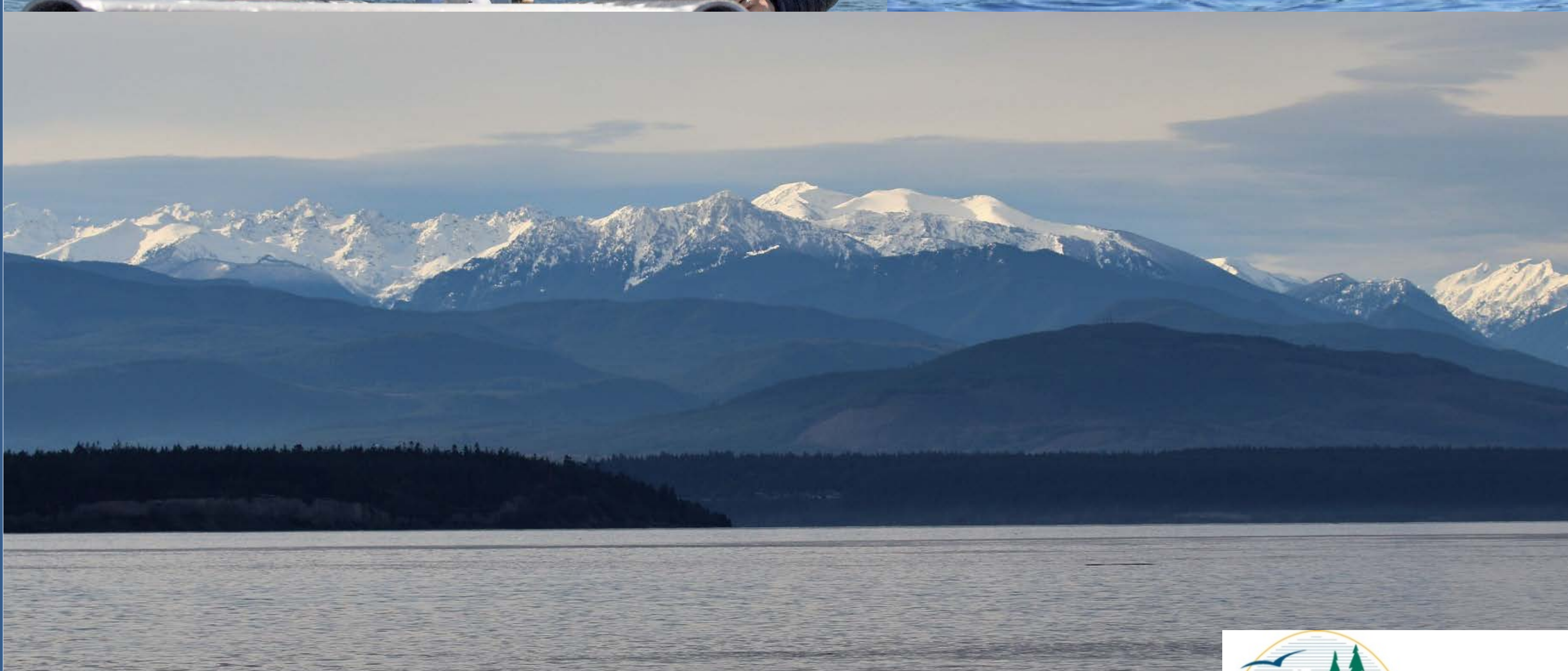
Fall-Spring 2019/2020 Marbled Murrelet At-Sea Densities for Four Strata Associated with U.S. Navy Facilities in Washington State: Annual Research Progress Report 2020



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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 $\geq$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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Literature Cited

Buckland, S., T. Rexstad, E. Marques, and T. Oedekoven. 2015. Distance Sampling: Methods and Applications, Springer Nature, Cham, Switzerland.

Greene, C., L. Kuehne, C. Rice, K. Fresh, and D. Penttila. 2015. Forty Years of Change in Forage Fish and Jellyfish Abundance across Greater Puget Sound, Washington (USA): Anthropogenic and Climate Associations. Marine Ecology Progress Series 525: 153–170.

Lorenz, T.J. and M.G. Raphael. 2018. Declining Marbled Murrelet Density, but Not Productivity, in the San Juan Islands, Washington, USA. Condor 120:201-222.

Mack, D.E., M.G. Raphael, and R.J. Wilk. 2003. Protocol for Monitoring Marbled Murrelets from Boats in Washington's Inland Waters. USDA Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, Olympia, WA.

McIver, W., J. Baldwin, M.M. Lance, S.F. Pearson, C. Strong, D. Lynch, M.G. Raphael, R. Young and N. Johnson. 2020. Marbled Murrelet Effectiveness Monitoring, Northwest Forest Plan: At-sea Monitoring - 2019 Summary Report.

McShane, C., T. Hamer, H. Carter, G. Swartzman, V. Friesen, D. Ainley, R. Tressler, K. Nelson, A. Burger, L. Spear, T. Mohagen, R. Martin, L. Henkel, K. Prindle, C. Strong, and J. Keany. 2004. Evaluation Report for the 5-year Status Review of the Marbled Murrelet in Washington, Oregon, and California. Unpublished report. EDAW, Inc. Seattle, Washington. Prepared for the U.S. Fish and Wildlife Service, Region 1. Portland, Oregon.

Miller, S.L.; Ralph, C.J.; Raphael, M.G.; Strong, G.; Thompson, C.; Baldwin, J.; Huff, M.H. 2006. At-sea Monitoring of Marbled Murrelet Population Status and Trend in the Northwest Plan Area. Pages 31-60 in: Huff, M.; Raphael, M.G.; Miller, S.L.; Nelson, S.K.; Baldwin, J.; tech. coords. Northwest Forest Plan—the First 10 Years (1994-2003): Status and Trends of Populations and Nesting Habitat for the Marbled Murrelet. Gen. Tech. Rep. PNW-GTR-650. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: PNW-GTR-650.

Miller, S.L., M.G. Raphael, G.A. Falxa, C. Strong, J. Baldwin, T. Bloxton, B.M. Gallagher, M. Lance, D. Lynch, S.F. Pearson, C.J. Ralph, and R.D. Young. 2012. Recent Population Decline of the Marbled Murrelet in the Pacific Northwest. Condor 114:771-781.

Pearson, S.F., and M. Lance. 2014. Estimating Marbled Murrelet Densities Adjacent to U.S. Navy Facilities in Puget Sound: Survey Protocol. Washington Department of Fish and Wildlife, Wildlife Science Division, Olympia, WA.

Raphael, M.G., J. Baldwin, G.A. Falxa, M.H. Huff, M.M. Lance, S.L. Miller, S.F. Pearson, C.J. Ralph, C. Strong, and C. Thompson. 2007. Regional Population Monitoring of the Marbled Murrelet: Field and Analytical Methods. Gen. Tech. Rep. PNW-GTR-716. USDA Forest Service, Pacific Northwest Research Station, Portland, OR.

Rice, C.A., J.J. Duda, C.M. Greene, and J.R. Karr. 2012. Geographic Patterns of Fishes and Jellyfish in Puget Sound Surface Waters. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 4:117-128.

Strong, C.S. 1998. Techniques for Marbled Murrelet Age Determination in the Field. Pacific Seabirds 25: 6–8.

U.S. Fish and Wildlife Service. 1997. Recovery Plan for the Threatened Marbled Murrelet (*Brachyramphus marmoratus*) in Washington, Oregon, and California. Portland, Oregon. 203 pp.

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

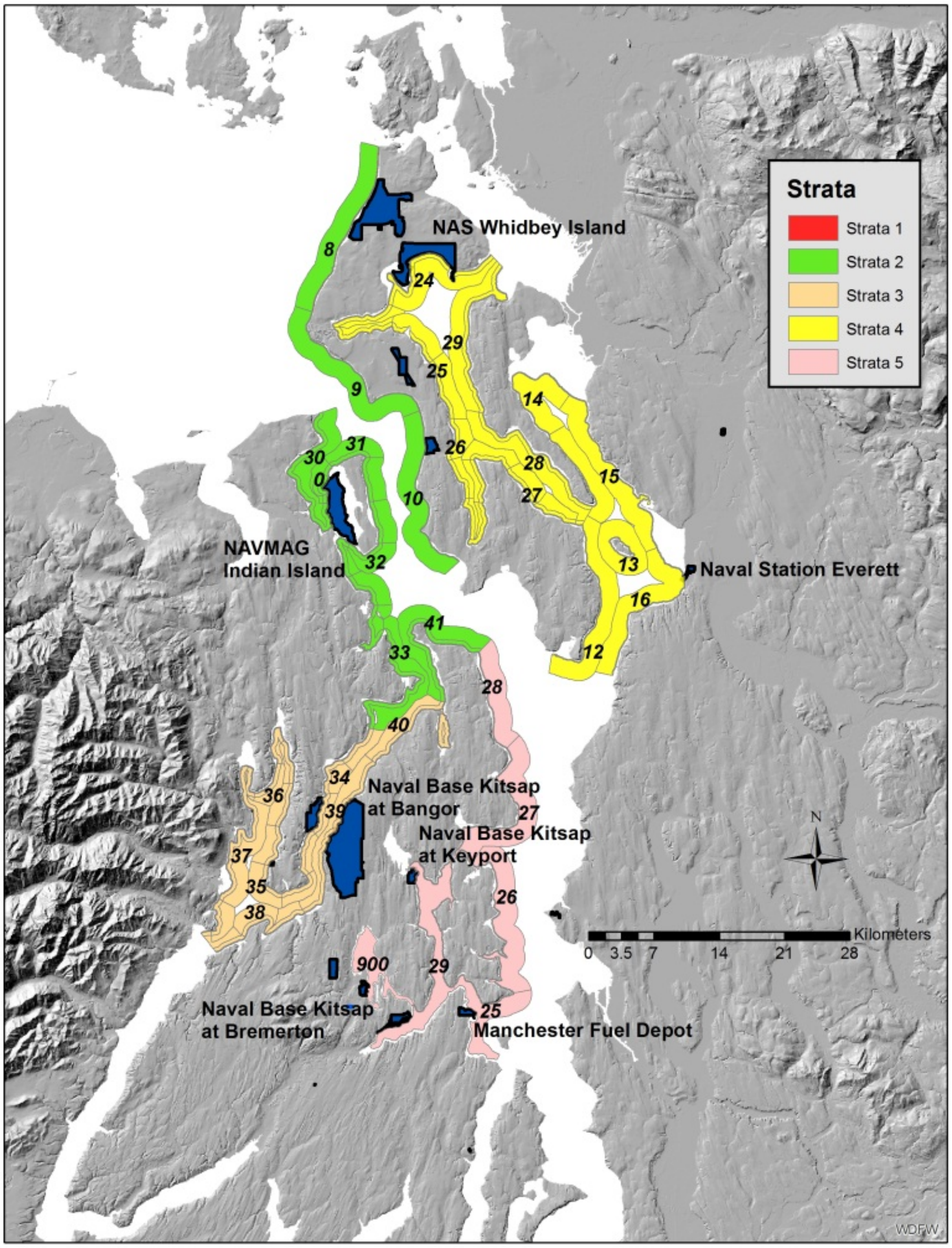

Figure 2. Density of marbled murrelets (± 95% CI) in the entire Puget Sound study area (Strata 2-5 combined) and by individual strata (S#) for each survey year (fall through spring). The location of each stratum is provided in Figure 1.

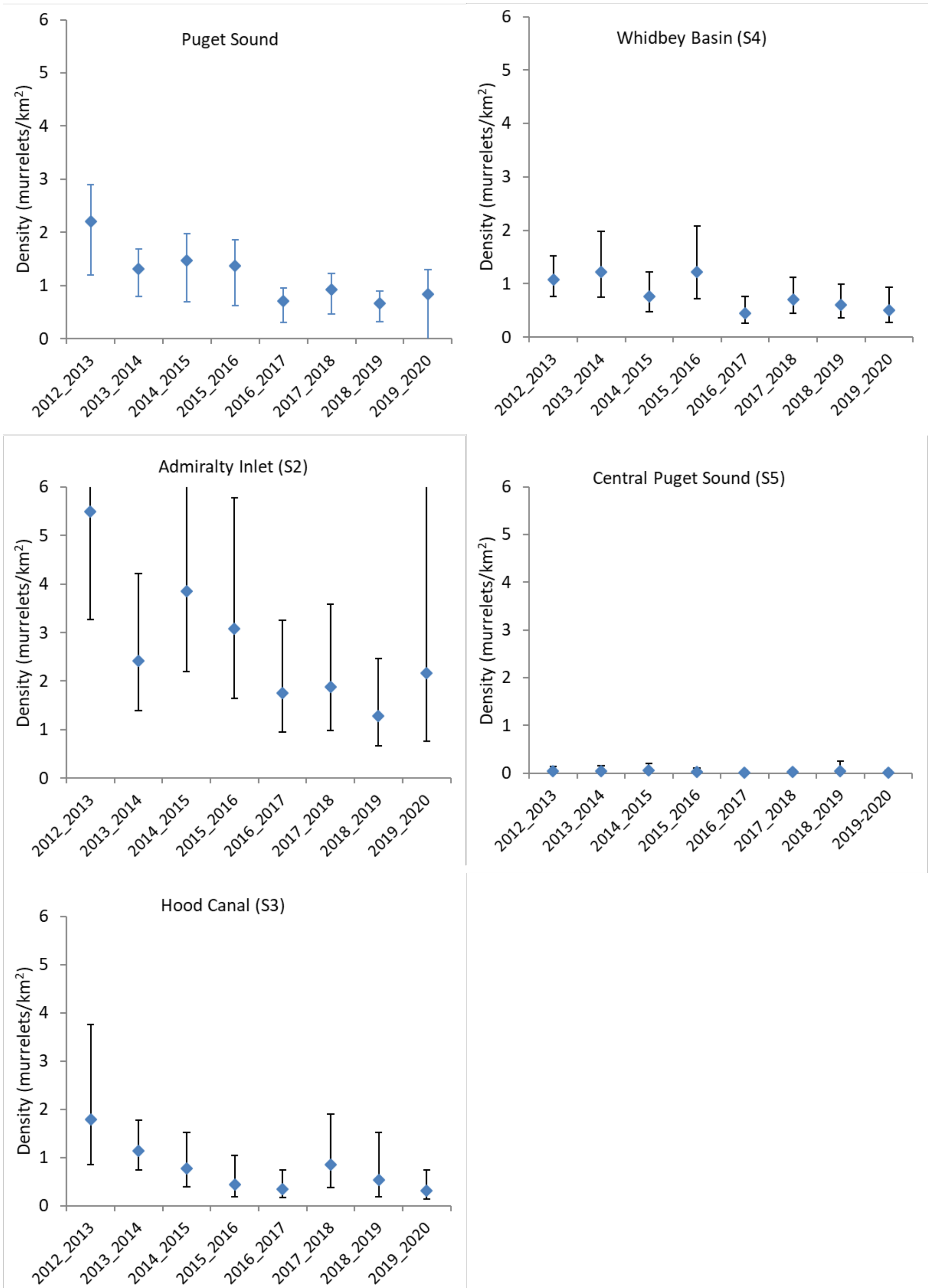

Table 1. Dates of PSU surveys by sampling season: (1) Early Fall (September/October - November), (2) Late Fall (November - December), (3) Early Winter (January - February), (4) Late Winter (late February – March). PSUs adjacent to Navy facilities are in bold and highlighted. Geographic locations of each 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					
				Sea State	
Beaufort Number	Wind Velocity (Knots)	Wind Description	Sea State Description	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