Chapter 31

Abundance and Distribution of Marbled Murrelets in Oregon and Washington Based on Aerial Surveys

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Abstract: To determine the abundance and distribution of Marbled Murrelets, aerial surveys of the Oregon coast, Washington outer coast, and shores of the western Strait of Juan de Fuca were conducted in August/September 1993. Based on these marine surveys, abundance estimates are established for Oregon (6,400-6,800 birds) and the waters surveyed in Washington (3,400-3,600 birds). A comparison of these estimates to those established by other surveys indicates that boat-based surveys may give higher estimates of murrelet abundance, and that population size has probably not decidedly changed over the last 10 years in either Oregon or Washington. On the Pacific Ocean coast of both states, murrelets were found to be unevenly distributed with birds being most abundant in central Oregon and northern Washington, and present in lower abundance in southern Oregon and from northern Oregon through southern and central Washington. This distribution appears to be related to shore type, and proximity to the entrances to major river mouths and embayments, at least in Oregon, and to available inland nesting habitat in both states. The ratio of hatch-year birds to the total number of murrelets seen during the surveys was estimated to be 5 percent. As a measure of production, this estimate is too low for population maintenance, but we conclude that murrelets in Oregon and Washington may not be in a long-term population decline.

Determination of abundance and distribution is an important element in the conservation management of the Marbled Murrelet (*Brachyramphus marmoratus*). Because of the secretive habits of murrelets frequenting inland areas, marine surveys are the most effective means for documenting population size. Only recently have systematic marine surveys for murrelets been conducted over the entire length of the Oregon coast, and no such surveys have been conducted over the extent of the Washington outer coast. Consequently, even though the opportunity to do so arose late in the nesting season, we carried out aerial surveys of the Oregon and Washington coasts during late August and early September 1993. This chapter reviews the results of these surveys, which are examined in more detail in two unpublished reports (Varoujean and Williams 1994a, b). In addition, we compare our findings to those of boat-based surveys conducted in both Oregon and Washington.

Methods

Survey Schedule

Various segments of the Oregon study area, which extended from Pt. Saint George/Crescent City, California, north to Tillamook Head, Oregon, were surveyed over the period 22-23 August 1993. Because of poor weather conditions and restricted visibility, only a small portion of the south-central Oregon coast was surveyed on 22 August 1993. The remainder of the south coast, and all of the coast north of Coos Bay were surveyed on 23 August. From the airport at Grays Harbor, various segments of the Washington study area, which extended from Tillamook Head, Oregon, north to Cape Flattery, Washington, were surveyed over the period 4-5 September. Because of a low cloud ceiling from Cape Elizabeth north, only the southern two-thirds of the outer Washington coast was surveyed on 4 September 1993. On 5 September the survey of the southern two-thirds of the outer Washington coast was completed, as was the survey of the coast from Cape Elizabeth north to Cape Flattery. Portions of the western Strait of Juan de Fuca extending from Neah Bay east to Port Angeles (on the Washington side), and from Port San Juan, east to Becher Bay (on the British Columbia side), were surveyed on 6 September. In general, survey viewing conditions in both Oregon and Washington were good to excellent with sea states of Beaufort 3 (occasional white caps) or less, and long, ocean swell heights of 1 m or less.

Survey Methods

In both studies the survey platform was a Partenavia, a high-wing, twin engine aircraft, that was flown at a ground speed of 145 km/h (90 mph), and at an altitude of 60 m (200 ft) above sea level. Position data were recorded from an onboard Loran-C instrument, to the nearest 0.1' of latitude and longitude by an investigator stationed in the co-pilot's seat. Position data were recorded approximately every minute of time to the nearest second. The data recorder's watch was synchronized to the nearest second with the watches used by the two observers. The two observers, one located on each side of the aircraft, recorded on audio tapes all seabirds and marine mammals seen on their respective survey transects. Additionally, observers recorded information pertaining to sea conditions, cloud cover and the amount of surface glare in their field of view. Each observer's transect was 50 m wide (i.e., the survey transect is 100 m wide when both observers are surveying) as established with a clinometer that was rotated up 50º from a line extending at an angle of 5º from the lower edge of the observation window to the surface of the water. Even though the observers were looking approximately straight down out of their respective windows, at times the surface glare from sunlight off the water would hamper or preclude surveying off one side of the aircraft. The analysis of sighting data, any time an observer noted that >20 percent of their field was obscured by glare, was limited to

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determinations of presence/absence of a species. Data on species abundance were not used.

Aerial surveys, because of the speed of the aircraft, may underestimate bird abundance through sighting error, i.e., observers not seeing birds that are present on transect. In an attempt to document how many birds observers miss seeing at these speeds, tests of aerial observer sighting abilities were conducted over fields of Marbled Murrelet decoys laid out along three 50 m wide by 2 km long courses in Humboldt Bay in February 1992. During the tests, a single engine Cessna was flown at a speed of 175 km/h (110 mph) and an altitude of 60 m ASL over the courses, while a single observer recorded the number of sighted murrelet decoys. On each course, six overflights were made, three with the observer on the glare side of the aircraft, and three with the observer on the non-glare side of the aircraft. The sighting error on the non-glare side of the aircraft resulted in 9-30 percent of the decoys being missed, but there were problems associated with the layout of the courses (some were not straight, which resulted in the plane flying over decoys), and with the density of decoys in the courses. This density was ten times higher than murrelet densities commonly encountered in coastal waters, resulting in an unknown bias. Regardless of the test shortcomings, it was felt that using a slower moving survey aircraft would further reduce sighting error. For this reason, the Partenavia, which is capable of flying at a speed of 145 km/h (90 mph) was used for the 1993 survey. Unfortunately, decoy tests at this ground speed were not conducted. We feel that sighting error was low (<10 percent), however, based on the excellent viewing conditions that prevailed during the survey period. Accordingly, the population estimates are not increased because of sighting error.

Potentially murrelets are also missed because they dive in response to the approach of the survey aircraft. Our experience indicates that murrelets were not avoidance diving in response to the approach of the Partenavia. When surveying in Oregon and Washington, the calmness of the sea's surface and the water clarity allowed us to see birds below the water's surface that had dived as, or just before, the plane passed over them. Additionally, we noted the presence of a concentric pattern of wavelets and, frequently, white excrement at the point where the bird dove. Most of these sightings were determined to be of Red-throated Loons (*Gavia stellata*) and Western/Clark's Grebes (*Aechmophorus occidentalis/clarkii*). No diving murrelets or murrelet-sized alcids, and no concentric patterns of wavelets on a scale of a diving murrelet-sized seabird were observed during either survey. Therefore, the aerial survey population estimates are not adjusted for bird avoidance-diving.

An onshore and an offshore survey line, each running approximately parallel to the coastline were flown in each segment of the Oregon study area. The onshore line was positioned so that the inboard observer was looking at water just offshore of the breaking wave zone. This placed the onshore survey line approximately 100 m from the shoreline. At times, however, in both Oregon and Washington the plane was flown farther offshore (typically 300 m from shore) to avoid disturbing seabirds on nesting colonies, and pinnipeds on hauling-out areas. The pilot, who used a map catalog of these sensitive areas as a reference, was made aware of his approach to these areas by the position-data recorder. Since the pilot would fly the plane in a half-circle arc around these areas, portions of the habitat along the onshore survey line lying just offshore of the wave zone, were undersampled. The offshore survey line was located 1,000–1,200 m from shore, far enough offshore to include the 18-m (10-fathom) bathymetric contour line. Given this survey coverage, it was appropriate to consider the study area for the Oregon coast to be a 1,000-m-wide band of coastal water. This area extended from Point Saint George/ Crescent City California north to Tillamook Head, an area of approximately 500 km^2. When reflected sun glare covered 20 percent or more of the field of view, only data from the non-glare side was used (reducing the survey track from 100-m to a 50-m-wide band). Even with this restriction, approximately 65 km^2 (13 percent) of the 500 km^2 study area was surveyed.

On the outer Washington coast, three sets of survey lines running approximately parallel to the coastline, were flown in each segment of the study area. As in Oregon, the onshore line was positioned so that the inboard observer was looking at water just offshore of the breaking wave zone. The nearshore (i.e. middle) line was located 1,600–2,000 m from the shoreline. As compared to the Oregon coast, the continental shelf on the Washington coast is relatively broad; hence, the offshore survey line had to be flown farther offshore than in Oregon to include the 18-m (10-fathom) bathymetric contour line. Consequently, the offshore line was located 3,500–4,500 m from shore. Given this survey coverage, it is appropriate to consider the study area for the outer Washington coast to be a 4,000 m wide band of coastal water extending from Tillamook Head north to Cape Flattery, an area of approximately 1,065 km^2. With sun glare at times precluding surveying on one side of the aircraft, approximately 80 km^2 (7.5 percent) of the 1,065 km^2 outer Washington coast study area was surveyed.

Aerial surveys were also flown inside Grays Harbor, Willapa Bay and the Columbia River during the Washington study. The study area for each of the embayments was based on the size of an irregular-shaped polygonal area as defined by the survey flight track. Only one complete survey was flown inside each embayment. With such poor temporal coverage of these tidally dominated waters, we feel it is inappropriate to project population estimates for these specific areas. Instead, the murrelets seen in and the survey effort for these embayments are applied to the offshore coastal segment adjacent to each embayment.

Due to restrictions on the availability of the survey aircraft, there was time to survey only one onshore line along the British Columbia shore, and one onshore and one offshore line on the Washington shore of the western Strait of Juan de Fuca. The study area for the Strait was considered to be a 1,000 m wide band of coastal water off both the Washington and British Columbia shorelines (areal estimates of 93 km^2 and 65 km^2, respectively).

During aerial surveys, Marbled Murrelet location is referenced to the time of sighting, and recorded to the nearest second by the observers. To obtain the location of murrelets, a sighting database file created from the transcribed audio tapes was later merged with the position database file, using interpolation and mapping software. Specifically, CAMRIS (Computer Aided Mapping and Resource Inventory System) was used. The interpolated murrelet database was then used to determine bird density (number of observed murrelets divided by the area of the survey transect). Population estimates are based on projections of the density estimates for 20' latitudinal blocks on the outer coast (except 12' near Pt. Saint George, and 24' near Cape Flattery). The projection of density is over the areal extent of a block, which is the length of a block times the width of the study area (1,000 m in Oregon, 4,000 m in Washington). Similarly, abundance data for the Strait of Juan de Fuca are shown in longitudinal blocks of varying length. This broad-scale approach was used to minimize the error of overestimating density, which can occur when block size is small enough to result in the counting of birds more than once as they move between adjacent blocks.

In 1993, steps were taken to insure that observers maximized the time they actually were looking out the window. The location of all other seabird species was referenced to 5-minute blocks of time as reported by the data recorder over the aircraft's intercom system. This freed the observers from having to look at their watches for every seabird sighting. Before this change, observers could spend 20–30 percent of the survey time being spent with an observer looking at their watch, not out the window, when in areas of high seabird abundance.

When possible, observers noted the number, group size, plumage and age of all seabirds seen, including Marbled Murrelets. When two murrelets were seen <5 m apart they were designated as a pair. Lone birds and birds seen to be >5 m apart were designated as singles. Groups larger than 2 birds were designated as such, regardless of the distance between individual birds in the group.

During the 1993 aerial survey, we noted that a number of adult Marbled Murrelets appeared to be in a transitional molt from alternate plumage to basic plumage (these birds appear mottled gray in color instead of mottled brown). By late August and early September 1993, Ralph and Long [this volume] noted that a number of adult murrelets in northern California had molted into basic (winter) plumage. Similarly, a number of adults in Puget Sound had by early September molted into basic plumage (Stein, pers. comm.). Given these findings, we classified Marbled Murrelets seen during the aerial survey as being in either alternate plumage (presumed to be adults) or black-and-white plumage, a category that comprises adults in basic plumage and hatch-year birds.

Results

Abundance

On-transect observations along the various segments of the Oregon coast resulted in the sighting of 882 Marbled Murrelets, and a projected population estimate of 6,138 birds (*table 1*). Observations along the various segments of the outer Washington coast resulted in the sighting of 226 murrelets, and a projected population estimate of 2,907 birds (*table 2*). Flights off the shores of the western Strait of Juan de Fuca resulted in the sighting of 36 Marbled Murrelets on the Washington side, and 18 murrelets on the British Columbia side, with projected population estimates for these two areas of 340 and 306 birds, respectively (*tables 3* and *4*). The combined population estimate for the Washington outer coast and western Strait on the Washington side is 3,250 birds.

These projected population estimates are probably underestimates in that, while surveying in aircraft, because foraging murrelets can be readily missed when they are diving. An analysis of dive data obtained from the tracking of radiotagged Marbled Murrelets (*table 5*) indicates that aerial surveys underestimate abundance by approximately 5–10 percent. Adjusting the projected population estimates for this source of underestimation yields adjusted population estimates of approximately 6,400–6,800 birds in Oregon and 3,400–3,600 birds in Washington.

Group Size and Plumage

In both Oregon and Washington (including birds from the British Columbia side of the Strait) approximately one-quarter of the Marbled Murrelets seen were recorded as being in black-and-white plumage (*tables 1* and *2*). Groups classified as pairs made up an higher proportion of groups seen in Oregon (45 percent) than in Washington (25 percent). But, if you examine each state separately, the proportional distribution of group size was similar regardless of plumage category (*tables 6* and *7*). It is unlikely that hatch-year birds would have a group-size distribution similar to those of adults, since many nesting and just post-nesting adults would still be paired in late August and early September. Further, with black-and-white birds making up one-quarter of the murrelets seen, and given our observations of some adults appearing to be in molt from alternate to basic plumage, it is likely that a substantial number of the black-and-white birds seen were adults in basic plumage.

Distribution

In Oregon, Marbled Murrelets were found to be most abundant off the central part of the state from Coos Bay north to Cascade Head (*table 1*). In contrast, murrelets were in general less abundant in the southern and northern thirds of the state. Based on distribution maps presented in Varoujean and Williams (1994a), murrelets appeared to be more abundant near the entrances to major rivers and embayments. Birds also appeared to be more abundant close

Table 1—Marbled Murrelet abundance based on an aerial survey conducted on 22-23 August 1993. The study area extended from Pt. Saint George, California, north to Tillamook Head, Oregon. Except for the survey track off northern California, the study area is broken into 20' latitudinal blocks. The projected population estimate for each latitudinal block is the density estimate (derived from the number of observed murrelets divided by the actual area surveyed) times the total study area in each block, assuming a study area width of 1,000 m

Location*	Birds+	Area surveyed (km^2)	Density ($birds/km^2$)	Population estimate
41° 48' Point St. George 42° 00' Brookings	17 AD 1 BW	1.48	12.1	268
42° 00' Brookings 42° 20' Cape Sebastian	19 AD 1 BW	3.70	5.4	200
42° 20' Cape Sebastian 42° 40' Humbug Mountain	32 AD 4 BW	5.55	6.5	240
42° 40' Humbug Mountain 43° 00' Croft Lake	21 AD 17 BW	3.91	9.7	359
43° 00' Croft Lake 43° 20' Coos Bay	39 AD 5 BW	4.53	9.7	359
43° 20' Coos Bay 43° 40' Umpqua River	87 AD 15 BW	7.13	14.3	529
43° 40' Umpqua River 44° 00' Siuslaw River	26 AD 8 BW	5.55	6.1	225
44° 00' Siuslaw River 44° 20' Yachats	109 AD 49 BW	5.55	28.5	1,055
44° 20' Yachats 44° 40' Yaquina Head	215 AD 56 BW	5.55	48.8	1,805
44° 40' Yaquina Head 45° 00' Cascade Head	54 AD 16 BW	5.55	12.6	466
45° 00' Cascade Head 45° 20' Cape Lookout	29 AD 16 BW	5.04	8.9	329
45° 20' Cape Lookout 45° 40' Nehalem Bay	18 AD 10 BW	5.55	5.0	185
45° 40' Nehalem Bay 46° 00' Tillamook Head	13 AD 5 BW	5.55	3.2	118
Total birds observed:	679 AD 203 BW 882		Projected population estimate:	6,138

*Location is represented as the extent of coastline between the latitudinal listings

+AD = Adults in alternate plumage; BW = Black/White plumage, which includes adults in basic plumage and hatch-year birds

Table 2—Marbled Murrelet population estimate based on an aerial survey conducted on the Washington outer coast on 4-5 September 1993. The study area extended from Tillamook Head, Oregon north to Cape Flattery, Washington. The projected population estimate for each latitudinal block is the density estimate (derived from the number of observed murrelets divided by the actual area surveyed) times the total study area in each block, assuming a study area width of 4,000 m

Location*	Birds+	Area surveyed (km^2)	Density (birds/km^2)	Population estimate
46º 00' Tillamook Head 46º 20' North Head	3 AD 1 BW	12.30	0.3	44
46º 20' North Head 46º 40' Willapa Bay	14 AD 2 BW	18.60	0.9	134
46º 40' Willapa Bay 47º 00' Ocean Shores	7 AD 2 BW	14.73	0.7	104
47º 00' Ocean Shores 47º 20' Cape Elizabeth	9 AD 2 BW	12.95	0.8	118
47º 20' Cape Elizabeth 47º 40' Destruction Island	6 AD 4 BW	11.10	0.9	133
47º 40' Destruction Island 48º 00' Carroll Island	35 AD 20 BW	10.70	5.1	755
48º 00' Carroll Island 48º 24' Cape Flattery	89 AD 32 BW	13.20	9.2	1,619
Total birds observed:	163 AD 63 BW 226		Projected population estimate:	2,907

*Location is represented as the extent of coastline between latitudinal listings

+ AD = Adults in alternate plumage; BW = Black/White plumage, which includes adults in basic plumage and hatch-year birds.

to shore, with approximately 75 percent of the sightings occurring on the onshore survey line.

By early September, which is late in the nesting season (Hamer and Nelson, this volume a), Marbled Murrelets were found to be most abundant off the rocky shores in the north part of the Washington outer coast from Destruction Island to Cape Flattery (*table 2*). In contrast, murrelets were present in densities of <1.0 bird/km^2 south of Destruction Island. Distribution maps presented in Varoujean and Williams (1994b) indicate that murrelets are not present in abundance off the entrances to the Columbia River, Willapa Bay and Grays Harbor. These areas, however, may play a role as murrelet habitat. Even though fewer than ten Marbled Murrelets were seen inside these embayments, a more thorough temporal coverage of these tidally dominated waters may find them to be important foraging areas in the summer months.

Overall only 10 percent of the murrelet sightings occurred beyond 2,000 m from shore (*table 8*). The continental shelf in southern Washington, relative to the northern one-third, is broad and exhibits a gradual bathymetric gradient from shore out to sea. Marbled Murrelets along the southern two-thirds of the state appear to be distributed evenly out to 4,000 m from shore. In this region waters are typically <10 m deep within 2,000 m of shore, and 10–20 m deep in the area between 2,000–4,000 m. From Cape Elizabeth north, the offshore bathymetric gradient is steeper, so that within 2,000 m from shore the water is up to 20 m deep. The depth ranges between 20 and 30 m from 2,000–4,000 m offshore. Murrelet abundance in this part of the study area is not evenly distributed, with an estimated density of 0.9 birds/km^2 in the outer half. This is approximately one-eighth of the density reported for waters <20 m deep in the inner half. Such low density, however, does correspond to the low densities of murrelets reported in the southern two-thirds of the state.

Based on distribution maps presented in Varoujean and Williams (1994a, b), the distribution of single birds, pairs of birds and larger groups, whether adults in alternate

Table 3—Marbled Murrelet population estimates based on an aerial survey conducted on the Washington coast of the western Strait of Juan de Fuca on 6 September 1993. The projected population estimate for each longitudinal block is the density estimate (derived from the number of observed murrelets divided by the actual area surveyed) times the study area in each block, assuming a study area width of 1,000 m

Location*	Birds+	Area surveyed (km^2)	Density (birds/km^2)	Study area (km^2)	Population estimate
124º 38' Koitlah Point 124º 18' Sekiu Point	10 AD 2 BW	2.76	4.3	27.78	119
124º 18' Sekiu Point 123º 57' Twin River	4 AD 0 BW	4.65	0.9	27.78	25
123º 57' Twin River 123º 43' Tongue Point	4 AD 1 BW	2.04	2.5	18.52	46
123º 43' Tongue Point 123º 27' Port Angeles	14 AD 1 BW	1.86	8.1	18.52	150
Total birds observed:	32 AD 4 BW 36		Projected population estimate:		340

* Location is represented as the extent of coastline between longitudinal listings
+ AD = Adults in alternate plumage; BW = Black/White plumage, which includes adults in basic plumage and hatch-year birds.

Table 4—Marbled Murrelet population estimates based on an aerial survey conducted on the British Columbia coast of the western Strait of Juan de Fuca on 6 September 1993. The projected population estimate for each longitudinal block is the density estimate (derived from the number of observed murrelets divided by the actual area surveyed) times the study area in each block, assuming a study area width of 1,000 m

Location*	Birds+	Area surveyed (km^2)	Density (birds/km^2)	Study area (km^2)	Population estimate
124º 28' Port San Juan 124º 12' Magdalena Bay	9 AD 0 BW	1.33	6.8	18.52	126
124º 12' Magdalena Bay 123º 59' Glacier Point	6 AD 3 BW	0.93	9.7	18.52	180
123º 59' Glacier Point 123º 45' Sooke Inlet	0 AD 0 BW	0.93	0.0	18.52	0
123º 45' Sooke Inlet 123º 38' Becher Bay	0 AD 0 BW	0.46	0.0	9.26	0
Total birds observed:	15 AD 3 BW 18		Projected population estimate:		306

* Location is represented as the extent of coastline between longitudinal listings
+ AD = Adults in alternate plumage; BW = Black/White plumage, which includes adults in basic plumage and hatch-year birds.

Table 5—Diving data for radiotagged Marbled Murrelets tracked during the 1988 field season in Oregon, and the 1991 field season in northern California (Varoujean and others 1989; Varoujean, unpubl. data).

Mean (± *s.e.*) duration of dive episode:
X_D = 0.30 hours (± 0.04), *n* = 13 days

Mean (± *s.e.*) percentage of time during dive episode spent submerged below the surface:
X_S = 67.6 percent (± 1.0 pct), *n* = 20 dive episodes

Percent time spent diving during daylight hours:
Dive episodes occur 6 times/day from 0530-2130 h (16 h period):
6 (X_D) = 1.80 h (± 0.24), which is 11.3 percent (± 1.5) of a 16 h day, or a range with ± 2 *s.e.* of 8.3-14.3 percent

Percent time spent actually below the surface during daylight hours:
Ranges from (X_S – 2 *s.e.*)(8.3 pct) to (X_S + 2 *s.e.*)(14.3 pct), or 5.4 to 9.9 percent

Table 6—Number (and percent) of Marbled Murrelets seen as singles, birds in pairs and in groups of >2 birds for birds in alternate, and black and white plumage. Data includes all sightings made during aerial surveys of the Oregon coast over the period 22-23 August 1993

	Group size			
	1	2	>2*	Category
Plumage category	No.(pct)	No.(pct)	No.(pct)	total
Alternate	144 (41)	170 (48)	41 (11)	355
Black/white	62 (48)	55 (43)	12 (9)	129
Group total	206 (43)	225 (46)	53 (11)	

*Groups ranged in size from 3-12 birds (alternate), and 3-5 birds (black/white)

Table 7—Number (and percent) of Marbled Murrelets seen as singles, birds in pairs and in groups of >2 birds for birds in alternate, and black and white plumage. Data includes all sightings made during aerial surveys of the outer coast of Washingtion, and the western Strait of Juan de Fuca over the period 4-6 September 1993.

	Group size			
	1	2	>2*	Category
Plumage category	No.(pct)	No.(pct)	No.(pct)	total
Alternate	84 (66)	32 (25)	11 (9)	127
Black/white	40 (71)	14 (25)	2 (4)	56
Group total	124 (68)	46 (25)	13 (7)	

*Groups ranged in size from 3-18 birds (alternate), and 3-4 birds (black/white)

Table 8—Distribution of Marbled Murrelets on the outer coast of Washington based on aerial survey results, 4-5 September 1993. From north to south the study area is divided into two sections, with the southern section, from Tillamook Head to Cape Elizabeth, located off sandy shores, and the northern section, from Cape Elizabeth to Cape Flattery located off predominately rocky shores. Within each section the study area is delineated by distance from shore into an inner (<2,000 m) and outer (2,000-4,000 m) half

Location*	Inner half (< 2,000 m) Birds+	Inner half (< 2,000 m) Density (birds/km²)	Outer half (2,000-4,000 m) Birds+	Outer half (2,000-4,000 m) Density (birds/km²)
46º 00' Tillamook Head – 47º 20' Cape Elizabeth	27 AD, 4 BW	1.0	6 AD, 3 BW	0.6
47º 20' Cape Elizabeth – 48º 24' Cape Flattery	124 AD, 51 BW	7.5	6 AD, 5 BW	0.9

* Location is represented as the extent of coastline between latitudinal listings
+ AD = Adults in alternate plumage; BW = Black/White plumage, which includes adults in basic plumage and hatch-year birds.

plumage or birds in black-and-white plumage, was similar, indicating no preferred use of a particular section of coast in either Oregon or Washington by any one group size or plumage category.

Production

The ratio of hatch-year birds to the total number of murrelets seen during the surveys is a potential estimator of production. Of the 882 murrelets seen in Oregon, 203 birds were recorded as being in black-and-white plumage, i.e., adults in basic plumage and hatch-year birds. To obtain an estimate of production requires ascertaining the number of hatch-year birds in the black-and-white plumage category. This was done by using figures obtained by Ralph and Long (this volume) from northern California on the proportion of hatch year birds to the total number of black-and-white birds identified to age. During the period 20-30 August they documented that 21 percent of the black-and-white birds identified to age were hatch years. Therefore, if you assume 21 percent of the 203 black-and-white birds seen during the aerial surveys (43 birds) are hatch years, the proportion of hatch-year birds to the total of 882 murrelets seen in Oregon is 4.9 percent.

As there is about a one week delay in the onset of murrelet nesting in Washington as compared to northern California (Hamer and Nelson, this volume a), it is more appropriate, even with the Washington survey occurring in early September, to again use the hatch-year ratio for the period 20-30 August, rather than the ratio of 11 percent documented by Ralph and Long (this volume) for the period 30 August–9 September. Twenty-one percent of the 70 black-and-white birds seen during the aerial surveys is 15 birds, so the proportion of hatch-years to the total of 280 murrelets seen in Washington and British Columbia is 5.4 percent.

Discussion

Abundance

In general, the population estimate of 6,400-6,800 birds corresponds to estimates previously reported for Oregon. Several spatially limited surveys were conducted in Oregon prior to 1992 (Nelson and others 1992), including boat-based surveys carried out during the summers of 1986-1988 by Varoujean and Williams (1987) and Varoujean and others (1989). These surveys, conducted while searching for murrelets to capture for radio tagging, established a mean density estimate of 23.2 birds/km² (n = 63, *s.e.* = 3.7). It was felt, however, that murrelet density was overestimated, in part, because the surveys were conducted off only central Oregon, where murrelets are more abundant. Furthermore, because murrelets were found to be episodically concentrating near the tidal plumes of river mouths and harbor entrances, density estimates derived from transects carried out solely within 3 km of these areas were significantly higher (t-test, P<0.01), and more variable than on transects that extended to and beyond 3 km from these entrances (out to 3 km: $\bar{x}$ = 54.1 birds/km², n = 14, *s.e.* = 13.7, range = 6.7-190.0; out to/beyond 3 km: $\bar{x}$ = 13.5 birds/km², n = 49, *s.e.* = 1.6, range = 3.5-32.0). Varoujean and Williams (1987) also noted variability in abundance in the same location offshore of sandy beaches over periods of 2–4 days, which they attributed to daily changes in the location and extent of rip-current plumes. Murrelets were observed aligning themselves on or near the boundaries of these plumes, presumably for the purpose of foraging. The presence, persistence, size and shape of these plumes depends on shoreline morphology, tidal state, tidal range, and the magnitude and direction of wind driven waves and long ocean swells (Brown and McLachlan, 1990). With tidal ebb and flow periods each lasting 6-7 hours, and with the hourly/daily variations in sea state that occur during the summer months along the Oregon coast, rip-current plume configuration on the scale of hours changes quickly. Additionally, plume development occurs in a sequential manner along various stretches of shore, because of the consistent differences between areas in the timing of the tide cycle. For example, between Coos Bay and the Siuslaw River, a distance of about 80 km, the onset of tidal ebb or flow consistently occurs 20 minutes earlier off Coos Bay. Given the various factors that can contribute to spatial and temporal variability in murrelet abundance near tidal and rip-current plumes, Varoujean and Williams (1987) felt that they could have been counting the same birds in more than one location on different days. For the same reasons, we presently feel that there is also the possibility that birds can be counted more than once on any one day when boat surveys are conducted over extensive (>40 km) stretches of coastline, especially if both an onshore and offshore line are being surveyed on the same day. For example, to carry out a boat survey on both an onshore and offshore line over a 45 km length of coast would require about 6 hours at 15 km/hr, over which time tidal conditions and sea state would change decidedly. It would be reasonable to assume that during this period every murrelet encountered on transect would be expected to take flight at least once, and, if they landed on a yet to be surveyed segment of a transect, counted again. At 80 km/hr (Varoujean and others 1989) a murrelet can take flight, and overtake a vessel that has passed it, or fly offshore into the path of a returning survey vessel in a matter of minutes. The probability of again encountering birds behaving in this manner are high. For example, onshore and offshore survey lines are typically located within 500 m and between 500 m and 1,000 m from shore, respectively. A transect width of 200 m (i.e., 100 m on each side of the vessel) samples 70 percent of the zone out to 500 m, given that the first 100 m from shore, the surf zone off a sandy beach is infrequently inhabited by murrelets. Similarly, a 200 m wide transect located between 500 m and 1,000 m would sample 50 percent of this zone. Consequently, the probability of counting any one bird, including birds that have already been counted elsewhere and moved into the path of the boat again, is 0.7 in the onshore zone, and 0.5 in the offshore zone.

Two adjustments were made to compensate for the potential sources of overestimation in calculating a population estimate based on the 1980's boat survey data. First, only the mean density estimate for transects out to and beyond 3 km of river mouths (13.5 birds/km^2) was used in the calculation. Second, a conservative estimate of 470 km^2 was used as the areal extent of suitable nearshore habitat over which it was applicable to apply the density estimate. This area was calculated using a study area width of 1 km, even though one-quarter of the survey transects were located 1.0-1.5 km from shore, and a north-south, straight line distance of 470 km as a measure of the length of the Oregon coastline. A population estimate based on the product of mean density (± 2 *s.e.*) and 470 km^2 of habitat is 4,850-7,850 birds. Note that the 1993 aerial survey estimate of 6,400-6,600 birds falls within this range.

In sharp contrast to the concordance between the population estimates of the 1980's boat surveys and 1993 aerial survey, is the disparity between these estimates and the nearly three-fold higher population estimate of 15,000-20,000 murrelets by Strong and others (this volume). This estimate is based on the results of boat surveys conducted in Oregon during the summers of 1992 and 1993, and is subject to the same overestimation errors just discussed in reference to the 1980's boat survey data. Interestingly, if we do not use a conservative approach in calculating a population estimate for the 1980's boat survey data, but rather apply the unadjusted density estimate of 23.2 birds/km^2 to a 750 km^2 study area (500 km of actual coastline times a 1.5-km-wide study area), we get an estimate of 17,400 birds.

Our aerial survey population estimates do not take into account the possibility that murrelets may have been distributed farther offshore than our offshore survey lines. Both Strong and others (1993) and Ralph and Miller (this volume) have shown that 20 percent of the murrelet population may be located beyond 1,000 m from shore, i.e., in waters deeper than 18 m. Our data, however, indicate that murrelet abundance declined sharply out to 1,000 m from shore in Oregon and out to 2,000 m from shore in Washington. But even if the 1993 aerial survey estimate for Oregon was adjusted for the possibility that 20 percent of the murrelet population was located offshore of our study area, the resultant estimate of 8,200 birds would still be only about one-half the estimate of 15,000–20,000 birds. So, in summary, we suggest that 15,000–20,000 birds is an overestimate of Marbled Murrelet abundance in Oregon. With reservations associated with comparing the 1980's boat to 1993 aerial survey results, we tentatively conclude that murrelet population size has remained relatively stable in Oregon over the last 10 years.

Between 1978 and 1985, several censuses of Marbled Murrelets were conducted along various routes along the outer coast of Washington and the Strait of Juan de Fuca (Speich and others 1992, Wahl and others 1981). Survey platforms included the use of aircraft on flights "of opportunity", and small boats. Even with differences in sampling methodology, the density estimates (0.2–8.3 birds/km^2) reported by Speich and others (1992) for spring and summer on the Washington outer coast do correspond to those reported for the September 1993 aerial survey. But their combined population estimate for the outer coast and western Strait was no more than 2,600 birds, about 1,000 fewer birds than our September 1993 estimate of 3,400–3,600 birds. This difference is likely attributable to the conservative approach taken by Speich and others (1992) in delineating the areal estimates over which they extrapolated their density estimates. But it is also possible that the higher 1993 estimate is due to differences in the timing of the respective studies. None of the surveys conducted by Speich and others (1992) took place later than August, whereas our survey was carried out in early September. It is possible that by early September, murrelets from British Columbia and Puget Sound have dispersed to the northern Washington outer coast. But the overall patterns of population shifts are unknown for this region (Rodway and others 1992), so there is no direct evidence indicating that the September 1993 estimates include birds from outside the study area. Therefore, at present we must conclude that the higher population estimate of the 1993 aerial survey does not represent a real increase in murrelet numbers due to either intrinsic population growth or the immigration of birds from outside the study area. If this is so, then there has been no marked change in the population size of Marbled Murrelets inhabiting the outer coast and western Strait of Washington in the last 10 years.

Distribution

Marbled Murrelet abundances as documented by the 1993 aerial surveys and the 1992-1993 boat surveys (Strong and others 1993; Strong, pers. comm.) were highest in the central portion of the state and lowest at the south and north ends of the study area. Additionally, this distribution corresponds to that described by Nelson and others (1992), and to the distribution of the remaining older-aged forest stands in Oregon, with the exception of the area between the Umpqua River and Coos Bay. This area exhibits high murrelet abundance even though there are only small, scattered stands of older-aged conifers located within 30–70 km inland of this section of Oregon's coast.

Ralph and Miller (pers. comm.) recorded a density estimate of 4.0 birds/km^2 based on a boat survey of an onshore and offshore line out to 1,400 m from shore conducted on 28 September 1992. This survey extended from Cape Sebastian south to the Smith River in California. But from the border south 6 km to the mouth of the Smith River, they documented a density of 37.2 birds/km^2. Potentially then, the numbers of murrelets frequenting waters near the border may be variable, and most likely at times represent birds from the northern California breeding population, which may account for our relatively high density estimate of 12.1 birds/km^2 for the area between Pt. Saint George and the border (*table 1*).

There is an indication from the aerial survey data that murrelets were present in greater numbers off the mouths of rivers and entrances to embayments in Oregon, as shown in Figures 1 and 2 of the report by Varoujean and Williams (1994a), and that murrelet numbers were variable off sandy shores. As regards Marbled Murrelet distribution and shore type in Oregon, Strong and others (1993) reported that bird densities were highest off sandy beach and mixed (sandy/rock) shores. In contrast, Varoujean and Williams (1987) noted that murrelet densities were significantly higher off (and within 3 km) of the mouths of major rivers and embayments as compared to either sandy beaches or rocky shores. Part of this disparity, however, may be attributed to the different areas surveyed and differences in survey effort. The survey by Strong and others (1993) occurred over the entire length of coast between Yaquina Bay and Coos Bay, whereas Varoujean and Williams (1987), in general, surveyed up to only 10 km north and south of the entrances to Yaquina and Coos Bay, and the mouths of the Siuslaw and Umpqua River. Strong and others (1993), Varoujean and Williams (1987) and Varoujean and others (1989) each documented that murrelet abundance is most variable off sandy shores.

Speich and others (1992) suggested that the Marbled Murrelet population on the Pacific Ocean coast of Washington was largely found north of Pt. Grenville with an uncertain number found in the waters off the southern coast, although the numbers there were thought to be low. This pattern was confirmed by the September 1993 aerial survey of the coast.

The southern portion of the state does not seem to be as important to murrelets during the breeding season as does the northern part of the Washington outer coast. It may however play an important role as a wintering area, based on 22 years of records collected off Grays Harbor (Speich and Wahl, this volume). Seabird surveys out of Grays Harbor were conducted on charter boats, and occurred during various seasons from 1971 to 1991. Although not specifically designed to do so, these surveys do provide information pertaining to the distribution and abundance of Marbled Murrelets. The general pattern of murrelet occurrence was one of high average abundances during the spring, fall and winter months, and higher abundances in habitats closer to shore (numbers encountered ranged from 0.4-2.8 birds/km travelled). Overall, the highest abundances occurred in Grays Harbor channel out to the 50 m depth contour; only rarely were Marbled Murrelets recorded in deeper habitat areas. Furthermore, murrelets were rarely seen during August and September surveys, a pattern that corresponds to the low abundance figures obtained during the September 1993 aerial surveys for this section of the Washington coast.

Production

Based on analyses conducted by Beissinger (this volume), the hatch-year proportion estimates of 4.9 percent in Oregon and 5.4 percent in Washington are too low for population maintenance, if these figures are used as measures of productivity in a population growth model. However, to conclude that the murrelet populations in Oregon and Washington are in general decline may be premature. There is an indication that other seabird species nesting in the area experienced low production rates during the 1993 nesting season (Varoujean and Williams 1994a, b). Western Gulls (*Larus occidentalis*), Glaucous-winged Gulls (*L. glaucescens*) and their intergrades, and California Gulls (*L. californicus*) had hatch-year proportions that ranged from 5-7 percent of the total population, and the proportion of Common Murre (*Uria aalge*) hatch-years was 1.6 percent. Preliminarily, these low measures of production are most likely attributable to low food availability that may have been caused by El Niño-like, warm water conditions prevalent in the study area through the summer. Even though the life histories of these seabird species differ from the Marbled Murrelet, it is possible that what caused low gull and murre production also caused reduced production in the murrelet during the 1993 nesting season.

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