Fall through spring 2015/2016 Marbled Murrelet At-Sea Densities In Five Strata Associated with U.S. Navy Facilities in Washington State: Annual Research Progress Report

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INTRODUCTION

The overarching goal of this project is to estimate on-the-water marbled murrelet (*Brachyramphus marmoratus*) densities during the fall-spring seasons (September - April) adjacent to the following facilities: (1) Pacific Beach; (2) Naval Air Station Whidbey Island (Crescent Harbor); (3) Manchester Fuel Department; (4) Naval Base Kitsap at Bangor, Zelatched Point, Toandos, Keyport and Bremerton; (5) Naval Magazine Indian Island; and (6) Naval Station Everett. However, because the nearshore marine environment and murrelet densities adjacent to any one of these facilities is too small to derive reliable site-specific at-sea murrelet densities, Washington Department of Fish and Wildlife (WDFW) used a stratified sampling approach outlined in Pearson and Lance (2012, updated 31 October 2013) to derive stratum specific density estimates. This approach uses line-transect or distance sampling methods (Buckland et al. 1993) to derive murrelet density estimates for five strata using nearshore and offshore transects placed in 35 primary sampling units (PSUs) (Figure 1).

METHODS

We (WDFW) used the approach and methods from the survey effort described by Raphael et al (2007) and Miller et al. (2012) and modified by Pearson and Lance (2012; updated 31 October 2013). We use this approach because: (1) it addresses issues of detectability, (2) it is customized to murrelet distributions and densities in this region, (3) it uses pre-survey information to develop the sampling design, (4) the methodology was peer reviewed (e.g., Raphael et al. 2007, Miller et al. 2012), and because (5) we wanted our survey effort for this project to be consistent with the spring/summer murrelet monitoring effort funded by USFWS, which will ultimately allow us to compare estimates for the same sampling units among seasons.

Sampling Design and Survey Effort

The survey design that follows is described in detail in Pearson and Lance (2012, updated 31 October 2013). Thirty-five primary sampling units (PSUs) were split among 5 strata (see Figure 1 and Table 1). To derive strata and PSUs, we segmented the entire coastline of Puget Sound into 20-km Primary Sampling Units (PSUs) within Puget Sound and on the outer coast adjacent to NAVFAC NW Pacific Beach. We then combined PSUs into appropriate management/ecological/density strata (Figure 1). The area adjacent to Pacific Beach was defined as Strata #1 (n = 3 PSUs). For this strata, we sample the PSU in front of NAVFAC Pacific Beach and the PSUs immediately to the north and south. We defined this as a separate strata because it is subject to coastal influences (part of the California Current system) that are dramatically different from those associated with Puget Sound (e.g., swell, upwelling events, ENSO and PDO events, etc.). This ecological difference was also recognized by the Marbled Murrelet Effectiveness Monitoring program (Raphael et al. 2007) and the Federal recovery plan for the murrelet (U.S. Fish and Wildlife Service 1997) when they split the coast of Washington (Conservation Zone 2) from the Puget Sound (Conservation Zone 1). Within Puget Sound, we defined strata based on identified Puget Sound Basins that were distinct in bathymetry and tidal patterns and that have somewhat unique oceanographic conditions (Ebbesmeyer and Barnes 1980, Babson et al. 2006, Moore et al. 2008).

Using this information, Puget Sound strata definitions are as follows: Strata #2 Admiralty Inlet (Figure 2: west side of Whidbey Island Naval Air Station, Admiralty Inlet and Naval Magazine Indian Island) = 8 PSUs; Strata #3 North Hood Canal (Figure 2: Bangor, Zelatched Point, Toandos, and Dabob Bay) = 7 PSUs; Strata #4 Whidbey Basin (Figure 2: Crescent Harbor by Naval Air Station Whidbey Island and Naval Station Everett) = 11 PSUs; Strata #5 Central Puget Sound (Figure 2: Bremerton, Manchester, Keyport) = 6 PSUs.

Average PSU area was 38.2 km^2 and covered about 20 km of shoreline (Figure 1). The average transect length per PSU was 34.5 km, divided between a nearshore segment (average length = 20.4 km) and an offshore segment (average length = 14.7 km) with more effort (more transect traveled) in the nearshore where murrelet densities are higher (Miller et al. 2006, Raphael et al. 2007). We used PSU numbers from the Marbled Murrelet Effectiveness Monitoring Program (Raphael et al. 2007) in order to make comparisons, if needed, with spring/summer derived encounter rates for these same PSUs. The Effectiveness Monitoring effort uses a similar survey design to this Navy effort but, because the area of interest is much larger in the Effectiveness Monitoring Program and the goals differ between these efforts, the geographic definitions of the strata are very different between programs but the geographic boundaries of the PSUs and their numbers are identical (Raphael et al. 2007). Although the Effectiveness Monitoring Program did not include a PSU in Dyes Inlet, the Navy requested this area be sampled. As a result, a new PSU was created and labeled "900" to avoid any confusion with those PSUs already established.

We conducted four replicate surveys of all PSUs in Strata 2-5 as follows:

Early Fall = 14 September -20 October 2015
Fall = 2 November – 17 December 2015
Winter = 6 January – 17 February 2016
Early Spring = 29 February – 7 April 2016

As designed, we conducted two surveys of all the PSUs in Stratum 1 (Pacific Beach) which occurred on 22-29 September 2015 and 30-31 March 2016.

The survey date for each PSU and overall survey schedule is provided in Table 1. To derive this schedule, we randomly selected a Strata first. Within Strata, we then randomly selected the order of the Core PSUs (those adjacent to Navy facilities) and surveyed them prior to surveying the remainder of the PSUs in a Strata to make sure that we surveyed those important PSUs in each replicate should bad weather/sea conditions prevent us from surveying all PSUs. We also randomly determined whether we surveyed the nearshore or offshore segments first. There were often Naval activities in Dabob Bay which prevented us from surveying on the dates selected by this process. As a result, we coordinated closely with range officers to alter our schedule as necessary.

Observer Training

The crew consisted of four observers/data recorders and a rotating boat operator (but a designated Captain). The data recorder and two observers (one responsible for each side of the boat) switched duties at the beginning of each primary sampling unit (PSU) to avoid survey fatigue. All of the observers had considerable experience monitoring seabirds at sea and work on surveys nearly year-round. All of the observers had completed our one week of training at least once and most twice because the training is annual. Office training included a presentation of background information, survey design and protocols, sampling methodology, line transect distance sampling methodology, and measurement quality objectives. On-water training included boat safety orientation, seabird identification, specific training on correctly assigning marbled murrelet plumages (Strong 1998), conducting transect surveys, and distance estimation testing using laser rangefinders. Boat safety training included instructions and reminders for weather and sea condition assessment, use of the radio, boat handling, proper boat maintenance, safety gear, rescue techniques, and emergency procedures. Observer training was designed to be consistent with training conducted by other groups within the Marbled Murrelet Effectiveness Monitoring Program (Raphael et al. 2007, Huff et al. 2003, Mack et al. 2003).

During practice transects, observers were taught how to scan, where to focus their eyes, and which portions of the scan area are most important. Distance estimates from the transect line are a critical part of the data collected and substantial time was spent practicing and visually 'calibrating' before surveys began. During distance trials, each individual's estimate of perpendicular distance was compared to a perpendicular distance recorded with a laser rangefinder. These trials were conducted using stationary buoys and bird decoys as targets, which were selected at a range of distances from the transect line and in locations in front of as well as to the sides of the boat where marbled murrelets would be encountered on real surveys (Raphael et al. 2007). Each observer completed 100 distance estimates during pre-survey training and was tested weekly. For the weekly tests, each observer estimated five perpendicular distances to floating targets and the actual perpendicular distance was measured with a laser rangefinder. After the first set of five, the observer's results were assessed. If all five estimates were within 15% of the actual distance, the trial was complete for that observer. If any of the five estimates were not within 15% of actual, the observer continued to conduct estimates in sets of five until all five distances were within 15% of the actual distance. In addition, one of the project leads accompanied the survey crew and observed their overall performance and ability to detect marbled murrelets during the survey season and completed an audit form created by the Murrelet Monitoring Program (Raphael et al. 2007, Huff et al. 2003). The results of the audit were shared with the observers after the survey day was completed for feedback and discussion.

Field Methods and Equipment

Two observers (one on each side of the boat) scanned from 0° off the bow to 90° abeam of the vessel. More effort was spent watching for marbled murrelets close to the transect line ahead of the boat (within 45° of line). Observers scanned continuously, not staring in one direction, with a complete scan taking about 4-8 seconds. Observers were instructed to scan far ahead of the boat for birds that flush in response to the boat and communicate between observers to minimize missed detections. Binoculars were used for species verification, but not for sighting birds. For each marbled murrelet sighting the following data were collected: group size (a collection of birds separated by less than or equal to 2 m at first detection and moving together, or if greater than 2 m the birds are exhibiting behavior reflective of birds traveling and foraging together and therefore not independent), plumage class (Strong 1998), and water depth (from boat depth finder).

Observers relayed data (species, number of birds, estimated perpendicular distance of the bird(s) from the trackline) via headsets to a person in the boat cabin who entered data directly onto a laptop computer with software (DLOG3 developed by R.G. Ford, Inc., Portland, OR.) that is interfaced with a GPS unit and collects real time location data. DLOG3 interfaces with a handheld GPS and GIS overlays of the Washington shoreline and adjacent bathymetry, and uses these data to record GPS coordinates and perpendicular distance to shore at operator-defined time intervals (e.g. every 30 seconds). Transect survey length was calculated from the GPS trackline recorded in DLOG3. Additional data such as PSU identification, weather and sea conditions, on/off effort, and names of observers were typed into the DLOG3 program on the computer during the survey.

The crew used a 26-foot Almar boat with twin-outboard engines. Survey speed was maintained at 8-12 knots, and survey effort was ended if glare obstructed ≥ 30-40% of a given surveyors view (code = 3), or if Beaufort wind scale was 3 or greater. Beaufort 3 is described as a gentle breeze, 7-10 knot winds, creating large wavelets, crests beginning to break, and scattered whitecaps (Beaufort scale is provided in Appendix I).

Data Analysis

We used transect distances, murrelet group size, and perpendicular distances for each marbled murrelet observation to derive density (birds/km^2) estimates by stratum using the program DISTANCE. For details about our analysis approach, see Miller et al. (2006) and Raphael et al. (2007). Briefly, the Distance or line transect survey approach requires observers to move along a fixed path (transect) and to count occurrences of the target animal (marbled murrelet) along the transect and, at the same time, obtain the distance of the object from the transect. This information, is then used to estimate the area covered by the survey and to derive an estimate of the way in which detectability increases from probability 0 (far from the transect) towards 1 (near the transect). The shape of this detectability function can then be used in conjunction with the counts, distances to the birds, and the distance traveled (transect length) to derived an estimate of Density (birds/km^2). For details, please see Buckland et al. (1993). In the Results, we provide murrelet density estimates by Strata and by ecosystem: 1) California Current (Pacific Beach Stratum), and 2) Puget Sound (all other Strata) for each of the sampling periods (see above) and across all sampling periods (global model). The density provided can be viewed as the murrelet population on the water on a given day within the area and time period defined.

RESULTS/DISCUSSION

When examining density estimates by stratum (Table 2), higher densities were consistently found in Stratum 2, but there was considerable variability in density for this stratum between sampling periods - most notably was the lower density in the early fall sampling period. Murrelet densities were considerably lower in Stratum 1 and 5 and generally intermediate in Stratum 3 and 4. There are very few birds in Stratum 5 with three or fewer detections of murrelets in three of the four sampling seasons.

Using overall densities across all three replicates, we estimated there were 1,291 (95% CI = 833-1,999) birds in all Puget Sound strata combined (Sept – April) which is similar to last year's results but lower than that of the fall/winter of 2012/2013, when we estimated there to be 2,081 (95% CI = 1,429-3,028) birds for the same seasonal time period and same area (Figure 2). There was some seasonal variation in our all Puget Sound estimate with relatively few birds detected during the early fall sampling period as observed previously (Table 2).

In Figure 2, we compare densities among strata and years. Overall, there is some variability among years, but with no apparent trends. At the stratum level, there appears to be a declining trend in the Hood Canal stratum. We see a fairly dramatic increase in murrelet numbers for Pacific Beach and suspect that trend is the result of seasonal variation. This year's late "early spring" survey was done nearly a month later than last year and we suspect breeding birds were starting to move back into that area. As in previous years, this graph emphasizes the high murrelet density and considerable variability in density in Admiralty inlet. This is an area of strong currents driven by large tidal exchanges, which may influence the availability of forage fish depending on the time of day and the phase of the moon. This is paticularly true if birds are moving between the south side of Point Wilson (currently sampled) and the north and West (currently not sampled). This suggest the need to add an additional PSU to the West of Point Wilson to help us understand this variability.

Although we cannot derive PSU scale density estimates because they represent a single sample and because relatively few birds are encountered within a PSU (also high variability at that spatial scale), we can qualitatively explore encounter rates (# murrelets encountered per kilometer of transect length sampled; Table 3) by PSU. As in previous years, the PSUs on the western side of Admiralty Inlet have the highest murrelet encounter rates (Table 3, especially PSUs 30,31,32) with very high densities in the area spanning from Point Wilson southward through Port Townsend Bay and around Marrowstone Island. Again, some PSUs have no detections (e.g., Stratum 5 PSUs 25, 29, 900 – area near Manchester and Bremerton). The variability that we are seeing within a given PSU (and within a stratum) throughout the fall/winter period suggests some movement of birds within the study area and perhaps in and out of the study area – especially in the Admiralty Inlet region. Again, because birds can move large distances during our sampling effort, there may be considerable variation in encounter rates among seasons and years at this spatial scale.

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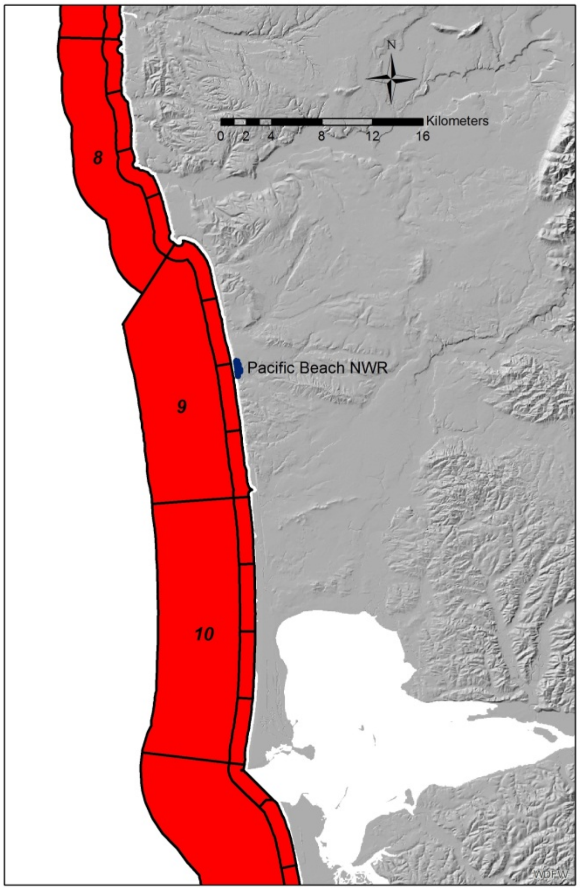
Figure 1. Stratum and primary sampling unit locations along the Washington coast (A) and in Puget Sound (B). Strata are defined in the figure Key and PSUs are numbered on the map.



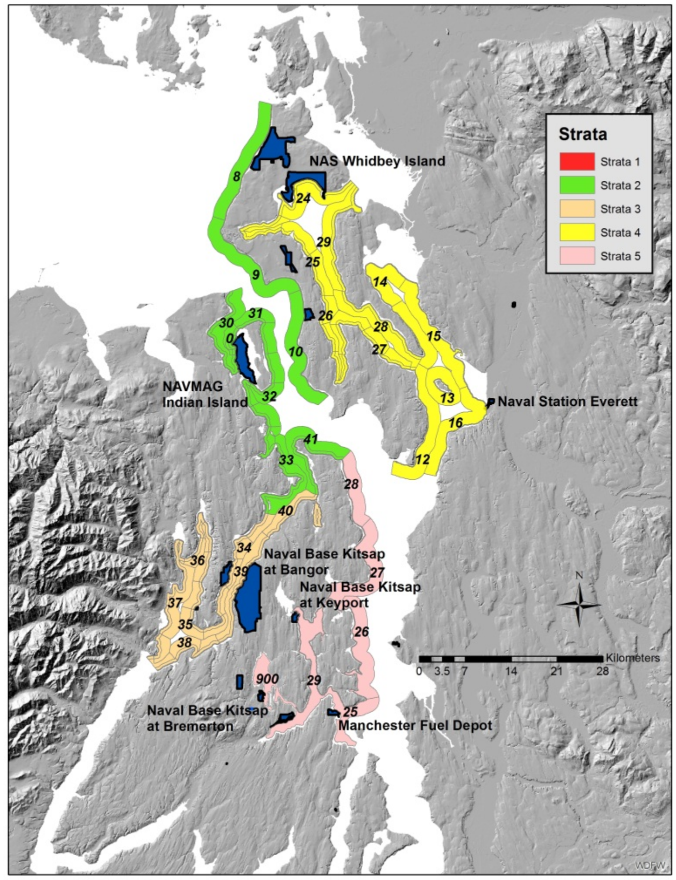


Figure 2. Density of marbled murrelets (± 95% CI) in the entire Puget Sound study area (Strata 2-5 combined) and by individual strata. Geographic location of each stratum is provided in Figure 1. Note that Pacific Beach (Stratum 1) is located on the outer Coast of Washington.

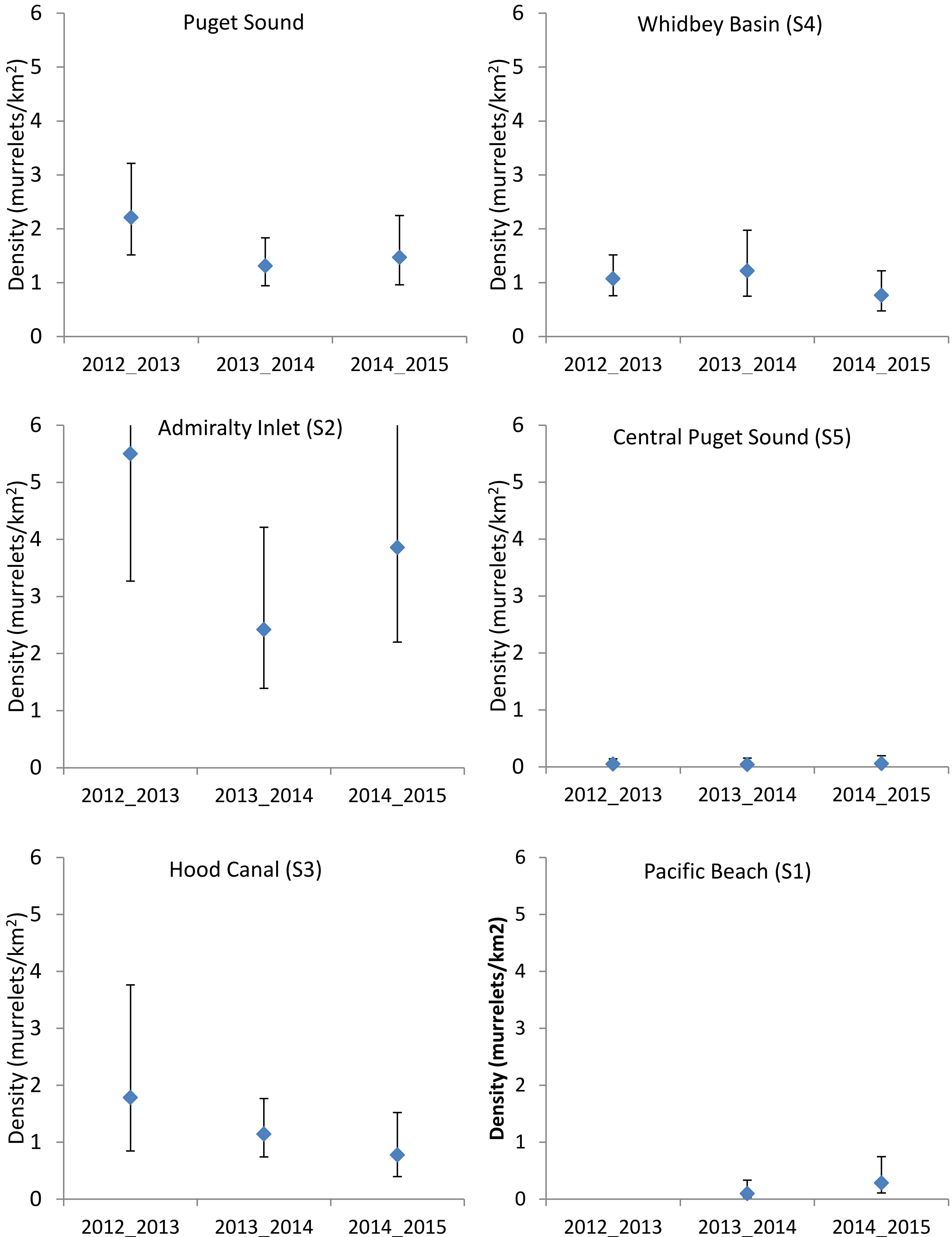


Table 1. Dates of Primary sampling unit (PSU) surveys by sampling season: Early fall = mid-Sept – Oct, Fall = Nov-mid-Dec, Winter = Jan-mid-Feb, Spring = late-Feb – mid-Apr. Primary sampling units adjacent to Naval facilities are in bold and highlighted. Geographic locations of each PSU can be determined by first identifying the Stratum number and then the PSU in Figure 1.

Stratum	PSU	Early Fall	Fall	Winter	Early Spring
1	8	29-Sep			30-Mar
	9	22-Sep			30-Mar
	10	29-Sep			31-Mar
2	**8**	21-Sep	20-Nov	25-Jan	22-Mar
	9	21-Sep	20-Nov	16-Feb	22-Mar
	10	16-Oct	20-Nov	16-Feb	15-Mar
	30	30-Sep	2-Nov	25-Jan	14-Mar
	31	30-Sep	2-Nov	25-Jan	7-Apr
	32	30-Sep	3-Nov	17-Feb	7-Apr
	33	14-Sep	4-Nov	17-Feb	7-Mar
	41	5-Oct	11-Dec	19-Jan	15-Mar
3	34	16-Oct	9-Nov	4-Feb	15-Mar
	35	17-Sep	17-Dec	4-Feb	11-Mar
	36	16-Sep	19-Nov	15-Jan	11-Mar
	37	17-Sep	18-Nov	4-Feb	11-Mar
	38	15-Sep	18-Nov	20-Jan	29-Feb
	39	15-Sep	9-Nov	20-Jan	29-Feb
	40	14-Sep	4-Nov	20-Jan	7-Mar
4	12	15-Oct	2-Dec	8-Feb	16-Mar
	13	15-Oct	25-Nov	28-Jan	5-Apr
	14	15-Oct	25-Nov	28-Jan	5-Apr
	15	8-Oct	24-Nov	6-Jan	16-Mar
	16	8-Oct	2-Dec	6-Jan	16-Mar
	24	13-Oct	23-Nov	7-Jan	17-Mar
	25	19-Oct	14-Dec	8-Jan	17-Mar
	26	19-Oct	1-Dec	8-Jan	28-Mar
	27	20-Oct	16-Dec	8-Feb	28-Mar
	28	20-Oct	16-Dec	8-Feb	5-Apr
	29	13-Oct	23-Nov	7-Jan	17-Mar
5	**25**	6-Oct	1-Dec	14-Jan	21-Mar
	26	6-Oct	14-Dec	14-Jan	21-Mar
	27	5-Oct	30-Nov	19-Jan	4-Apr
	28	5-Oct	30-Nov	19-Jan	4-Apr
	29	23-Sep	6-Nov	11-Jan	9-Mar
	900	23-Sep	6-Nov	13-Jan	21-Mar

Table 2. Estimates of marbled murrelet density (birds/km^2) and population size by sampling season (and all seasons combined = global model) for four Puget Sound Strata, all Puget Sound strata combined, and for coastal the Washington stratum (Stratum 1). Strata are defined in Figure 1. No birds were detected in Stratum 5 in early fall and winter resulting in no estimate for those periods.

Year	Stratum	Density (birds /km^2)	StdErr	%CV	Birds	Birds 95% CL Lower	Birds 95% CL Upper	Area (km^2)	f(0)	Std. Err. Of f(0)	E(s)	Std. Err. Of E(s)	Truncation Distance
All sampling periods combined – Early Fall through Early Spring (mid-Sept – mid-Apr)													
2015/ 2016	**All but 1**	**1.370**		**22.09**	**1,291**	**833**	**1999**	**942**	**0.0101**	**0.001**	**1.80**	**0.028**	**211**
2015/ 2016	1	1.404	0.326	23.25	**554**	316	973	394.9					
2015/ 2016	2	3.080	0.979	31.77	**791**	421	1485	256.7					
2015/ 2016	3	0.444	0.194	43.69	**72**	31	170	162.5					
2015/ 2016	4	1.222	0.331	27.13	**422**	247	720	345.1					
2015/ 2016	5	0.033	0.019	23.67	**6**	2	18	177.6					
Early Fall (mid Sept– late-Oct)													
2015	**All but 1**	**0.550**		**28.92**	**518**	**287**	**936**	**942.0**	**0.01**	**0.000**	**1.69**	**0.10**	**211**
2015	1	1.092	0.783	71.71	**431**	28	6569	394.9					
2015	2	0.970	0.353	35.59	**249**	111	562	256.7					
2015	3	0.030	0.034	100.00	**5**	1	41	162.5					
2015	4	0.760	0.339	44.06	**263**	104	667	345.1					
2015	5	0.000			**0**			177.6					
Fall (Nov –mid-Dec)													
2015	**All**	**1.503**		**23.12**	**1416**	**879**	**2282**	**942.0**	**0.01**	**0.001**	**1.73**	**0.05**	**211**
2015	2	1.706	0.482	28.25	**438**	231	832	256.7					
2015	3	1.705	0.631	37.03	**277**	117	658	162.5					
2015	4	2.032	0.800	39.37	**701**	303	1624	345.1					
2015	5	0.000			**0**			177.6					
Winter (Jan – mid-Feb)													
2016	**All**	**1.526**		**45.45**	**1964**	**743**	**5187**	**942.0**	**0.01**	**0.001**	**1.77**	**0.04**	**211**
2016	2	5.143	3.216	62.53	**1320**	342	5105	256.7					
2016	3	0.080	0.081	100.26	**13**	2	100	162.5					
2016	4	1.779	0.955	53.68	**614**	201	1875	345.1					
2016	5	0.000			**0**			177.6					

Early Spring (Late Feb – mid-Apr)													
2016	**All but 1**	**1.867**		**42.37**	**1759**	**682**	**4536**	**942.0**	**0.01**	**0.001**	**1.75**	**0.05**	**211**
2016	1	1.881		12.90	**743**	565	976	394.9					
2016	2	6.210		46.59	**1594**	566	4490	256.7					
2016	3	0.055		99.30	**9**	1	67	162.5					
2016	4	0.388		37.00	**134**	61	295	345.1					
2016	5	0.121		70.36	**22**	4	108	177.6					

Table 3. September – April marbled murrelet encounter rate (# birds detected/km transect length sampled) by primary sampling unit. Primary sampling units adjacent to Naval facilities are in bold and highlighted. Sampling seasons: Early fall = mid-Sept – Oct, Fall = Nov-mid-Dec, Winter = Jan-mid-Feb, Early Spring = late-Feb – mid-Apr. Primary sampling units adjacent to Naval facilities are in bold. Geographic locations of each PSU can be determined by first identifying the Stratum number and then the PSU in Figure 1.

Stratum	PSU	Early Fall	Fall	Winter	Early Spring	Average
1	8	0.082			0.311	0.197
	9	0.000			0.263	0.132
	10	0.000			0.392	0.196
2	**8**	0.282	0.000	0.808	0.000	0.272
	9	0.225	0.447	0.255	0.281	0.302
	10	0.059	0.058	0.000	1.863	0.495
	30	0.245	4.422	0.509	3.304	2.120
	31	0.501	3.219	0.070	0.640	1.107
	32	0.519	0.115	0.165	0.275	0.269
	33	0.205	0.000	0.420	0.000	0.156
	41	0.229	0.373	0.674	1.078	0.589
3	34	0.030	0.000	0.058	0.000	0.022
	35	0.000	0.000	0.322	0.029	0.088
	36	0.000	0.000	0.000	0.000	0.000
	37	0.000	0.000	0.388	0.000	0.097
	38	0.000	0.093	0.369	0.000	0.115
	39	0.000	0.000	0.116	0.000	0.029
	40	0.000	0.000	0.979	0.000	0.245
4	12	0.087	0.057	0.057	0.000	0.050
	13	0.145	0.000	0.077	0.057	0.070
	14	0.068	0.000	0.000	0.000	0.017
	15	0.636	0.000	0.027	0.000	0.166
	16	0.058	0.235	0.146	0.082	0.130
	24	0.503	1.208	1.645	0.188	0.886
	25	0.000	0.290	0.755	0.159	0.301
	26	0.000	0.123	0.000	0.000	0.031
	27	0.000	0.057	0.321	0.058	0.109
	28	0.057	0.000	0.113	0.058	0.057
	29	0.384	2.006	0.684	0.000	0.768
5	**25**	0.000	0.000	0.000	0.000	0.000
	26	0.000	0.000	0.362	0.000	0.091
	27	0.000	0.000	0.000	0.056	0.014
	28	0.000	0.042	0.000	0.043	0.021
	29	0.000	0.000	0.000	0.000	0.000
	900	0.000	0.000	0.000	0.000	0.000

Appendix I

BEAUFORT WIND SCALE WITH CORRESPONDING SEA STATE CODES

Beaufort Number	Wind Velocity (Knots)	Wind Description	Sea State Description	Sea State	
				Term and Height of Waves (Feet)	Condition Number
0	Less than1	Calm	Sea surface smooth and mirror-like	Calm, glassy 0	0
1	1-3	Light Air	Scaly ripples, no foam crests		
2	4-6	Light Breeze	Small wavelets, crests glassy, no breaking	Calm, rippled 0 – 0.3	1
3	7-10	Gentle Breeze	Large wavelets, crests begin to break, scattered whitecaps	Smooth, wavelets 0.3-1	2
4	11-16	Moderate Breeze	Small waves, becoming longer, numerous whitecaps	Slight 1-4	3
5	17-21	Fresh Breeze	Moderate waves, taking longer form, many whitecaps, some spray	Moderate 4-8	4
6	22-27	Strong Breeze	Larger waves, whitecaps common, more spray	Rough 8-13	5
7	28-33	Near Gale	Sea heaps up, white foam streaks off breakers	Very rough 13-20	6
8	34-40	Gale	Moderately high, waves of greater length, edges of crests begin to break into spindrift, foam blown in streaks		
9	41-47	Strong Gale	High waves, sea begins to roll, dense streaks of foam, spray may reduce visibility		
10	48-55	Storm	Very high waves, with overhanging crests, sea white with densely blown foam, heavy rolling, lowered visibility	High 20-30	7
11	56-63	Violent Storm	Exceptionally high waves, foam patches cover sea, visibility more reduced	Very high 30-45	8
12	64 and over	Hurricane	Air filled with foam, sea completely white with driving spray, visibility greatly reduced	Phenomenal 45 and over	9

Figure 8-1. Beaufort wind scale.