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Fall through spring 2014/2015 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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Washington Department of
Fish and Wildlife
Wildlife Program
Science Division

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Fall through spring 2014/2015 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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Wildlife Science Division

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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.

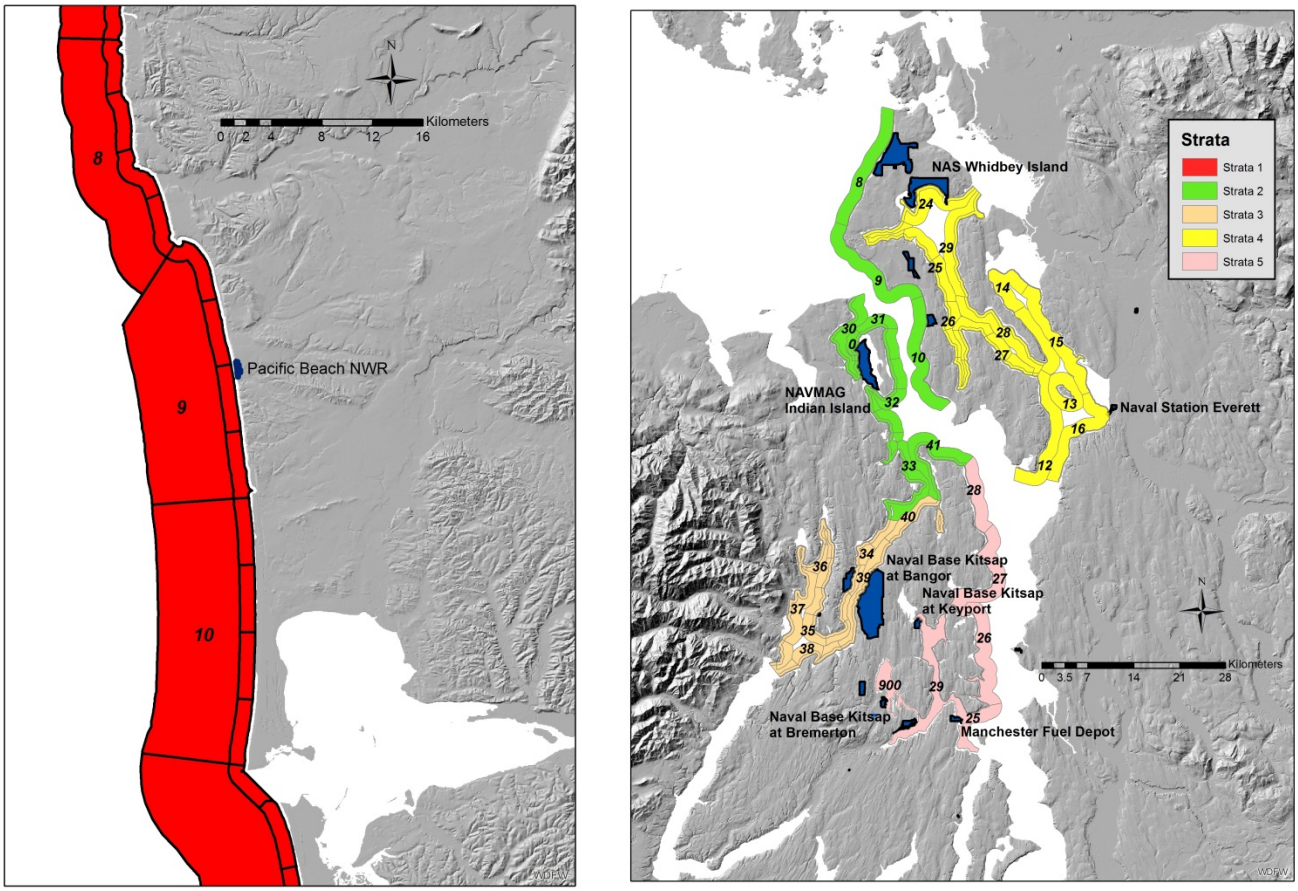

Figure 2. Density of marbled murrelets (± 95% CI) in the entire Puget Sound study area (strata 2-5 combined) and by individual strata. Geographic location of each stratum is provided in Figure 1. Note that Pacific Beach is located on the outer Coast of Washington.

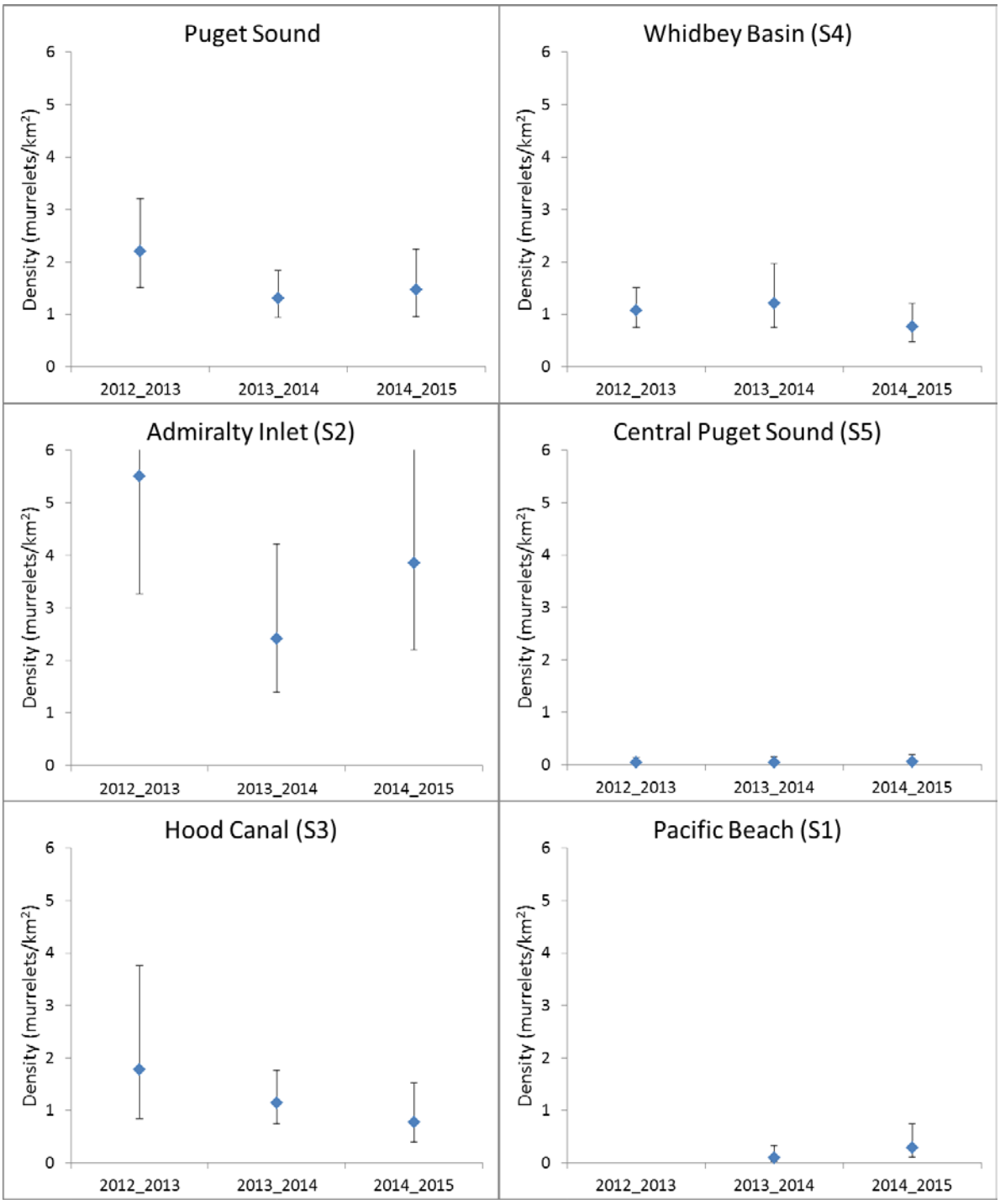

Table 1. Dates of Primary sampling unit (PSU) surveys by sampling season: Early fall = mid-Sept – Oct, Fall = Nov-mid-Dec, Winter Jan-mid-Feb, Spring = March – mid-Apr. Primary sampling units adjacent to Naval facilities are in bold. Geographic locations of each PSU can be determined by first identifying 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/km^2) 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)	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.

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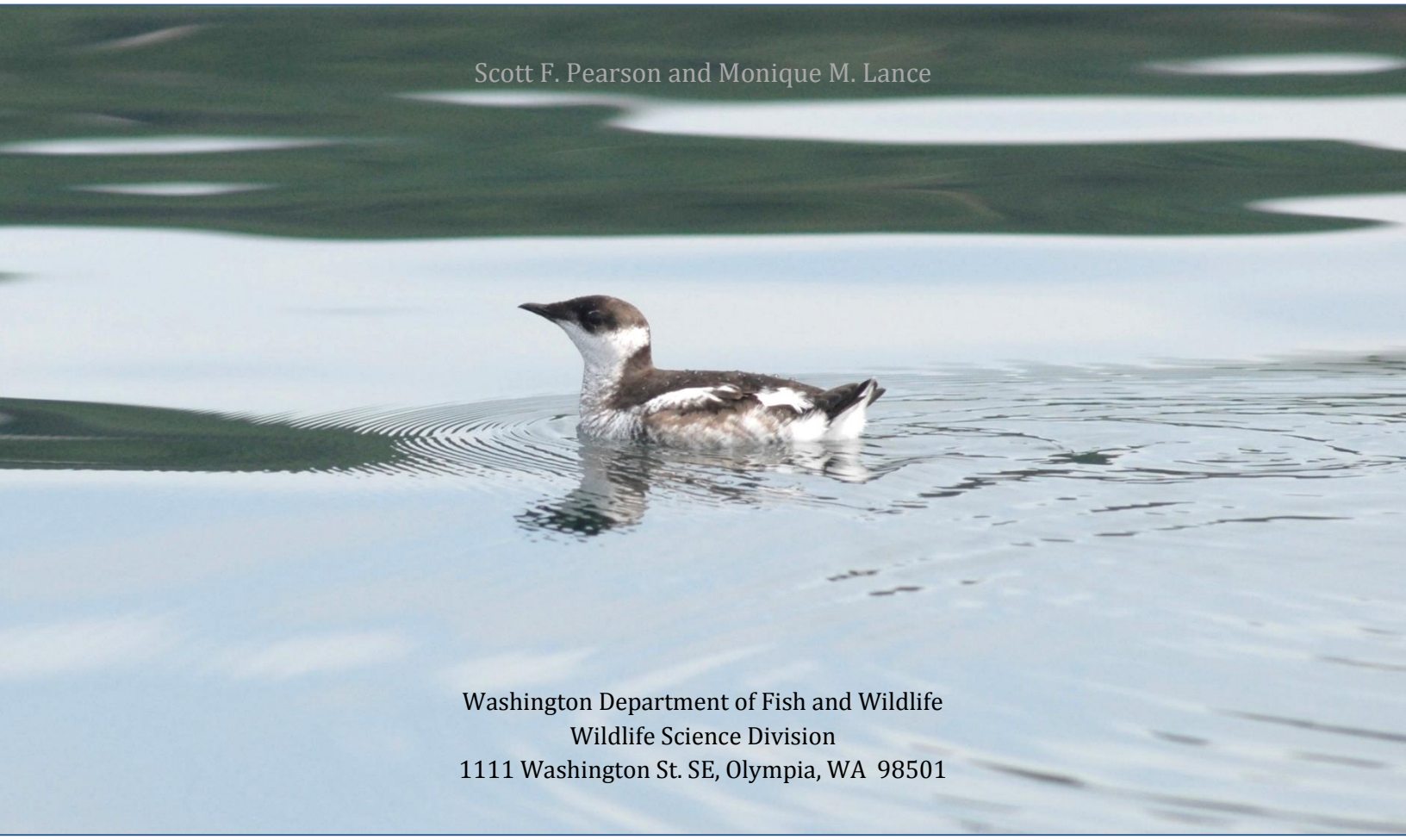

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This report is being prepared for the U.S. Navy under the NAVFAC NW Cooperative Agreement N44255-14-2-0007 and N44255-12-2-0009.

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.

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.

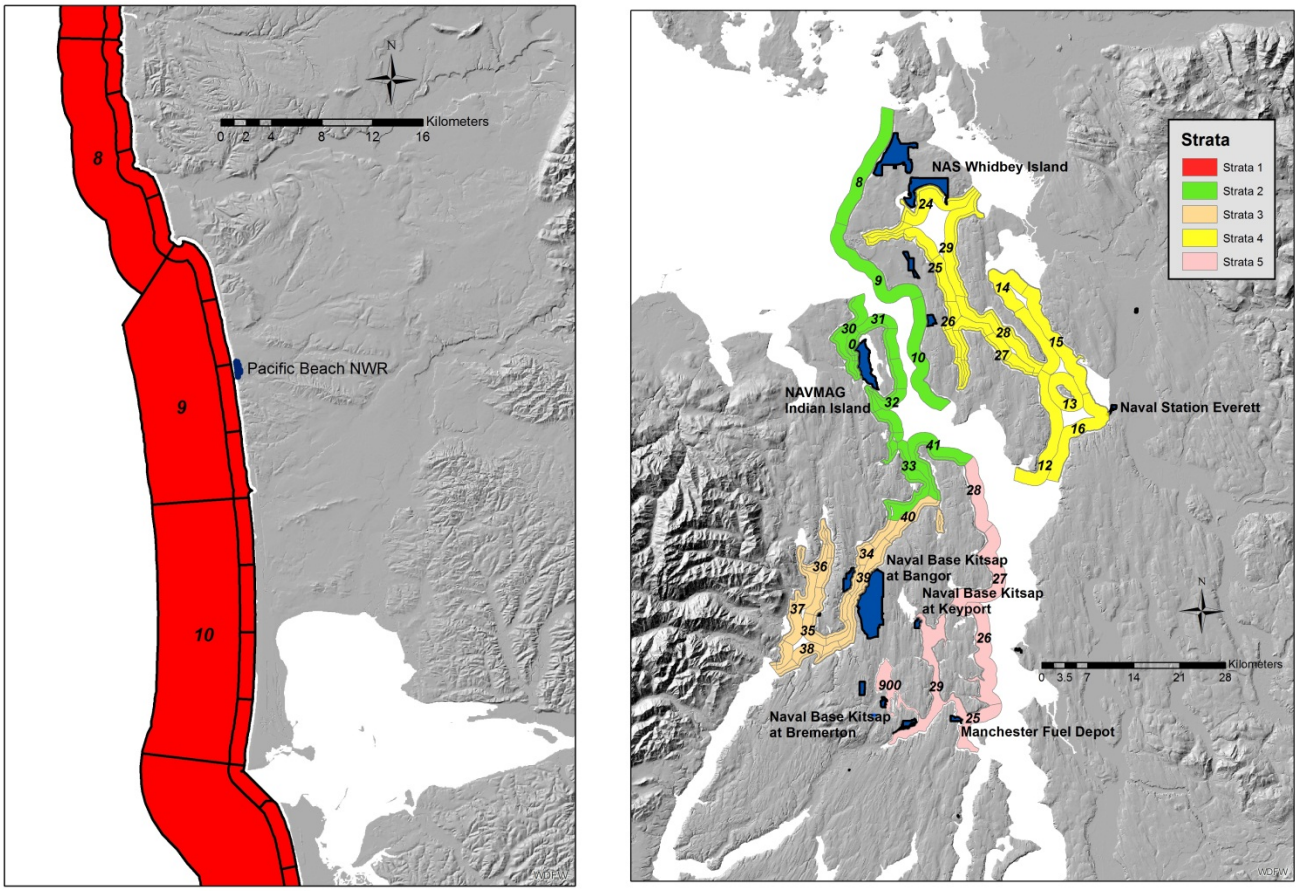


Figure 2. Density of marbled murrelets (± 95% CI) in the entire Puget Sound study area (Strata 2-5 combined) and by individual strata. Geographic location of each stratum is provided in Figure 1. Note that Pacific Beach (Stratum 1) is located on the outer Coast of Washington.

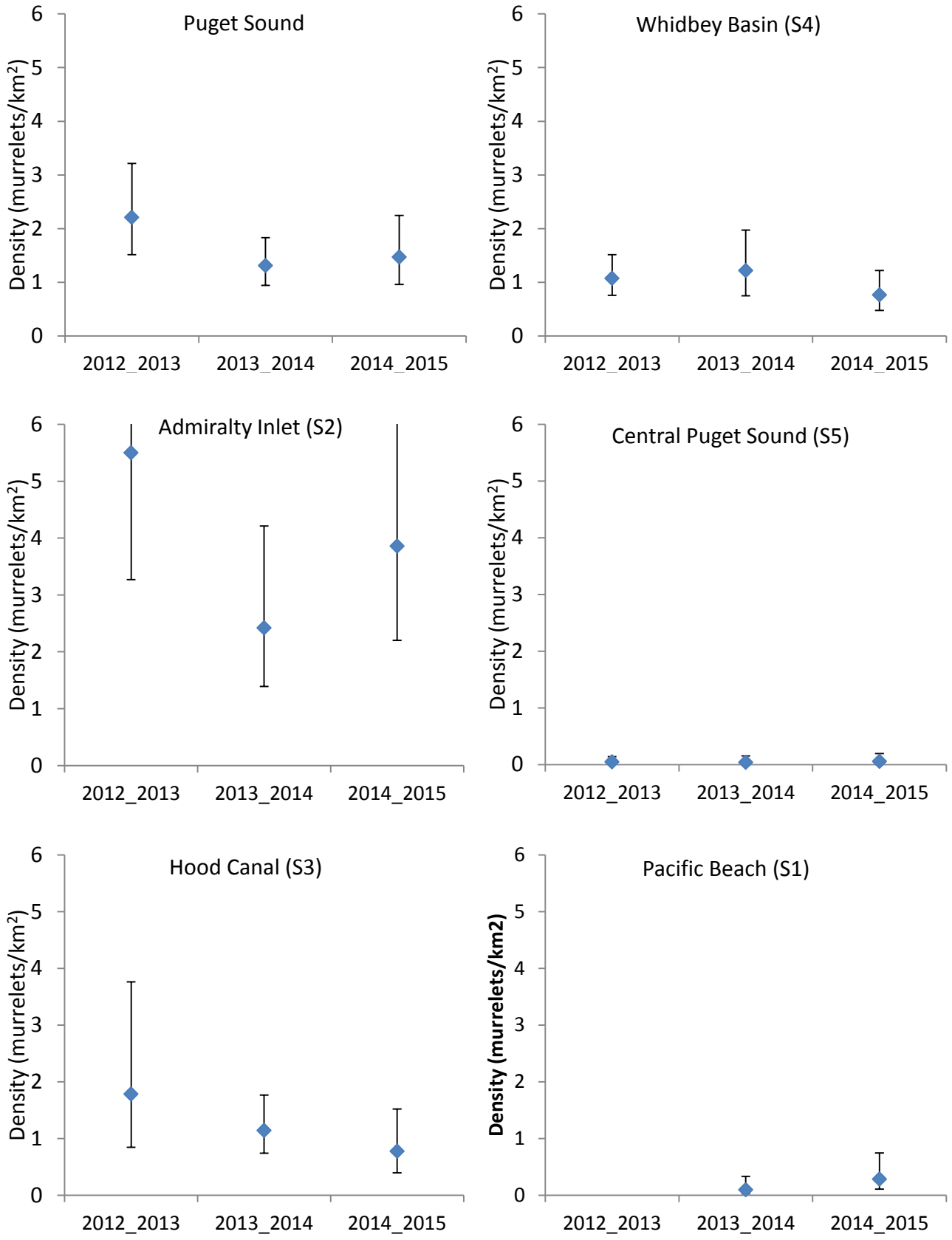


Table 1. Dates of Primary sampling unit (PSU) surveys by sampling season: Early fall = mid-Sept – Oct, Fall = Nov-mid-Dec, Winter = Jan-mid-Feb, Spring = late-Feb – mid-Apr. Primary sampling units adjacent to Naval facilities are in bold and highlighted. Geographic locations of each PSU can be determined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

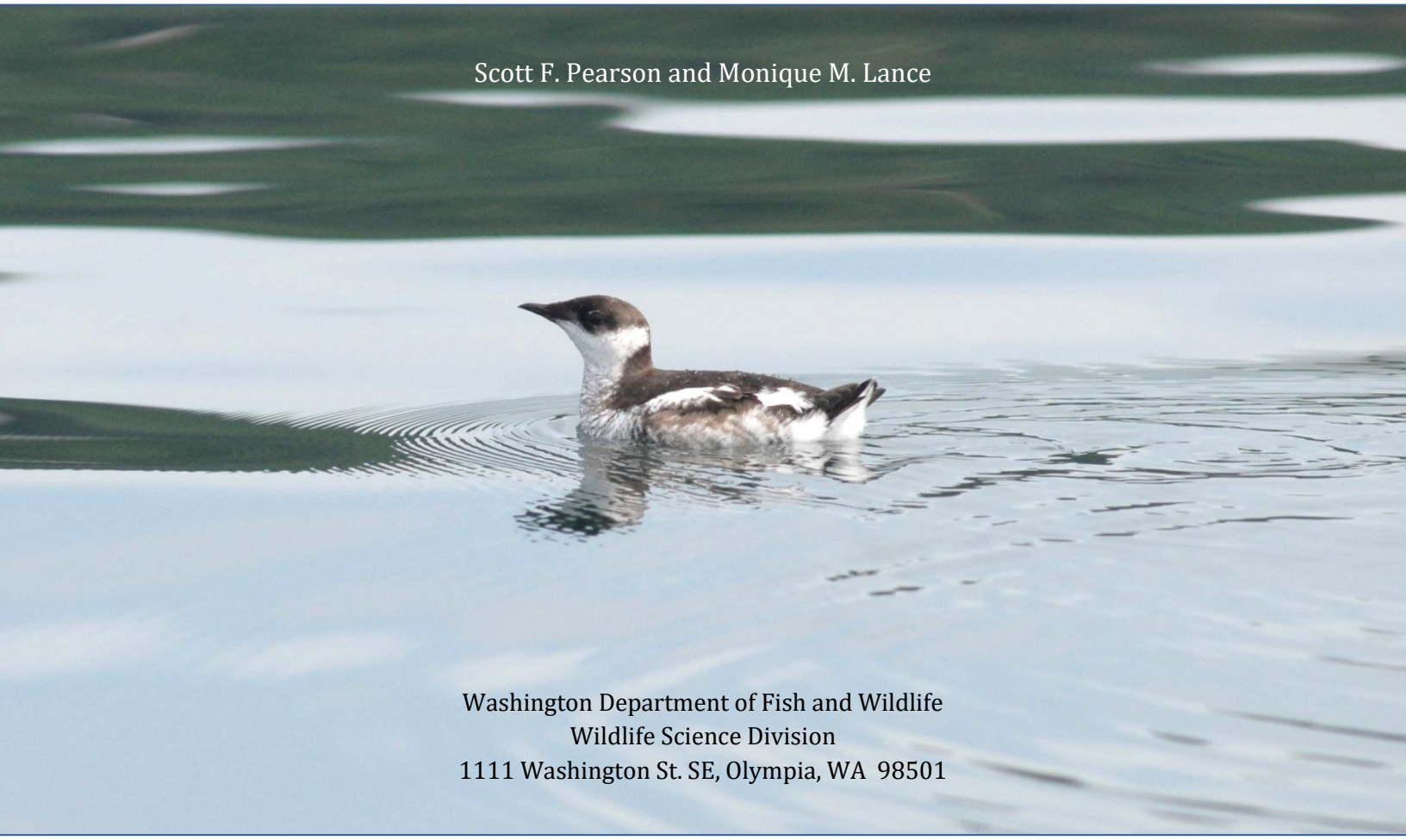
Appendix I

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.

Fall through spring 2016/2017 Marbled Murrelet At-Sea Densities In Five Strata Associated with U.S. Navy Facilities in Washington State: Annual Research Progress Report

Scott F. Pearson and Monique M. Lance



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This report is being prepared for the U.S. Navy under the NAVFAC NW Cooperative Agreement N44255-16-2-0004

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) Naval Air Station Whidbey Island (Crescent Harbor); (2) Manchester Fuel Department; (3) Naval Base Kitsap at Bangor, Zelatched Point, Toandos, Keyport and Bremerton; (4) Naval Magazine Indian Island; and (5) 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 four strata using nearshore and offshore transects placed in 32 primary sampling units (PSUs) (Figure 1). Note that the coastal unit (Pacific Beach) was not surveyed this year.

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 Stratum #1 (n = 3 PSUs) but this unit was not surveyed this year.

Using this information, Puget Sound strata definitions are as follows: Stratum #2 Admiralty Inlet (Figure 2: west side of Whidbey Island Naval Air Station, Admiralty Inlet and Naval Magazine Indian Island) = 8 PSUs; Stratum #3 North Hood Canal (Figure 2: Bangor, Zelatched Point, Toandos, and Dabob Bay) = 7 PSUs; Stratum #4 Whidbey Basin (Figure 2: Crescent Harbor by Naval Air Station Whidbey Island and Naval Station Everett) = 11 PSUs; Stratum#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 = 22 September -27 October 2016
Fall = 31 October – 7 December 2016
Winter = 11 January – 21 February 2017
Early Spring = 27 February – 2 April 2017

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 new 26-foot Lee Shore (Fog Lark) 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 derive 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 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

During the Fall-Spring 2016/2017 season, we surveyed 4,336 km of transects and detected 723 murrelets during those surveys. Because these were replicated surveys, these are not all unique birds. All 32 PSUs were sampled during each of the four "seasons" as planned.

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. As in past years, Murrelet densities were very low in Stratum 5, generally intermediate in Strata 3 and 4, and highest in Stratum 2.

Using overall densities across all four replicates and all four strata, we estimated there were 662 (95% CI = 421-1,039) birds in all Puget Sound strata (Sept – April) which is the lowest estimate among all five years. 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, and it appears that murrelets are declining within all Strata combined. At the stratum level,

there appears to be a declining trend in the Hood Canal and Admiralty Inlet strata. 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 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

This survey effort, design and analysis were funded by the U.S. Navy. We thank Cindi Kunz for her excellent help with all stages of this work. A special thank you to Chad Norris our boat captain and biologists Corey VanStratt, Kathy Gunther, Erin Stehr, and Drew Schwitters. We thank Brian Cosentino for GIS support. We thank C. Kunz for reviewing an earlier draft of this report.

Figure 1. Stratum and primary sampling unit locations in Puget Sound. Strata are defined in the figure Key and PSUs are numbered on the map. Note that Stratum #1 was not sampled this year and is not pictured below.

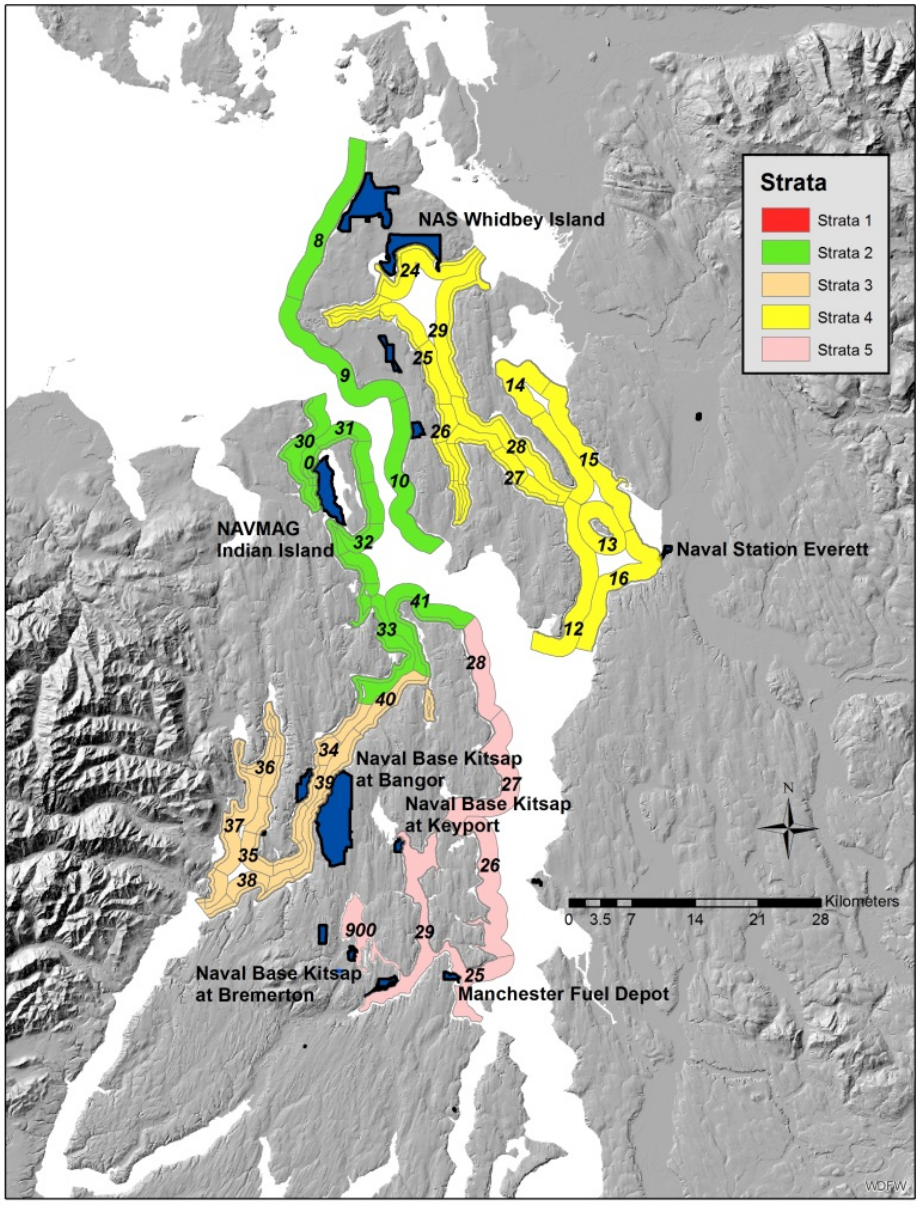


Figure 2. Density of marbled murrelets (± 95% CI) in the entire Puget Sound study area (Strata 2-5 combined) and by individual strata. Geographic location of each stratum is provided in Figure 1.

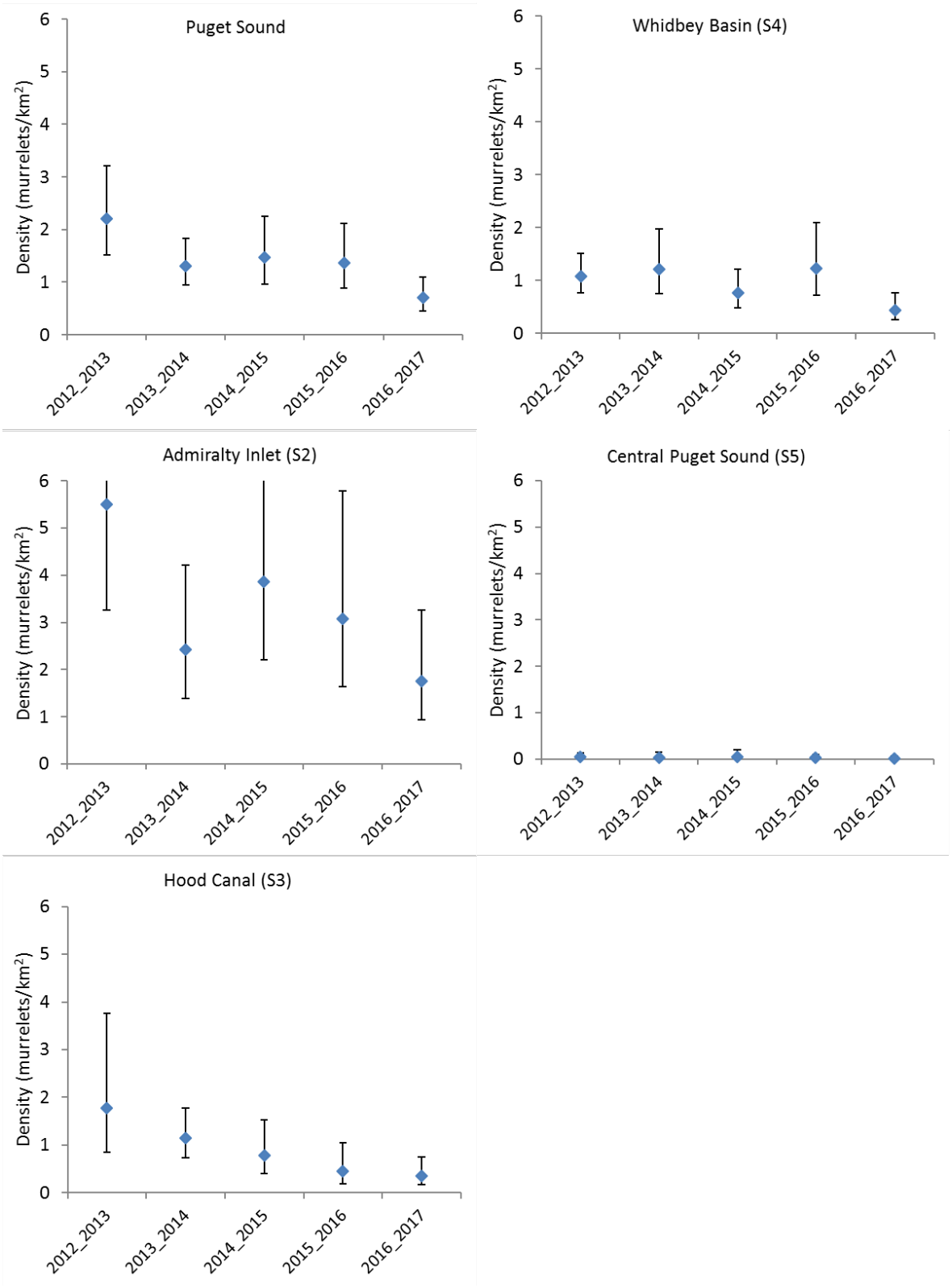


Table 1. Dates of Primary sampling unit (PSU) surveys by sampling season: Early fall = late-Sept – Oct; Fall = late Oct - mid-Dec; Winter = Jan - mid-Feb; Spring = late-Feb – early-Apr. Primary sampling units adjacent to Naval facilities are in bold and highlighted. Geographic locations of each PSU can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

Stratum	PSU	Early Fall	Fall	Winter	Early Spring
2	**8**	12-Oct	9-Nov	12-Jan	9-Mar
	9	12-Oct	9-Nov	12-Jan	9-Mar
	10	18-Oct	30-Nov	8-Feb	31-Mar
	30	17-Oct	31-Oct	7-Feb	27-Mar
	31	17-Oct	31-Oct	7-Feb	27-Mar
	32	24-Oct	15-Nov	21-Feb	27-Mar
	33	24-Oct	8-Nov	21-Feb	31-Mar
	41	18-Oct	30-Nov	8-Feb	31-Mar
3	34	26-Oct	15-Nov	1-Feb	22-Mar
	35	22-Sep	21-Nov	30-Jan	8-Mar
	36	22-Sep	21-Nov	30-Jan	6-Mar
	37	22-Sep	21-Nov	30-Jan	8-Mar
	38	28-Sep	10-Nov	11-Jan	8-Mar
	39	28-Sep	10-Nov	11-Jan	22-Mar
	40	26-Oct	8-Nov	1-Feb	7-Mar
4	12	29-Sep	6-Dec	17-Feb	2-Apr
	13	29-Sep	7-Dec	31-Jan	1-Mar
	14	19-Oct	7-Dec	31-Jan	2-Apr
	15	30-Sep	4-Nov	25-Jan	27-Feb
	16	30-Sep	4-Nov	25-Jan	27-Feb
	24	26-Sep	14-Nov	13-Jan	28-Feb
	25	27-Oct	1-Dec	13-Feb	15-Mar
	26	19-Oct	16-Nov	13-Feb	28-Feb
	27	4-Nov	1-Dec	13-Feb	30-Mar
	28	19-Oct	16-Nov	17-Feb	1-Mar
	29	26-Sep	14-Nov	13-Jan	30-Mar
5	**25**	4-Oct	22-Nov	23-Jan	14-Mar
	26	4-Oct	22-Nov	23-Jan	23-Mar
	27	5-Oct	28-Nov	14-Feb	23-Mar
	28	5-Oct	28-Nov	14-Feb	23-Mar
	29	3-Oct	3-Nov	17-Jan	13-Mar
	900	3-Oct	3-Nov	17-Jan	13-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, and all Puget Sound strata combined. Strata are defined in Figure 1. Birds were only detected in Stratum 5 in the Spring sampling period.

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 (late-Sept – early-Apr)													
2016/2017	**All**	**0.702**		**22.54**	**662**	**421**	**1039**	**942**	**0.009**	**0.000**	**1.83**	**0.028**	**211**
2016/2017	2	1.754	0.546	31.15	**450**	243	836	256.7					
2016/2017	3	0.349	0.133	38.30	**57**	27	121	162.5					
2016/2017	4	0.443	0.124	27.91	**153**	88	265	345.1					
2016/2017	5	0.010	0.010	101.69	**2**	0	10	177.6					
Early Fall (late Sept– late-Oct)													
2016	**All**	**0.309**		**33.44**	**291**	**144**	**588**	**942.0**	**0.008**	**0.001**	**1.70**	**0.12**	**211**
2016	2	0.743		41.41	**191**	77	476	256.7					
2016	3	0.417	0.326	78.17	**68**	13	361	162.5					
2016	4	0.094	0.043	45.64	**33**	13	85	345.1					
2016	5	0.000			**0**			177.6					
Fall (late October –mid-Dec)													
2016	**All**	**1.560**		**36.16**	**1470**	**669**	**3228**	**942.0**	**0.01**	**0.001**	**1.89**	**0.05**	**211**
2016	2	3.976	1.999	50.28	**1021**	344	3031	256.7					
2016	3	0.764	0.420	0.42	**124**	34	460	162.5					
2016	4	0.941	0.291	30.90	**325**	167	632	345.1					
2016	5	0.000			**0**			177.6					
Winter (Jan – mid-Feb)													
2017	**All**	**0.492**		**34.10**	**463**	**233**	**922**	**942.0**	**0.01**	**0.001**	**1.75**	**0.04**	**211**
2017	2	0.859	0.401	46.63	**221**	79	614	256.7					
2017	3	0.214	0.125	58.59	**35**	9	128	162.5					
2017	4	0.603	0.322	53.48	**208**	69	628	345.1					
2017	5	0.000			**0**			177.6					
Early Spring (Late Feb – early-Apr)													
2017	**All**	**0.392**		**35.65**	**369**	**167**	**812**	**942.0**	**0.01**	**0.001**	**1.75**	**0.05**	**211**
2017	2	1.250		39.70	**321**	132	783	256.7					
2017	3	0.035		101.28	**6**	1	44	162.5					
2017	4	0.103		78.79	**35**	8	166	345.1					
2017	5	0.038		108.20	**7**	4	1	64					

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 = late-Sept – late-Oct; Fall = late-Oct -mid-Dec; Winter = Jan-mid - Feb; Early Spring = late-Feb – early-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
2	**8**	0.029	0.167	0.000	0.000	0.049
	9	0.057	0.458	0.534	0.113	0.290
	10	0.000	0.000	0.000	1.086	0.271
	30	0.344	2.174	0.810	0.028	0.839
	31	0.300	5.696	0.104	0.270	1.592
	32	0.585	0.770	0.126	0.098	0.395
	33	0.123	0.116	0.087	0.610	0.234
	41	0.058	0.282	0.117	0.467	0.231
3	34	0.234	0.000	0.000	0.000	0.059
	35	0.000	0.121	0.088	0.000	0.052
	36	0.000	0.000	0.000	0.000	0.000
	37	0.000	0.116	0.000	0.000	0.029
	38	0.000	0.572	0.156	0.000	0.182
	39	0.000	0.057	0.057	0.000	0.029
	40	0.528	0.067	0.000	0.065	0.165
4	12	0.000	0.058	0.172	0.000	0.057
	13	0.000	0.050	0.000	0.000	0.013
	14	0.000	0.000	0.000	0.000	0.000
	15	0.108	0.000	0.026	0.000	0.034
	16	0.000	0.262	0.963	0.000	0.306
	24	0.062	0.533	0.278	0.063	0.234
	25	0.023	0.097	0.070	0.138	0.082
	26	0.000	0.000	0.000	0.000	0.000
	27	0.057	0.118	0.059	0.000	0.058
	28	0.000	0.317	0.116	0.000	0.108
	29	0.055	0.489	0.110	0.000	0.163
5	**25**	0.000	0.000	0.000	0.000	0.000
	26	0.000	0.000	0.000	0.000	0.000
	27	0.000	0.000	0.000	0.000	0.000
	28	0.000	0.000	0.000	0.081	0.020
	29	0.000	0.000	0.000	0.000	0.000
	900	0.000	0.000	0.000	0.000	0.000

Appendix I

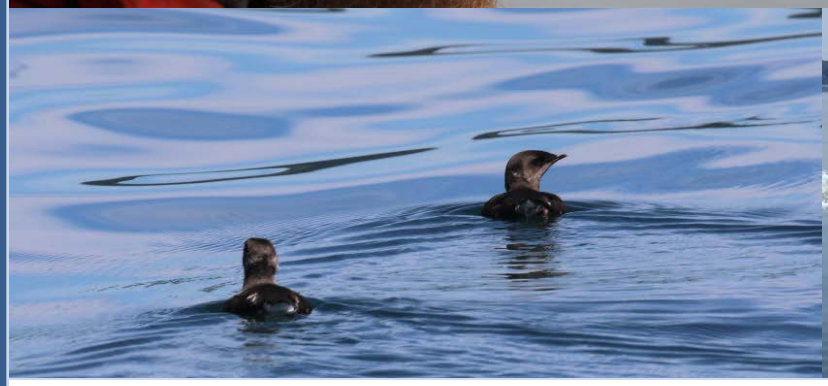
BEAUFORT WIND SCALE WITH CORRESPONDING SEA STATE CODES					
Beaufort Number	Wind Velocity (Knots)	Wind Description	Sea State Description	Sea State	
				Term and Height of Waves (Feet)	Condition Number
0	Less than1	Calm	Sea surface smooth and mirror-like	Calm, glassy 0	0
1	1-3	Light Air	Scaly ripples, 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

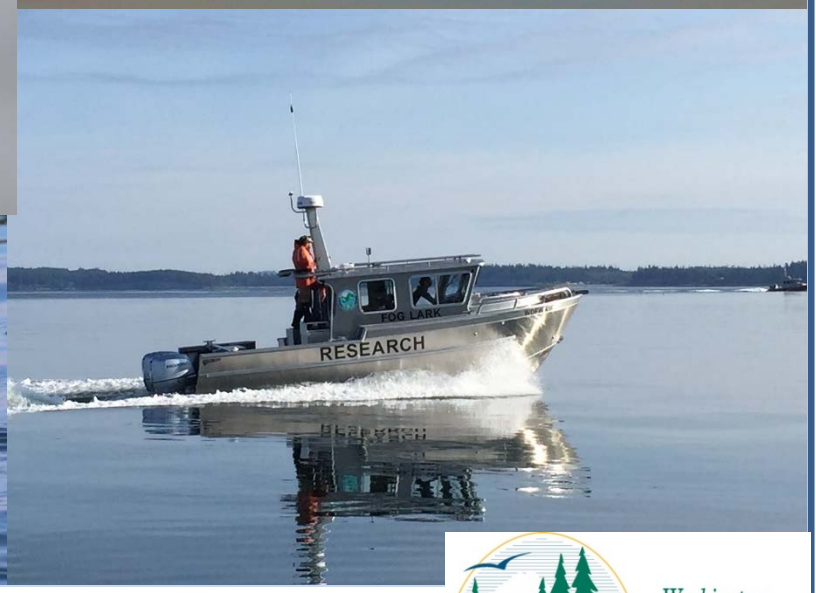
Figure 8-1. Beaufort wind scale.

Fall through spring 2017/2018 Marbled Murrelet At-Sea Densities

In Five Strata Associated with U.S. Navy Facilities in Washington State:

Annual Research Progress Report 2018





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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 Stratum #1 (n = 3 PSUs) but this unit was not surveyed this year.

Using this information, Puget Sound strata definitions are as follows: Stratum #2 Admiralty Inlet (Figure 2: west side of Whidbey Island Naval Air Station, Admiralty Inlet and Naval Magazine Indian Island) = 8 PSUs; Stratum #3 North Hood Canal (Figure 2: Bangor, Zelatched Point, Toandos, and Dabob Bay) = 7 PSUs; Stratum #4 Whidbey Basin (Figure 2: Crescent Harbor by Naval Air Station Whidbey Island and Naval Station Everett) = 11 PSUs; Stratum #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 = 18 September - 25 October 2017
Fall = 31 October – 15 December 2017
Winter = 2 January – 21 February 2018
Early Spring = 27 February – 30 April 2018

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 team 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). 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 team used a new 26-foot Lee Shore (R/V Fog Lark) 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 derive 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 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

During the Fall-Spring 2017/2018 season, we surveyed 4,263 km of transects and detected 1,033 murrelets during those surveys. Because these were replicated surveys, these are not all unique birds. All 32 PSUs were sampled during three of the four "seasons" as planned. PSUs 27 and 28 were not surveyed during the winter season due to unsuitable survey conditions. Because few to no birds are detected in this Stratum (see Figure Figure 2, "Central Puget Sound" graph) and its PSUs, the lack of sampling effort will have almost no influence on our Sound-wide estimate.

When examining density estimates by stratum (Table 2), higher densities were consistently found in Stratum 2 except for the fall when similar densities were estimated for Strata 2 and 3. The densities for these Strata increased in the Fall sampling period suggesting an influx of birds into this region. As in past years, Murrelet densities were very low to no birds in Stratum 5, generally intermediate in Strata 3 and 4, and highest in Stratum 2.

Using overall densities across all four replicates and all four strata, we estimated there were 868 murrelets (95% CI = 579-1,302), which is similar to last year's low estimate of 662 (95% CI = 421-1,039) birds in all Puget Sound strata (Sept – April). Last year's estimate is the lowest estimate among all six years (see Figure 2: "Puget Sound" graph). 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. Across all six years, there is some variability among years, but it appears that murrelets are declining for all Strata combined. Eventhough this six-year trend appears to be a declining one for all strata combined, this year's population estimate was slightly higher than last year's low estimate for all strata combined. At the stratum level, there appears to be a declining trend in the Admiralty Inlet strata and, until this last year, in Hood Canal also (this year's Hood Canal estimate is higher than the previous few years). 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 suggests 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 PSU 30) with high densities in the area spanning from Point Wilson southward through Port Townsend Bay and around Marrowstone Island. Again, some PSUs have no to few detections. Looking across strata, some PSUs have high densities in a single season (e.g., Stratum 2, PSU 31 in early spring; Stratum 3, PSU 38 in fall; and Stratum 4, PSU 24 in winter). This variation in density over time and space suggests movement of birds tracking food resources throughout the larger region. Interestingly, there is a strong influx of birds into Stratum 2 in the early spring as birds enter the pre-breeding season and perhaps indicates birds moving closer to suitable nesting habitat on the Olympic Penninsula. As in previous years, Stratum 5 had very few to no birds, which supports the poor availability of forage fish in south to central Puget Sound (Rice et al. 2012, Greene et al. 2015).

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

This survey effort, design and analysis were funded by the U.S. Navy. We thank Cindi Kunz for her excellent help with all stages of this work. A special thank you to Chad Norris our boat captain and biologists Corey VanStratt, Drew Schwitters, Kelly Beach, Elisa Weiss, and Caanan Cowles. We thank Brian Cosentino for GIS support. We thank C. Kunz for reviewing an earlier draft of this report.

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Figure 1. Stratum and primary sampling unit locations in Puget Sound. Strata are defined in the figure Key and PSUs are numbered on the map. Note that Stratum #1 was not sampled this year and is not pictured below.

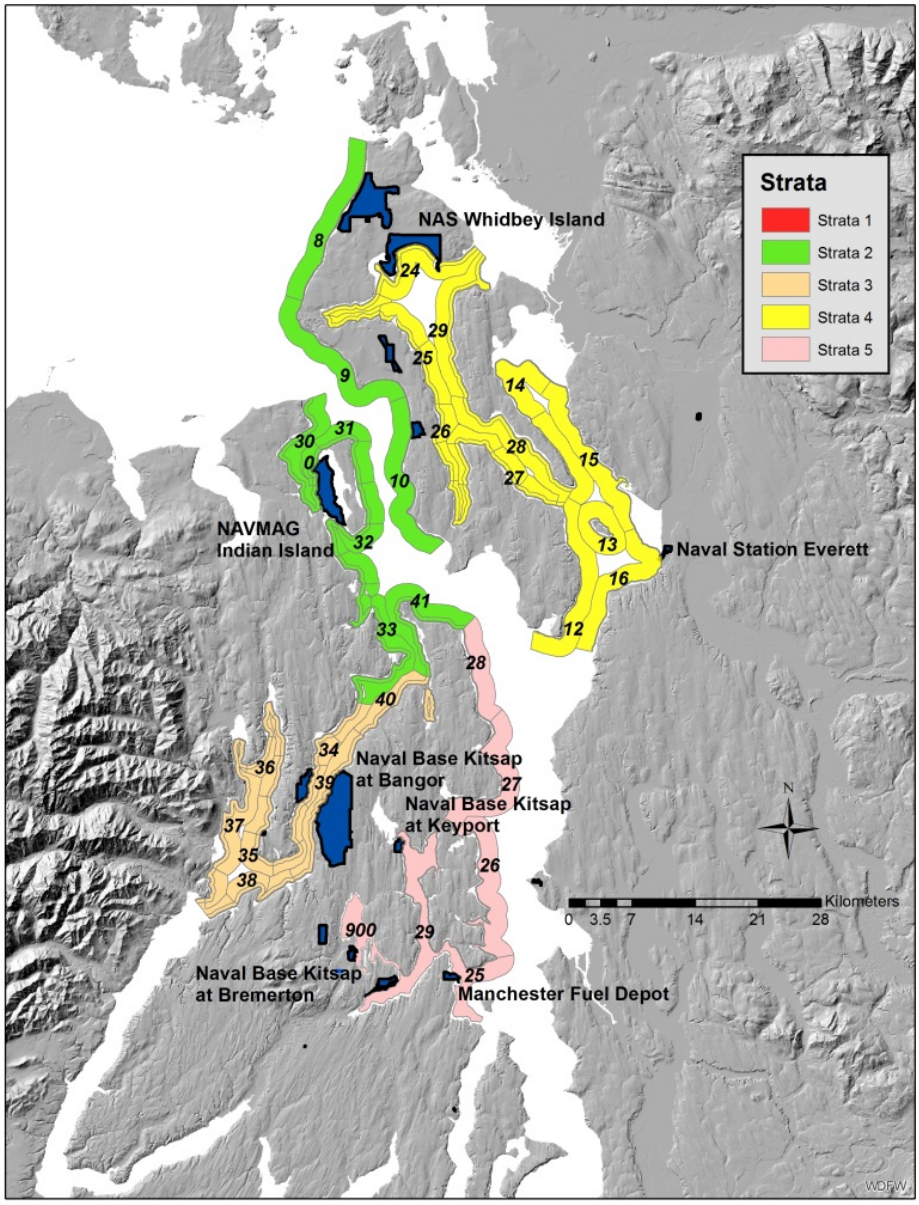


Figure 2. Density of marbled murrelets (± 95% CI) in the entire Puget Sound study area (Strata 2-5 combined) and by individual strata. Geographic location of each stratum is provided in Figure 1.

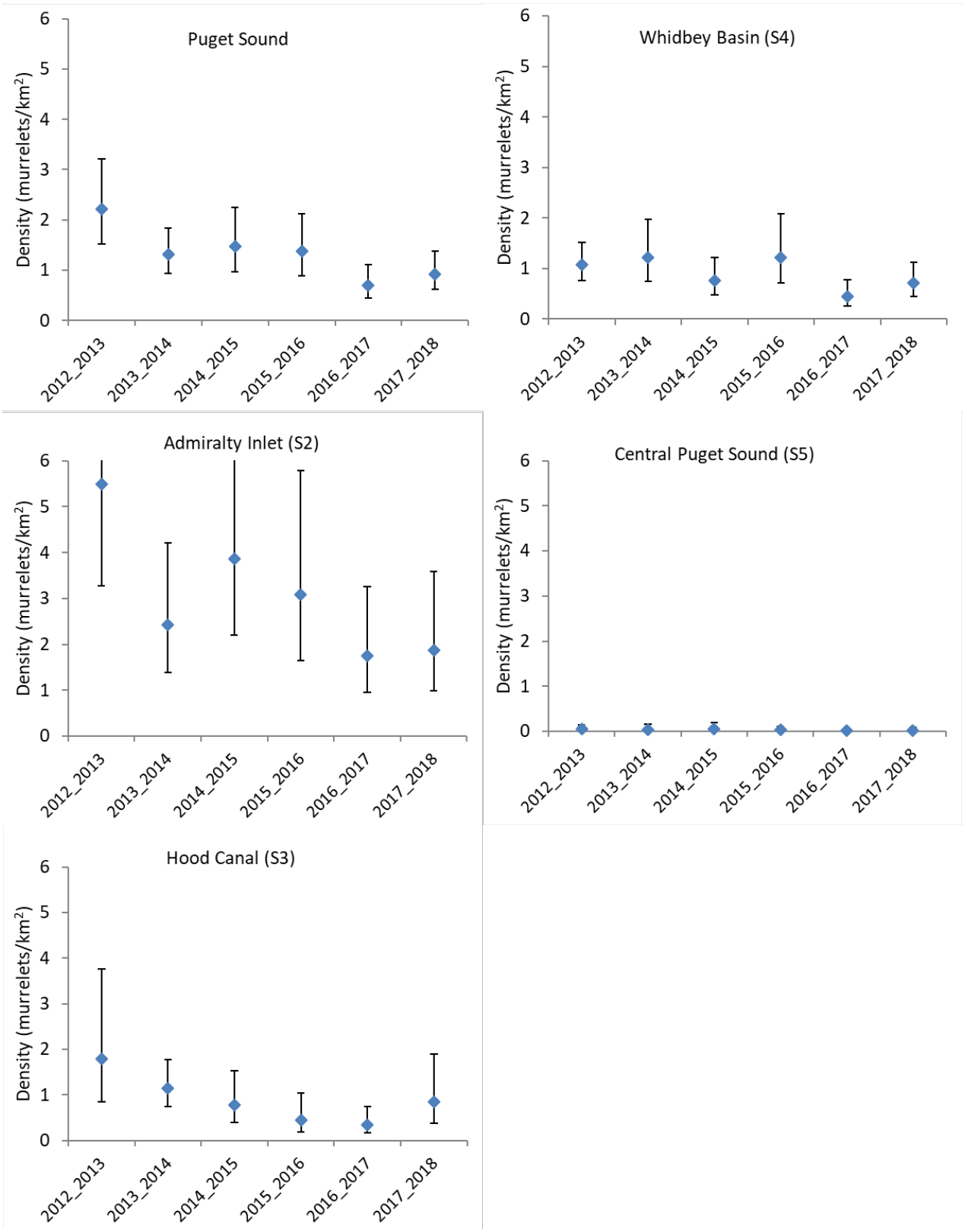


Table 1. Dates of Primary sampling unit (PSU) surveys by sampling season: Early fall = mid-Sept – Oct; Fall = late Oct - mid-Dec; Winter = Jan - Feb; Spring = late-Feb – late-Apr. Primary sampling units adjacent to Naval facilities are in bold and highlighted. Geographic locations of each PSU can be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

Stratum	PSU	Early Fall	Fall	Winter	Early Spring
2	**8**	20-Sep	13-Dec	2-Jan	15-Mar
	9	4-Oct	13-Dec	31-Jan	19-Mar
	10	4-Oct	13-Dec	31-Jan	30-Mar
	30	20-Sep	29-Nov	2-Jan	19-Mar
	31	3-Oct	2-Dec	3-Jan	19-Mar
	32	3-Oct	2-Dec	3-Jan	2-Apr
	33	13-Oct	7-Nov	13-Feb	2-Apr
	41	13-Oct	7-Nov	12-Jan	30-Mar
3	34	10-Oct	6-Nov	13-Feb	27-Mar
	35	5-Oct	12-Nov	9-Jan	20-Mar
	36	5-Oct	12-Nov	9-Jan	20-Mar
	37	5-Oct	12-Nov	9-Jan	20-Mar
	38	2-Oct	6-Nov	22-Jan	27-Mar
	39	2-Oct	6-Nov	22-Jan	26-Mar
	40	10-Oct	7-Nov	12-Jan	26-Mar
4	12	23-Oct	14-Dec	5-Feb	9-Apr
	13	20-Oct	14-Dec	21-Feb	30-Apr
	14	23-Oct	15-Dec	21-Feb	30-Apr
	15	12-Oct	9-Nov	1-Feb	21-Mar
	16	12-Oct	9-Nov	1-Feb	21-Mar
	24	16-Oct	17-Nov	26-Jan	21-Mar
	25	16-Oct	17-Nov	30-Jan	3-Apr
	26	24-Oct	16-Nov	26-Jan	27-Feb
	27	24-Oct	15-Dec	5-Feb	19-Apr
	28	24-Oct	15-Dec	30-Jan	19-Apr
	29	16-Oct	17-Nov	26-Jan	3-Apr
5	**25**	19-Sep	1-Nov	8-Jan	12-Mar
	26	25-Oct	1-Nov	8-Jan	29-Mar
	27	21-Sep	31-Oct	no data	29-Mar
	28	21-Sep	31-Oct	no data	29-Mar
	29	18-Sep	2-Nov	17-Jan	28-Mar
	900	19-Sep	2-Nov	17-Jan	28-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, and all Puget Sound strata combined. Strata are defined in Figure 1. Birds were only detected in Stratum 5 in the Fall and Early Spring sampling 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 – late-Apr)													
2017/2018	**All**	**0.922**		**20.30**	**868**	**579**	**1302**	**942.0**	**0.008**	**0.000**	**1.907**	**0.031**	**211**
2017/2018	2	1.877	0.611	32.54	**482**	252	920	256.7					
2017/2018	3	0.847	0.346	40.88	**138**	61	308	162.5					
2017/2018	4	0.710	0.163	22.89	**245**	155	386	345.1					
2017/2018	5	0.022	0.015	70.49	**4**	1	14	177.6					
Early Fall (mid-Sept– late-Oct)													
2017	**All**	**0.482**		**43.27**	**454**	**185**	**1119**	**942.0**	**0.010**	**0.001**	**1.915**	**0.133**	**211**
2017	2	1.196	0.133	57.49	**307**	90	1051	256.7					
2017	3	0.176	0.010	56.78	**29**	8	100	162.5					
2017	4	0.344	0.204	59.16	**119**	36	394	345.1					
2017	5	0			**0**			64					
Fall (late October –mid-Dec)													
2017	**All**	**1.488**		**19.03**	**1401**	**828**	**2371**	**942.0**	0.010	0.001	**1.970**	**0.063**	**211**
2017	2	2.389	0.812	33.99	**613**	284	1320	256.7					
2017	3	2.496	1.504	60.25	**406**	105	1570	162.5					
2017	4	1.083	0.396	36.53	**374**	171	816	345.1					
2017	5	0.050	0.050	100.88	**9**	1	76	177.6					
Winter (Jan – Feb)													
2018	**All**	**0.468**		**40.79**	**890**	**379**	**2091**	**942.0**	**0.007**	**0.001**	**1.833**	**0.057**	**211**
2018	2	1.336	1.222	91.5	**343**	55	2158	256.7					
2018	3	0.915	0.451	49.27	**235**	76	726	162.5					
2018	4	0.904	0.385	42.61	**312**	126	769	345.1					
2018	5	0			**0**			177.6					
Early Spring (Late Feb – late-Apr)													
2018	**All**	**1.078**		**47.29**	**1016**	**359**	**2869**	**942.0**	**0.004**	**0.001**	**1.888**	**0.036**	**211**
2018	2	2.973	1.822	61.28	**763**	202	2888	256.7					
2018	3	0.172	0.068	39.59	**28**	11	71	162.5					
2018	4	0.629	0.302	47.92	**217**	79	596	345.1					
2018	5	0.039	0.042	107.2	**7**	1	66	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 – late-Oct; Fall = late-Oct – late-Dec; Winter = early-Jan - Feb; Early Spring = late-Feb – late-Apr. 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
2	**8**	0.173	0.317	0.140	0.000	0.158
	9	0.029	1.037	0.000	0.285	0.338
	10	0.000	0.346	0.057	0.000	0.101
	30	0.119	1.312	3.038	3.773	2.061
	31	0.664	0.069	0.000	1.873	0.651
	32	1.279	0.351	0.000	0.293	0.481
	33	0.058	0.068	0.000	0.059	0.046
	41	0.000	0.231	0.000	0.224	0.114
3	34	0.058	0.487	0.799	0.115	0.365
	35	0.000	0.119	1.021	0.116	0.314
	36	0.000	0.000	0.000	0.000	0.000
	37	0.000	0.000	0.202	0.000	0.051
	38	0.030	2.264	0.058	0.059	0.603
	39	0.000	0.597	0.000	0.000	0.149
	40	0.128	0.000	0.075	0.071	0.068
4	12	0.000	0.289	0.057	0.115	0.115
	13	0.000	0.103	0.000	0.086	0.047
	14	0.000	0.000	0.000	0.000	0.000
	15	0.028	0.667	0.000	0.083	0.195
	16	0.000	0.059	0.175	0.145	0.095
	24	0.533	0.852	1.289	0.689	0.841
	25	0.091	0.413	0.576	0.000	0.270
	26	0.000	0.000	0.000	0.000	0.000
	27	0.000	0.000	0.263	0.420	0.171
	28	0.029	0.000	0.058	0.058	0.036
	29	0.111	0.248	0.380	0.000	0.185
5	**25**	0.000	0.000	0.000	0.000	0.000
	26	0.000	0.000	0.000	0.000	0.000
	27	0.000	0.000	Not surveyed	0.000	0.000
	28	0.000	0.040	Not surveyed	0.084	0.041
	29	0.000	0.016	0.000	0.000	0.004
	900	0.000	0.149	0.000	0.000	0.037

Appendix I

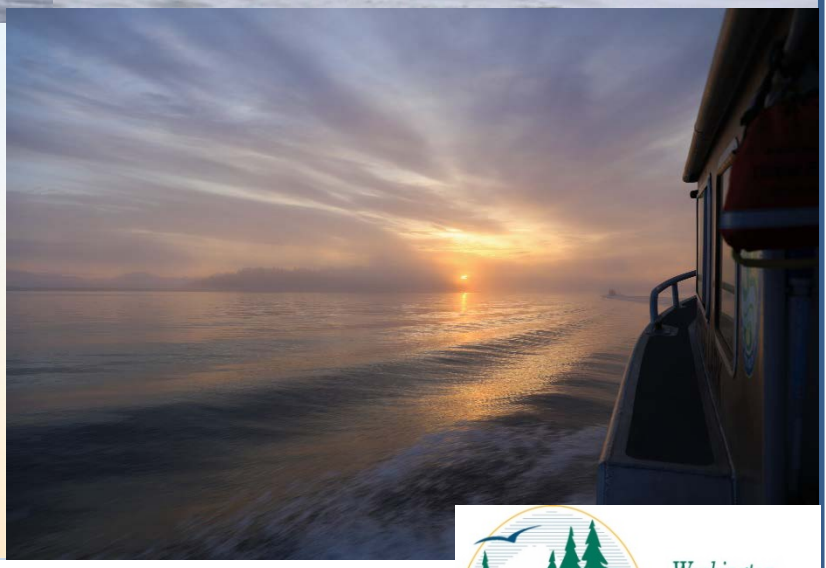
BEAUFORT WIND SCALE WITH CORRESPONDING SEA STATE CODES					
Beaufort Number	Wind Velocity (Knots)	Wind Description	Sea State Description	Sea State	
				Term and Height of Waves (Feet)	Condition Number
0	Less than1	Calm	Sea surface smooth and mirror-like	Calm, glassy 0	0
1	1-3	Light Air	Scaly ripples, 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.

Fall through spring 2018/2019 Marbled Murrelet At-Sea Densities

In Five Strata Associated with U.S. Navy Facilities in Washington State:

Annual Research Progress Report 2019



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INTRODUCTION

The 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) Naval Air Station Whidbey Island (Crescent Harbor); (2) Manchester Fuel Department; (3) Naval Base Kitsap at Bangor, Zelatched Point, Toandos, Keyport and Bremerton; (4) Naval Magazine Indian Island; and (5) Naval Station Everett. These surveys have been conducted annually since September of 2012 and, now that we have seven years of survey effort, we can begin to examine murrelet trends during the non-breeding season. 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 four strata using nearshore and offshore transects placed in 32 primary sampling units (PSUs) (Figure 1). Note that the coastal unit (Pacific Beach) was not surveyed this year.

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 Stratum #1 (n = 3 PSUs) but this unit was not surveyed this year.

Using this information, Puget Sound strata are depicted in Figure 2 and defined as follows:

- Stratum #2 Admiralty Inlet (8 PSUs): west side of Whidbey Island Naval Air Station, Admiralty Inlet and Naval Magazine Indian Island;
- Stratum #3 North Hood Canal (7 PSUs): Bangor, Zelatched Point, Toandos, and Dabob Bay;
- Stratum #4 Whidbey Basin (11 PSUs): Crescent Harbor by Naval Air Station Whidbey Island and Naval Station Everett;
- Stratum #5 Central Puget Sound (6 PSUs): Bremerton, Manchester, Keyport

Average PSU area depicted in Figure 1 was 38.2 km^2 and covered about 20 km of shoreline. 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:

Fall = 10 September - 20 November 2018
Late Fall/Early Winter = 14 November 2018 – 11 January 2019
Winter = 11 January – 28 February 2019
Early Spring = 5 March – 16 April 2019

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 team 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). 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 team used the 26-foot Lee Shore (Research Vesssel Fog Lark) 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 derive 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 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

During the Fall-Spring 2018/2019 season, we surveyed 4,251 km of transects and detected 644 murrelets during those surveys. Because these were replicated surveys, these are not all unique individuals. All 32 PSUs were sampled during each of the four "seasons" as planned.

When examining density estimates by stratum (Table 2), higher densities were consistently found in Stratum 2 except for the Fall (Nov - mid-Jan) when densities were higher in Stratum 3. Highest densities in the Puget Sound region occurred in the Winter (mid-Jan - Feb). As in past years, Murrelet densities were very low to no birds in Stratum 5, generally intermediate in Strata 3 and 4, and highest in Stratum 2.

Using overall densities across all four replicates and all four strata, we estimated there 631murrelets (95% CI = 415-960) in all Puget Sound strata (Sept – April), which is the lowest density estimate in the seven years of sampling (see Figure 2: "Puget Sound" graph). There was some seasonal variation in our all Puget Sound estimate with relatively few birds detected during the early fall and spring sampling periods (Table 2).

In Figure 2, we compare densities among strata and years. Across all seven years, there is some variability among years, but it appears that murrelets are declining for all Strata combined. At the stratum level, there appears to be a declining trend in the Admiralty Inlet strata and in Hood Canal. 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 suggests 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 had relatively high murrelet encounter rates (Table 3, especially PSU 30) with high densities in the area spanning from Point Wilson southward through Port Townsend Bay. The west side of Hood Canal near Bangor had relatively high murrelet encounter rates and so did the PSUs near Everett and Crescent Harbor. Unusual for this seven year data set was the high detection of birds in the fall along the east side of Bainbridge Island. Again, some PSUs have no to few detections and some, like the Bainbridge Island PSU, have high densities in a single season. This variation in density over time and space suggests movement of birds tracking food resources throughout the larger region. As in previous years, Stratum 5 had very few to no birds, which supports the poor availability of forage fish in south to central Puget Sound (Rice et al. 2012, Greene et al. 2015).

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. 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.

With six years of data (2013-2019) from the Puget Sound region, we can now start to think about assesing population trends. When examining a potential linear trend over this time period, there is strong evidence for a 16.42% annual decline in the Puget Sound wintering population ($p = 0.032$, $r^2 = 0.66$; Figure 2 - *Puget Sound*). During this period of Navy funded survey work, the density of murrelets has decreased from a high of 2.21 birds per km^2 (95% CI = 1.52-3.21%) during the winter of 2012/2013 to the current low of 0.67 birds per km^2 (95% CI = 0.44-1.02%) during the winter of 2018/2019 (Figure 2 - *Puget Sound*), this represents a 60% decline in the wintering murrelet population.

There are now several independent efforts indicating that the murrelet population in the U.S. portion of the Salish Sea (Puget Sound, San Juan Archipelago, and Strait of Juan de Fuca) is declining. The long-term monitoring effort Northwest Forest Plan Effectiveness Monitoring Program indicates a 4.9 percent annual decline for the 2001-2018 period (McIver et al. 2019). This

spring/ summer effort uses the identical line transect survey methodology reported here and some of the same primary sampling units. Similarly, Lorenz and Raphael (2018) found the murrelet populations in the San Juan Islands (the region of the Salish Sea with highest murrelet densities) to have declined from 11.16 to 5.76 murrelets km^2 between 1995 and 2012. Despite this consistent and ominous decline in overall murrelet density, they found that the density of juvenile murrelets and murrelet productivity ratio (juveniles:adults) did not decline over this time period (Lorenz and Raphael 2018). They concluded that the declining density of murrelets in the San Juan Islands was due to declines in adult murrelets only, not juveniles. Interestingly, the annual estimates of overall murrelet density were positively correlated with winter El Niño Southern Oscillation (ENSO) indices (Lorenz and Raphael 2018). In ENSO years, numbers increased dramatically suggesting that the Salish Sea may provide a refugia marine habitat for murrelets when prey availability along the outer Pacific Coast is poorer than usual (Lorenz and Raphael 2018).

Conclusions

- With seven years of Navy-funded survey effort during the non-breeding season, we can now describe for the first time non-breeding murrelet trends in Puget Sound.
- In addition, we are getting a better understanding of the year-to-year variability in murrelet abundance during the non-breeding season.
- Three independent survey efforts (two breeding season surveys and this non-breeding season survey) all indicate long-term and precipitous murrelet declines in Puget Sound and, more broadly, in the Salish Sea.
- Our next step is to summarize all of the Navy-funded murrelet survey results for this region and compre those results to other surveys to more formally examine how murrelet populations are changing seasonally. This work will be compiled into a manuscript for publication in the peer-reviewed literature.
- We recommend using hierarchichal distance survey models to: (1) examine both the marine and terrestrial factors responsible for murrelet declines, and (2) build maps that help us understand hotspots of murrelet abundance and how those hot (and cold) spots vary among seasons.

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Figure 1. Stratum and primary sampling unit locations in Puget Sound. Strata are defined in the figure Key and PSUs are numbered on the map. Note that Stratum #1 was not sampled this year and is not pictured below.

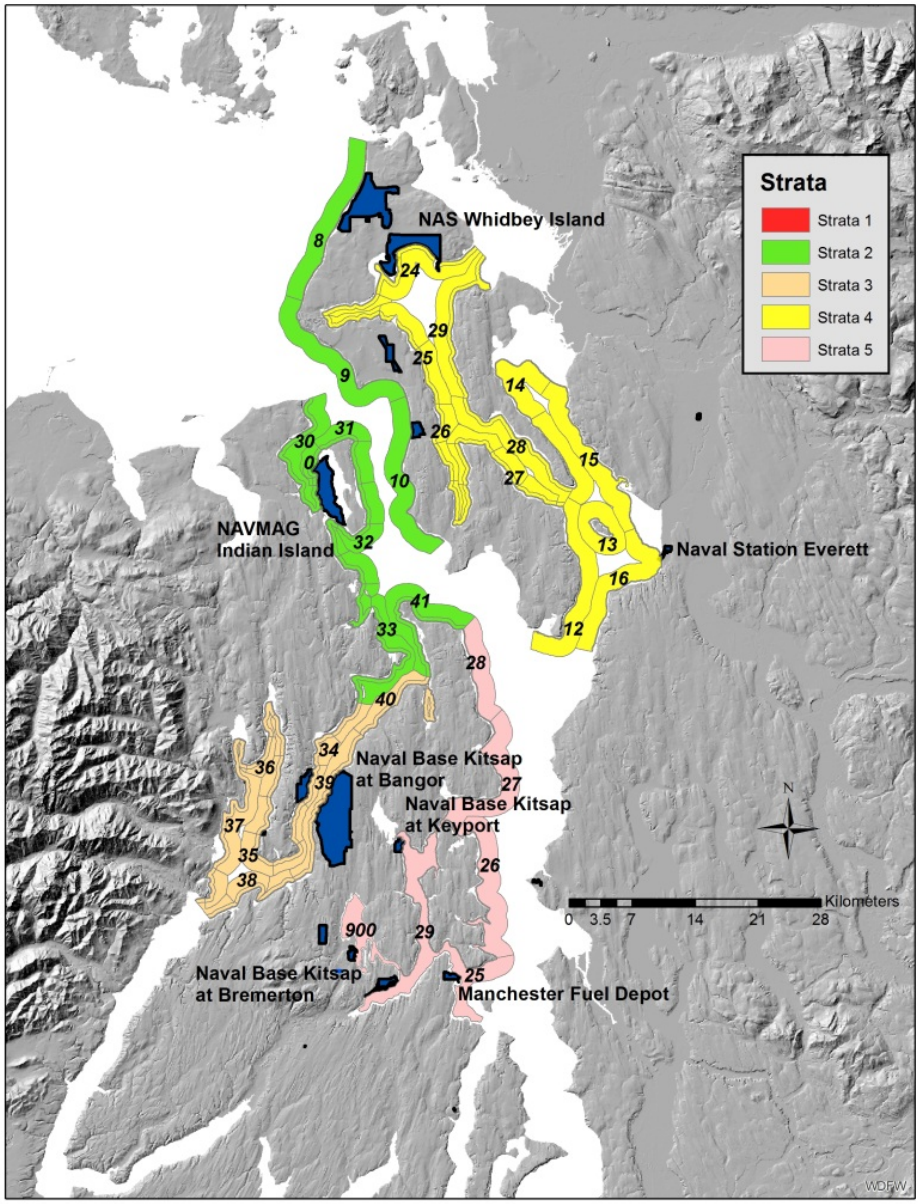


Figure 2. Density of marbled murrelets (± 95% CI) in the entire Puget Sound study area (Strata 2-5 combined) and by individual strata. Geographic location of each stratum is provided in Figure 1.

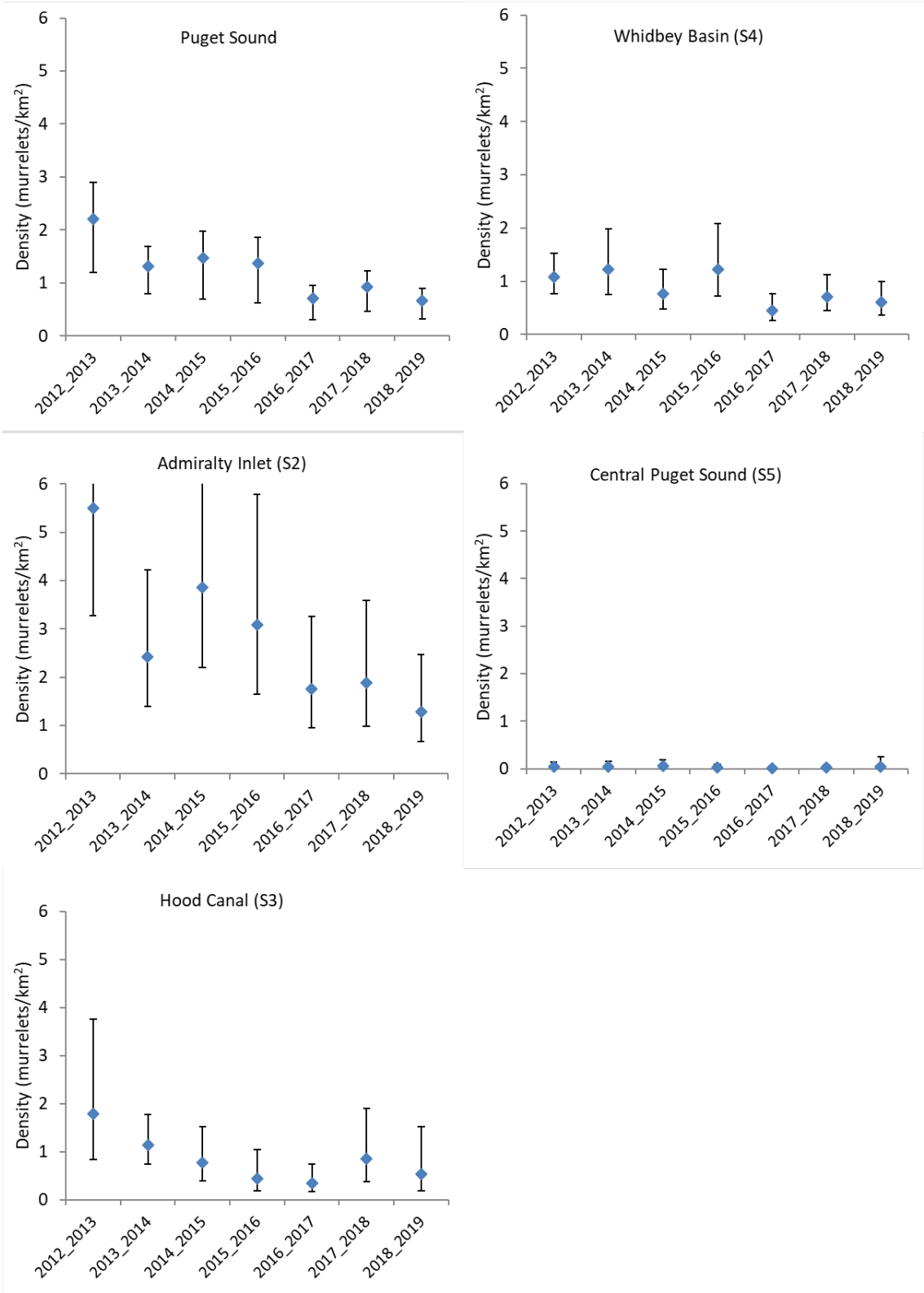


Table 1. Dates of Primary sampling unit (PSU) surveys by sampling season: Early fall = mid-Sept – Nov; Fall = Nov - mid-Jan; Winter = mid-Jan - Feb; Spring = Mar – mid-Apr. Primary sampling units adjacent to Naval facilities are in bold and highlighted. Geographic locations of each PSU can be determined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

Stratum	PSU	Early Fall	Fall	Winter	Spring
2	**8**	14-Sep	5-Dec	11-Jan	5-Mar
	9	24-Oct	5-Dec	11-Jan	29-Mar
	10	24-Oct	11-Jan	28-Feb	8-Mar
	30	10-Oct	28-Nov	14-Jan	5-Mar
	31	10-Oct	5-Dec	14-Jan	29-Mar
	32	14-Sep	8-Jan	6-Feb	13-Mar
	33	26-Oct	8-Jan	6-Feb	13-Mar
	41	24-Oct	7-Jan	19-Feb	8-Mar
3	34	11-Oct	15-Dec	24-Jan	25-Mar
	35	5-Oct	12-Dec	20-Feb	18-Mar
	36	12-Sep	30-Nov	31-Jan	18-Mar
	37	5-Oct	21-Dec	31-Jan	18-Mar
	38	12-Sep	21-Dec	24-Jan	6-Mar
	39	11-Oct	15-Dec	24-Jan	6-Mar
	40	26-Oct	30-Nov	19-Feb	25-Mar
4	12	30-Oct	6-Dec	28-Feb	19-Mar
	13	30-Oct	6-Dec	7-Feb	16-Apr
	14	5-Nov	4-Dec	30-Jan	16-Apr
	15	4-Oct	4-Dec	30-Jan	19-Mar
	16	4-Oct	4-Dec	30-Jan	19-Mar
	24	18-Oct	29-Nov	15-Jan	15-Mar
	25	1-Nov	29-Nov	16-Jan	15-Mar
	26	18-Oct	29-Nov	16-Jan	4-Apr
	27	18-Oct	10-Dec	7-Feb	8-Apr
	28	5-Nov	10-Dec	7-Feb	8-Apr
	29	1-Nov	6-Dec	15-Jan	4-Apr
5	**25**	17-Oct	19-Dec	21-Feb	28-Mar
	26	17-Oct	19-Dec	21-Feb	28-Mar
	27	20-Nov	7-Jan	27-Feb	12-Apr
	28	20-Nov	7-Jan	27-Feb	12-Apr
	29	9-Oct	14-Nov	29-Jan	14-Mar
	900	10-Sep	14-Nov	29-Jan	14-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, and all Puget Sound strata combined. Strata are defined in Figure 1. Birds were only detected in Stratum 5 in the Fall and Early Spring sampling 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 – late-Apr)													
2018/2019	**All**	**0.670**		**21.27**	**631**	**415**	**960**	**942.0**	**0.009**	**0.000**	**1.937**	**0.040**	**211**
2018/2019	2	1.286	0.423	32.93	**330**	172	634	256.7					
2018/2019	3	0.533	0.291	54.73	**87**	30	247	162.5					
2018/2019	4	0.599	0.154	25.75	**207**	124	344	345.1					
2018/2019	5	0.044	0.045	101.83	**8**	1	45	177.6					
Early Fall (mid-Sept – Nov)													
2018	**All**	**0.444**		**30.81**	**418**	**220**	**794**	**942.0**	**0.010**	**0.001**	**1.841**	**0.094**	**211**
2018	2	1.048	0.417	39.83	269	111	651	256.7					
2018	3	0.0321	0.0319	5.10	5	1	39	162.5					
2018	4	0.4178	0.1881	45.04	144	56	371	345.1					
2018	5	0			0			177.6					
Fall (Nov - mid-Jan)													
2017	**All**	**0.681**		**34.52**	**642**	**316**	**1303**	**942.0**	0.010	0.001	**1.766**	**0.055**	**211**
2017	2	0.491	0.235	47.89	**126**	43	367	256.7					
2017	3	1.366	0.981	71.81	**222**	46	1070	162.5					
2017	4	0.851	0.399	46.97	**294**	109	791	345.1					
2017	5	0			**0**			177.6					
Winter (mid-Jan - Feb)													
2018	**All**	**1.176**		**41.34**	**1108**	**449**	**2734**	**942.0**	**0.010**	**0.001**	**1.971**	**0.055**	**211**
2018	2	2.842	1.70	59.90	**730**	199	2679	256.7					
2018	3	0.342	0.186	54.38	**56**	16	191	162.5					
2018	4	0.832	0.327	39.30	**287**	124	662	345.1					
2018	5	0.198	0.213	107.5	**35**	4	333	177.6					
Spring (Mar – mid-Apr)													
2018	**All**	**0.207**		**39.63**	**195**	**86**	**442**	**942.0**	**0.006**	**0.001**	**1.889**	**0.066**	**211**
2018	2	0.506	0.267	52.79	**130**	42	400	256.7					
2018	3	0.164	0.118	72.28	**27**	6	124	162.5					
2018	4	0.111	0.050	45.40	**38**	15	97	345.1					
2018	5	0			**0**			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 – Nov; Fall = Nov - mid-Jan; Winter = mid-Jan - Feb; Spring = Mar – mid-Apr. Geographic locations of each PSU can be determined by first identifying the Stratum number and then the PSU in Figure 1.

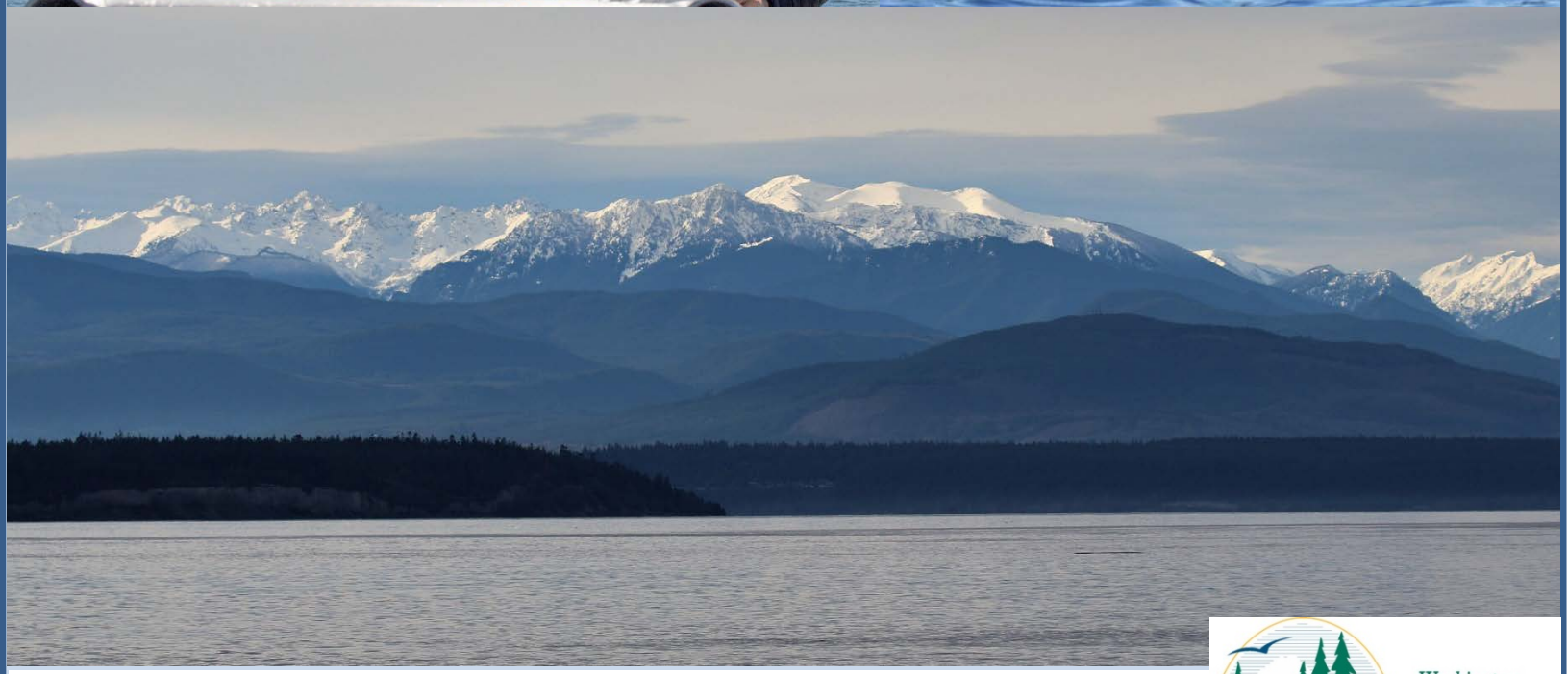
Stratum	PSU	Early Fall	Fall	Winter	Spring	Average
2	**8**	0.520	0.056	0.000	0.058	0.159
	9	0.000	0.149	0.000	0.088	0.059
	10	0.000	0.000	0.000	0.374	0.094
	30	1.020	0.116	0.029	0.000	0.291
	31	0.304	0.029	0.000	0.058	0.098
	32	0.579	0.000	0.000	0.000	0.145
	33	0.148	0.000	0.000	0.055	0.051
	41	0.000	0.029	0.261	0.000	0.073
3	34	0.029	1.084	0.469	0.000	0.396
	35	0.000	0.194	0.560	0.150	0.226
	36	0.000	0.000	0.000	0.000	0.000
	37	0.000	0.000	0.000	0.000	0.000
	38	0.000	0.000	0.000	0.000	0.000
	39	0.000	0.059	0.177	0.000	0.059
	40	0.000	0.000	0.000	0.057	0.014
4	12	0.000	0.145	0.088	0.000	0.058
	13	0.000	0.000	0.339	0.085	0.106
	14	0.000	0.571	0.055	0.000	0.157
	15	0.000	0.000	0.000	0.000	0.000
	16	0.000	0.543	1.486	0.606	0.659
	24	0.399	0.070	3.416	0.175	1.015
	25	0.143	0.214	0.362	0.000	0.180
	26	0.000	0.000	0.062	0.000	0.016
	27	0.000	0.000	0.174	0.315	0.122
	28	0.316	0.000	0.000	0.000	0.079
	29	0.471	0.000	0.000	0.000	0.118
5	**25**	0.000	0.378	0.000	0.000	0.094
	26	0.000	1.693	0.234	0.000	0.482
	27	0.000	0.174	0.059	0.000	0.058
	28	0.000	0.037	0.000	0.144	0.045
	29	0.000	0.000	0.059	0.000	0.015
	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.

Fall-Spring 2019/2020 Marbled Murrelet At-Sea Densities for Four Strata Associated with U.S. Navy Facilities in Washington State: Annual Research Progress Report 2020



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INTRODUCTION

The goal of this project is to estimate on-the-water marbled murrelet (*Brachyramphus marmoratus*) densities during the fall-spring non-breeding seasons (September - April) adjacent to the following U.S. Department of the Navy (Navy) facilities:

1. Naval Air Station (NAS) Whidbey Island (Crescent Harbor);
2. Manchester Fuel Depot;
3. Naval Base Kitsap (NBK) Bangor, including Zelatched Point, and Toandos;
4. NBK Keyport;
5. NBK Bremerton;
6. Naval Magazine (NAVMAG) Indian Island; and
7. Naval Station (NAVSTA) Everett.

These surveys have been conducted annually since September of 2012 and, now that 8 years of survey data have been collected, marbled murrelet density trends during the non-breeding season can be examined. Because the nearshore marine environment and marbled murrelet densities adjacent to any one of these Navy 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 (2014) to derive stratum-specific density estimates. This approach uses line-transect or distance sampling methods (Buckland et al. 2015) to derive murrelet density estimates for four strata using nearshore and offshore transects placed in 32 primary sampling units (PSUs) (Figure 1). Note that Stratum 1 (coastal Pacific Ocean [Pacific Beach]) was not surveyed this year.

METHODS

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 (2014). This approach was used because: (1) it addresses issues of detectability, (2) it is customized to marbled 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) the survey efforts for this project needed to be consistent with the spring/summer marbled murrelet monitoring effort funded by the U.S. Fish and Wildlife Service (USFWS), which will ultimately allow the comparison of density estimates for the same PSUs among seasons.

Sampling Design and Survey Effort

The survey design that follows is described in detail in Pearson and Lance (2014). A total of 32 PSUs were split among 4 strata (Figure 1 and Table 1). To derive strata and PSUs, we segmented the entire coastline of Puget Sound into 20-kilometer (km) PSUs. PSUs were then combined into appropriate management/ ecological/density strata (Figure 1). Using this information, Puget Sound strata are depicted in Figure 1 and defined as follows:

- Stratum 2 – Admiralty Inlet (8 PSUs): west side of NAS Whidbey Island, NAS Whidbey Island-Lake Hancock, and NAVMAG Indian Island;
- Stratum 3 – North Hood Canal (7 PSUs): NBK Bangor (including Zelatched Point, Toandos Peninsula), and Dabob Bay;
- Stratum 4 – Whidbey Basin (11 PSUs): NAS Whidbey Island-Crescent Harbor and NAVSTA Everett; and

- Stratum 5 – Central Puget Sound (6 PSUs): NBK Keyport, NBK Bremerton, and Manchester Fuel Depot.

Average PSU area depicted in Figure 1 was 38.2 square kilometers (km^2). 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 Program effort uses a similar survey design to this Navy effort. However, because the area of interest is much larger in the Effectiveness Monitoring Program and the goals differ between the 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 already established PSUs.

Three replicate surveys of all PSUs were conducted in strata 2-5 as follows:

1) Early Fall (September/October - November)
2) Late Fall (November - December)
3) Early Winter (January - February)
4) Late Winter (late February – March).

Note that most of the spring 2020 survey season was cancelled due to the COVID-19 pandemic and the Governor's and WDFW's orders to stay at home.

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

Observer Training

The team 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 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 a required 1 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 (Mack et al. 2003; Raphael et al. 2007).

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). 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 meters [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 was interfaced with a global positioning system (GPS) unit and collects real time location data. DLOG3 interfaces with a handheld GPS and geographic information system (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 team used the 26-foot Research Vesssel Fog Lark (a Lee Shore 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. 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

Transect distances, murrelet group size, and perpendicular distances for each marbled murrelet observation were used to derive density estimates (birds/km^2) by stratum using the program DISTANCE. For details about the approach to analysis, 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 derive an estimate of density (birds/km^2). For details, please see Buckland et al. (2015). The Results/Discussion section below provides marbled murrelet density estimates by stratum for each of the sampling periods (see above) and across all sampling periods (global model). The density provided can be viewed as the marbled murrelet population on the water on a given day within the area and time period defined. For population trends, we used a linear regression to the natural logarithm of annual density estimates to test for declining trends. For our analysis, the natural logarithm best fits and tests existing demographic models (USFWS 1997; McShane et al. 2004) that predict the murrelet population is declining by a constant percentage each year. We tested the null hypothesis that the slope equals zero or greater (no change or increase in murrelet numbers) against the alternative hypothesis of the slope being less than zero (i.e., a one-tailed test for decreasing murrelet densities).

RESULTS/DISCUSSION

During the fall-spring 2019/2020 sampling year, 3,344 km of transects were surveyed and 920 marbled murrelets were detected during those surveys. Because these were replicated surveys, these are not all unique individuals. All 32 PSUs were sampled during each of the three "seasons" and only 4 PSUs were surveyed in the spring season due to the COVID-19 pandemic (Table 1).

When comparing densities among seasons for all strata combined, the highest densities were observed in the winter (Jan – early March), they were intermediate in fall (Nov – Dec), and lowest in early fall (mid Sept – Nov) (Table 2; compare bold density estimates). Comparing densities among strata within season, they were similar among strata in both early-fall (although a little lower in Stratum 2) and fall, and there was a large winter density increase in Stratum 2 and concurrent decrease in density in Strata 3 and 4 resulting in considerable differences among strata in the winter sampling season (Table 2). This change in density in the winter may reflect some movement of murrelets among strata or from birds moving in and out of the study area. It is imporant to note that the high winter density estimate in Stratum 2 resulted from two February surveys to PSUs 30 and 31 where 556 murrelets were detected.

When examining annual estimated densities for all non-breeding sampling windows or seasons (e.g. early fall, fall, winter, spring) combined and across all 8 survey years, murrelet densities during the non-breeding season have been declining by 13.5% annually in the Puget Sound region (Table 3; Figure 2). In addition, the rate of decline is similar among strata (however, S5 is not statistically significant; Table 3).

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 km of transect length sampled) by PSU (Table 4). As in previous years, the PSUs of Stratum 2 on the western side of Admiralty Inlet had relatively high murrelet encounter rates (Table 4, especially PSUs 30 and 31) with high encounter rates in the area spanning from Point Wilson southward through Port Townsend Bay and then moderate densities down to Port Ludlow. Moderate densities were observed in Crescent Bay and the northwest side of Whidbey and the west side of Camano Island. Hood Canal densities were relatively low this year compared to previous years. Again, some PSUs have no to few detections and some, like the PSU around Indian Island, have high encounter rates in a single season. This variation in encounter rate over time and space suggests movement of birds tracking food resources throughout the larger region. As in previous years, Stratum 5 had very few to no birds, which supports the poor availability of forage fish in south to central Puget Sound (Rice et al. 2012; Greene et al. 2015).

With 8 years of data (2013-2020) from the Puget Sound region, an assessment of the temporal and spatial changes in murrelet abundance can be conducted and a manuscript summarizing those analyses is in preparation. This manuscript is expected to be submitted for publication in 2020. During this period of Navy-funded marbled murrelet survey work, the density of murrelets has decreased from a high of 2.21 birds per km^2 (95% CI = 1.52-3.21) during the winter of 2012/2013 to a low of 0.67 birds per km^2 (95% CI = 0.44-1.02) during the winter of 2018/2019 (Figure 2 - Puget Sound). This year's estimate of 0.834 birds per km^2 (95% CI = 0.38 - 4.0) overlaps broadly with the recent low density estimate, but with greater uncertainty in the estimate due primarily to the large number of birds detected on only two surveys.

There are now several independent efforts indicating that the murrelet population in the U.S. portion of the Salish Sea (Puget Sound, San Juan Archipelago, and Strait of Juan de Fuca) is declining. The long-term monitoring effort Northwest Forest Plan Effectiveness Monitoring Program indicates a 4.8% annual decline for the 2001-2019 period (McIver et al. 2020). This spring/ summer effort uses the identical line transect survey methodology reported here and some of the same primary sampling units. Similarly, Lorenz and Raphael (2018) found the murrelet populations in the San Juan Islands (the region of the Salish Sea with highest marbled murrelet densities) to have declined from 11.16 to 5.76 murrelets per km^2 between 1995 and 2012. Despite this consistent decline in overall murrelet density, they found that the density of juvenile murrelets and murrelet productivity ratio (juveniles:adults) did not decline over this time period (Lorenz and Raphael 2018). They concluded that the declining density of murrelets in the San Juan Islands was due to declines in adult murrelets only, not juveniles. Interestingly, the annual estimates of overall murrelet density were positively correlated with winter El Niño Southern Oscillation (ENSO) indices (Lorenz and Raphael 2018). In ENSO years, numbers increased dramatically suggesting that

the Salish Sea may provide a marine habitat refugium for murrelets when prey availability along the outer Pacific coast is poorer than usual (Lorenz and Raphael 2018).

Conclusions

- With 8 years of Navy-funded survey effort in Puget Sound during the non-breeding season, for the first time population trends of marbeled murrelets during the non-breeding season can be described.
- In addition, we are getting a better understanding of the year-to-year variability in murrelet abundance during the non-breeding season.
- Three independent survey efforts (two breeding season surveys and this non-breeding season survey) all indicate long-term murrelet declines in Puget Sound and, more broadly, in the Salish Sea.
- The next step is to summarize all of the Navy-funded murrelet survey results for this region and compare those results to other surveys to more formally examine how murrelet populations are changing seasonally. This work will be compiled into a manuscript for publication in the peer-reviewed literature in 2020.
- Hierarchichal distance survey models are recommended to: (1) examine both the marine and terrestrial factors responsible for murrelet declines, and (2) build maps that help understand hotspots of murrelet abundance and how those hot (and cold) spots vary among seasons. This work will be initiated in the fall of 2020 in partnership with the Dr. Beth Gardner at the University of Washington.

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Figure 1. Stratum and PSU locations in Puget Sound. Strata are defined in the figure key and PSUs are numbered on the map.

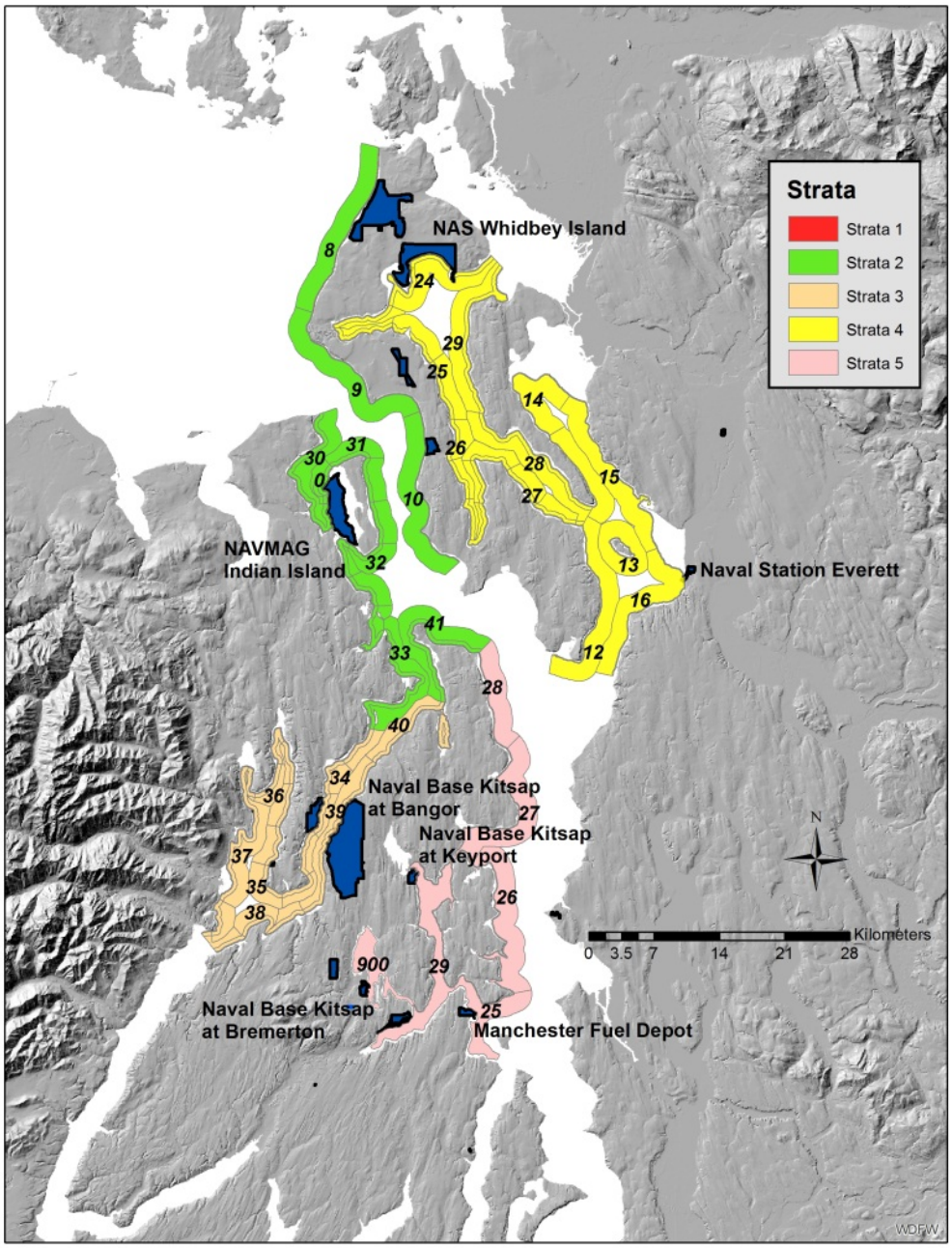

Figure 2. Density of marbled murrelets (± 95% CI) in the entire Puget Sound study area (Strata 2-5 combined) and by individual strata (S#) for each survey year (fall through spring). The location of each stratum is provided in Figure 1.

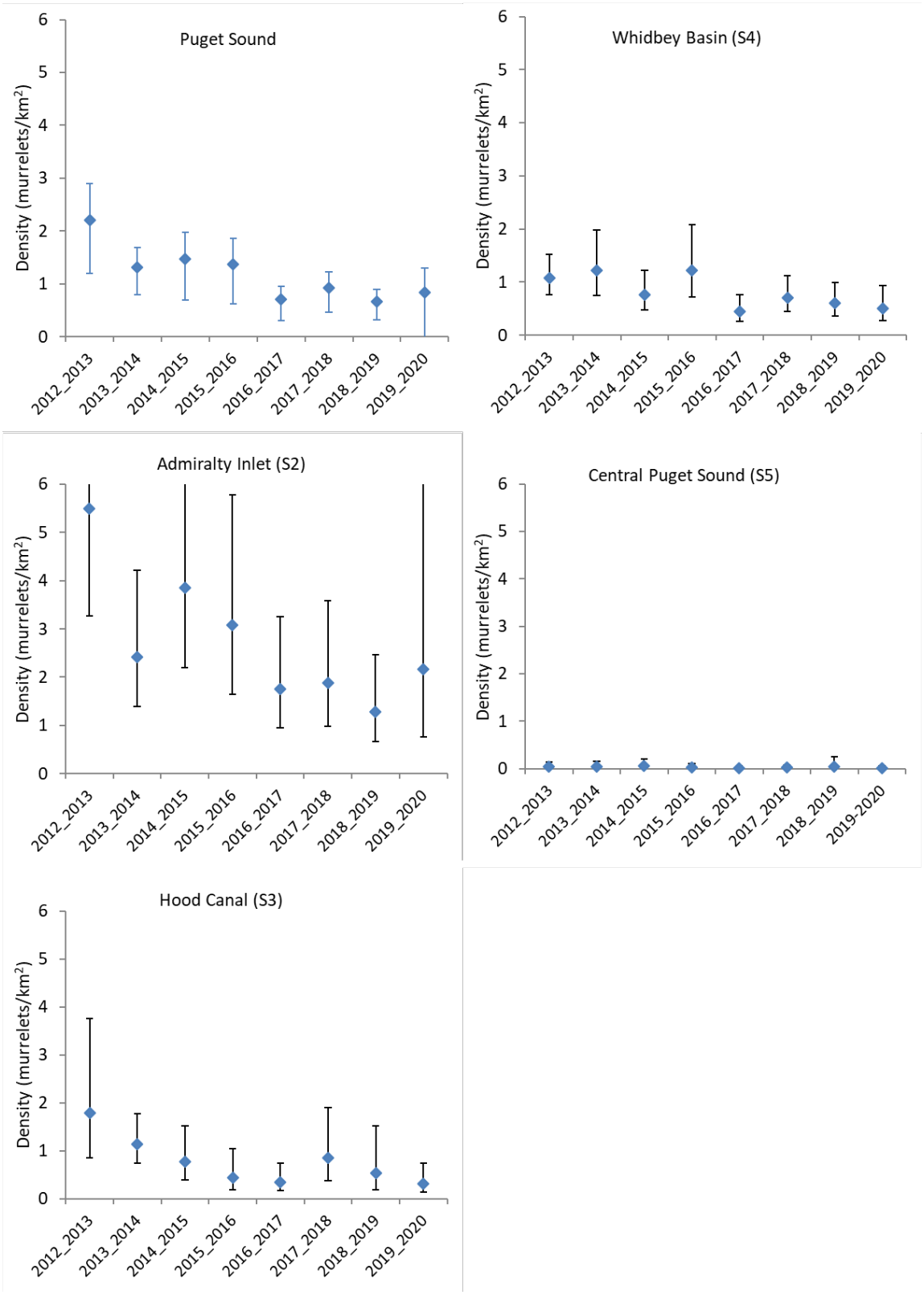

Table 1. Dates of PSU surveys by sampling season: (1) Early Fall (September/October - November), (2) Late Fall (November - December), (3) Early Winter (January - February), (4) Late Winter (late February – March). PSUs adjacent to Navy facilities are in bold and highlighted. Geographic locations of each PSU by stratum can be found in Figure 1. Note that nearly the entire 2020 spring season was cancelled due to the COVID-19 pandemic.

Stratum	PSU	Early Fall (2019)	Fall (2019)	Winter (2020)	Spring (2020)
2	**8**	10-Sep	12-Nov	7-Feb	
	9	4-Nov	5-Dec	10-Feb	
	10	16-Sep	13-Nov	10-Feb	
	30	10-Sep	12-Nov	7-Feb	
	31	13-Sep	13-Nov	10-Feb	
	32	13-Sep	13-Nov	24-Feb	
	33	15-Oct	6-Dec	28-Jan	
	41	16-Sep	5-Dec	28-Jan	
3	34	9-Oct	14-Nov	9-Jan	12-Mar
	35	18-Sep	18-Nov	8-Jan	
	36	18-Sep	18-Nov	8-Jan	
	37	18-Sep	18-Nov	8-Jan	
	38	19-Sep	14-Nov	9-Jan	12-Mar
	39	19-Sep	14-Nov	9-Jan	12-Mar
	40	4-Oct	6-Dec	28-Jan	
4	12	6-Nov	9-Dec	3-Feb	
	13	28-Oct	9-Dec	27-Feb	
	14	28-Oct	3-Feb	4-Mar	
	15	28-Oct	6-Nov	3-Feb	
	16	25-Sep	9-Dec	30-Jan	6-Mar
	24	14-Oct	20-Nov	6-Feb	
	25	14-Oct	13-Dec	4-Mar	
	26	5-Nov	13-Dec	4-Mar	
	27	5-Nov	13-Dec	27-Feb	
	28	6-Nov	25-Jan	27-Feb	
	29	14-Oct	20-Nov	6-Feb	
5	**25**	24-Sep	10-Dec	27-Jan	
	26	24-Sep	17-Dec	27-Jan	
	27	25-Sep	27-Jan	6-Mar	
	28	25-Sep	25-Jan	6-Mar	
	29	23-Sep	19-Nov	17-Jan	
	900	23-Sep	19-Nov	29-Jan	

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, and all Puget Sound strata combined. Strata are defined in Figure 1. Birds were only detected in Stratum 5 in the winter sampling period. Because only 4 PSUs were surveyed in the spring survey season, we did not have an adequate sample size to generate density estimates and consequently, have excluded that season from this table.

Year	Stratum	Density (birds/km^2)	Standard Error	%CV	Birds	Birds 95% CL Lower	Birds 95% CL Upper	Area (km^2)	f(0)	Standard Error of f(0)	E(s)	Standard Error of E(s)	Truncation Distance
All sampling periods combined – Early Fall through Winter (mid-Sept – early Mar)													
2019/2020	**All**	**0.834**		**39.75**	**786**	**358**	**1723**	**942.0**	**0.006**	**0.001**	**1.997**	**0.051**	**211**
2019/2020	2	2.168	1.1811	54.47	**557**	194	1593	256.7					
2019/2020	3	0.319	0.1365	42.82	**52**	22	121	162.5					
2019/2020	4	0.507	0.1582	31.22	**175**	94	324	345.1					
2019/2020	5	0.011	0.011	102.57	**2**	0	11	177.6					
Early Fall (mid-Sept – Nov)													
2019	**All**	**0.298**		**51.82**	**281**	**100**	**791**	**942.0**	**0.008**	**0.002**	**1.783**	**0.107**	**211**
2019	2	0.2767	0.1227	44.35	**71**	28	179	256.7					
2019	3	0.623	0.0638	102.38	**10**	1	77	162.5					
2019	4	0.5784	0.3946	68.23	**200**	52	766	345.1					
2019	5	0			**0**			177.6					
Fall (Nov - Dec)													
2019	**All**	**0.633**		**27.01**	**596**	**348**	**1020**	**942.0**	**0.007**	**0.001**	**1.741**	**0.053**	**211**
2019	2	0.7001	0.3885	55.50	**180**	54	593	256.7					
2019	3	0.7651	0.3333	43.56	**124**	47	329	162.5					
2019	4	0.8453	0.2662	31.49	**292**	152	560	345.1					
2019	5	0			**0**			177.6					
Winter (Jan – early Mar)													
2020	**All**	**1.575**		**58.36**	**1,483**	**421**	**5225**	**942.0**	**0.006**	**0.001**	**2.213**	**0.083**	**211**
2020	2	5.545	3.365	60.68	**1,424**	386	5246	256.7					
2020	3	0.114	0.114	100.13	**18**	2	140	162.5					
2020	4	0.102	0.048	47.08	**35**	13	94	345.1					
2020	5	0.032	0.035	107.88	**6**	1	54	177.6					

Notes: CV = coefficient of variation; CL = confidence level; Std. Err. = standard error; f(0) = value of probability density function at zero for line transects; E(s) = estimate of expected value of cluster size; Truncation Distance = all murrelet detections beyond this distance were not included in the analysis following the recommendation of Buckland(2015) to reduce the undue influence of groups detected far from the transect line on density estimates.

Table 3. Estimates of average annual rate of marbled murrelet population change based on at-sea abundance surveys in four strata in the Puget Sound region. Confidence limits are for the estimates of percent annual change. The P-value is based on a 2-tailed test for whether the annual rate of change is less than zero, significant values ($p < 0.05$) are shaded in gray.

Region (Stratum)	Period of Analysis	Annual Rate of Change (%)	95% Conf. Limits		Adjusted R^2	*P*-value
			Lower	Upper		
Puget Sound (all strata)	2012-2020	-13.5	-20.7	-5.6	0.692	0.007
Admiralty Inlet (S2)	2012-2020	-13.7	-23.5	-2.7	0.534	0.024
Hood Canal (S3)	2012-2020	-17.2	-29.1	-3.2	0.527	0.025
Whidbey Basin (S4)	2012-2020	-11.2	-20.3	-1.2	0.478	0.035
Central Puget Sound (S5)	2012-2020	-14.9	-31.5	5.7	0.248	0.119

Table 4. September – March marbled murrelet encounter rate (# birds detected/km transect length sampled) by PSU. PSUs adjacent to Navy facilities are in bold and highlighted. Sampling seasons: Early Fall = mid-Sept – Nov 2019; Fall = Nov – Dec 2019; Winter = Jan – early Mar 2020; Spring = early to mid-Mar 2020. Geographic locations of each PSU by stratum can be found in Figure 1.

Stratum	PSU	Early Fall (2019)	Fall (2019)	Winter (2020)	Spring (2020)	Average
2	**8**	0.029	0.171	0.720		0.307
	9	0.118	0.113	0.028		0.087
	10	0.029	0.000	0.000		0.010
	30	0.000	0.890	10.945		3.945
	31	0.000	0.034	5.316		1.783
	32	0.326	0.221	0.703		0.416
	33	0.118	0.000	0.000		0.039
	41	0.000	0.346	0.207		0.184
3	34	0.131	0.176	0.000	0.000	0.077
	35	0.000	0.176	0.237		0.138
	36	0.000	0.000	0.000		0.000
	37	0.000	0.000	0.000		0.000
	38	0.000	0.692	0.000	0.000	0.173
	39	0.000	0.202	0.000	0.000	0.050
	40	0.000	0.203	0.000		0.068
4	12	0.087	0.029	0.000		0.039
	13	0.172	0.260	0.000		0.144
	14	0.000	0.000	0.000		0.000
	15	0.249	0.277	0.000		0.175
	16	0.000	0.708	0.060	0.059	0.207
	24	0.062	0.569	0.163		0.265
	25	0.000	0.189	0.046		0.078
	26	0.000	0.000	0.000		0.000
	27	0.000	0.142	0.000		0.047
	28	0.088	0.000	0.000		0.029
	29	1.090	0.437	0.059		0.529
5	**25**	0.000	0.000	0.000		0.000
	26	0.000	0.000	0.000		0.000
	27	0.000	0.000	0.000		0.000
	28	0.000	0.000	0.042		0.014
	29	0.000	0.000	0.000		0.000
	900	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

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Cover Photo: Marbled Murrelet by Scott Pearson

INTRODUCTION

The goal of this project is to estimate on-the-water marbled murrelet (*Brachyramphus marmoratus*) densities during the fall-spring non-breeding seasons (September - April) adjacent to the following U.S. Department of the Navy (Navy) facilities:

1. Naval Air Station (NAS) Whidbey Island (Crescent Harbor);
2. Manchester Fuel Depot;
3. Naval Base Kitsap (NBK) Bangor, including Zelatched Point, and Toandos;
4. NBK Keyport;
5. NBK Bremerton;
6. Naval Magazine (NAVMAG) Indian Island; and
7. Naval Station (NAVSTA) Everett.

These surveys have been conducted annually since September of 2012 and, now that 9 years of survey data have been collected, marbled murrelet density trends during the non-breeding season can be examined. Because the nearshore marine environment and marbled murrelet densities adjacent to any one of these Navy 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 (2014) to derive stratum-specific density estimates. This approach uses line-transect or distance sampling methods (Buckland et al. 2015) to derive murrelet density estimates for four strata using nearshore and offshore transects placed in 32 primary sampling units (PSUs) (Figure 1). Note that Stratum 1 (coastal Pacific Ocean [Pacific Beach]) was not surveyed again this year.

METHODS

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 (2014). This approach was used because: (1) it addresses issues of detectability, (2) it is customized to marbled 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) the survey efforts for this project needed to be consistent with the spring/summer marbled murrelet monitoring effort funded by the U.S. Fish and Wildlife Service (USFWS), which will ultimately allow the comparison of density estimates for the same PSUs among seasons.

Sampling Design and Survey Effort

The survey design that follows is described in detail in Pearson and Lance (2014). A total of 32 PSUs were split among 4 strata (Figure 1 and Table 1). To derive strata and PSUs, we segmented the entire coastline of Puget Sound into 20-kilometer (km) PSUs. PSUs were then combined into appropriate management/ ecological/density strata (Figure 1). Using this information, Puget Sound strata are depicted in Figure 1 and defined as follows:

- Stratum 2 – Admiralty Inlet (8 PSUs): west side of NAS Whidbey Island, NAS Whidbey Island-Lake Hancock, and NAVMAG Indian Island;
- Stratum 3 – North Hood Canal (7 PSUs): NBK Bangor (including Zelatched Point, Toandos Peninsula), and Dabob Bay;
- Stratum 4 – Whidbey Basin (11 PSUs): NAS Whidbey Island-Crescent Harbor and NAVSTA Everett; and

- Stratum 5 – Central Puget Sound (6 PSUs): NBK Keyport, NBK Bremerton, and Manchester Fuel Depot.

Average PSU area depicted in Figure 1 was 38.2 square kilometers (km^2). 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 Program effort uses a similar survey design to this Navy effort. However, because the area of interest is much larger in the Effectiveness Monitoring Program and the goals differ between the 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 already established PSUs.

Four replicate surveys of all 32 PSUs were conducted in strata 2-5 as follows:

1) Early Fall (mid September - October)
2) Late Fall (November – mid December)
3) Early Winter (January – early February)
4) Late Winter/Early Spring (mid February – March).

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

Observer Training

All observers had considerable experience monitoring seabirds at sea and work on surveys nearly year-round. All observers had completed a required 1 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 (Mack et al. 2003; Raphael et al. 2007).

Each observer completed 100 distance estimates prior to starting our 2020 sampling season. 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, followed by weekly testing throughout the survey period. Distance trials involve each individual observer's estimate of perpendicular distance being 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 (see Raphael et al. 2007 for details). Each observer was tested weekly throughout the survey season. During weekly tests, each observer estimated five perpendicular distances to floating targets. If all five estimates were within 15% of the actual distance, the trial was complete. 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.

Audits have been conducted in the past by project leads to evaluate the survey team's overall performance and ability to detect marbled murrelets during the survey season (Raphael et al. 2007, Huff et al. 2003). The results of those audits were shared with the observers after the survey day was completed for feedback and discussion. There were no audits performed this year due to COVID-19 operating procedures which precluded an additional person on the boat. This team is highly experienced and conducts surveys with these strict protocols year-round.

Field Methods and Equipment

In all previous years, the survey team consisted of a boat captain and data recorder inside the cabin and two observers (one responsible for each side of the boat) located on observation platforms outside and aft of the cabin about 3 feet apart. Prior to this year, all team members were on the boat and rotated among these duties at the beginning of each PSU (or as needed) to avoid survey fatigue. This year, we changed our data collection logistics to ensure the health and safety of our team and a minimum physical spacing of six feet. To accomplish this, we reduced the team on the boat from four to three and the data recorder was remote (at home) and communicated with the team via Bluetooth wireless headset connected to a satellite or cellular phone connection. Positions on the boat also changed, with our boat captain always operating the boat from inside the cabin and not rotating with other team members.

For the observers, positions were rotated each week but remained fixed within a week. The port observer remained on the port observation platform aft of the cabin to offset the weight of the boat captain on the starboard side. The starboard observer moved to the center bow hatch to ensure minimum physical spacing of six feet. A custom bulkhead was built to separate the main cabin (where the boat captain resides) from the v-birth. Wireless headsets stayed permanently with each observer and were not shared. Eye-level for the bow observer was slightly (less than 1 foot) lower than the observation platforms used aft of the cabin. Observers felt that murrelet detectability was not compromised by the change in observation locations.

The two observers 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 meters [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 the data recorder who entered data directly onto a laptop computer with software (DLOG3 developed by R.G. Ford, Inc., Portland, OR). A second laptop on the boat was interfaced with a global positioning system (GPS) unit and collects real time location data. DLOG3 interfaces with a handheld GPS and geographic information system (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. Data were synched from the boat computer (track log) with that from the remote data recorder (observations) using time stamps on all observatons and gps locations in the program R.

The team used the 26-foot Research Vesssel Fog Lark (a Lee Shore 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. 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

Transect distances, murrelet group size, and perpendicular distances for each marbled murrelet observation were used to derive density estimates (birds/km^2) by stratum using the program DISTANCE. For details about the approach to analysis, 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 derive an estimate of density (birds/km^2). For details, please see Buckland et al. (2015). The Results/Discussion section below provides marbled murrelet density estimates by stratum for each of the sampling periods (see above) and across all sampling periods (global model). The density provided can be viewed as the marbled murrelet population on the water on a given day within the area and time period defined. For population trends, we used a linear regression to the natural logarithm of annual density estimates to test for declining trends. For our analysis, the natural logarithm best fits and tests existing demographic models (USFWS 1997; McShane et al. 2004) that predict the murrelet population is declining by a constant percentage each year. We tested the null hypothesis that the

slope equals zero or greater (no change or increase in murrelet numbers) against the alternative hypothesis of the slope being less than zero (i.e., a one-tailed test for decreasing murrelet densities).

RESULTS/DISCUSSION

During the fall-spring 2020/2021 sampling year, 4,270 km of transects were surveyed and 1,143 marbled murrelets were detected during those surveys. Because these were replicated surveys, these are not all unique individuals. All 32 PSUs were sampled during each of the four"seasons" (Table 1). When comparing densities among seasons for all strata combined, the highest densities were observed in the late fall and winter (Nov – early-Feb) and lowest densities were observed in the early fall (mid-Sep – Nov) and late winter/early spring (Feb – Mar) (Table 2; compare bold density estimates). Overall density was quite low in the mid-Sep to Nov time period and increased five fold by December. The dramatic overall increase in density in the winter is likely caused by birds moving into the study area because density increased in all strata. Densities were consistently serveral times higher in Stratum 2 when compared to any other strata regardless of the sampling season (Table 2). In general, Stratum 4 had the next highest density and, as in previous years, Stratum 5 had few to no birds detected (Table 2). Also, as in previous years, very high murrelet encounters in PSUs 30 and 31 in the winter and spring (n = 121 and 227 respectively) have a large influence on the Stratum 2 density.

When examining annual estimated densities for all non-breeding sampling windows or seasons (e.g. early fall, fall, winter, spring) combined and across all 9 survey years, murrelet densities during the non-breeding season have been declining by 12.6% annually in the Puget Sound region (Table 3; Figure 2). Declines in Strata 3 and 4 are fairly consistent among years while declines in Stratum 2 are much more variable (Table 3; Figure 2).

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 km of transect length sampled) by PSU (Table 4). As in previous years, the PSUs of Stratum 2 on the western side of Admiralty Inlet had relatively high murrelet encounter rates (Table 4, especially PSUs 30 and 31) with high encounter rates in the area spanning from Point Wilson southward through Port Townsend Bay and then moderate densities down to Port Ludlow. Moderate densities were observed in Crescent Bay and the northwest side of Whidbey and the west side of Camano Island. Similar to last year, Hood Canal densities were relatively low. Again, some PSUs have no to few detections and some have high encounter rates in a single season. This variation in encounter rate over time and space suggests movement of birds tracking food resources throughout the larger region. As in previous years, Stratum 5 had very few to no birds, which supports the poor availability of forage fish in south to central Puget Sound (Rice et al. 2012; Greene et al. 2015).

With 9 years of data (2013-2021) from the Puget Sound region, we can begin to examine longer-term changes in non-breeding season murrelet use of Puget Sound. During this time period, density of murrelets has decreased from a high of 2.21 birds per km^2 (95% CI = 1.52-3.21) in the winter of 2012/2013 to a low of 0.67 birds per km^2 (95% CI = 0.44-1.02) in the winter of 2018/2019 (Figure 2 - Puget Sound). This year's estimate of 1.05 birds per km^2 (95% CI = 0.71 – 1.57) suggests some increase in density over the past two non-breeding seasons.

There are now several independent efforts indicating that the murrelet population in the U.S. portion of the Salish Sea (Puget Sound, San Juan Archipelago, and Strait of Juan de Fuca) is declining. The long-term monitoring effort Northwest Forest Plan Effectiveness Monitoring Program indicates a 5.0% annual decline for the 2001-2020 period in the Puget Sound and Strait of Juan de Fuca region (McIver et al. 2021). This spring/ summer effort uses the identical line transect survey methodology reported here and some of the same primary sampling units. Similarly, Lorenz and Raphael (2018) found the murrelet populations in the San Juan Islands (the region of the Salish Sea with highest marbled murrelet densities) to have declined from 11.16 to 5.76 murrelets per km^2 between 1995 and 2012. Despite this consistent decline in overall murrelet density, they found that the density of juvenile murrelets and murrelet productivity ratio (juveniles:adults) did not decline over this time period (Lorenz and Raphael 2018). They concluded that the declining density of murrelets in the San Juan Islands was due to declines in adult murrelets only, not juveniles. Interestingly, the annual estimates of overall murrelet density were positively correlated with winter El Niño Southern Oscillation (ENSO) indices (Lorenz and Raphael 2018). In ENSO years, numbers increased dramatically suggesting that the Salish Sea may provide a marine habitat refugium for murrelets when prey availability along the outer Pacific coast is poorer than usual (Lorenz and Raphael 2018).

CONCLUSIONS

- With 9 years of Navy-funded survey effort in Puget Sound during the non-breeding season, we have a strong data set to assess relatively short-term population trends.
- We continue to gain a better understanding of the year-to-year variability in murrelet abundance during the non-breeding season.
- Three independent survey efforts (two breeding season surveys and this non-breeding season survey) all indicate long-term murrelet declines in Puget Sound and, more broadly, in the Salish Sea.
- Hierarchichal distance survey models are recommended to: (1) examine both the marine and terrestrial factors responsible for murrelet declines, and (2) build maps that help understand hotspots of murrelet abundance and how those hot (and cold) spots vary among seasons. This work was initiated in the fall of 2020 in partnership with the Dr. Beth Gardner and Dr. Jamie Bursa at the University of Washington and will be continued by Ph.D. student Sierra Gilman.

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Figure 1. Stratum and PSU locations in Puget Sound. Strata are defined in the figure key and PSUs are numbered on the map.

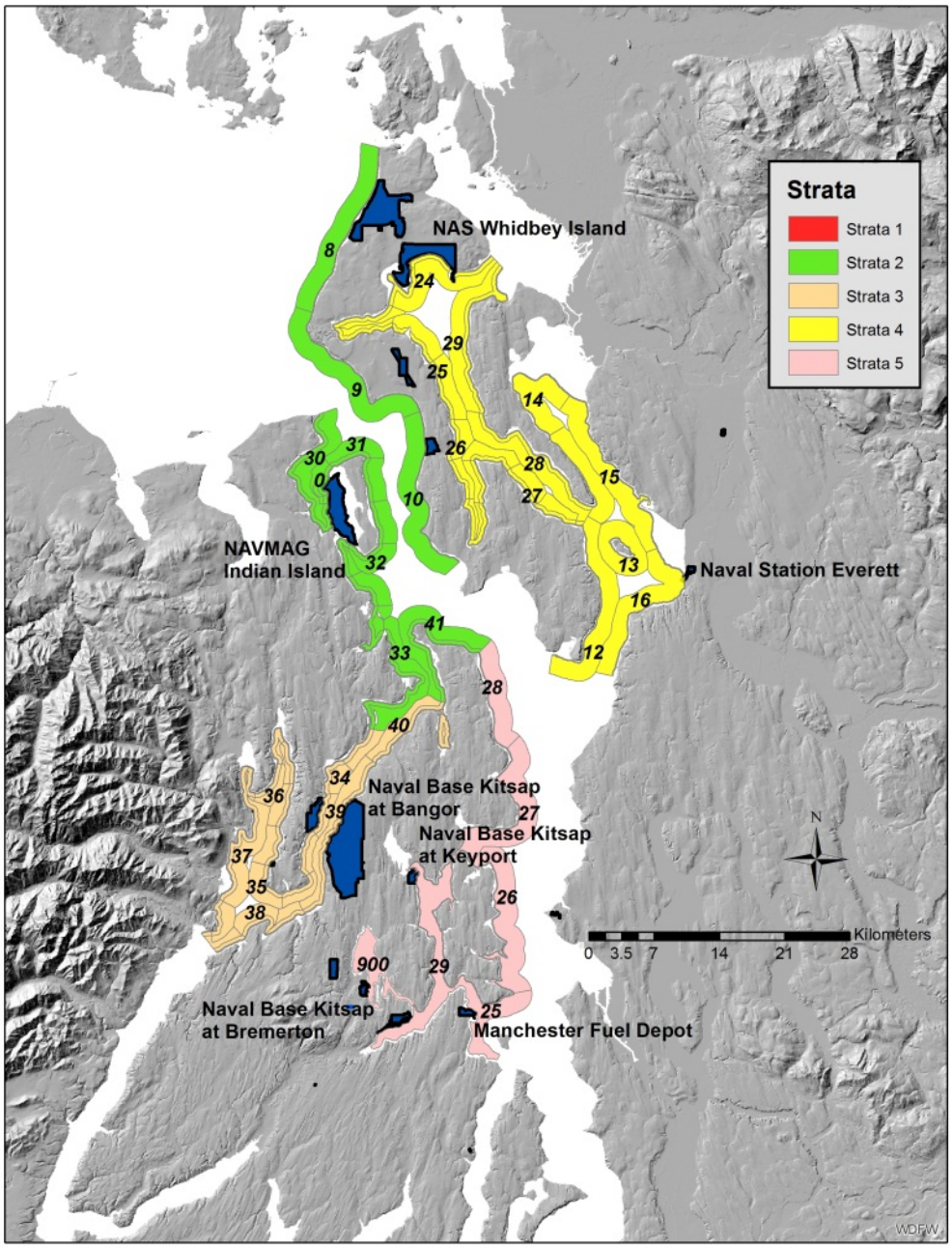

Figure 2. Density of marbled murrelets (± 95% CI) in the entire Puget Sound study area (Strata 2-5 combined) and by individual strata (S#) for each survey year (fall through spring). The location of each stratum is provided in Figure 1.

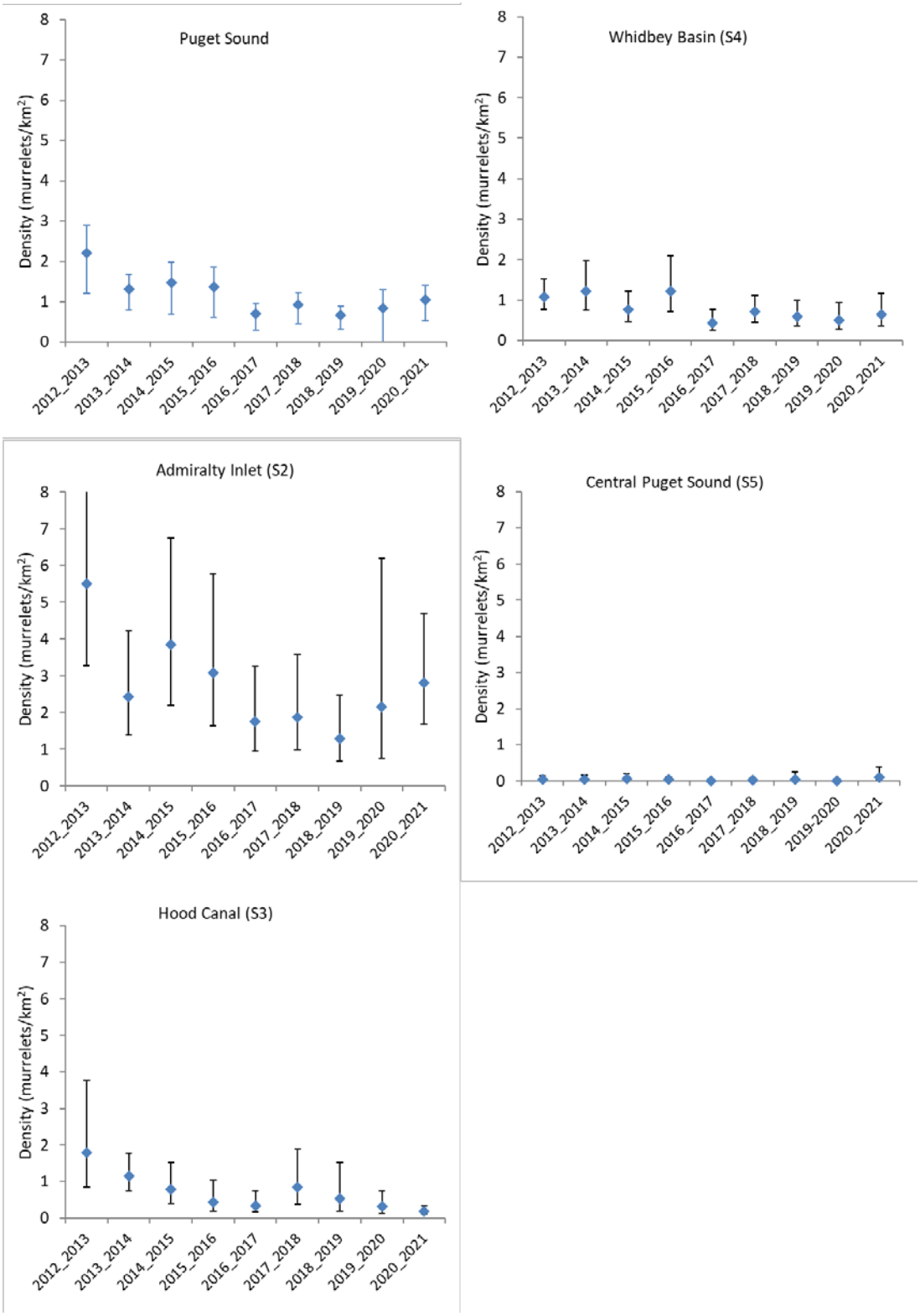

Table 1. Dates of PSU surveys by sampling season: (1) Early Fall (mid-September/October), (2) Late Fall (November – mid-December), (3) Early Winter (January – early February), (4) Spring (mid February – March). PSUs adjacent to Navy facilities are in bold and highlighted. Geographic locations of each PSU by stratum can be found in Figure 1.

Stratum	PSU	Early Fall 2020	Fall 2020	Winter 2021	Spring 2021
2	**8**	14-Oct	23-Nov	20-Jan	12-Mar
	9	14-Oct	4-Dec	28-Jan	23-Mar
	10	29-Oct	4-Dec	29-Jan	23-Mar
	30	1-Oct	23-Nov	28-Jan	11-Mar
	31	7-Oct	23-Nov	20-Jan	12-Mar
	32	29-Oct	9-Dec	29-Jan	26-Mar
	33	7-Oct	19-Nov	4-Feb	16-Feb
	41	7-Oct	9-Dec	25-Jan	26-Mar
3	34	22-Sep	2-Nov	4-Feb	16-Feb
	35	29-Sep	5-Nov	19-Jan	9-Mar
	36	29-Sep	5-Nov	19-Jan	22-Feb
	37	29-Sep	5-Nov	19-Jan	9-Mar
	38	27-Sep	2-Nov	13-Jan	10-Feb
	39	27-Sep	2-Nov	13-Jan	10-Feb
	40	22-Sep	19-Nov	15-Jan	11-Mar
4	12	28-Sep	9-Dec	7-Jan	15-Mar
	13	28-Oct	10-Dec	3-Feb	25-Mar
	14	28-Oct	10-Nov	3-Feb	3-Mar
	15	30-Sep	10-Nov	7-Jan	3-Mar
	16	28-Sep	10-Nov	7-Jan	3-Mar
	24	30-Sep	11-Nov	6-Jan	2-Mar
	25	5-Oct	1-Dec	8-Feb	2-Mar
	26	20-Oct	1-Dec	8-Feb	16-Mar
	27	20-Oct	10-Dec	15-Jan	16-Mar
	28	5-Oct	11-Nov	15-Jan	17-Mar
	29	20-Oct	11-Nov	6-Jan	18-Mar
5	**25**	6-Oct	25-Nov	14-Jan	9-Feb
	26	6-Oct	25-Nov	14-Jan	17-Feb
	27	19-Oct	2-Dec	14-Jan	17-Feb
	28	19-Oct	2-Dec	5-Feb	17-Feb
	29	12-Oct	20-Nov	8-Jan	26-Feb
	900	12-Oct	20-Nov	8-Jan	9-Feb

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, and all Puget Sound strata combined. Strata are defined in Figure 1.

Year	Stratum	Density (birds/km^2)	Standard Error	%CV	Birds	Birds 95% CL Lower	Birds 95% CL Upper	Area (km^2)	f(0)	Standard Error of f(0)	E(s)	Standard Error of E(s)	Truncation Distance
All sampling periods combined – Early Fall through Winter (mid-Sept – late Mar)													
2020/2021	**All**	**1.051**		**19.98**	**990**	**2626**	**664**	**942.0**	**0.007**	**0.001**	**1.885**	**0.032**	**211**
2020/2021	2	2.809	0.7192	25.61	**721**	432	1205	256.7					
2020/2021	3	0.192	0.0524	27.35	**31**	18	54	162.5					
2020/2021	4	0.643	0.1923	29.92	**222**	123	400	345.1					
2020/2021	5	0.092	0.0736	80.47	**16**	4	70	177.6					
Early Fall (mid-Sept – Nov)													
2020	**All**	**0.289**		**35.64**	**272**	**128**	**578**	**942.0**	**0.008**	**0.002**	**2.146**	**0.143**	**211**
2020	2	0.894	0.359	40.16	**230**	97	544	256.7					
2020	3	0.087	0.041	47.15	**14**	5	40	162.5					
2020	4	0.082	0.053	64.10	**28**	8	103	345.1					
2020	5	0			**0**			177.6					
Fall (Nov - Dec)													
2020	**All**	**1.560**		**36.16**	**1470**	**669**	**3228**	**942.0**	**0.009**	**0.001**	**1.963**	**0.077**	**211**
2020	2	3.976	1.999	50.28	**1021**	344	3031	256.7					
2020	3	0.764	0.420	54.98	**124**	34	460	162.5					
2020	4	0.941	0.291	30.90	**325**	167	632	345.1					
2020	5	0			**0**			177.6					
Winter (Jan – early-Feb)													
2021	**All**	**1.799**		**38.40**	**1696**	**731**	**3935**	**942.0**	**0.000**	**0.001**	**2.063**	**0.065**	**211**
2021	2	4.821	2.413	50.06	**1,238**	408	3757	256.7					
2021	3	0.269	0.153	56.92	**44**	12	158	162.5					
2021	4	1.037	0.504	48.66	**358**	129	994	345.1					
2021	5	0.318	0.344	108.31	**56**	6	541	177.6					
Spring (mid-Feb - Mar)													
2021	**All**	**0.777**		**50.25**	**731**	**241**	**2221**	**942.0**	**0.008**	**0.001**	**1.767**	**0.069**	**211**
2021	2	2.542	1.424	56.02	**653**	191	2228	256.7					
2021	3	0.127	0.095	74.69	**21**	4	105	162.5					
2021	4	0.150	0.077	51.49	**52**	18	151	345.1					
2021	5	0.037	0.040	106.56	**7**	1	62	177.6					

Notes: CV = coefficient of variation; CL = confidence level; Std. Err. = standard error; f(0) = value of probability density function at zero for line transects; E(s) = estimate of expected value of cluster size; Truncation Distance = all murrelet detections beyond this distance were not included in the analysis following the recommendation of Buckland(2015) to reduce the undue influence of groups detected far from the transect line on density estimates.

Table 3. Estimates of average annual rate of marbled murrelet population change based on at-sea abundance surveys in four strata in the Puget Sound region. Confidence limits are for the estimates of percent annual change. The P-value is based on a 2-tailed test for whether the annual rate of change is less than zero, significant values ($p < 0.05$) are shaded in gray.

Region (Stratum)	Period of Analysis	Annual Rate of Change (%)	95% Conf. Limits		Adjusted R^2	*P*-value
			Lower	Upper		
Puget Sound (all strata)	2012-2021	-12.6	-21.1	-3.2	0.520	0.017
Admiralty Inlet (S2)	2012-2021	-25.8	-46.3	2.7	0.316	0.067
Hood Canal (S3)	2012-2021	-13.8	-21.7	-5.2	0.610	0.008
Whidbey Basin (S4)	2012-2021	-7.5	-13.6	-1.0	0.444	0.030
Central Puget Sound (S5)	2012-2021	0.1	-0.7	0.9	0.129	0.781

Table 4. September – March marbled murrelet encounter rate (# birds detected/km transect length sampled) by PSU. PSUs adjacent to Navy facilities are in bold and highlighted. Sampling seasons: (1) Early Fall (mid-September/October), (2) Late Fall (November – mid-December), (3) Early Winter (January – early February), (4) Spring (mid-February – March). Geographic locations of each PSU by stratum can be found in Figure 1.

Stratum	PSU	Early Fall 2020	Fall 2020	Winter 2021	Spring 2021	Average
2	**8**	0.130	0.472	1.007	0.000	0.402
	9	0.955	0.854	0.057	0.234	0.525
	10	0.085	0.056	0.000	0.513	0.164
	30	0.000	1.681	1.928	3.618	1.807
	31	0.135	0.268	7.787	1.294	2.371
	32	0.480	1.864	0.704	0.059	0.777
	33	0.266	0.000	0.230	0.262	0.190
	41	0.065	0.349	0.192	0.309	0.229
3	34	0.030	0.000	0.000	0.000	0.008
	35	0.000	0.085	0.029	0.000	0.029
	36	0.000	0.246	0.000	0.000	0.062
	37	0.055	0.000	0.060	0.000	0.029
	38	0.030	0.094	0.172	0.120	0.104
	39	0.000	0.000	0.114	0.000	0.029
	40	0.000	0.032	0.000	0.061	0.023
4	12	0.000	0.186	0.000	0.000	0.047
	13	0.024	0.058	0.120	0.000	0.051
	14	0.000	0.000	0.035	0.000	0.009
	15	0.000	1.248	0.195	0.104	0.387
	16	0.029	0.059	0.231	0.058	0.094
	24	0.000	0.684	0.380	0.000	0.266
	25	0.000	0.851	1.023	0.047	0.480
	26	0.000	0.061	0.000	0.000	0.015
	27	0.000	0.000	0.000	0.000	0.000
	28	0.000	0.000	0.000	0.000	0.000
	29	0.147	0.528	0.496	0.082	0.313
5	**25**	0.000	0.000	0.000	0.000	0.000
	26	0.000	0.000	0.000	0.000	0.000
	27	0.000	0.000	0.000	0.000	0.000
	28	0.000	0.080	0.638	0.041	0.190
	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