9,911	9,911	1,932	18,558
		Center-south	1,170	1,395	458	2,471
		South	3,061	2,868	284	9,147
		State total	17,334	17,428	4,262	35,686
Vessel Strip	1992	North	945	936	665	1,219
		Central	4,543	4,828	3,240	5,846
		Central offshore	3,768	3,768	1,228	6,308
		Center-south	3,675	3,675	1,470	3,675
		South	3,970	4,660	944	7,407
		State total	16,909	17,867	7,547	24,455
	1993	North	697	624	126	1,548
		Center	1,895	2,131	1,031	2,758
		Central offshore	8,777	8,777	1,760	15,794
		Center-south	938	1,126	350	2,011
		South	2,535	2,350	184	5,698
		State total	14,842	15,008	3,451	27,809
Aerial Strip	1992	North	852	929	321	1,373
		Central	1,836	1,919	1,222	4,265
		Central offshore	1,522	1,522	495	2,549
		Center-south	915	847	265	1,638
		South	468	426	242	680
		State total	5,593	5,643	2,545	10,505
	1993	North	155	160	44	312
		Central	249	249	288	2,450
		Central offshore	1,153	1,153	231	2,075
		Center-south	638	635	170	1,740
		South	215	219	36	597
		State total	2,410	2,416	769	7,174
Shore Point[1]	1992	North	47	43	6	73
		Central	2,185	1,770	1,510	3,300
		Central offshore	143	143	93	193
		South	585	579	73	1,248
		State total	2,677	2,535	1,679	4,814
	1993	North	124	145	13	323
		Central	1,136	1,036	480	3,440
		Central offshore	1,148	1,148	591	3,843
		South	1,209	866	48	2,311
		State total	4,566	3,195	1,132	9,817

[1] The offshore proportion for shore observations was calculated for birds over 1 km offshore, rather than 500 m as in other cases. The center-south region was combined with center for shore estimates.

Offshore Transects

Transects sampling offshore waters were grouped in 500-m increments of distance from shore, and each sampling day was treated as a replicate within the groups. The data within each 500-m group were then modeled with a detection curve for line transect and a density calculated using the DISTANCE program, or summed and divided by transect length for strip transects as described above. In this way, a separate density estimate was calculated for each 500-m increment offshore for both line and strip transect methods in 500-m by 1000-m blocks. These densities were then multiplied by the length of the central region for independent abundance estimates within each 500-m increment offshore. The sum of these abundance estimates were added to the central region when incorporating birds offshore in overall population estimates (this offshore component is shown separately in *table 1*).

Aerial Estimates

Similar strip transect methods as were used on the vessel were used in aerial surveys. Each observer's results were treated as a separate transect (sometimes only one observer could conduct transects due to glare on one side, for example), so total strip width was 50 m and the number of transect samples was greater. Densities were calculated by dividing the total number of murrelets seen by each observer in a region on a transect by the length of that region. Densities were multiplied to measure square kilometers, and then multiplied by the length of each region for population estimates as with vessel surveys. For the central region the proportion of birds occurring over 500 m from shore, based on vessel offshore transect data, were added to the region's estimate.

An independent estimate was calculated for each day, and these data were then averaged for the regional estimate, as with vessel estimates.

Shore-Based Estimates

To summarize shore-based observations, we assumed a 145º angle of view (given a 150 m wide surf zone and setback from the shoreline) and measured an approximate viewing limit of 1.2 km out to sea, which gave a scanning area of roughly 2 km^2. To compensate for low viewing angle over surf, we halved the scanning area to 1 km^2 as an actual survey area when computing densities. The average number of murrelets counted from all points in each day was multiplied by the length of the regions coastline for an independent daily estimate, as was done for air and vessel transects. These values were then averaged for a regional population estimate. The proportion of birds greater than 1 km offshore from the vessel offshore strip transect data were added to central region estimates as with aerial estimates.

Field Effort

Field work was carried out from 1 June to 15 August in 1992 and from 10 May to 1 August in 1993. Our research effort was primarily devoted to vessel surveys, and most of the vessel transects took place in the central region, between the Siletz and Siuslaw rivers (*table 2*).

Table 2—Summary of survey effort for Marbled Murrelets off the Oregon coast in 1992 and 1993. Initial training transects and transects fragmented by weather or data recording errors were discarded prior to analyses. Vessel surveys were separated into extensive coastline and offshore distribution transects

Coastal		Kilometers surveyed				Days of surveys			
Region	Year	Air[1]	Vessel		Shore	Air	Vessel		Shore
			Coast	Offshore			Coast	Offshore	
North	1992	767	329	–	18	2	4	–	4
	1993	450	274	–	14	2	4	–	4
Central	1992	824	743	90	136	4	19	9	29
	1993	532	856	292	82	2	20	11	23
Center-south	1992	600	75	–	3	4	1	–	1
	1993	300	225	–	8	2	5	–	4
South	1992	672	208	–	21	2	3	–	6
	1993	585	167	–	11	1	4	–	4
Combined		4,730	2,877	382	293	6	54	20	70

[1] Air survey strip width was only 50 m wide as each observer's data was considered an independent survey (flights actually covered half the listed km).

Results and Discussion

Distribution and Behavior

Distribution Along Oregon's Coastline

Marbled Murrelets were distributed irregularly along the length of the state, with peak number occurring in the central region for all survey methods and years of surveys (*fig. 3* and *4*). In 1993 it appeared as if the population was distributed somewhat farther north (*fig. 3*). The area from Cascade Head to Florence almost always held high numbers of birds. High densities were recorded between Florence and Coos Bay on the one survey of that area in 1992, but this was not seen again on repeated surveys in 1993. Because of the continuing ambiguity of results for this area, it was treated as a separate region in population estimates. In both years there was evidence of a shift to the north late in the season, though it was slight in 1993.

Distribution in Relation to Shore

Distribution in relation to distance from shore was dramatically different in the two years (*fig. 5*). Marbled Murrelets were very concentrated within 1 km of shore for much of the 1992 season, and broadly scattered within 5 km of shore in 1993. In most cases this resulted in lower densities on coastline transects in 1993 (*table 3*). In 1992 there was a late-season shift to farther offshore which coincided with the shift farther north described earlier (*fig. 6* and Strong and others 1993). Offshore distribution was more variable in 1993 but no seasonal shift away from shore was apparent.

Behavior

In contrast to distribution offshore, recorded behaviors of murrelets were essentially the same in the two years (*fig. 7*). Although we did not see any murrelet groups as large as

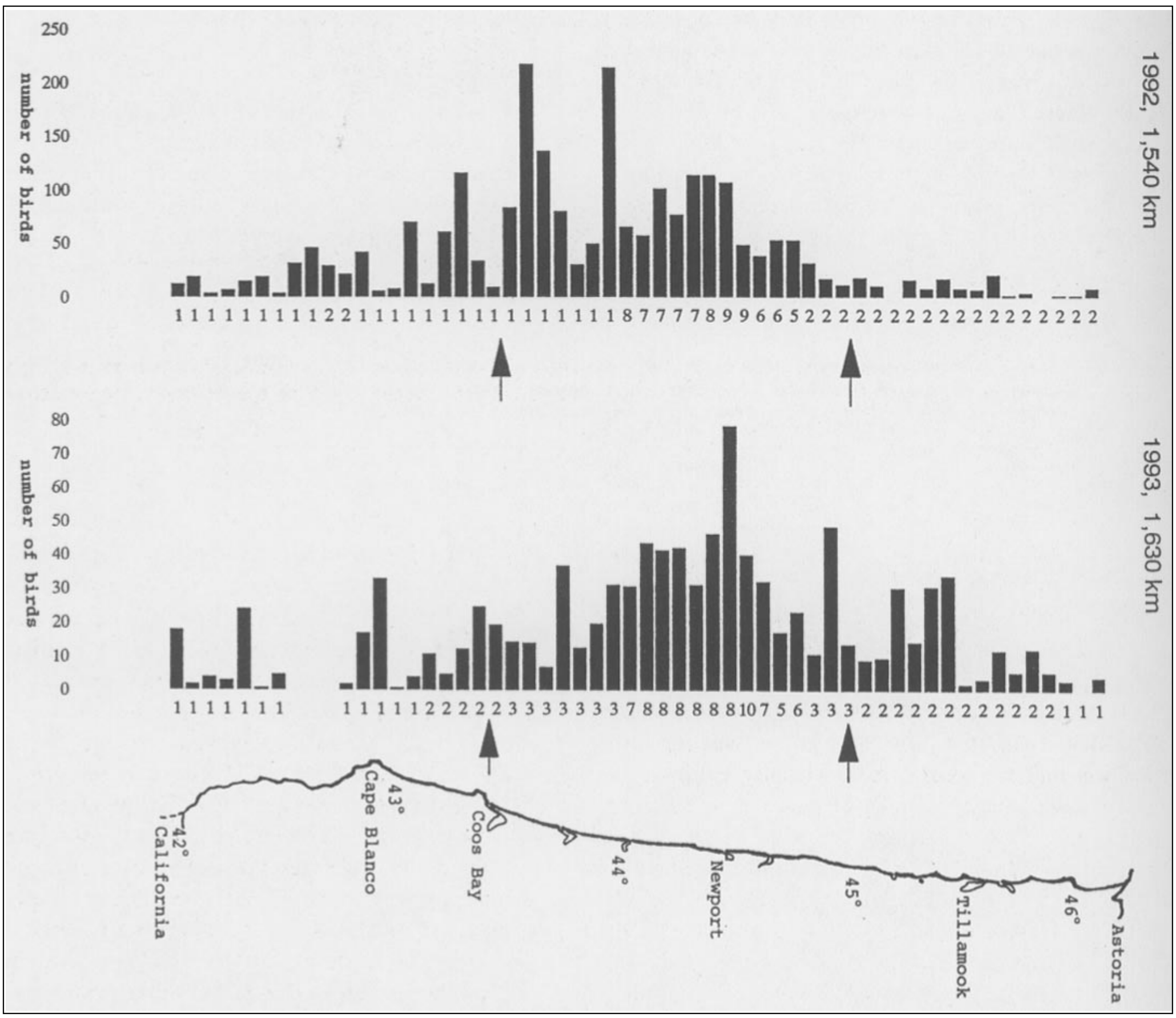

Figure 3—Average numbers of Marbled Murrelets from 100 m boat transect strips in 10 km segments off the Oregon coast. Numbers on x axis represent the number of times each segment was surveyed. Arrows indicate divisions between north, center, and south regions.

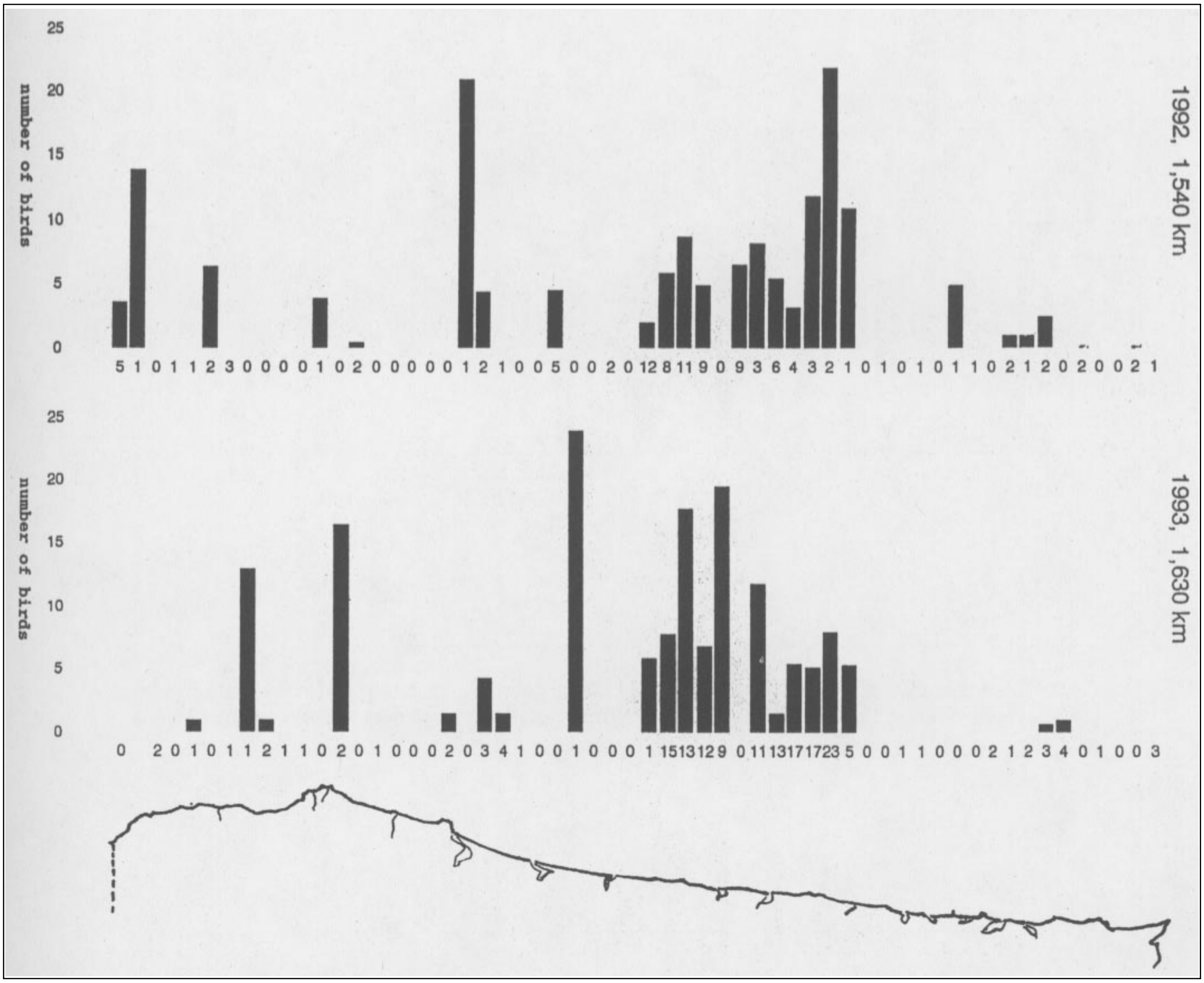

Figure 4—Average numbers of Marbled Murrelets at sea counted from shore in Oregon. Numbers on x axis represent the number of counts within a 10-km section of coast. Arrows indicate division between regions. Refer to *fig. 3* for locations along the Oregon coast.

the largest in 1992, groupings of murrelets was also very similar in 1992 and 1993 (*fig. 8*).

Distance from the boat at which murrelets were reported was similar among years, except in the 20 to 50 m range (*fig. 1*). It is likely that this resulted from bias in reporting distances in 1992 when we had predetermined our strip width to be 50 m for density estimates. In 1993 there was no such presupposition and we took care to visually calibrate our estimates with a 50 m measured buoy line and among ourselves. Based on the curve in *Figure 1* and on density computations for various strip widths (*fig. 2*) we selected a strip width of 50 m on either side of the boat (100 m). This strip width included 74 percent of all birds seen in 1992 and 64.2 percent in 1993, not including flying birds. Fewer birds were reported closer than 20 m since they usually took evasive action at greater distances. Marbled Murrelets dove in avoidance of the boat at a mean distance of 26.5 m (*s.d.* = 18.6 m), and they flew in avoidance at 42.6 m (*s.d.* = 36.1 m).

Population Estimates

Comparison of Aerial, Vessel, and Shore-Based Estimates

Vessel estimates using line or strip transect analyses produced far higher estimates than air or shore-based surveys (*table 1*). All methods used densities calculated for 1 km^2 in the estimates (*table 3*) except for the central region, where there was information on offshore distribution (*fig. 5*). For the central region, 1 km^2 densities were halved to estimate only the number out to 500 m, and estimates from offshore sample densities, in 500-m blocks, were summed and added to the estimate (the offshore component is shown separately in *Table 1*). We added the same proportionate number of birds to air and shore-based estimates in the central region as were added to vessel estimates in accounting for offshore distribution. Differences between estimates, then, were due to differences in mean densities of birds detected with each method and year (*table 3*). Of the three survey methods, vessel transect data had the highest

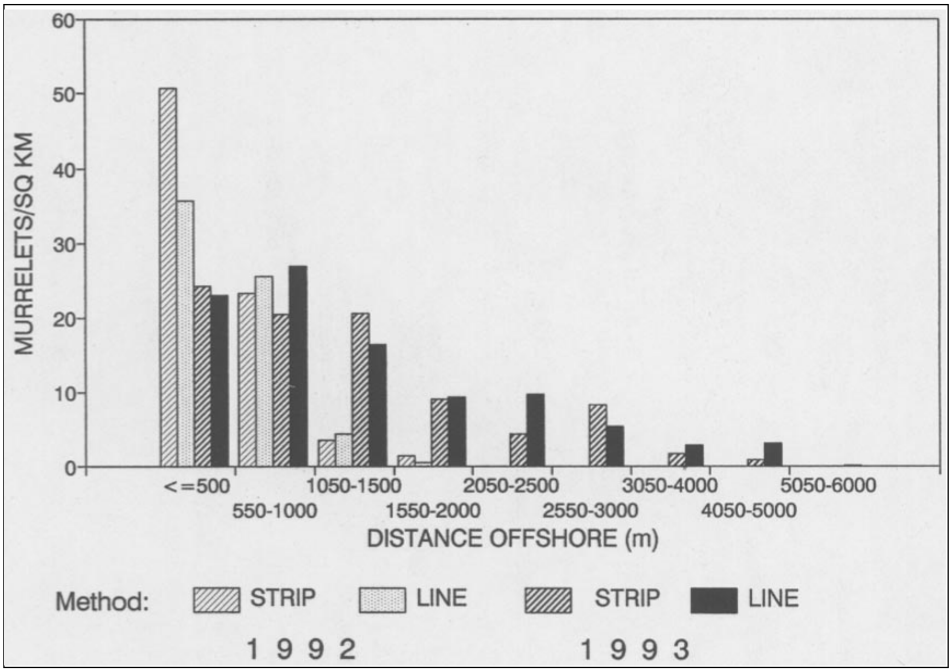

Figure 5—Average densities of Marbled Murrelets in 1 km^2 based on line and 100 m strip boat transects for nine categories of distance from shore. The 1992 transects were conducted to a maximum of 2.5 km offshore.

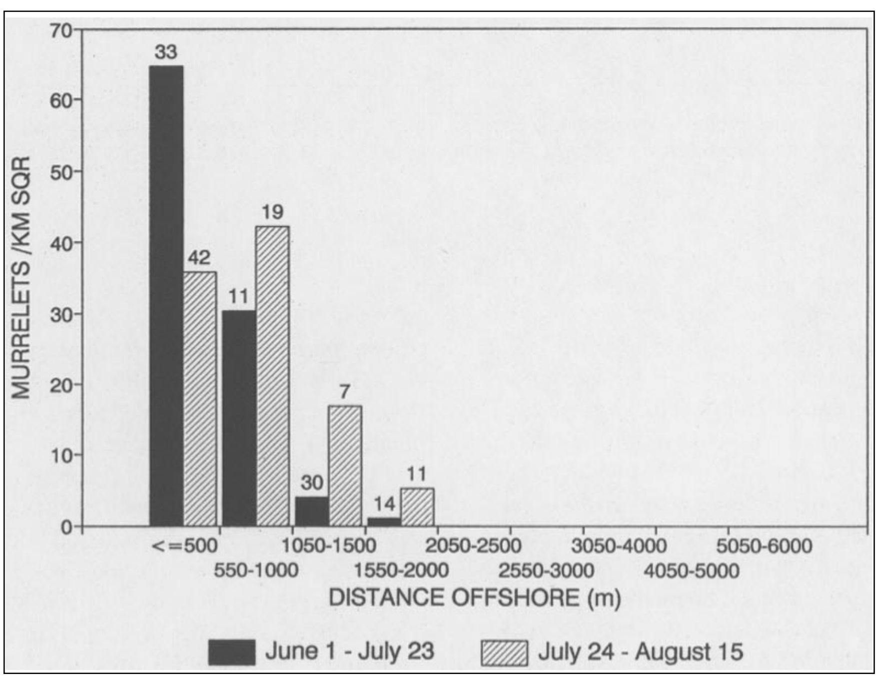

Figure 6—Number of Marbled Murrelets per km of vessel transect in nine categories of distance from shore in 1992, before and after 24 July. Figures at top of bars represent number of kilometers surveyed within each distance category.

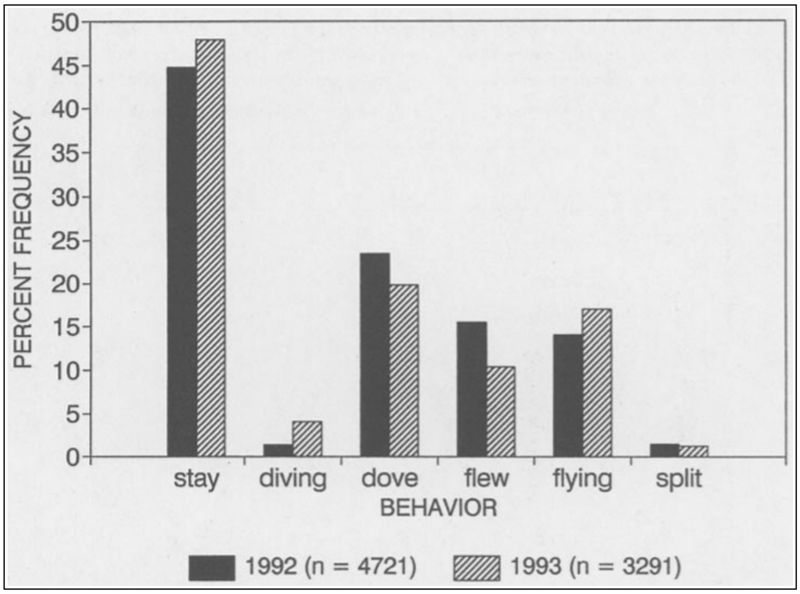

Figure 7—Behavior of murrelet groups observed while on transect: **stay**, remained on the water surface; **diving**, engaged in diving activity; **dove**, dove in apparent avoidance of boat; **flew**, flew in apparent response to the boat; **flying**, flying past when detected; **split**, group separated in apparent avoidance of the boat (in all other instances group members behaved the same).

reliability of detection due to proximity, duration of observation, and number of observers.

The average density of birds seen from air was 33.1 percent (1992) and 16.3 percent (1993) of that seen by boat strip transects (*table 2*), even though they transected the same offshore zone at a similar time of year. The brief scanning time when flying over the transect strip at 90 knots may be the greatest factor affecting detection rates by air. Slight variations in plane altitude and speed, banking on turns, observers checking time and location, and distraction from other species all contributed to further reduce scanning time for murrelets. In addition, on the 1 July 1993 flights, the senior author scanned an area in advance of the plane and noted Marbled Murrelets diving in response to the plane's approach. The extent of this behavior cannot be quantified absolutely, and probably varies with type of plane. On the 1 July 1993 north bound survey, at least nine birds dove in front of the plane (8 percent).

Estimates using counts from shore were in the same general range of those based on aerial surveys, though there was no consistency across years (*table 1*). Shore counts had the highest variability in numbers with coefficients of variation averaging over 100 (*table 3*, *fig. 4*). The high variability resulted from Marbled Murrelets' locally patchy and shifting distribution (Nelson and Hardin 1993b, Strong and others 1993). Low average numbers seen could also be due to their patchy distribution. Difficulty in detecting birds from a low, distant vantage point under variable conditions may also have reduced the number of detections in some cases. Even though we compensated for difficulty in detection by halving the calculated area scanned when computing densities, values were still far lower than from the vessel. These results may have occurred because the smallest effort was invested in shore surveys. Increased effort may have reduced variability and improved results. Weighting of high counts in proportion with the patchiness of high density areas could possibly generate average densities more representative of the population.

Strip and Line Transect Vessel Estimates

Line transects generated the highest estimates, and they were consistently higher than strip transect estimates using the same data. Strip transect estimates were between 60 percent and 88 percent of line estimates, but the difference was only marginally significant in one case (center region, 1992, t-test, P = 0.023) and not significant in others where sample size was sufficient.

Strip transects may be conservative if the assumption that all birds within the strip are detected is not met. This was apparently the case when the strip was 130 m and greater distances from the vessel (*fig. 2*). Estimates using a 130 m strip width were 90.6 and 92.8 percent of those for a 100 m strip for 1992 and 1993, respectively. We interpreted this as indicating that 7 to 10 percent of the birds were not detected with the larger strip width. The strip width of 80 m resulted in even higher estimates, but 11.5 percent and 8.7 percent of the birds had avoided the vessel beyond this strip width in 1992 and 1993, respectively (compared with 6.9 percent and 5.2 percent for a 100 m strip). The selection of a 100-m strip, then,

Table 3—Mean density of Marbled Murrelets per km² from air, vessel, and shore–based surveys in the summers of 1992 and 1993. Km = km of coastline travelled by vessel, used in extrapolating density to population estimates. Sample size* n *refers to number of days surveying (vessel, shore) or number of overflights by each observer (aerial, see methods). C.V. = coefficient of variation (*s*/ $\bar{x}$ · 100, where* s *= standard deviation and $\bar{x}$ = mean)

Method	Year	Region	Km	*n*	Density	Range	C.V.
Vessel Line	1992	North	155	4	7.2	4.3 – 9.8	31.4
		Central	134	14	103.4	18.0 –160.9	49.8
		Center–south	75	1	130.5	–	–
		South	195	3	26.9	11.3 – 40.7	54.7
	1993	North[1]	155	4	5.9	3.5 – 9.1	49.5
		Central	134	16	34.0	9.2 – 89.8	66.3
		Center–south	75	4	15.6	6.3 – 28.9	69.9
		South	195	4	15.7	8.8 – 35.5	83.9
Vessel Strip	1992	North	155	4	6.1	5.0 – 7.4	18.5
		Central	134	14	67.8	11.5 –120.0	49.7
		Center–south	75	1	98.0	–	–
		South	195	3	20.4	8.3 – 22.9	54.2
	1993	North[1]	155	4	4.5	3.6 – 7.0	49.6
		Central	134	16	28.3	6.0 – 81.1	62.9
		Center–south	75	4	12.5	4.9 – 23.3	72.1
		South	195	4	13.0	7.5 – 28.3	78.6
Aerial Strip	1992	North	195	6	5.5	1.8 – 11.2	58.8
		Central	134	12	13.7	4.2 – 34.4	68.7
		Center–south	75	9	12.2	4.7 – 32.5	103.3
		South	195	5	2.4	1.7 – 5.5	38.4
	1993	North	155	3	1.0	0.3 – 1.4	61.2
		Central	134	4	3.7	2.4 – 4.8	26.8
		Center–south	75	4	8.5	4.0 – 22.7	112.3
		South	195	3	1.1	0.3 – 2.7	71.4
Shore Point	1992	North	155	4	0.3	0.0 – 0.6	106.7
		Central	209	30	10.7	0.8 – 31.0	130.0
		South	195	6	3.0	0.2 – 6.0	85.0
	1993	North	155	4	0.8	0.0 – 1.7	93.8
		Central	209	23	5.5	0.0 – 21.7	106.3
		South	195	5	6.2	0.0 – 14.0	97.3

[1] The 21 July transect density of 29.4/km² (line) or 24.2/km² (strip) was not included here, see text. Vessel offshore densities varied with distance from shore and are shown in *figures 5* and *6*.

was a compromise between losing birds to avoidance at narrower strips and not detecting birds in wider strips. Both of these effects are present with a 100 m strip and, combined, could result in as much as 10 percent under estimation. This may explain some of the difference between strip and line method results.

Line transects may err either high or low, depending on how well the detection curve model represents the true detection distribution. Because birds avoided the vessel and we adjusted for this in the data to model detection curves, fits to any model are necessarily approximations. In spite of these factors, the general agreement between the two methods suggests we are in range of an accurate population estimate.

Averages Versus Weighted Averages

Because transect length and number of shore observations varied by day, we were able to compare estimates weighted by effort with direct averages of each day (*table 1*). Estimates weighted by transect length were quite consistently higher for vessel transects, slightly higher for aerial transects, and lower for shore counts (*table 1*). There was no significant correlation of transect length to densities, however, and no significant differences between regional estimates were found (*t*-tests). Some vessel transects in each region were aborted when fair conditions degraded to poor, resulting in shorter transects under worse conditions, which may have resulted in lower densities (see ‘observation conditions’). In the central region, the two most frequently taken transects were 72 km (Newport to Florence) and 27 km (Depoe Bay to Newport) in length; approximately 10 km of the shorter route was off rocky shore (Boiler Bay to Otter Crest) which always had very low murrelet densities and would make a smaller contribution in weighted data. This probably explains the consistency of higher estimates for weighted vessel data.

Year Comparisons

Densities averaged far higher in 1992 for all methods and regions except shore counts (*table 3*). This was due to extremely high concentrations of birds very close to shore in 1992 (*fig. 5*). The inshore concentration was most pronounced before mid - July 1992 (*fig. 6*), but data for the whole year were averaged for analyses here.

Overall population estimates were significantly different between the two years for aerial and both line and strip vessel estimates (*t*-tests, $P < 0.01$). Differences between years likely reflects their different distribution offshore and some error in the assumption of equal densities within 500-m (central region) and 1,000-m (north and south regions) increments of distance from shore. For example, due to the scarcity of birds offshore in 1992, the assumption of equal density in 1-km squares and truncation beyond this may have caused over estimation in that year. From the offshore transect data, only 45 percent of the birds occurred over 500 m from shore in 1992, compared with 82 percent in 1993 (*fig. 5, table 1*). Using the same logic, the 1993 estimates in other than the central region may have been under estimates, since well over half of the observations occurred beyond 500 m and many birds were present beyond 1 km. This consideration would bring the overall state totals closer together in the two years.

Murrelets and other seabird species were concentrated close to shore in 1992 because of an apparent high availability

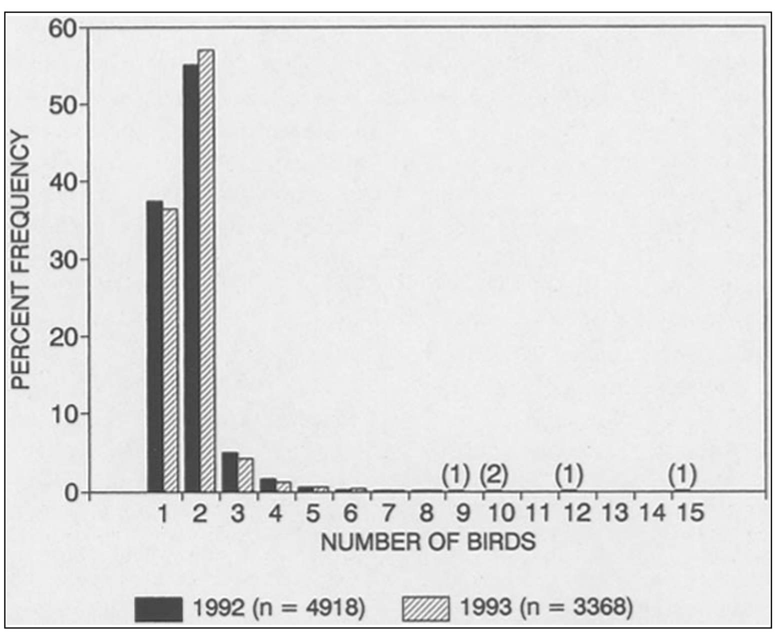

Figure 8—Group size of Marbled Murrelets seen during vessel surveys. Groups of over 8 birds were not recorded in 1993. The numbers in parenthesis indicate number of groups that were too few to show up on a bar graph.

of prey there, such as smelt species (Strong and others 1993). With the exception of Surf Scoters (*Melanitta perspicallata*), other seabirds were more scattered and farther offshore as well in 1993. In 1993, Common Murres (*Uria aalge*) and Pigeon Guillemots (*Cepphus columba*) largely abandoned nest sites in June, and very few (murres) or no (guillemots) fledglings were seen at the end of the nesting period. It is probable that very low prey availability caused the reproductive failure for these alcid species, and likely that Marbled Murrelets were also impacted. Both 1992 and 1993 were cited as 'El Niño years', but waters off Oregon were warmer and upwelling weaker in 1993 (NOAA Coastal Ocean Programs 1992-1993).

Regional Characteristics

We did not attempt to extrapolate from the central region's offshore distribution where we lacked data on offshore distribution for the north and south regions. In the northern region, inshore densities were much lower. Assumption of a proportionate dispersal offshore as for the central region would probably be invalid as it would result in extremely scattered birds. Other data show Marbled Murrelets to have a very clumped distribution (Nelson and Hardin 1993a, Strong and others 1993). Low overall densities on the north coast was characteristic of all survey methods and years, with the exception of one vessel transect on 21 July 1993. On that day, Murrelets were concentrated in the vicinity of Netarts Bay, and the average density (24.2 birds/km^2) was far higher than any other records for the region. This 'outlier' was interpreted as a movement of non-nesting birds from the central region. It is possible these birds failed or did not attempt to nest due to low prey availability in that year (see above).

The southern region has very different physical characteristics than the rest of the state, with many offshore rocks, rocky shorelines, and variable bathymetry. Coastline densities here were most variable (C.V., *table 3*), though our survey effort was small and, in 1993, took place under largely fair to poor conditions (Beaufort state 3 to 4). Because of these considerations, we have lower confidence in our density estimates for this region. It may be appropriate to further divide the region north and south of Cape Blanco, based on physical characteristics and recorded murrelet densities. Near the California border (south of Goat Island), murrelets from nesting areas in California's protected redwood parks may forage in Oregon waters, thereby confusing measures of the state population.

Interpreting results was problematic in the center-south subregion. The single survey of the region in 1992 generated the highest daily average densities recorded, but four surveys of the area in 1993 each recorded densities well below the rest of the central region (*table 3*). Aerial surveys in 1993, however, again produced relatively high densities, although this may have resulted from vagaries in aerial surveying. To account for the different offshore distribution between years in this area, and bring the estimates into closer agreement, we only extrapolated to a 500-m wide block of area in computing the 1992 density estimate.

Other Adjustments to the Estimate

While not including a factor for birds beyond 1 km in northern and southern Oregon may be seen to cause underestimation, other considerations of distribution and sampling may compensate for this. The surf zone off Oregon's beaches typically ranges from 100 to 400 m out to sea, depending on swell size. While we did observe Marbled Murrelets within the surf zone, particularly in 1992, they occurred at lower densities than beyond the breakers. If we were to assume, as an approximation, that the inshore 100 m was without murrelets, the effect would be to reduce the estimate by 10 percent.

A proportion of the birds that flew in response to the vessel went in the direction of vessel travel where they could have been double-counted if they landed in the transect's path. In 1993, we quantified this and found that 21.9 percent of the birds which flew went in the vessel's direction of travel. This was far less than 50 percent since murrelets usually flew against the wind, and we usually ran transects with the wind (birds rarely departed east or west). Of 10.7 percent of birds which flew in avoidance (*fig. 7*), 22 percent flew in direction of travel. If each were double-counted once, the adjustment would be 0.107 x 0.22 = 2.3 percent of the estimate. This, for example, would amount to 350 birds double-counted in the 1993 strip transect state estimate, a relatively minor difference. It is possible that many birds may relocate independently of vessel movement during the course of our transects, which last 2-9 hours. But because there is equal probability of birds either relocating into our path or moving out of it, no error was anticipated from this behavior.

Offshore sampling in central Oregon accounted for a relatively small proportion of the total survey effort, but the contribution to the total estimate from those data was large, particularly in 1993 (*table 2*). Selection of offshore sampling locations took place prior to each day's sampling, and were where murrelets were found to be consistently present during coastline transects. This has the potential for bias to areas of higher density within the whole region, although the effect is probably slight. Specific areas of abundance were virtually impossible to predict, since the clumped distribution of birds shifted daily on a scale of 10's of kilometers (Strong and others 1993).

In 1992 there was a significant correlation between observation conditions and number of birds sighted (r = 0.112, P < 0.001), but not in 1993. We did not detect a difference in the average distance at which birds were seen between excellent and good conditions; it only decreased at fair or poor conditions (ANOVA, P < 0.001). This suggests that our observations had consistency of detections with respect to weather at Beaufort states less than 3.

In addition to the above considerations, other aspects of Marbled Murrelet biology and behavior may affect the results of marine transects for population estimation. Birds tending nest sites are not included in the above estimates. Marbled Murrelet chicks are left on their own soon after hatching (Marshall 1988), so the largest period of absence from the water is during incubation. Information on breeding chronology and breeding status were not adequate to adjust for this factor.

The above estimates provide no information on the size of the breeding population in Oregon. A relatively large proportion of some alcid populations do not breed for lack of a nest site or other reasons, constituting a 'floater population' (Ainley and others 1990a, 1990b; Divoky and others 1974; Manuwal 1974). The proportion of non-breeding adults probably varies somewhat by year, as it does for other alcids, depending on such variables as oceanographic conditions (affecting prey availability) and weather. The proportion of non breeding adult murrelets may be considerable for the Oregon population if loss of nesting habitat has left many pairs without nest sites.

We have no data to account for Marbled Murrelets which may occur at greater than 6 km from shore. However, other researchers have recorded Marbled Murrelets in offshore waters of the west coast as very scarce (Ainley and others, this volume; Wahl 1984) or entirely absent (Briggs and others 1989, 1992; Nelson and others 1992). For lack of better data, we assumed that an insignificant number of murrelets occurred beyond 6 km and that birds in that area were unlikely to be part of the breeding population.

Conclusions

Distribution

The different offshore distribution pattern between 1992 and 1993 was likely due to differences in prey species and/or prey availability in the two years, although data to support this assertion is sparse and indirect. In 1992, when Marbled Murrelets were so concentrated inshore, they and other seabird species were only seen to eat smelt. When they dispersed farther offshore late in 1992, all prey seen were sand lance (Strong and others 1993). In 1993 murrelets and other species were all farther offshore than in 1992, and the few prey items seen appeared to be sand lance. Murres suffered a dismal nesting failure on the Oregon coast in 1993 (unpubl. data; Lowe, pers. comm.). Pigeon Guillemots also fared poorly, as indicated by the complete lack of guillemot fledglings seen on the water in 1993. Although both years were reported as El Niño years, water temperatures in Oregon were higher in the summer of 1993 (NOAA Coastal Ocean Program 1992-1993), and the effects of the ongoing El Niño event on seabirds were much more apparent in that year.

The higher numbers of birds encountered in northern Oregon in 1993 (*table 3*) and the more northerly distribution within the central region in 1993 (*fig. 3*) cannot be easily interpreted. In 1992 when birds moved farther offshore late in the season, they also moved farther north (Strong and others 1993). The very high densities of birds recorded on the July 21, 1993 survey, relative to all other data for the region (Nelson and others 1992) were interpreted as post breeding or non-breeding birds which may reflect fewer nesting attempts in that more severe El Niño year. Additional years of data are needed to characterize distribution along the coastline of both northern and southern Oregon.

Population Measures

These are the first estimates of the Oregon Marbled Murrelet population which used extensive, repeated, and standardized vessel transect data to quantify abundance patterns parallel and perpendicular to the coast. Given this, it is not surprising that estimates presented here are far higher than previously given for Oregon (Nelson and others 1992, using shore-based observations; Varoujean and Williams 1987, using a small sample of vessel observations; and Varoujean and Williams [this volume] using aerial surveys). The consistency of our estimated totals in the 15,000 to 20,000 range using different analyses and between very different years, is supportive of their general validity. Individual daily estimates of the central and north coast regions were also consistent around the mean values (see coefficient of variation (C.V.) in *table 3*), with the exception of the July 1993 north coast transect mentioned above. The few surveys of the south coast took place in conditions and locations too variable to characterize a central tendency. Greater survey effort of the southern Oregon coast and offshore sampling of the northern and southern coasts, are urgently needed to strengthen these estimates.

Aerial transects have systematic problems (high flight speed, missed scanning time, diving avoidance behavior) and great sensitivity to conditions (glare, wind, banking on turns, density of other species) which make estimation results weak and certainly conservative (every factor listed has the effect of potentially reducing detections). Improved data recording methods can increase scanning time, which is probably the greatest factor affecting detections (Varoujean and Williams, this volume), but estimates still may only provide an index of abundance, rather than an absolute measure. It may be possible to develop a correction factor between aerial and vessel detections if the difference is consistent. Aerial surveys do provide an instantaneous 'snapshot' measure of distribution over large areas of coastline not obtainable by other methods.

Shore-based surveys appear inadequate to measure population, and even presence-absence information for a given location could require repeated surveys through a season. An intensive, daily shore survey effort could possibly produce useful population assessments, probably by weighting high count surveys and otherwise statistically accounting for their patchy distribution. The main strength of shore-based surveys may be in studying behavior, since there is minimal possibility of interfering or disturbing the bird. Information on grouping, foraging, dive times, diurnal activity patterns, and social interaction are some areas of research that are easily accomplished from shore. Shore based observation is also likely to be the least expensive and logistically easiest means of studying Marbled Murrelets at sea.

Population Versus Breeding Population

Correcting estimates to account for birds tending the nest, or those not part of the breeding population, is valid. Our knowledge of nest-tending behavior and breeding status, however, is so limited that applying factors from other studies or species may only be misleading at present. Nesting site limitations have been shown to also limit breeding populations of other alcids (Ainley 1990, Divoky and others 1974, Manuwal 1974, Nelson 1987, Preston 1968). If loss of old-growth and ancient forest nesting habitat is the major factor affecting populations of Marbled Murrelets from California to Washington (Carter and Erickson 1992, Leschner and Cummins 1992a, Marshall 1988a), then we would expect the 'floating' proportion of non-breeding adults to be very high, probably over 50 percent. Members of the alcid family are long lived, in the range of 20 - 40 years (Ainley 1990, Sealy 1975a), so the possibility of a 'remnant' population is realistic. If only a small proportion of the measured population is nesting then the low number of fledglings observed on the water may be explained. Given this, we would expect total populations, as estimated from vessel survey data, to decline in coming years due to lack of recruitment. Population monitoring and measurements of productivity are crucial to evaluating this concern. Information on the life history and longevity of the bird will also be important in interpreting results of population and productivity monitoring.

Future Research

This report establishes the feasibility and preferences of using vessel surveys for population assessment on the Oregon coast. Population monitoring and more refined population estimates are attainable objectives using methods outlined in this paper. Other areas of at-sea research which may be essential to developing effective management and protection strategies for Marbled Murrelets are relating at-sea habitat use and distribution to forest nesting habitats, finding a means of assessing yearly productivity and population demographics, and more developing knowledge of prey species' composition and availability in relation to oceanographic parameters and location of nesting habitat.

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