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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 work 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 between seasons.

Sampling Design and Survey Effort

The survey design that follows is described in detail in Pearson and Lance (2012). 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) 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) = 7 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 = 16 Sept – 31 Oct 2014
Fall = 3 Nov – 16 Dec 2014
Winter = 6 Jan – 11 Feb 2015
Early Spring = 3 Mar – 7 Apr 2015

As designed, we conducted two surveys of all the PSUs in Stratum 1 (Pacific Beach) which occurred on 8-9 October 2014 and 4-5 March 2015.

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.

Observer Training

The crew consisted of one dedicated boat operator and three observers/data recorders. 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 of 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 in 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 zero detections of murrelets in two of the four sampling seasons.

Using overall densities across all three replicates, we estimated there were 1,384 (95% CI = 904-2,117) birds in all Puget Sound strata combined (Sept – April) which is slightly higher than the fall/winter of 2013/2014 (1,237 birds, 95% CI = 887-1,725) and 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 (Table 2).

In Figure 2, we compare densities among strata and years. With only three years of data it is a bit premature to assess trends over time. In general there is some variability among years, but with no apparent trends. Again, 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.

ACKNOWLEDGEMENTS

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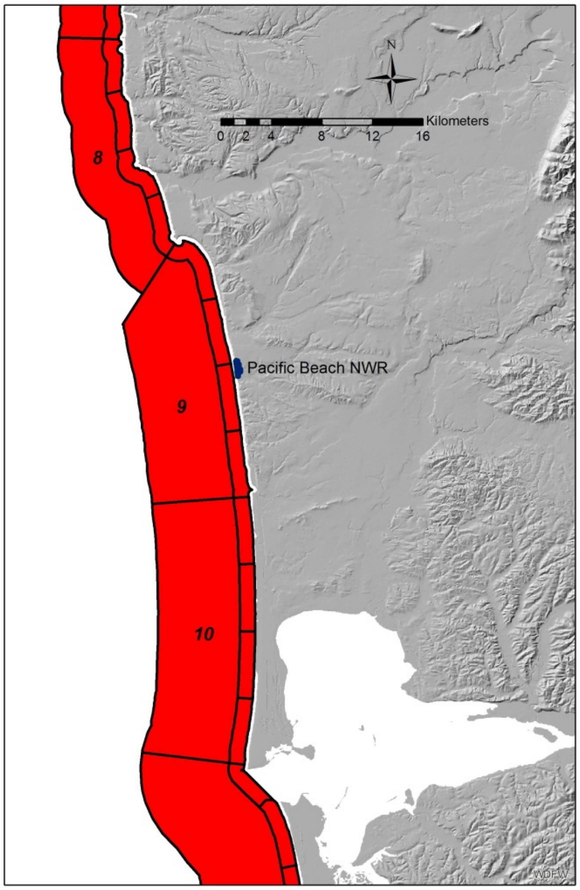
Figure 1. Stratum and primary sampling unit locations along the Washington coast (A) and in Puget Sound (B). Strata are defined in the figure Key and PSUs are numbered on the map.



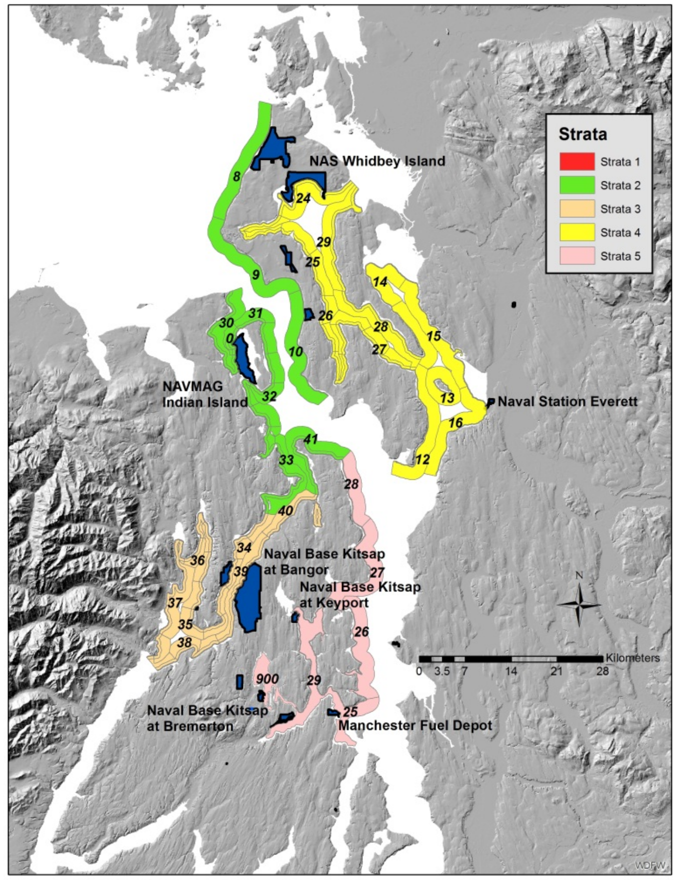


Figure 2. Density of marbled murrelets (± 95% CI) in the entire Puget Sound study area (strata 2-5 combined) and by individual strata. Geographic location of each stratum is provided in Figure 1. Note that Pacific Beach is located on the outer Coast of Washington.

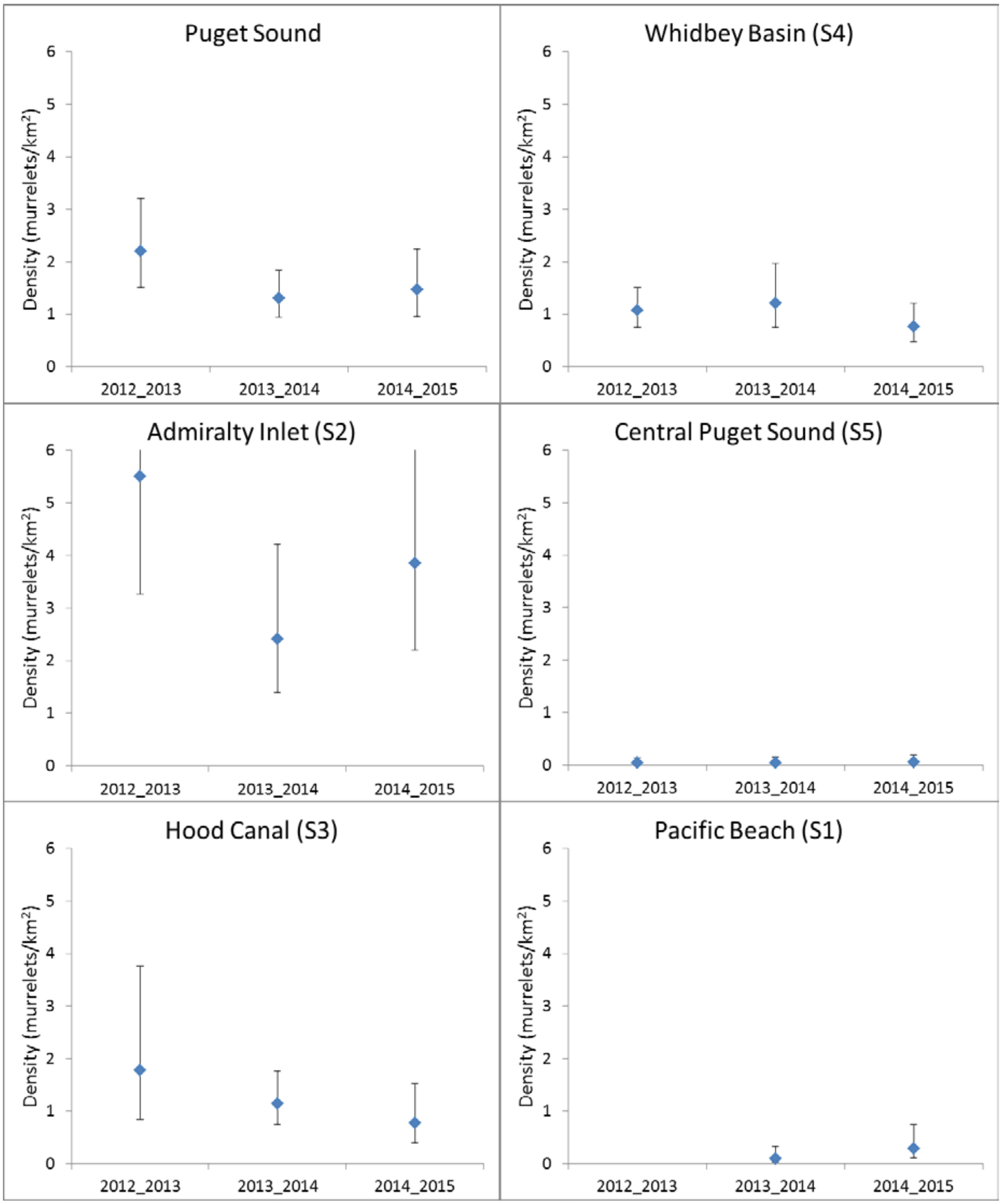


Table 1. Dates of Primary sampling unit (PSU) surveys by sampling season: Early fall = mid-Sept – Oct, Fall = Nov-mid-Dec, Winter Jan-mid-Feb, Spring = March – mid-Apr. Primary sampling units adjacent to Naval facilities are in bold. Geographic locations of each PSU can be determined by first identifying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

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

Table 2. Estimates of marbled murrelet density (birds/km²) and population size by sampling season (and all seasons combined = global model) for five Puget Sound Strata and all strata combined. 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 - Fall through Spring (mid-Sept – mid-Apr)													
14/15	**All but 1**	**1.469**		**21.36**	**1,384**	**904**	**2,117**	**942.0**	**0.009**	**0.001**	**1.882**	**0.032**	**211**
14/15	1	0.285	0.113	39.51	**113**	43	294	394.9					
14/15	2	3.856	1.083	28.09	**990**	566	1,733	256.7					
14/15	3	0.778	0.263	33.76	**126**	65	247	162.5					
14/15	4	0.763	0.181	23.67	**263**	165	421	345.1					
14/15	5	0.056	0.037	66.28	**10**	3	35	177.6					
Early Fall (mid-Sept – Oct)													
2014	**All but 1**	**0.688**		**25.68**	**648**	**385**	**1,092**	**942.0**	**0.01**	**0.001**	**1.84**	**0.10**	**211**
2014	1	0.397	0.224	56.27	**157**	19	1,312	394.9					
2014	2	1.315	0.431	32.81	**338**	163	700	256.7					
2014	3	0.135	0.093	69.19	**22**	5	100	162.5					
2014	4	0.852	0.329	38.64	**294**	130	665	345.1					
2014	5	0.0			**0**			177.6					
Fall (Nov –mid-Dec)													
2014	**All but 1**	**2.084**		**38.87**	**1,964**	**815**	**4,732**	**942.0**	**0.01**	**0.001**	**1.74**	**0.04**	**211**
2014	2	4.366	2.933	67.17	**1,121**	266	4,718	256.7					
2014	3	1.519	0.626	41.24	**247**	95	643	162.5					
2014	4	1.638	0.460	28.07	**565**	309	1,035	345.1					
2014	5	0.172	0.139	80.67	**31**	5	188	177.6					
Winter (Jan – mid-Feb)													
2015	**All but 1**	**1.728**		**35.43**	**1,628**	**740**	**3,577**	**942.0**	**0.01**	**0.001**	**1.97**	**0.09**	**211**
2015	2	5.152	2.189	42.48	**1,323**	512	3,420	256.7					
2015	3	0.346	0.288	83.40	**56**	10	330	162.5					
2015	4	0.721	0.280	38.79	**249**	109	568	345.1					
2015	5	0.0			**0**			177.6					

Spring (Mar – mid-Apr)													
2015	**All but 1**	**1.835**		**36.73**	**1,729**	**762**	**3,920**	**942.0**	**0.01**	**0.001**	**1.999**	**0.07**	**211**
2015	1	0.265	0.171	64.49	**105**	9	1,245	394.9					
2015	2	5.901	2.451	41.54	**1,515**	597	3,848	256.7					
2015	3	1.348	0.798	59.22	**219**	58	830	162.5					
2015	4	0.028	0.028	100.09	**10**	1	61	345.1					
2015	5	0.052	0.053	101.14	**9**	1	80	177.6					

Table 3. September – April marbled murrelet encounter rate (# birds detected/km transect length sampled) by primary sampling unit. Sampling seasons: Early fall = mid-Sept – Oct, Fall = Nov-mid-Dec, Winter Jan-mid-Feb, Spring = March – 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	Spring	Average
1	**8**	0.094			0.048	0.071
	9	0.067			0.099	0.083
	10	0.000			0.000	0.000
2	**8**	0.396	0.144	0.029	0.000	0.142
	9	0.341	0.255	0.029	0.542	0.292
	10	0.000	0.115	0.488	1.215	0.454
	30	0.400	5.168	1.975	3.841	2.846
	31	0.000	0.623	3.109	1.358	1.272
	32	0.483	0.706	2.893	0.063	1.036
	33	0.120	0.118	0.000	2.322	0.640
	41	0.030	0.231	0.261	1.017	0.385
3	**34**	0.000	0.172	0.000	0.984	0.289
	35	0.147	0.652	0.030	0.059	0.222
	36	0.000	0.122	0.000	0.000	0.031
	37	0.029	0.030	0.000	0.000	0.015
	38	0.000	0.000	0.000	0.000	0.000
	39	0.000	0.903	0.282	0.261	0.362
	40	0.000	0.274	0.000	0.302	0.144
4	12	0.087	0.285	0.029	0.000	0.100
	13	0.087	0.058	0.000	0.000	0.036
	14	0.039	0.000	0.000	0.000	0.010
	15	0.000	0.334	0.077	0.000	0.103
	16	0.000	0.732	0.204	0.000	0.234
	24	0.359	0.374	0.380	0.000	0.278
	25	0.093	0.911	0.324	0.000	0.332
	26	0.061	0.000	0.000	0.000	0.015
	27	0.000	0.057	0.000	0.000	0.014
	28	0.486	0.201	0.000	0.000	0.172
	29	0.499	0.543	0.273	0.056	0.343
5	**25**	0.000	0.000	0.000	0.000	0.000
	26	0.000	0.025	0.000	0.000	0.006
	27	0.000	0.000	0.000	0.056	0.014
	28	0.000	0.283	0.000	0.082	0.091
	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)	Sea State: 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.