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NORTHWEST FOREST PLAN
THE FIRST 25 YEARS (1994–2018)

Status and Trend of Marbled Murrelet Populations in the Northwest Forest Plan Area, 2000 to 2018

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Cover photo: Juvenile marbled murrelet. Photo by Rich MacIntosh, USFWS.

Abstract

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The Northwest Forest Plan (NWFP) is an ecosystem management plan for federal lands in the U.S. Pacific Northwest. To evaluate the NWFP's effectiveness at conserving the marbled murrelet (*Brachyramphus marmoratus*), we estimated murrelet abundance at sea annually from 2000 to 2018 in inshore marine waters associated with the NWFP area. We divided this area of coastal waters into five geographic subareas corresponding with conservation zones established in the U.S. Fish and Wildlife Service's recovery plan for the marbled murrelet. We used line transect distance estimation methods to account for detectability. Our abundance estimate for the planwide area in 2017 was about 23,000 murrelets. We did not find evidence for a linear trend for the overall NWFP area (0.3 percent per year). At the state scale, we found strong evidence for a declining linear trend in Washington (-3.9 percent per year). For Oregon, we found strong evidence for an increasing linear trend (2.0 percent per year). In California, we found strong evidence for an increasing linear trend (4.5 percent per year). At the individual conservation zone scale, we found strong evidence for a linear decline in Conservation Zone 1 (-4.9 percent per year), some evidence for a negative trend in Conservation Zone 2 (-3.0 percent per year, some evidence for positive linear trend in Conservation Zone 3 (1.4 percent per year), and strong evidence for a linear increase in Conservation Zone 4 (3.7 percent per year). Because of the extreme variability associated with the trend in Conservation Zone 5 (7.3 percent annual rate of change; 95 percent confidence interval: -4.4 to 20.3 percent, years 2000 to 2017), we concluded that there was no evidence for a trend in that conservation zone. These results indicate a pattern of decreasing at-sea abundance in the northern part of the plan area and increasing abundance to the south. We have no definitive explanation for this north-south pattern; however, one potential explanation might be the emigration of birds from other areas of the species' range. A large-scale "marine heatwave" influenced the California Current during 2014–2016, which may have influenced distribution of murrelets, though the mechanism for this change in distribution is not yet clear. These at-sea population monitoring results indicate that the NWFP goal to stabilize and increase marbled murrelet population sizes has not yet been achieved.

Keywords: Abundance trends, *Brachyramphus marmoratus*, effectiveness monitoring, marbled murrelet, Northwest Forest Plan, NWFP, old-growth forest, population monitoring, seabird.

Preface

In the 1980s, public controversy intensified in the Pacific Northwest over timber harvest in old-growth forests, declining species populations (such as northern spotted owl [*Strix occidentalis caurina*], marbled murrelet [*Brachyramphus marmoratus*], and Pacific salmon), and the role of federal forests in regional and local economies. This ultimately led to the adoption of the Northwest Forest Plan (NWFP), which amended existing management plans for 19 national forests and grasslands and seven Bureau of Land Management districts in California, Oregon, and Washington (about 9.7 million ha) of federal land within the 23-million-ha range of the northern spotted owl). The NWFP provides a framework for an ecosystem approach to the management of those 9.7 million ha of federal lands. It established the overarching conservation goals of (1) protecting and enhancing habitat for species associated with late-successional and old-growth forests, (2) restoring and maintaining the ecological integrity of watersheds and aquatic ecosystems, and (3) providing a predictable level of timber sales and other services, as well as maintaining the stability of rural communities and economies.

The NWFP relies on monitoring to detect changes in ecological and social systems relevant to its success in meeting conservation objectives, and on adaptive management processes that evaluate and use monitoring information to adjust conservation and management practices (Mulder et al. 1999). An interagency effectiveness monitoring framework was implemented to meet requirements for tracking status and trend for watershed condition, late-successional and old-growth forests, social and economic conditions, tribal relationships, and population and habitat for marbled murrelets and northern spotted owls. This report is one of a set of status and trend monitoring reports on these topics that addresses questions about the effectiveness of the NWFP in meeting its objectives through its first 25 years. Monitoring results for the first 10, 15, and 20 years are documented in a series of reports or publications (Falxa and Raphael 2016, Huff et al. 2006, Miller et al. 2012, Raphael et al. 2011) available online at https://www.fs.fed.us/r6/reo/monitoring/marbled-murrelet.php.

This report and Lorenz et al. (2021) are continuations in a series of monitoring reports from the Marbled Murrelet Effectiveness Monitoring module under the NWFP, which focuses on monitoring results on the status and trends for marbled murrelet populations and nesting habitat through the first 25 years of the NWFP (1994–2018), following the design described in *Marbled Murrelet Effectiveness Monitoring Plan for the Northwest Forest Plan* (Madsen et al. 1999).

Contents

Introduction

Implemented in 1994, the Northwest Forest Plan (NWFP) represented a change in how federal lands were managed in western Washington and Oregon and northwest California. The plan was developed in response to public controversy during the late 1980s and early 1990s surrounding the harvest of old-growth forests on federal lands. While public concerns included the loss of old-growth forest ecosystems as a whole, the controversy was reinforced, in part, by concerns about the impacts of tree harvest on the northern spotted owl (*Strix occidentalis caurina*), which was listed in 1990 as threatened under the federal Endangered Species Act (USFWS 1990). In 1992, the marbled murrelet (*Brachyramphus marmoratus*; hereafter murrelet), a seabird dependent on older coniferous forests for nesting, was also listed as threatened in Washington, Oregon, and California (Raphael et al. 2002, USFWS 1992). For both species, loss and degradation of habitat from timber harvesting, exacerbated by catastrophic events including fire and windstorms, were the primary terrestrial factors contributing to the listings (USFWS 1990, 1992).

The NWFP provides a framework for an ecosystem management approach for about 10 million ha of federal lands within the range of the northern spotted owl (USDA and USDI 1994). The plan establishes three overarching conservation goals: (1) protecting and enhancing habitat for species associated with late-successional and old-growth forests; (2) restoring and maintaining the ecological integrity of watersheds and aquatic ecosystems; and (3) providing a predictable level of timber sales and other human services, while maintaining the stability of rural communities and economies. A specific conservation goal of the NWFP is to maintain and restore murrelet nesting habitat and populations (Madsen et al. 1999). The NWFP (USDA and USDI 1994) identified the following as a primary question for evaluating the plan's effectiveness in achieving this goal: "Is the murrelet population stable or increasing?" The objective of this report is to address this question based on data collected during the NWFP's first 25 years.

Ecological monitoring programs were established to evaluate the effectiveness of the NWFP for meeting conservation objectives and to inform management decisions (Mulder et al. 1999). Specifically, monitoring programs were established to assess the status and trends of six parameters: (1) late-successional and old-growth forests, (2) northern spotted owl habitat and populations, (3) murrelet habitat and populations, (4) federal agency relationships with American Indian tribes, (5) watershed conditions, and (6) socioeconomic conditions.

Although the murrelet is a seabird that spends most of its time living and foraging in coastal marine waters, it was selected for monitoring because it is dependent on late-successional and old-growth forests for nesting (Madsen et al. 1999, Raphael et al. 2014). The murrelet nests mostly on large branches or other suitable platforms in large coniferous trees (Nelson 1997, Ralph et al. 1995). The amount and distribution of nesting habitat is key to murrelet conservation (Piatt et al. 2007; Ralph et al. 1995; Raphael 2006; Raphael et al. 2016a; USFWS 1997, 2009, 2019). Timber harvesting has reduced historical old-growth forests to only a small percentage (5 to 20 percent, depending on region) of their original extent (Morrison 1988; Norheim 1996, 1997). Most terrestrial habitat that remains consists of fragmented patches in national forest wilderness areas, national and state parks, and reserves (Lorenz et al. 2021.). The NWFP identified goals for murrelet nesting habitat including providing substantially more suitable habitat for murrelets than existed at the start of the plan, providing larger contiguous blocks of murrelet nesting habitat, and increasing or maintaining the geographic distribution of populations and terrestrial habitat (Madsen et al. 1999). Monitoring murrelet population trends will indicate whether the NWFP is successfully providing nesting habitat to support a stable and well-distributed murrelet population (Madsen et al. 1999). Lorenz et al. (2021) provides results from the NWFP monitoring of nesting habitat.

Murrelet monitoring for the NWFP has both habitat and population components (Madsen et al. 1999). For habitat monitoring, the approach is to establish a baseline level of nesting habitat by first modeling habitat relationships, and then comparing a more recent estimate to the baseline (Huff et al. 2006; Lorenz et al. 2021; Raphael et al. 2006, 2011, 2016a). At-sea abundance is monitored using a unified sampling design and standardized survey methods (Falxa et al. 2016; Miller et al. 2006, 2012; Raphael et al. 2007; also, see this report). Thus, trends in both murrelet nesting habitat and abundance at sea are tracked through time. The ultimate goal is to relate abundance trends to the amount and distribution of nesting habitat (Madsen et al. 1999, Raphael et al. 2015).

What Is New Since the 20-Year Report?

In this report, the status and trend analyses incorporate several more years of sampling data, through 2017 and 2018. Survey methods changed in 2014; specifically, a reduced sampling-effort design was implemented, as follows: Conservation Zones 1 and 3 are sampled in even years (e.g., 2016, 2018); Conservation Zones 2 and 4 are sampled in odd years; and Conservation Zone 5 is sampled every fourth year, in conjunction with Conservation Zone 4. As a result of this survey methodology change, our statistical methods for evaluating status and trends of murrelet at-sea abundance also changed (see "Methods"). With less frequent sampling, it will take longer to detect trend changes at both the conservation zone scale and the entire NWFP study area. Note that if changes in trend result from movement of murrelets among conservation zones in a particular year, this may be missed or difficult to assess using the every-other-year sampling strategy because of the spatial distribution of sampling relative to potential bird movements.

Methods

Sampling Design

The objectives of our murrelet population monitoring are to estimate at-sea abundance and trends in coastal waters adjacent to the NWFP area, which extends from the U.S. border with British Columbia south to San Francisco Bay, California (fig. 1). The NWFP area encompasses five of the six murrelet conservation zones (sampling strata) designated by the Marbled Murrelet Recovery Plan (USFWS 1997). Conservation Zone 6, including San Mateo and Santa Cruz Counties in central California, is not in the NWFP area; populations in Conservation Zone 6 have been monitored by a variety of research entities, most recently by the U.S. Geological Survey (Felis et al. 2019).

The target population is also defined by the area of navigable waters within 3 to 8 km of shore (distance varies by conservation zone), and temporally from mid-May through the end of July, when breeding murrelets at sea are likely to be associated with inland nesting habitat. The total area of coastal waters within this area and containing the target population is about 8785 km^2. Within each conservation zone (fig. 1), two or three geographic strata were designated based on patterns of murrelet density at sea (Miller et al.

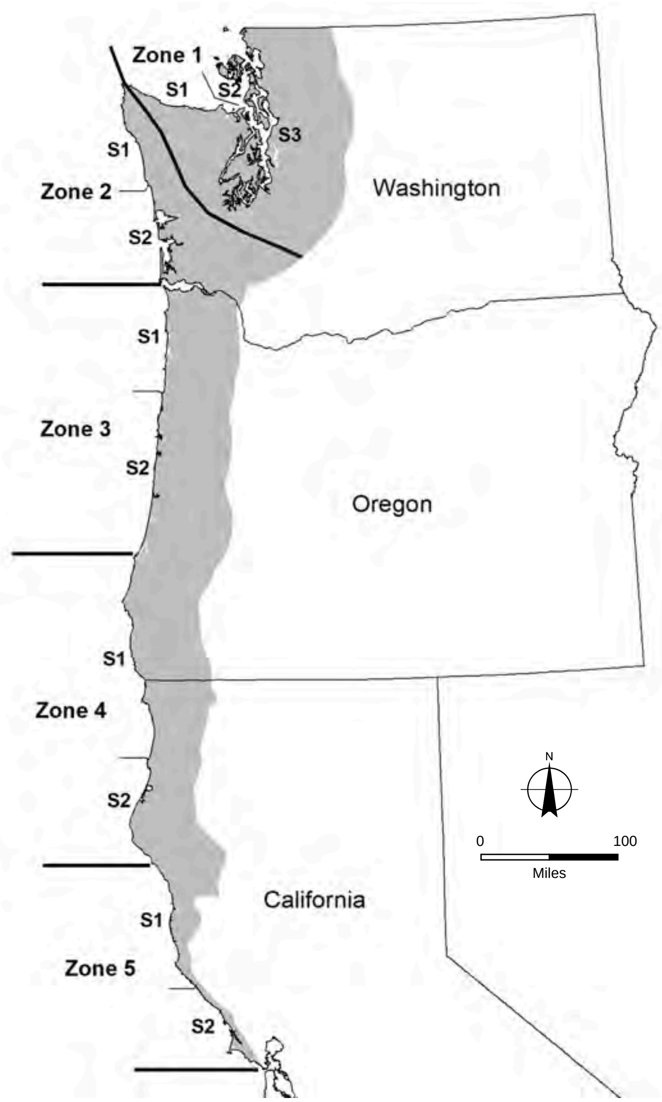

Figure 1—The five at-sea marbled murrelet survey (conservation) zones, and strata within zones adjacent to the Northwest Forest Plan (NWFP) area. The shaded area corresponds to the overlap between the NWFP area and the approximate breeding distribution of the murrelet.

2006, Raphael et al. 2007). The distance from shore of the offshore boundary among target populations varied among conservation zones and strata and was selected in each area to capture at least 95 percent of the murrelets on the water (Bentivoglio et al. 2002, Miller et al. 2006, 2012, Raphael et al. 2007). Sampling was designed to allocate more effort to strata with greater murrelet densities (Raphael et al. 2007).

Although the NWFP was implemented in 1994, it took several years to develop a monitoring plan and sampling design. After completion of the monitoring plan for murrelets (Madsen et al. 1999), at-sea abundance monitoring began in 2000, with the exception of Conservation Zones 1 and 2 (start year 2001). To assess murrelet density and abundance within each conservation zone and stratum, we established primary sampling units (PSUs) that are roughly rectangular areas with about 20 km of coastline that are contiguous throughout the entire sampling area. PSUs and strata boundaries remained constant throughout the sampling period. Each conservation zone includes 14 to 22 unique PSUs, except for Conservation Zone 1, where the complex shoreline of the Puget Sound area resulted in 98 PSUs. Conservation Zones 2 through 5 received 30 PSU surveys per conservation zone per year; most or all unique PSUs in these conservation zones were sampled each year. Sampling generally was distributed broadly within each conservation zone and throughout the duration of the sampling period, with the exception of Conservation Zone 2 Stratum 2 and Conservation Zone 5. In these regions with low murrelet density, sampling was limited to one or two survey trips per year. In Conservation Zone 1, an initial sample of 30 PSUs was randomly selected out of the 98 available PSUs, and each selected PSU was sampled twice each year for a total of 60 samples per year in this conservation zone (Raphael et al. 2007). This same random PSU selection for Conservation Zone 1 was then sampled each year to increase precision of the annual trend estimate rather than selecting a new random sample every year. In Conservation Zone 5, the target sample was reduced to 15 PSUs in 2004 to balance logistics, cost, and precision in this area with few murrelets. Conservation Zone 5 was not sampled in 2006, 2009, 2010, 2012, 2014, 2015, or 2016 due to funding limitations and the reduced effort allocated to that conservation zone (see “Protocol Clarifications and Refinements”).

We divided PSUs into inshore and offshore subunits (fig. 2) in order to allocate more sampling effort and minimize variance in inshore subunits where murrelet density is generally greater (Bentivoglio et al. 2002). PSUs in stratum 3 of Conservation Zone 1 were not divided into subunits, as the convoluted inland waterways of Puget Sound were not feasible to designate an ”offshore” subunit and in some cases, there was little distance between opposite shorelines in the narrow inlets and fjord-like portions of Puget Sound and a zigzag transect was used (Raphael et al. 2007).

Inshore PSU subunits generally have greater murrelet densities, so they were sampled with more effort using transects placed parallel to shore. Offshore PSU subunit transects were oriented diagonally to the shoreline, often in a zigzag configuration (fig. 2) to sample across the gradient of murrelet density that, generally, declines with distance from shore (Ralph and Miller 1995; Strong 2015, 2016). PSU sampling details for each conservation zone and stratum are summarized in Raphael et al. (2007).

We used two observers for each survey, one on each side of the boat’s centerline, each surveying a 90-degree arc to the left or right of the bow, but emphasizing search effort within the area in front of the boat (within 45° of transect line) to reduce the risk of missing birds located near the transect line (Raphael et al. 2007). We estimated murrelet density using line transect methods and distance sampling methodology (Buckland et al. 2001, 2004; Thomas et al. 2004), where the perpendicular distance from the transect line to each detected murrelet (flying or on-water) or group of murrelets was estimated to the nearest 1 m. Observers were in audio communication throughout all surveys, avoiding double counting or missed records of detection. Vessel speed was maintained at 8 to 12 knots and was reduced to the lower end of this range in areas of high bird densities or when observing conditions were compromised.

In Conservation Zone 1, a 5.2-m Boston Whaler survey vessel was used from 2000 to 2012. Thereafter, a 7.9-m aluminum boat was used, the same as has been used in Conservation Zone 2 since 2001. In Conservation Zones 3, 4, and 5, a 6.4-m Boston Whaler has been used since the inception of the project. The second Washington vessel was larger and observers stood higher in relation to the water surface, likely

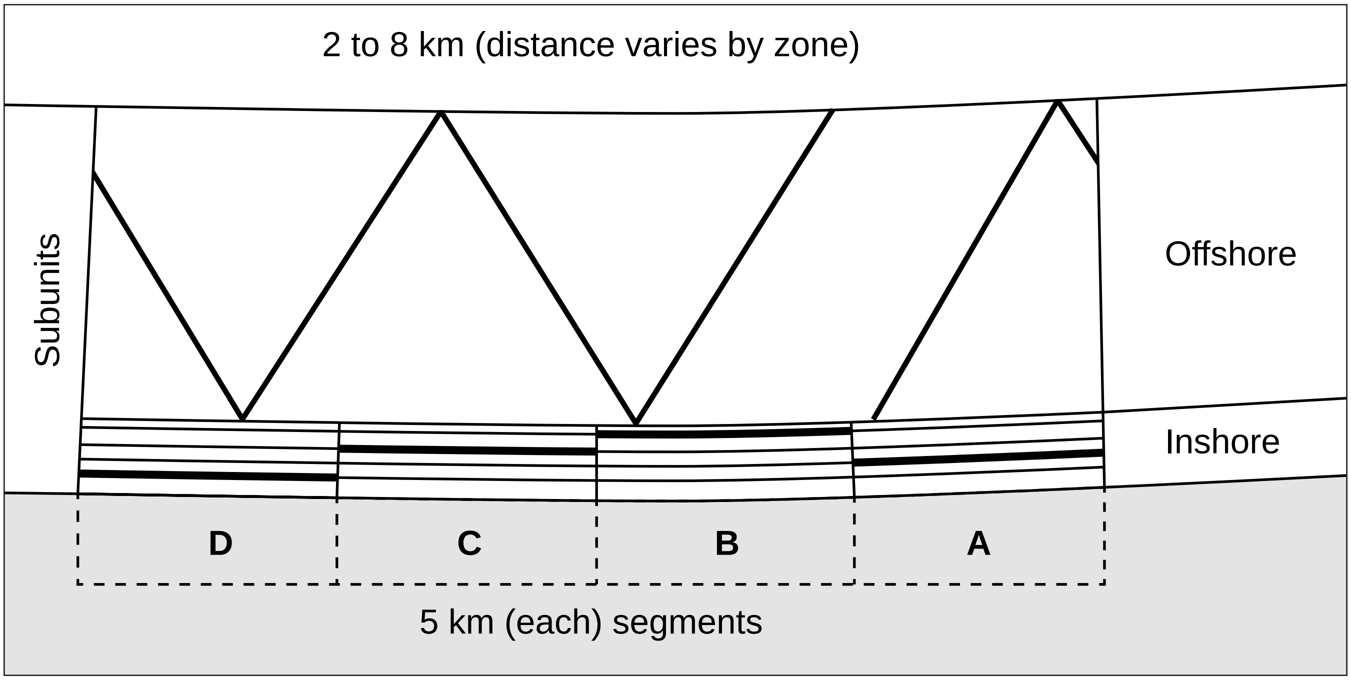

Figure 2—Example of marbled murrelet primary sampling unit with inshore and offshore subunits showing parallel and zigzag transects. The inshore subunit is divided into four equal-length segments (about 5 km each) and four equal-width bins (bands parallel to and at increasing distances from shore). One bin is randomly selected without replacement (depicted by heavier line) for each segment of transect in the inshore subunit, and the starting point of the offshore subunit is selected at random.

improving detectability of small birds, particularly on the open coast where swell can conceal birds from observers positioned at a lower elevation. Although we acknowledge the likelihood of differential detectability based on observer height, the same platform elevation within conservation zones has been consistent throughout the time series. The exception to this was in the inland waters of Conservation Zone 1 where a higher platform has been used since 2012. Because sea conditions are generally much better in this conservation zone and ocean swells are minimal, we considered this factor to be negligible regarding detectability of murrelets.

Accuracy of straight-line distance estimates is key for density estimates using distance sampling methods. Distance training and calibration occurred regularly throughout the season to maintain consistency in distance estimates among observers and across years. Quality assurance tests were repeated throughout the entire survey period testing each observers' ability to accurately estimate distances to buoy targets which were measured with a laser rangefinder (Raphael et al. 2007). Observers made a set of 5 to 10 estimates of perpendicular distance to targets, and the observer's results were assessed; if all estimates were within 15 percent of the actual distance, the trial was complete for that observer (Raphael et al. 2007). If any of the five estimates were not within 15 percent of actual distance, the observer continued to conduct estimates in sets of five until all estimated distances were within 15 percent of the actual distance. Because surface waves can obscure murrelets on the water, observers noted sea state using the Beaufort scale. The Beaufort scale is an empirical measure that relates windspeed to observed conditions at sea, ranging from a value of zero (calm, flat sea conditions) to 12 (hurricane force winds). Surveys were nearly always conducted in Beaufort 2 or less per our protocol (Raphael et al. 2007). Portions of surveys were rarely conducted in Beaufort 3 conditions, and such portions of surveys had to account for less than a third of a PSU for the survey to be valid. Description of the complete survey protocol is provided in Raphael et al. (2007) and in Miller et al. (2006). Minor adjustments to the survey protocol are described below (see "Protocol

Clarifications and Refinements”). In addition to recording all murrelet detections, observers also recorded other seabirds and marine mammals detected during sampling.

Using this protocol, we conducted at-sea abundance surveys in the five conservation zones beginning in 2000 and sampled all conservation zones (except Conservation Zone 5) in each year between 2000 and 2013. Surveys were initiated every other year starting in 2014 in Conservation Zones 3 and 4 and starting in 2016 for Conservation Zones 1 and 2. Prior to reducing our survey effort in 2014, we conducted a mean of 167 PSU sampling surveys throughout all conservation zones combined (range 146 to 200), with a mean transect effort of 5960 km per year (range 5,430 to 6,630) (table 1). As a result of the reduced survey effort being fully implemented in 2016, we conducted a mean of 86 PSU surveys with a mean transect effort of 3110 km (table 1).

Analysis

Density and abundance estimates—
Departures from the protocol in Conservation Zones 1 and 2 in 2000 likely affected density estimates for those conservation zones (Miller et al. 2012). Therefore, we used data from only 2001 through 2018 for all estimates and analyses involving these conservation zones, namely those for Conservation Zone 1, Conservation Zone 2, Washington State, and “All-Zones” (the five conservation zones combined). Because Conservation Zone 5 was not sampled in eight of the years (2006, 2009, 2010, 2012, 2014-2016, 2018), we used density estimates from the most recent year of Conservation Zone 5 survey results.

For each year of survey, we estimated average murrelet density (murrelets per square kilometer), with an associated estimate of precision for each conservation zone, for the entire target population, and for the three states within

Table 1—Number of primary sampling unit (PSU) surveys completed for the Northwest Forest Plan, and the total kilometers of survey transect sampled from 2000 to 2018

Year	Zone	Number of PSU surveys	Survey effort
			Kilometers
2000	1	N/A	N/A
	2	N/A	N/A
	3	24	1002
	4	57	1493
	5	29	792
2001	1	60	2158
	2	23	1039
	3	27	1067
	4	54	1421
	5	22	602
2002	1	60	2228
	2	27	983
	3	31	1239
	4	56	1397
	5	26	705
2010	1	60	2246
	2	30	1342
	3	30	1169
	4	26	676
	5	No surveys	
2011	1	60	2222
	2	30	1356
	3	31	1201
	4	33	840
	5	16	469
2012	1	60	2231
	2	34	1567
	3	29	1168
	4	27	702
	5	No surveys	

Table 1—Number of primary sampling unit (PSU) surveys completed for the Northwest Forest Plan, and the total kilometers of survey transect sampled from 2000 to 2018 (continued)

Year	Zone	Number of PSU surveys	Survey effort	Year	Zone	Number of PSU surveys	Survey effort
			Kilometers				*Kilometers*
2003	1	60	2210	2013	1	60	2246
	2	35	1359		2	30	1361
	3	30	1132		3	29	1159
	4	55	1418		4	31	808
	5	19	508		5	15	454
2004	1	57	2133	2014	1	60	2243
	2	30	1375		2	29	1357
	3	30	1188		3	31	1193
	4	32	836		4	No surveys	
	5	16	412		5	No surveys	
2005	1	60	2234	2015	1	60	2245
	2	26	1136		2	29	1354
	3	28	1108		3	No surveys	
	4	31	812		4	37	960
	5	15	432		5	No surveys	
2006	1	60	2230	2016	1	60	2019
	2	29	1300		2	No surveys	
	3	31	1185		3	32	1295
	4	30	776		4	No surveys	
	5	No surveys			5	No surveys	
2007	1	60	2213	2017	1	No surveys	
	2	31	1429		2	30	1360
	3	30	1151		3	No surveys	
	4	29	750		4	32	824
	5	14	423		5	13	395
2008	1	60	2235	2018	1	60	2186
	2	31	1441		2	No surveys	
	3	30	1122		3	32	1269
	4	31	802		4	No surveys	
	5	13	385		5	No surveys	
2009	1	60	2230				
	2	31	1380				
	3	31	1111				
	4	35	912				
	5	No surveys					

Note: Numbers in some years may differ slightly from those in summary reports as a result of additional data quality reviews performed in 2019. N/A = not applicable.

the area sampled. We used the software program DISTANCE version 6.2 (Thomas et al. 2010) to estimate the probability of detecting a murrelet that is present at distance zero [$f(0)$] and the mean number of murrelets per group [or mean cluster size; $E(s)$] for each year and conservation zone from inshore and offshore subunit surveys. We truncated the distance data prior to analysis by discarding the 5 percent of observations with the greatest distances for each conservation zone, which can improve modeling of detection functions, as recommended by Buckland et al. (2001). We set DISTANCE to use the mean observed cluster size as the estimate for E(s) unless an internal test found evidence that detection is a function of cluster size, in which case DISTANCE applied a correction (Buckland et al. 2001). For each year, the data from Conservation Zones 4 and 5 were combined for estimating the detection function, $E(s)$, $f(0)$, and truncation distance. We did this because the low number of murrelet detections in Conservation Zone 5 were insufficient for estimating these parameters. DISTANCE also provided the number of groups of murrelets observed per kilometer (ER = encounter rate) for each PSU subunit survey. We then estimated density (murrelets per square kilometer) for each PSU subunit survey (Raphael et al. 2007) using the estimates and encounter rate from DISTANCE with the following formula:

$$\hat{d} = 1000 \cdot \hat{f}(0) \cdot \hat{E}(s) \cdot \frac{ER}{2}$$

Where $\hat{f}(0)$ is the value of the probability density function of observing a cluster of birds zero meters from the transect line. That function is either a half-normal or uniform key function with a cosine adjustment chosen using the Akaike information criterion (Buckland et. al. 2001). The “hats” over the letters designate estimates. Strata, conservation zone, and all-zones density estimates were constructed from average densities weighted by the area of the respective geographic scale.

Target abundance estimates for each conservation zone and for the five conservation zones combined (All-Zones) were produced using standard methods for stratified sampling (Cochran 1977, Sokal and Rohlf 1981). We used the total area within each stratum to expand the density estimates from DISTANCE, and associated estimates of precision, to calculate the average numbers of murrelets by conservation zone, state, and for all conservation zones combined for the target period. Estimates of precision were produced using bootstrap resampling methods with consideration of PSU samples that might be clustered in time or space (Miller et al. 2006, Raphael et al. 2007). Density and abundance estimates were equivalent for purposes of trend analysis because the total area (area sampled) was constant over the study for all conservation zones, and because abundance is simply a multiple of density. Details on methods used to calculate abundance estimates and confidence intervals are provided in Raphael et al. (2007).

To portray variation in at-sea density at a finer spatial scale, we obtained a mean density at the PSU scale by first averaging the annual density for each PSU at two scales: the entire PSU, and for the separate inshore and offshore subunits. We then calculated the mean density for each PSU and its subunits by averaging the annual values throughout the sample period.

Estimating trends—

We tested for linear trends in murrelet density in the NWFP area from 2000 through 2018, excluding the year 2000 from analyses that involved Conservation Zones 1 and 2, as previously noted. We estimated trends for each conservation zone, for All-Zones, and for each state. For Conservation Zone 5, the single-conservation zone trend analysis used data just from years with surveys from 2000 through 2018; for the All-Zones and California analyses, we used the most recent year of Conservation Zone 5 densities for the years not sampled (2006, 2009, 2010, 2012, 2014, 2015, 2016, and 2018). Because Conservation Zone 5 supported less than 1 percent of the target population for all years prior to 2017, missing data had very little effect on population estimates and no measurable influence on trend magnitude or significance for those years.

We fit a linear regression to the natural logarithm of annual density estimates to test for trends in individual Conservation Zones 1 through 5 and in All-Zones. We tested the null hypothesis that the slope was not different from zero against the alternate hypothesis that the slope was greater than zero (increasing murrelet density) or the slope was less than zero (decreasing murrelet density) (i.e., a two-tailed test for detecting change in murrelet densities). In a model where the percentage of change for a conservation zone, state, or All Zones ”*r*” is constant from year to year, and *d* represents the murrelet density estimate in a given year:

$$d_{Year} = d_{2000} \times \left(1 + \frac{r}{100}\right)^{\text{Year-2000}} \times e^{\text{error}}$$

and when we take the natural logarithm of both sides, we end up with a standard linear model:

$$\hat{d}_{All} = \frac{\sum_{z=1}^{5} \hat{d}_z a_z}{\sum_{z=1}^{5} a_z}$$

where *a* and *b* are constants to be estimated and error ~ $N(0,\sigma^2)$. Under such a model the percentage of change from year to year is constant and is equal to $r = 100(e^b - 1)$.

To evaluate the evidence for a linear trend, we considered (1) the magnitude of the annual trend estimate, particularly in relation to zero, where zero represents a stable population; and (2) the width and location of the 95 percent confidence intervals surrounding that trend estimate, also in relation to zero. The evidence for a population trend, versus a stable population, is stronger when the trend estimate and its 95 percent confidence interval do not overlap zero, and when the trend estimate is farther from zero. When the confidence interval of a trend estimate is tight around zero, then we would conclude that there is no evidence of a trend. Finally, when the confidence interval of a trend estimate broadly overlaps zero and the trend estimate is not close to zero, this indicates evidence that is not conclusive for or against a nonzero trend. Confidence intervals that are mainly above or below zero, but slightly overlap zero, provide evidence of a trend.

Protocol Clarifications and Refinements

The field and analytical methods used in the murrelet population monitoring have been presented in detail elsewhere (Raphael et al. 2007). Variation in field methodology during 2000 to 2013 are detailed in the 20-year report (Falxa et al. 2016). No additional changes were made to field methods during 2014 to 2018.

Estimates of abundance and trend at the state scale—
To estimate murrelet abundance and trend at the state scale, we used the same analytic approach as described above, except that we calculated average annual murrelet densities for each of the three states within the sample area: Washington, Oregon, and California. We calculated average densities by weighting the murrelet density for each conservation zone, or portion thereof, within a state, by the area of coastal waters sampled within that conservation zone or portion of conservation zone. For Washington, this involved the weighted average density for Conservation Zones 1 and 2. The Oregon estimate averaged the density for Conservation Zone 3 and the portion of Conservation Zone 4 within Oregon (PSUs 1 through 9; PSU 9 spans the Oregon-California border, but is predominately in Oregon). The California estimate averaged the density for the California portion of Conservation Zone 4 (PSUs 10 through 22) and all of Conservation Zone 5. Our California estimate does not include murrelets occurring in Conservation Zone 6 (south of the Golden Gate Bridge of San Francisco Bay), because Conservation Zone 6 is outside of the NWFP area, and thus is not sampled by this program.

Because surveys are no longer conducted every year in every conservation zone, estimates of abundances and densities for Washington, Oregon, California, and All-Zones are only produced for the year immediately preceding the current year. For example, to estimate the murrelet density for Oregon in 2017, Conservation Zone 3 was surveyed in 2016 and 2018, which were averaged to obtain a 2017 density estimate. The resulting density is then combined with the portion of Conservation Zone 4 surveyed in 2017 to obtain the Oregon 2017 estimate.

Treatment of years with no surveys in Conservation Zone 5—
Conservation Zone 5 was not surveyed in 8 years: 2006, 2009, 2010, 2012, 2014, 2015, 2016, and 2018. We instituted measures to formalize treatment of missing Conservation Zone 5 data in our analyses, which have been applied to the entire dataset. When estimating trend for Conservation Zone 5, we use only data from years with surveys. For All-Zones and California population and density estimates and trend analyses, we used the Conservation Zone 5

estimates from years that were surveyed and the most recent previous survey estimates for a year not surveyed. We estimated the All-Zones density and standard error of density using the following formulas, where a_z is the area of Conservation Zone *Z*:

$$\hat{d}_{All} = \frac{\sum_{z=1}^{5} \hat{d}_z a_z}{\sum_{z=1}^{5} a_z}$$

$$\hat{\sigma}_{All} = \frac{\sqrt{\sum_{z=1}^{5} a_z^2 \hat{\sigma}_z^2}}{\sum_{z=1}^{5} a_z}$$

Accounting for clustering of surveys when constructing confidence intervals—

For a given conservation zone and year, the different PSU samples typically show some grouping in space and time. This occurs because of practical limitations and efficiencies of conducting surveys from a limited number of coastal ports where survey vessels can be launched, compounded by weather-limiting days when surveys can be conducted. For example, PSUs 3 and 4 in Conservation Zone 3, Stratum 1 might be surveyed on the same day. We needed to account for the spatial and temporal dependence of these surveys when estimating confidence intervals. The estimates of E(*s*), f(0), truncation distance, and density presented in this report and used in all other analyses are based on the original data as described in Raphael et al. (2007), and not on bootstrap estimates. Although the bootstrap process results in estimates of parameters, truncation distance, and density, we used those estimates only to estimate confidence intervals.

These are the bootstrap analysis steps used to estimate the standard errors and confidence intervals, for each year and conservation zone:

- Within each stratum of a conservation zone, we assign labels (“clusters”) to groups of surveys close in time and space for that year. “Close” is defined as being both within three PSUs of each other spatially and surveyed within 4 or fewer days of each other temporally. This produces a set of *n* clusters for that stratum and year.
- We then randomly select *n* clusters with replacement from that set of clusters. Sampling with replacement means that any cluster might be chosen more than once or not at all for a single bootstrap selection.
- Suppose there are *k* surveys within a selected cluster. We then randomly select with replacement *k* surveys within the cluster.
- All of the observations from the selected surveys in all strata are placed in one bootstrap-created dataset which is then used to provide estimates of density, *f*(0), *E(s)*, and the truncation for the conservation zone.
- This process is repeated 1,000 times for each conservation zone for a given year.
- The standard errors of the estimates of density for each stratum and conservation zone, and for *f(0)*, *E(s)*, and the truncation distance for each conservation zone are estimated using the standard deviations of the 1,000 bootstrap estimates. As noted above, the original data are used to estimate density, The estimates of E(*s*), f(0), and truncation distance, and the bootstrap process provides only the estimates of precision for those parameter estimates.

Treatment of abbreviated PSU surveys—

The target survey effort for a PSU was occasionally not achieved because of deteriorating weather conditions, resulting in an incomplete survey. In 2004, we clarified the treatment of incomplete PSU surveys, allowing for limited use of data from such surveys. For a given conservation zone in a single year, one but not both of the following cases of incomplete survey data would be allowed for each conservation zone:

- Data from up to three incomplete PSU samples could be used, providing that no more than 25 percent of the total transect length was missing from any PSU sample, and that no PSU would have more than one incomplete survey; or
- Data can be used from one PSU sample with up to 50 percent of either the total inshore or offshore segment length missing.

For any incomplete survey used, the survey length is adjusted in the analyses to match the actual transect length. Surveys not meeting the above criteria were discarded from all analyses.

In addition, effective in 2004, data for a single PSU sample must be collected within a single day. Prior to 2004, sampling effort for a single PSU sample was occasionally conducted over two days, with the inshore subunit sampled one day, and the offshore subunit sampled on a second day.

Minimum visibility conditions for conducting surveys—
Fog is a common feature of coastal waters, and can limit surveyor visibility of murrelets. Effective since 2011, we adopted a rule to conduct surveys only when conditions permit a surveyor to see a murrelet at 150 m. Murrelets beyond this distance have little effect on density or population estimates, in part owing to the truncation that occurs in program distance. Previously, the minimal visibility distance was not standardized, and varied from 100 to 200 m, depending on conservation zone.

Comprehensive review of data—
In 2014, we developed and implemented a new, automated procedure to screen all data from 2000 through 2013, as an improved data quality assurance process. This procedure improved our ability to detect potential data inconsistencies, such as might have occurred during data entry or transcription by the different field crews and data managers, and employs cross-referencing between and within database fields, as well as screening for values that are outside of the range of values normally observed for a given data field.

In 2018, a review of the data revealed a few inconsistencies. Each problematic data line identified by this process was manually reviewed by the individual(s) responsible for gathering the data, and original field data forms and records were consulted as needed. We corrected any errors found and created a new database which was the basis for all population density and trend analyses presented in this report. Although the corrections represent a very small percentage of data records, they did affect several years, and some density and trend estimates presented here differ slightly from versions prior to 2018, including those in Falxa et al. (2016).

Field audit form—
As part of the field observer training, the methods (Raphael et al. 2007: 12) call for one of the crew supervisors for a given conservation zone to accompany survey crews three times during the survey season to assess adherence to established protocols and the crew's ability to detect murrelets. To assist in conducting audits of crews, we developed a field audit form (app. B in Falxa et al. 2016). The survey leader for each conservation zone conducted audits of crews in their conservation zone each season, and the monitoring program coordinator (i.e., Falxa in 2014 and 2015, McIver in 2017) audited crews from the different conservation zones periodically to evaluate for consistency in protocol implementation across crews and conservation zones. Audits not only evaluate consistency with protocols, they have also led to protocol clarifications, such as the minimum visibility rule discussed above.

Temporal and Spatial Variation in Murrelet Distribution as a Function of Distance From Shore

During the planning phase of the monitoring program, we subdivided each PSU into inshore and offshore subunits to allow allocation of greater sampling effort to inshore areas, where densities of murrelets tend to be greater (Raphael et al. 2007). We calculated and inspected the ratios of inshore to offshore density for each year-conservation zone combination to evaluate whether those ratios support the protocol's current allocation of greater sampling effort inshore. Ratio values >1.0 indicate a greater density of murrelets in the inshore subunits relative to the offshore.

We performed simple correlation analyses between our stratum density estimates and the ratio data over all years to see if variation in the inshore–offshore distribution could influence our density estimates. We did this to see if a shift in murrelet distribution resulted in a smaller proportion of the population occurring within our sample area, which could lead to underestimates of population size in those years. We calculated the average annual density in the inshore and offshore subunits at the stratum scale for all years of survey data through 2018. Conservation Zone 5 was excluded from this analysis because the data include many density estimates of zero. Stratum 3 of Conservation Zone 1 was also excluded from the analysis, as PSUs within this stratum do not have separate nearshore and offshore subunits.

We evaluated whether the ratio of inshore density to offshore density changed in a consistent manner over time during the years of sampling. For each PSU stratum, we visually looked for patterns suggesting a systematic change between 2000 and 2018 in murrelet distribution as a function of distance from shore. For those strata that appeared to have the potential for a trend in the ratio over time, we ran a linear regression on the ratio over time and used the R squared values to assess the strength of any relationship.

Other Piscivorous Species

While monitoring murrelets in Conservation Zone 1, we also recorded other species detected. As a result, we can examine whether the declining murrelet population trend is unique to the murrelet, or widespread among piscivorous species. For this comparison, we selected two alcid species that were also local breeders and year-round residents in this conservation zone, and that also have high dependence on small schooling pelagic fish for at least part of the year, including rhinoceros auklet (*Cerorhinca monocerata*) and pigeon guillemot (*Cepphus columba*). The analytical approach used for these species was identical to that described above for the murrelet, although the effective detection distances differed among these species.

Results

Survey Effort

Table 1 details the transect effort (kilometers) by year, conservation zone, and number of PSU surveys. An average of 5780 km of survey effort occurred from 2005 to 2013, and the average effort since 2014, when the sampling reduction occurred, was 3740 km (table 1).

Abundance Estimates

Estimates of density and abundance by conservation zone and for all conservation zones are presented by year in table 2. Among conservation zones, murrelet density varied from less than 0.03 murrelets per square kilometer in Conservation Zone 5 (year 2007) to 7.5 murrelets per square kilometer in Conservation Zone 4 (year 2015) (table 2). Population size estimates at the conservation zone scale ranged from about 30 murrelets in Conservation Zone 5 (year 2007) to about 8,700 murrelets in Conservation Zone 4 (year 2015); table 2). Conservation Zone 5 supported far fewer murrelets than any other conservation zone, with population estimates not exceeding about 250 murrelets (years 2000-13), until year 2017, when about 870 birds were estimated (table 2).

When looking at density for all conservation zones combined, the area-weighted mean murrelet density ranged from 1.89 birds per square kilometer (2010) to 2.75 murrelets per square kilometer (2015) (table 2), with corresponding at-sea abundance estimates ranging from 16,600 birds in 2010 to 24,100 birds in 2015 (table 2).

By state, murrelet density was greater off the coast of Oregon, where average density was 4.12 murrelets per square kilometer, compared to area-weighted average densities of about half this in Washington (1.6 murrelets per square kilometer) and California (about 2.4 murrelets per square kilometer) (table 3). Washington experienced a drop in density from 2.32 murrelets per square kilometer in 2002 to a low of 0.97 in 2014. Whereas, the murrelet density has increased in both Oregon and California in recent years. Washington supported the greatest number of murrelets at the beginning of the monitoring effort but had the least number of murrelets in 2017 (table 3).

Abundance Trends

For the “All-Zones” five-conservation zone area (2001 to 2017), there was a 0.3 percent increase per year with a confidence interval around zero (95 percent confidence interval: −0.9 to 1.6 percent) (table 4, figs. 3 and 4). Conservation Zone 1 declined 4.9 percent per year (2000–2018), 95 percent confidence interval: -7.3 to -2.4 percent) (table 4, figs. 3 and 4); Conservation Zone 2: declined 3.0 percent per year (2001 to 2017), 95 percent confidence interval -6.8 to 0.9 percent; Conservation Zone 3 increased 1.4 percent per year (2000 to 2018); 95 percent confidence interval: -0.4 to 3.3 percent; Conservation Zone 4 increased 3.7 percent per year (2000 to 2017), 95 percent confidence interval: 1.4 to 6.1 percent) (table 4, figs. 3 and 4); Conservation Zone 5: increased 7.3 percent per year (2000 to 2017); 95 percent confidence interval: -4.4 to 20.3 percent) (table 4, figs. 3 and 4).

We observed a 3.9 percent decrease per year (2001 to 2017) in Washington (95 percent confidence interval: -5.8 to -2.0 percent), a 2.0 percent increase per year (2000 to 2017) in Oregon (95 percent confidence interval: 0.5 to 3.6 percent), and a 4.5 percent increase per year (2000 to 2017) in California (95 percent confidence interval: 2.2 to 6.9 percent) (table 4, figs. 3 and 4).

Table 2—Marbled murrelet population estimates, 2000 to 2018[a]

						95% confidence limits					
Year	**Zone**	**Stratum**	**Density**	**CV[b]**	**Birds**	**Lower**	**Upper**	**Area**	**f(0)**	**E(s)**	**Truncation distance**
			Per square kilometer	*Percent*				*Square kilometers*			*Meters*
2000	3	All	4.129	18.6	6,587	3,987	8,756	1 595	0.0165	1.623	100
2000	3	1	1.336	32.2	883	357	1,350	661			
2000	3	2	6.104	19.6	5,704	3,296	7,608	935			
2000	4	All	4.216	30.9	4,887	3,417	9,398	1 159	0.0097	1.730	180
2000	4	1	6.024	34.0	4,420	2,931	8,784	734			
2000	4	2	1.097	32.1	467	297	881	425			
2000	5	All	0.090	80.6	79		260	883			
2000	5	1	0.179	80.6	79		260	441			
2000	5	2	0.000					441			
2001	All	All	2.531	9.8	22,337	18,038	26,635	8 826			
2001	1	All	2.553	18.0	8,936	5,740	11,896	3 501	0.0133	1.594	142
2001	1	1	4.506	23.1	3,809	2,432	5,689	845			
2001	1	2	1.764	21.4	2,111	948	2,816	1 196			
2001	1	3	2.067	37.2	3,016	404	5,003	1 459			
2001	2	All	1.241	35.3	2,094	791	3,555	1 688	0.0147	1.447	85
2001	2	1	1.976	36.4	1,436	424	2,416	727			
2001	2	2	0.685	75.7	658	131	1,674	961			
2001	3	All	4.636	13.2	7,396	5,230	9,075	1 595	0.0166	1.735	140
2001	3	1	1.724	23.0	1,140	657	1,700	661			
2001	3	2	6.695	14.1	6,257	4,241	7,814	935			
2001	4	All	3.286	22.1	3,809	3,020	6,238	1 159	0.0101	1.749	170
2001	4	1	4.570	24.9	3,353	2,497	5,781	734			
2001	4	2	1.072	7.4	456	320	896	425			
2001	5	All	0.115	39.5	102	11	177	883			
2001	5	1	0.198	173.1	87		147	441			
2001	5	2	0.032	129.1	14		57	441			
2002	All	All	2.581	11.8	22,683	17,440	27,926	8 788			
2002	1	All	2.788	21.5	9,758	5,954	14,149	3 501	0.0103	1.761	194
2002	1	1	7.207	32.8	6,092	2,716	9,782	845			
2002	1	2	1.879	26.9	2,248	909	3,309	1 196			
2002	1	3	0.972	34.7	1,419	580	2,515	1 459			
2002	2	All	1.329	25.6	2,193	828	2,978	1 650	0.0197	1.434	70
2002	2	1	2.660	27.6	1,927	688	2,705	724			
2002	2	2	0.288	39.6	267		436	926			
2002	3	All	3.583	24.1	5,716	3,674	9,563	1 595	0.0118	1.892	150
2002	3	1	0.696	34.1	460	258	886	661			
2002	3	2	5.624	24.7	5,256	3,301	8,732	935			

Table 2—Marbled murrelet population estimates, 2000 to 2018[a] (continued)

Year	Zone	Stratum	Density	CV[b]	Birds	95% confidence limits: Lower	95% confidence limits: Upper	Area	f(0)	E(s)	Truncation distance
			Per square kilometer	*Percent*				*Square kilometers*			*Meters*
2002	4	All	4.112	15.1	4,766	3,272	6,106	1 159	0.0108	1.724	175
2002	4	1	5.186	15.9	3,805	2,501	4,892	734			
2002	4	2	2.260	33.1	961	437	1,665	425			
2002	5	All	0.282	42.3	249	27	400	883			
2002	5	1	0.510	46.1	225	8	371	441			
2002	5	2	0.054	71.1	24		54	441			
2003	All	All	2.531	9.1	22,234	18,275	26,194	8 786			
2003	1	All	2.428	16.6	8,495	5,795	11,211	3 498	0.0087	1.817	300
2003	1	1	6.644	22.1	5,617	3,372	7,795	845			
2003	1	2	1.441	32.9	1,721	911	2,794	1 195			
2003	1	3	0.793	32.8	1,156	252	1,912	1 458			
2003	2	All	2.059	23.0	3,399	2,032	5,157	1 650	0.0171	1.398	80
2003	2	1	2.679	25.4	1,941	1,110	3,013	724			
2003	2	2	1.574	39.4	1,458	568	2,567	926			
2003	3	All	3.686	16.1	5,881	3,992	7,542	1 595	0.0132	1.664	130
2003	3	1	1.192	23.8	788	499	1,212	661			
2003	3	2	5.450	17.8	5,093	3,244	6,680	935			
2003	4	All	3.806	17.3	4,412	3,488	6,495	1 159	0.0086	1.704	180
2003	4	1	4.960	19.7	3,640	2,622	5,392	734			
2003	4	2	1.816	27.2	773	557	1,424	425			
2003	5	All	0.055	61.1	48		85	883			
2003	5	1	0.109	61.1	48		85	441			
2003	5	2	0.000					441			
2004	All	All	2.455	10.5	21,572	17,144	26,000	8 786			
2004	1	All	1.562	22.0	5,465	2,921	7,527	3 498	0.0108	1.789	280
2004	1	1	3.833	30.0	3,241	1,365	4,845	845			
2004	1	2	1.513	25.4	1,807	1,042	2,777	1 195			
2004	1	3	0.286	60.0	417		727	1 458			
2004	2	All	1.823	27.0	3,009	1,669	4,634	1 650	0.0115	1.411	115
2004	2	1	3.373	33.4	2,444	1,217	4,093	724			
2004	2	2	0.611	25.0	565	314	841	926			
2004	3	All	5.051	13.7	8,058	5,369	9,819	1 595	0.0141	1.697	110
2004	3	1	1.721	20.7	1,137	707	1,732	661			
2004	3	2	7.405	15.1	6,921	4,278	8,564	935			
2004	4	All	4.272	26.9	4,952	3,791	9,021	1 159	0.0093	1.700	200
2004	4	1	5.331	32.2	3,911	2,729	7,732	734			
2004	4	2	2.447	43.5	1,041	608	2,421	425			

Table 2—Marbled murrelet population estimates, 2000 to 2018[a] (continued)

Year	Zone	Stratum	Density	CV[b]	Birds	95% confidence limits Lower	95% confidence limits Upper	Area	f(0)	E(s)	Truncation distance
			Per square kilometer	*Percent*				*Square kilometers*			*Meters*
2004	5	All	0.099	60.5	88	18	214	883			
2004	5	1	0.091	64.5	40		104	441			
2004	5	2	0.107	93.6	47		137	441			
2005	All	All	2.300	10.7	20,209	15,976	24,442	8 785			
2005	1	All	2.275	20.5	7,956	4,900	11,288	3 497	0.0156	1.758	150
2005	1	1	2.501	37.7	2,114	698	3,661	845			
2005	1	2	2.426	25.4	2,895	1,186	4,210	1 194			
2005	1	3	2.021	30.1	2,947	1,198	5,019	1 458			
2005	2	All	1.561	20.4	2,576	1,675	3,729	1 650	0.0136	1.418	130
2005	2	1	2.785	19.1	2,018	1,233	2,764	724			
2005	2	2	0.603	56.7	558	166	1,461	926			
2005	3	All	3.669	16.9	5,854	3,580	7,447	1 595	0.0127	1.841	150
2005	3	1	0.808	32.2	534	269	962	661			
2005	3	2	5.693	17.8	5,320	3,156	6,760	935			
2005	4	All	3.169	23.6	3,673	2,740	6,095	1 159	0.0108	1.518	170
2005	4	1	4.487	25.5	3,292	2,329	5,562	734			
2005	4	2	0.895	42.1	381	243	901	425			
2005	5	All	0.169	31.8	149	69	251	883			
2005	5	1	0.141	48.1	62	8	121	441			
2005	5	2	0.197	39.7	87	36	156	441			
2006	All	All	2.087	8.2	18,335	15,395	21,275	8 785			
2006	1	All	1.687	18.1	5,899	4,211	8,242	3 497	0.0138	1.765	139
2006	1	1	2.760	16.3	2,333	1,628	3,182	845			
2006	1	2	1.418	24.9	1,693	777	2,551	1 194			
2006	1	3	1.284	40.4	1,873	595	3,440	1 458			
2006	2	All	1.443	18.0	2,381	1,702	3,433	1 650	0.0130	1.567	107
2006	2	1	2.261	19.9	1,638	1,038	2,372	724			
2006	2	2	0.802	34.0	743	380	1,344	926			
2006	3	All	3.731	12.7	5,953	4,546	7,617	1 595	0.0114	1.814	145
2006	3	1	1.034	29.6	684	352	1,070	661			
2006	3	2	5.638	14.1	5,269	3,886	6,827	935			
2006	4	All	3.410	14.9	3,953	3,164	5,525	1 159	0.0106	1.622	150
2006	4	1	4.821	15.5	3,538	2,698	4,894	734			
2006	4	2	0.977	47.8	416	209	981	425			
2006	5	Not surveyed. Interpolated estimate used for All Zone calculation.									

Table 2—Marbled murrelet population estimates, 2000 to 2018[a] (continued)

Year	Zone	Stratum	Density	CV[b]	Birds	95% confidence limits Lower	95% confidence limits Upper	Area	f(0)	E(s)	Truncation distance
			Per square kilometer	*Percent*				*Square kilometers*			*Meters*
2007	All	All	1.971	13.7	17,317	12,654	21,980	8 785			
2007	1	All	1.997	24.2	6,985	4,148	10,639	3 497	0.0117	1.642	378
2007	1	1	3.445	27.6	2,912	1,025	4,392	845			
2007	1	2	1.218	21.9	1,453	708	1,993	1 194			
2007	1	3	1.796	51.3	2,620	206	5,629	1 458			
2007	2	All	1.536	26.7	2,535	1,318	3,867	1 650	0.0135	1.496	126
2007	2	1	2.851	32.0	2,065	964	3,336	724			
2007	2	2	0.508	25.5	470	234	666	926			
2007	3	All	2.518	19.8	4,018	2,730	5,782	1 595	0.0106	1.653	150
2007	3	1	0.526	58.5	348	26	744	661			
2007	3	2	3.927	20.4	3,670	2,525	5,378	935			
2007	4	All	3.234	34.8	3,749	2,659	7,400	1 159	0.0106	1.607	180
2007	4	1	4.730	37.5	3,470	2,329	7,025	734			
2007	4	2	0.655	36.9	279	146	549	425			
2007	5	All	0.033	37.7	30		49	883			
2007	5	1	0.067	37.7	30		49	441			
2007	5	2	0.000					441			
2008	All	All	2.064	8.9	18,134	14,983	21,284	8 785			
2008	1	All	1.344	17.6	4,699	3,000	6,314	3 497	0.0109	1.739	206
2008	1	1	3.572	25.1	3,019	1,439	4,472	845			
2008	1	2	0.899	27.6	1,073	580	1,640	1 194			
2008	1	3	0.416	30.8	607	288	970	1 458			
2008	2	All	1.169	22.1	1,929	1,164	2,868	1 650	0.0112	1.535	187
2008	2	1	2.584	22.4	1,872	1,132	2,801	724			
2008	2	2	0.062	49.1	57		116	926			
2008	3	All	3.857	14.7	6,153	4,485	8,066	1 595	0.0113	1.750	130
2008	3	1	0.337	28.4	223	107	353	661			
2008	3	2	6.345	15.3	5,930	4,233	7,816	935			
2008	4	All	4.560	17.9	5,285	3,809	7,503	1 159	0.0100	1.705	200
2008	4	1	6.386	19.5	4,685	3,167	6,687	734			
2008	4	2	1.410	39.0	600	302	1,195	425			
2008	5	All	0.076	48.1	67	9	132	883			
2008	5	1	0.065	60.1	29		81	441			
2008	5	2	0.087	70.3	38		68	441			
2009	All	All	1.963	10.6	17,246	13,656	20,836	8 785			
2009	1	All	1.608	21.2	5,623	3,786	8,497	3 497	0.0094	1.694	254

Table 2—Marbled murrelet population estimates, 2000 to 2018[a] (continued)

						95% confidence limits					
Year	Zone	Stratum	Density	CV[b]	Birds	Lower	Upper	Area	f(0)	E(s)	Truncation distance
			Per square kilometer	*Percent*				*Square kilometers*			*Meters*
2009	1	1	3.811	27.7	3,221	1,777	5,107	845			
2009	1	2	0.689	26.3	822	489	1,302	1 194			
2009	1	3	1.083	42.9	1,580	410	3,299	1 458			
2009	2	All	0.770	21.7	1,271	800	1,902	1 650	0.0092	1.469	191
2009	2	1	1.621	23.7	1,175	695	1,796	724			
2009	2	2	0.105	61.7	97		206	926			
2009	3	All	3.696	17.7	5,896	3,898	7,794	1 595	0.0131	1.696	120
2009	3	1	0.650	42.5	430	187	893	661			
2009	3	2	5.849	19.0	5,467	3,339	7,250	935			
2009	4	All	3.786	19.9	4,388	3,599	6,952	1 159	0.0100	1.661	150
2009	4	1	5.304	20.9	3,892	3,031	6,170	734			
2009	4	2	1.167	67.3	497	244	1,390	425			
2009	5	Not surveyed. Interpolated estimate used for All Zone calculation.									
2010	All	All	1.889	11.1	16,595	12,969	20,220	8 785			
2010	1	All	1.256	20.0	4,393	2,719	6,207	3 497	0.0100	1.717	200
2010	1	1	2.004	26.8	1,694	957	2,712	845			
2010	1	2	1.783	23.6	2,128	1,021	3,052	1 194			
2010	1	3	0.391	43.1	571	62	1,142	1 458			
2010	2	All	0.779	25.5	1,286	688	1,961	1 650	0.0114	1.582	145
2010	2	1	1.336	23.8	968	552	1,439	724			
2010	2	2	0.343	71.9	318		784	926			
2010	3	All	4.503	16.7	7,184	4,453	9,425	1 595	0.0138	1.770	160
2010	3	1	1.071	50.1	708	239	1,354	661			
2010	3	2	6.930	17.7	6,476	3,691	8,468	935			
2010	4	All	3.162	28.5	3,665	2,248	6,309	1 159	0.0120	1.624	165
2010	4	1	3.774	34.3	2,769	1,463	5,087	734			
2010	4	2	2.106	36.3	896	431	1,700	425			
2010	5	Not surveyed. Interpolated estimate used for All Zone calculation.									
2011	All	All	2.501	12.6	21,972	16,566	27,378	8 785			
2011	1	All	2.055	17.4	7,187	4,807	9,595	3 497	0.0089	1.666	289
2011	1	1	5.580	20.3	4,717	2,621	6,399	845			
2011	1	2	1.243	23.7	1,484	790	2,147	1 194			
2011	1	3	0.676	65.8	986	206	2,384	1 458			

Table 2—Marbled murrelet population estimates, 2000 to 2018[a] (continued)

						95% confidence limits					
Year	**Zone**	**Stratum**	**Density**	**CV[b]**	**Birds**	**Lower**	**Upper**	**Area**	**f(0)**	**E(s)**	**Truncation distance**
			Per square kilometer	*Percent*				*Square kilometers*			*Meters*
2011	2	All	0.721	33.4	1,189	571	2,106	1 650	0.0110	1.496	161
2011	2	1	1.314	30.8	952	400	1,572	724			
2011	2	2	0.256	102.0	237	38	772	926			
2011	3	All	4.661	16.3	7,436	5,067	9,746	1 595	0.0126	1.678	120
2011	3	1	0.980	38.6	648	343	1,455	661			
2011	3	2	7.264	17.4	6,788	4,304	9,054	935			
2011	4	All	5.196	34.9	6,023	2,782	10,263	1 159	0.0122	1.644	145
2011	4	1	6.724	42.2	4,933	1,643	8,767	734			
2011	4	2	2.561	47.3	1,090	592	2,472	425			
2011	5	All	0.155	53.0	137	16	295	883			
2011	5	1	0.243	64.8	107	5	259	441			
2011	5	2	0.068	78.8	30		66	441			
2012	All	All	2.400	11.3	21,086	16,401	25,770	8 785			
2012	1	All	2.414	20.7	8,442	5,090	12,006	3 497	0.0109	1.847	164
2012	1	1	7.166	24.4	6,056	3,289	8,823	845			
2012	1	2	1.507	30.4	1,799	812	2,892	1 194			
2012	1	3	0.402	48.1	587	168	1,227	1 458			
2012	2	All	0.719	33.5	1,186	564	2,360	1 650	0.0131	1.485	106
2012	2	1	1.178	29.2	853	325	1,289	724			
2012	2	2	0.360	89.9	333		1,459	926			
2012	3	All	3.986	15.5	6,359	4,136	8,058	1 595	0.0112	1.765	186
2012	3	1	0.895	34.9	591	227	1,042	661			
2012	3	2	6.172	15.9	5,768	3,775	7,330	935			
2012	4	All	4.279	24.9	4,960	3,414	8,011	1 159	0.0107	1.652	140
2012	4	1	6.050	27.6	4,439	2,916	7,497	734			
2012	4	2	1.225	39.6	521	166	940	425			
2012	5	Not surveyed. Interpolated estimate used for All-Zone calculation.									
2013	All	All	2.236	11.1	19,643	15,377	23,909	8 785			
2013	1	All	1.257	27.9	4,395	2,298	6,954	3 497	0.0109	1.695	137
2013	1	1	2.379	31.4	2,010	861	3,253	845			
2013	1	2	0.657	20.1	784	508	1,124	1 194			
2013	1	3	1.097	64.4	1,600	381	3,717	1 458			
2013	2	All	0.758	19.3	1,251	889	1,796	1 650	0.0117	1.569	132

Table 2—Marbled murrelet population estimates, 2000 to 2018[a] (continued)

Year	Zone	Stratum	Density	CV[b]	Birds	95% confidence limits Lower	95% confidence limits Upper	Area	f(0)	E(s)	Truncation distance
			Per square kilometer	*Percent*				*Square kilometers*			*Meters*
2013	2	1	1.604	19.8	1,162	843	1,728	724			
2013	2	2	0.096	58.3	89		189	926			
2013	3	All	4.939	16.3	7,880	5,450	10,361	1 595	0.0112	1.637	160
2013	3	1	0.991	43.8	655	151	1,226	661			
2013	3	2	7.731	17.8	7,225	4,707	9,667	935			
2013	4	All	5.216	20.5	6,046	4,531	9,282	1 159	0.0128	1.607	146
2013	4	1	7.384	21.8	5,418	3,939	8,516	734			
2013	4	2	1.477	36.7	629	279	1,184	425			
2013	5	All	0.080	45.4	71	5	118	883			
2013	5	1	0.160	45.4	71	5	118	441			
2013	5	2	0.000					441			
2014	All	All	2.423	9.2	21,283	17,452	25,114	8 785			
2014	1	All	0.801	20.6	2,801	1,598	3,876	3 497	0.0102	1.664	172
2014	1	1	1.235	28.0	1,044	558	1,643	845			
2014	1	2	1.274	27.2	1,521	600	2,219	1 194			
2014	1	3	0.162	70.9	236		541	1 458			
2014	2	All	1.318	30.7	2,176	1,038	3,574	1 650	0.0131	1.508	122
2014	2	1	2.879	31.5	2,086	925	3,466	724			
2014	2	2	0.098	65.6	90		214	926			
2014	3	All	5.541	12.4	8,841	6,819	11,276	1 595	0.0108	1.720	140
2014	3	1	1.477	34.1	976	286	1,587	661			
2014	3	2	8.415	13.1	7,864	6,156	10,240	935			
2014	4	Not surveyed. Interpolated value used for All-Zone calculation.									
2014	5	Not surveyed. Extrapolated value used for All-Zone calculation.									
2015	All	All	2.747	9.5	24,134	19,658	28,610	8 785			
2015	1	All	1.227	24.1	4,290	2,640	6,565	3 497	0.0111	1.786	191
2015	1	1	2.218	35.8	1,875	829	3,383	845			
2015	1	2	1.945	29.9	2,321	1,148	3,863	1 194			
2015	1	3	0.064	92.6	94		267	1 458			
2015	2	All	1.941	30.4	3,204	1,883	5,609	1 650	0.0093	1.866	175
2015	2	1	2.849	27.9	2,064	1,176	3,316	724			
2015	2	2	1.231	71.2	1,140	144	3,290	926			
2015	3	Not surveyed. Average of 2014 and 2016 estimates used for All-Zone estimate.									
2015	4	All	7.542	16.8	8,743	7,409	13,125	1 159	0.0118	1.701	159
2015	4	1	9.897	17.3	7,262	5,906	10,692	734			
2015	4	2	3.480	48.9	1,481	859	3,713	425			
2015	5	Not surveyed. Extrapolated value used for All-Zone estimate.									

Table 2—Marbled murrelet population estimates, 2000 to 2018[a] (continued)

Year	Zone	Stratum	Density	CV[b]	Birds	95% confidence limits Lower	95% confidence limits Upper	Area	f(0)	E(s)	Truncation distance
			Per square kilometer	*Percent*				*Square kilometers*			*Meters*
2016	All	All	2.577	10.0	22,638	18,204	27,071	8 785			
2016	1	All	1.319	30.0	4,614	2,298	7,571	3 497	0.0112	1.675	224
2016	1	1	2.693	36.6	2,276	969	4,062	845			
2016	1	2	1.655	51.7	1,975	617	4,075	1 194			
2016	1	3	0.249	37.7	362	106	621	1 458			
2016	2	Not surveyed. Extrapolated value used for All-Zones estimate.									
2016	3	All	4.271	13.8	6,813	5,389	8,821	1 595	0.0116	1.661	130
2016	3	1	0.862	27.9	570	346	944	661			
2016	3	2	6.681	14.8	6,244	4,760	8,195	935			
2016	4	Not surveyed. Extrapolated value used for All-Zones estimate.									
2016	5	Not surveyed.									
2017	All	All	2.623	10.0	23,040	18,527	27,552	8 785			
2017	2	All	1.065	23.2	1,758	1,041	2,623	1 650	0.0097	1.648	154
2017	2	1	2.127	25.8	1,541	820	2,353	724			
2017	2	2	0.235	36.5	218	56	363	926			
2017	3	Not surveyed.									
2017	4	All	7.397	14.5	8,574	6,358	11,155	1 159	0.0118	1.658	170
2017	4	1	9.147	15.1	6,711	4,654	8,700	734			
2017	4	2	4.378	11.3	1,863	968	3,313	425			
2017	5	All	0.983	39.7	868	457	1,768	883			
2017	5	1	0.765	190.2	337	63	765	441			
2017	5	2	1.202	48.8	531	301	1,179	441			
2018	All	Will have 2018 estimate in 2019.									
2018	1	All	1.097	34.7	3,837	1,911	6,956	3 497	0.0080	1.739	242
2018	1	1	1.375	42.6	1,162	297	2,158	845			
2018	1	2	1.044	29.0	1,246	595	1,976	1 194			
2018	1	3	0.980	86.7	1,428		4,177	1 458			
2018	2	Not surveyed.									
2018	3	All	5.274	19.2	8,414	5,866	12,183	1 595	0.0123	1.640	120
2018	3	1	1.026	46.3	678	290	1,533	661			
2018	3	2	8.277	20.3	7,736	5,203	11,195	935			
2018	4	Not surveyed									
2018	5	Not surveyed									

Note: Numbers in some years may differ slightly from those in Falxa et al. (2016) and previous summary reports, as a result of data quality reviews performed in 2019-2020.

[a] Based on at-sea surveys conducted in Conservation Zones 1 through 5

[b] CV = the coefficient of variation, CI = confidence interval, f(0) = probability density function of the observed distances evaluated at 0 m from the boat; E(s) = mean number of birds in an observed cluster.

Table 3—Summary of 2000 to 2017 marbled murrelet at-sea density and abundance estimates at the state scale[a]

Year	State	Density	No. of murrelets	95% confidence limits		Area
				Lower	Upper	
		Per square kilometer				*Square kilometers*
2001	Washington	2.13	11,030	7,554	14,505	5188
2002	Washington	2.32	11,951	7,687	16,216	5151
2003	Washington	2.31	11,894	8,729	15,058	5149
2004	Washington	1.65	8,474	5,625	11,322	5149
2005	Washington	2.05	10,533	7,179	13,887	5148
2006	Washington	1.61	8,280	6,024	10,536	5148
2007	Washington	1.85	9,520	5,946	13,095	5148
2008	Washington	1.29	6,628	4,808	8,448	5148
2009	Washington	1.34	6,894	4,495	9,294	5148
2010	Washington	1.10	5,679	3,840	7,518	5148
2011	Washington	1.63	8,376	5,802	10,950	5148
2012	Washington	1.87	9,629	6,116	13,142	5148
2013	Washington	1.10	5,646	3,195	8,097	5148
2014	Washington	0.97	4,977	3,248	6,706	5148
2015	Washington	1.46	7,494	4,711	10,276	5148
2016	Washington	1.38	7,095	4,060	10,130	5148
2017	Washington	1.16	5,984	3,204	8,764	5148
2000	Oregon	3.85	7,983	4,992	10,974	2071
2001	Oregon	4.43	9,168	6,654	11,682	2071
2002	Oregon	3.64	7,530	4,727	10,332	2071
2003	Oregon	3.56	7,380	5,370	9,390	2075
2004	Oregon	4.40	9,112	6,833	11,391	2071
2005	Oregon	3.36	6,966	4,812	9,121	2071
2006	Oregon	3.68	7,617	5,916	9,318	2071
2007	Oregon	2.59	5,357	3,332	7,381	2071
2008	Oregon	3.64	7,541	5,682	9,400	2071
2009	Oregon	3.58	7,423	5,208	9,638	2071
2010	Oregon	3.95	8,182	5,743	10,622	2071
2011	Oregon	4.05	8,379	5,943	10,816	2071
2012	Oregon	3.76	7,780	5,605	9,956	2071
2013	Oregon	4.74	9,819	7,195	12,443	2071
2014	Oregon	5.50	11,384	8,839	13,930	2071
2015	Oregon	5.30	10,975	8,188	13,762	2071
2016	Oregon	4.85	10,053	7,527	12,580	2071
2000	California	2.28	3,571	1,884	5,258	1566
2001	California	1.31	2,049	600	3,497	1566

Table 3—Summary of 2000 to 2017 marbled murrelet at-sea density and abundance estimates at the state scale[a] (continued)

Year	State	Density	No. of murrelets	95% confidence limits		Area
				Lower	Upper	
		Per square kilometer				*Square kilometers*
2002	California	2.04	3,202	2,181	4,224	1566
2003	California	1.90	2,985	1,753	4,217	1567
2004	California	2.55	3,986	2,197	5,775	1566
2005	California	1.73	2,710	1,896	3,523	1566
2006	California	1.56	2,438	1,727	3,149	1566
2007	California	1.56	2,440	1,465	3,415	1566
2008	California	2.53	3,964	2,802	5,126	1566
2009	California	1.87	2,928	1,589	4,268	1566
2010	California	1.69	2,644	1,098	4,191	1566
2011	California	3.33	5,217	1,962	8,472	1566
2012	California	2.24	3,514	1,812	5,216	1566
2013	California	2.67	4,178	2,662	5,694	1566
2014	California	3.14	4,922	3,410	6,433	1566
2015	California	3.62	5,666	3,970	7,361	1566
2016	California	3.51	5,489	3,995	6,984	1566
2017	California	3.90	6,111	4,473	7,749	1566

[a] Numbers in some years may differ slightly from those in Falxa et al. (2016) and summary reports, as a result of data quality reviews performed in 2019

Table 4—Estimates of average annual rate of change (percent) in marbled murrelet at-sea abundance based on at-sea surveys

Zone or state	Period of analysis[b]	Annual rate of change (%)	95% confidence limits[a]		Adjusted r^2	*P*-value[c]
			Lower	Upper		
Zone 1[d]	2001 to 2018	-4.9	-7.3	-2.4	0.503	<0.001
Zone 2	2001 to 2017	-3.0	-6.8	0.9	0.105	0.119
Zone 3[d]	2000 to 2018	1.4	-0.4	3.3	0.104	0.111
Zone 4	2000 to 2017	3.7	1.4	6.1	0.425	0.004
Zone 5	2000 to 2017	7.3	−4.4	20.3	0.085	0.199
Washington	2001 to 2017	-3.9	-5.8	-2.0	0.523	<0.001
Oregon	2000 to 2017	2.0	0.5	3.6	0.279	0.014
California	2000 to 2017	4.5	2.2	6.9	0.487	<0.001
All-Zones	2001 to 2017	0.34	−0.9	1.6	0.000	0.569

[a] Confidence limits are for the estimates of percentage of annual change.
[b] The period of analysis extends to either 2017 or 2018 depending on which year sampling units were last surveyed.
[c] The P-value is based on a two-tailed test for whether the annual rate of change is different from zero, significant values are shaded in gray. Based on updated population estimates reported in tables 1 and 3. Numbers in some years may differ slightly from those in summary reports, as a result of additional data quality reviews performed in 2019.
[d] Surveyed in 2018.

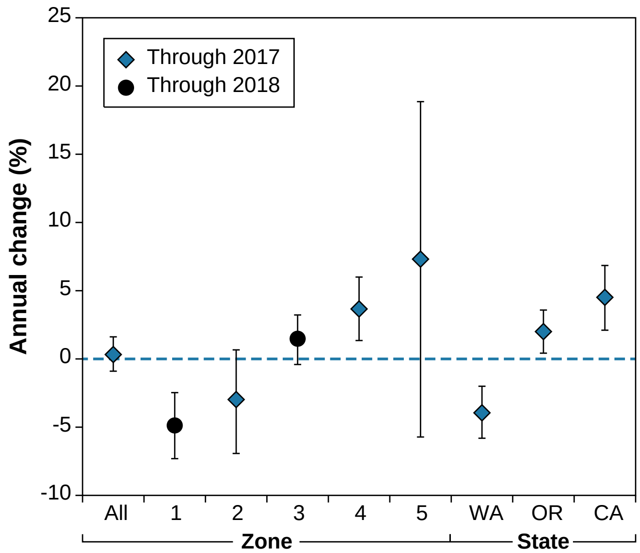

Figure 3—Percentage of annual change (95 percent confidence interval) in murrelet density by conservation zone, for "All-Zones" combined, and by state. Trends are through 2017 for the blue diamonds and through 2018 for the black circles. If the confidence intervals do not overlap zero, then there is support for either a positive (e.g., Conservation Zone 4) or a negative (e.g., Conservation Zone 1) trend. Note that these results are provided in a tabular form in table 4. WA = Washington, OR = Oregon, CA = California.

Temporal and Spatial Variation in Murrelet Distribution as a Function of Distance From Shore

To minimize the variance in our overall murrelet density estimate, we devoted more sampling effort in the inshore region where, based on preliminary data, murrelet density was higher (Bentivoglio et al. 2002, Ralph and Miller 1995, Raphael et al. 2007, Strong et al. 1995). Figure 4 shows that there has been considerable variation in the density of murrelets inshore relative to the density in the offshore regions of each strata within conservation zones, and this occurred within strata over the years as well as between strata. Conservation Zone 3 Stratum 2 had the greatest proportion of birds in the inshore region (note the different scale for each strata). Our assumption of greater inshore density is supported in nearly all year/strata/conservation zone combinations, with a mean ratio at the stratum scale of 8.0 (averaged over all strata and years, n = 132). Only five of the year/strata combinations had values of less than 1 (i.e., higher densities in the offshore region), and these all occurred in Conservation Zone 2.

We ran simple correlation analyses between our stratum density estimates and the ratio data (see fig. 5) across all years to see if variation in the inshore-offshore distribution could have an effect on our density estimates. No relation was found at this scale (R squared values of less than 0.073 in all cases). We also tested for a trend in the inshore–offshore ratio over the years, based on the potential for this in Conservation Zone 1 Stratum 2, Conservation Zone 3 Stratum 2, and Conservation Zone 4 (fig. 5). While there was a negative slope in these cases, up to -0.360, it accounted for little of the variation in the ratios (R squared maximum of 0.279).

Other Piscivorous Species

The two other alcid species included in the analysis, the rhinoceros auklet and pigeon guillemot, do not demonstrate an increasing or declining population trend (table 5, fig. 6).

Table 5—Annual linear change for two other year-round or locally breeding piscivorous seabird species detected during murrelet surveys in Conservation Zone 1, 2001 to 2018

		95% confidence interval			
Species	% change	Lower	Upper	P-value	Adjusted r^2
Rhinoceros auklet	1.21	-1.68	4.17	0.38	0.01
Pigeon guillemot	0.17	-1.69	2.06	0.85	0.06

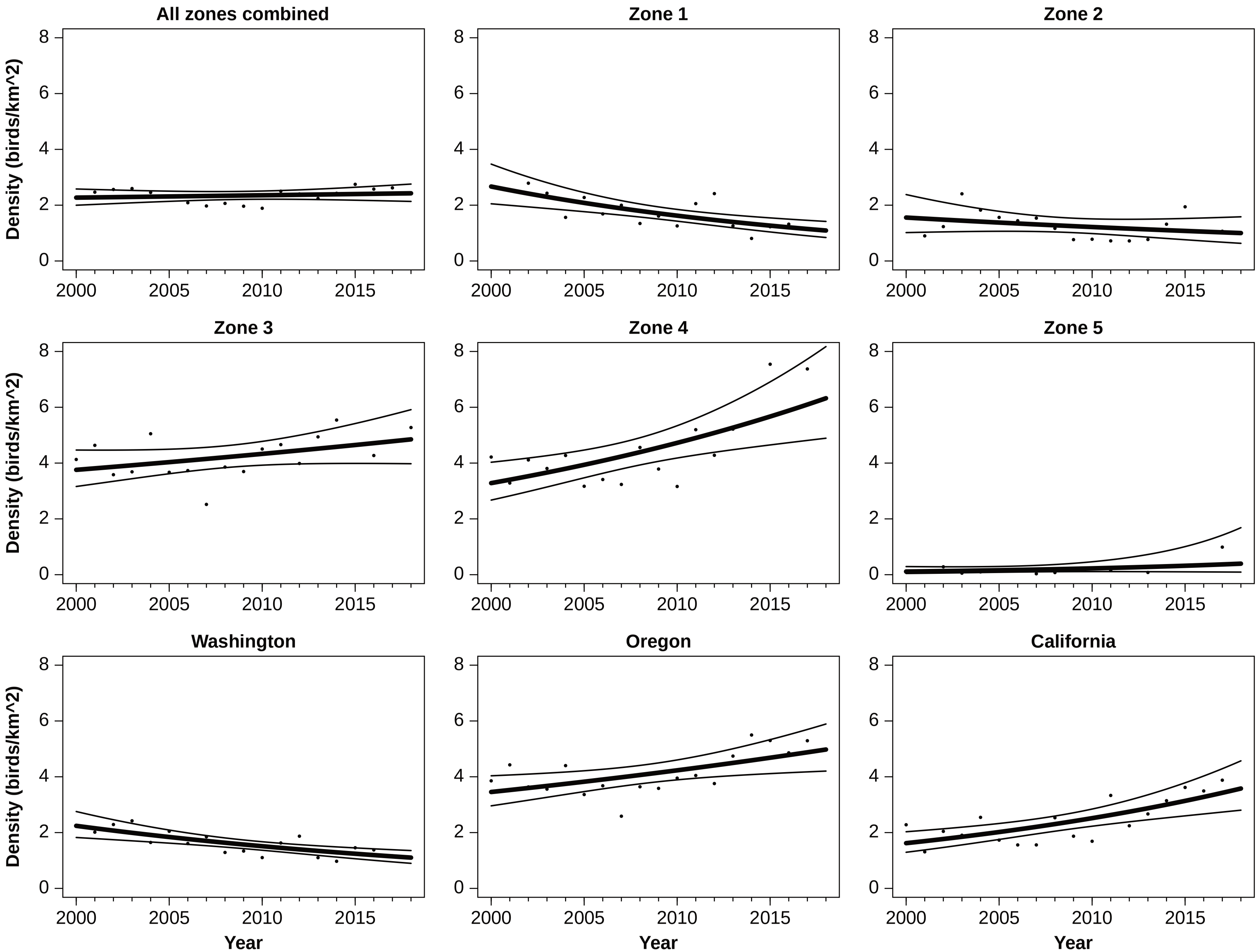

Figure 4—Marbled murrelet population trend analyses for all zones, individual conservation zones, and state scales. Graphs show regression lines fitted through the annual population estimates for the period of analysis (through 2017 for conservation Zones 2 throuogh 5; through 2018 for Conservation Zones 1 and 3), with 95 percent confidence limits.

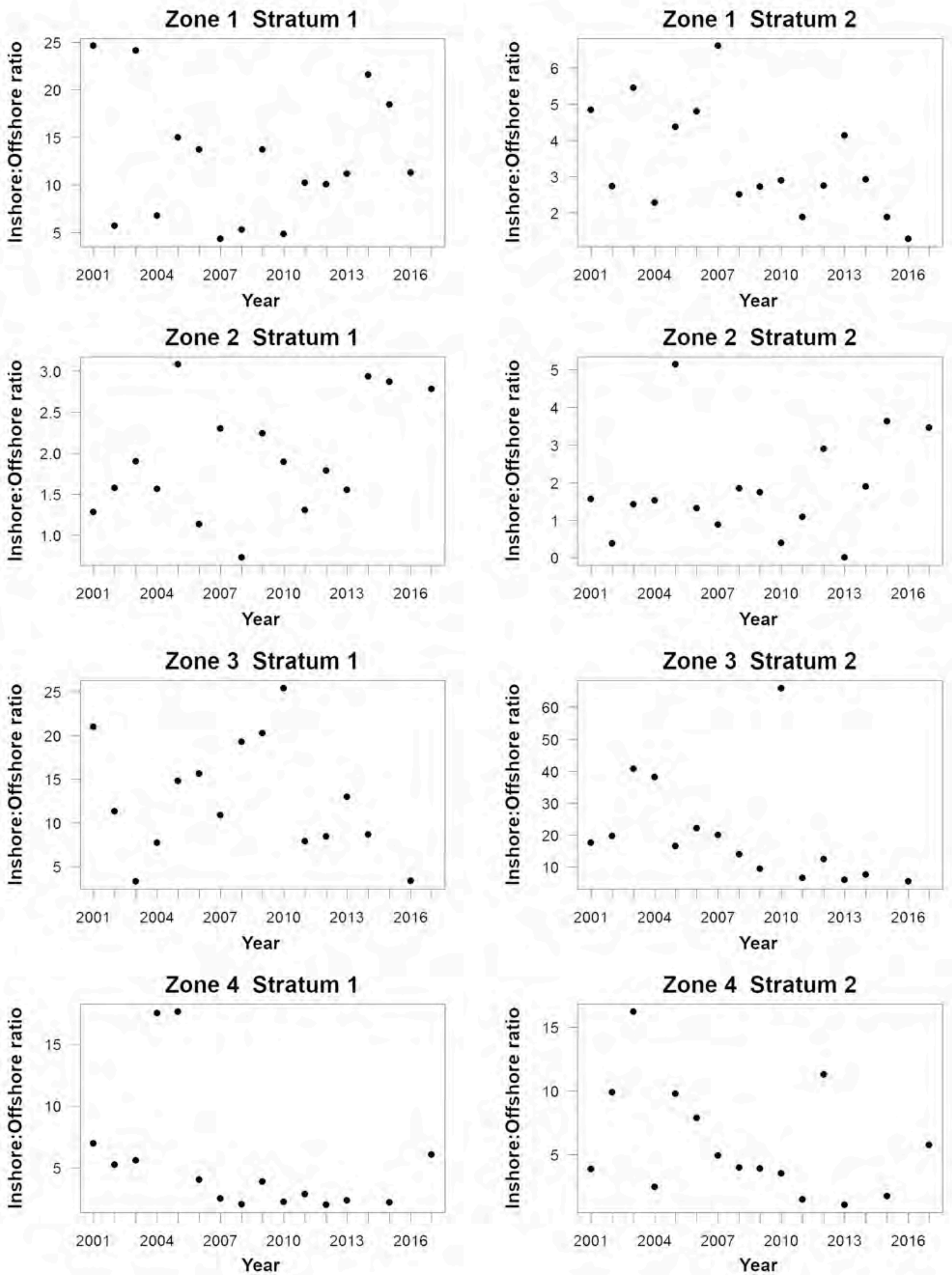

Figure 5—Ratios of inshore to offshore density by year and stratum within each conservation zone. See text for details.

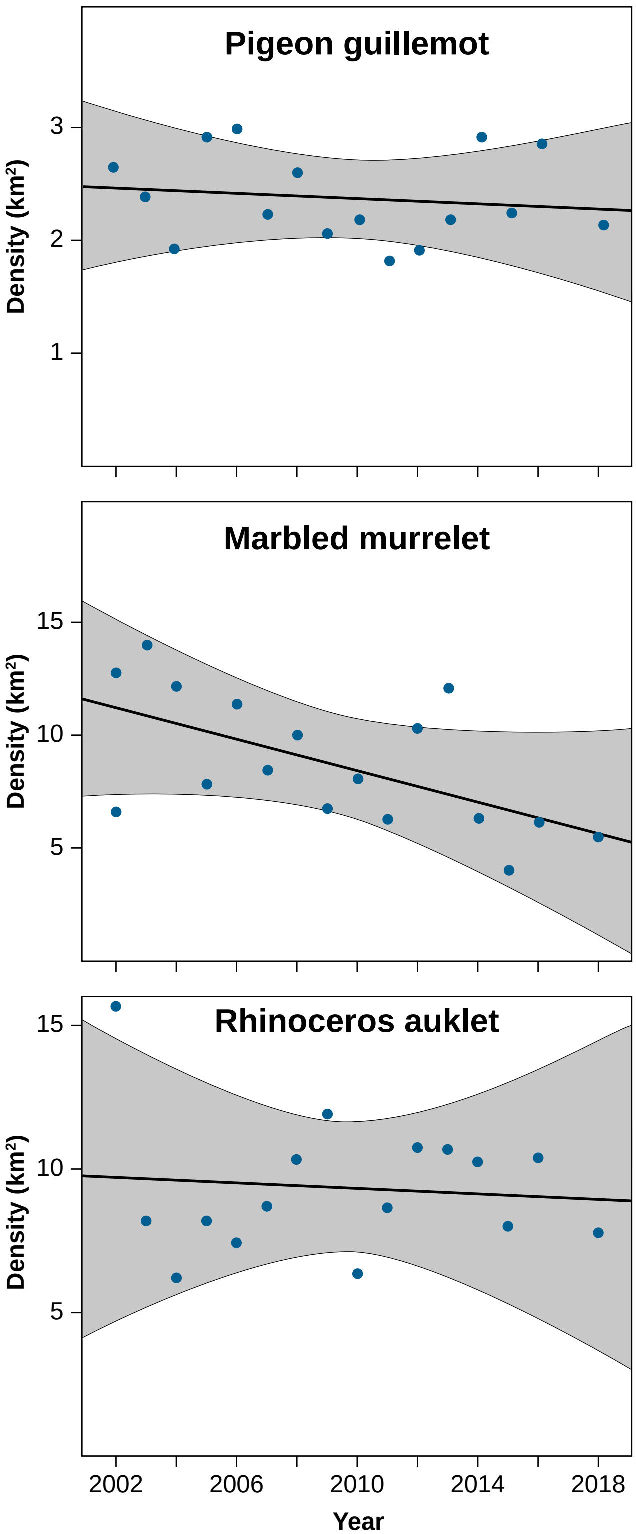

Figure 6—Density estimates for pigeon guillemot, marbled murrelet, and rhinoceros auklet in Conservation Zone 1, 2000-2018.

Discussion

This report provides the fourth comprehensive evaluation of murrelet population status and trends, following the 10- (Miller et al. 2006), 15- (Miller et al. 2012), and 20-year (Falxa et al. 2016) progress reports. Our new analyses indicate that murrelet abundance at sea continues to vary over space and time throughout the NWFP area. Such variation is not surprising given that some of the factors likely affecting changes to murrelet density at sea, such as, strength and timing of upwelling, sea surface temperature, or marine human footprint (e.g., Raphael et al. 2015), and those factors are expected to vary across the NWFP area, which encompasses about 11 degrees of latitude.

The 20-year report (Falxa et al. 2016) relied upon an adequate amount of at-sea abundance data to assess trends at the conservation-zone scale. Although this 25-year report includes information from five additional years of survey effort (years 2014-18), the annual effort was reduced starting in 2014 (see "Methods"), which reduced our ability to detect trends.

At the All-Zone scale, there is no evidence for a population trend because the magnitude of the change is very small (positive 0.34 percent change per year), and the confidence intervals are tight around zero (fig. 3). This lack of trend at the All-Zone scale does not indicate the population is stable throughout the NWFP area. Instead, there are abundance declines in the north that are offset by abundance increases in the south (fig. 3). In Conservation Zone 1 in the north, there is strong evidence for declining abundance at sea (4.9 percent decline per year during 17 years or a 57 percent overall decline). Note that the confidence intervals in figure 3 are tight and do not overlap zero, indicating strong support for a linear decline. In contrast, there is strong support for an increase in abundance at sea in Conservation Zone 4 in the south (3.7 percent increase per year during 17 years or a 48 percent overall increase). Again, the confidence intervals do not overlap zero, indicating strong support for the increasing trend. There is some evidence (only slight overlap of 95 percent confidence intervals with zero; fig. 3) for opposite trends in Conservation Zones 2 and 3, with declines to the north and increases to the south. However, the magnitudes of these trends are different (-3.0 vs. 1.4 percent) with very different implications for these two conservation zones. The decrease in Conservation Zone 2 represents an approximately 39 percent decline in abundance during this 17-year period (2001 to 2017) versus a 22 percent increase over a 19-year period (2000 to 2018) for Conservation Zone 3. From a conservation perspective, the potential magnitude of declines in Conservation Zones 1 and 2 warrant concern. The confidence intervals for Conservation Zone 5 are extremely large (nearly 25 percent span), indicating extreme uncertainty in the trend for this conservation zone, even if the linear trend appears positive. The broad confidence intervals in Conservation Zone 5 are driven by the anomalously high abundance estimate in 2017, the most recent year it was surveyed

At the conservation-zone scale, greatest densities occurred in Conservation Zones 4 and 3 in 2017–2018, and Conservation Zone 5 had the least density (2017) (table 2). In contrast to density, which is weighted by area, differences in abundance estimates among conservation zones are influenced by both murrelet density and the area of marine coastal waters being sampled.

Our analysis of murrelet distribution relative to shore indicated no bias associated with focusing our sampling on the nearshore or attributable to birds being beyond the sampled waters. If density estimates decreased during years of low nearshore:offshore ratios, then there would be reason for concern that the "missing" birds were beyond our sampling area. Although there was the appearance of a declining proportion of birds in the inshore subunit of some strata within Conservation Zone 4 (fig. 5), the low R squared values indicated relatively poor support for a linear annual decline.

Influence of Marine Conditions on Murrelet Abundance and Distribution

The distribution and abundance of murrelets in the marine environment during the nesting season appear to be influenced by both marine and terrestrial factors (Meyer et al. 2002, Raphael et al. 2015). We observed local decreases in murrelet density in Conservation Zone 1 and increases in the conservation zones to the south, especially since 2012. We do not know if these changes resulted from birds moving among conservation zones (or at even larger spatial scales, e.g., from Alaska or British Columbia), and to what degree local reproduction and survival influence these apparent trends. Although the marine distribution and abundance derived from our monitoring efforts correlate with the amount and extent of adjacent murrelet nesting habitat (see Lorenz et al. 2016; Raphael et al. 2015, 2016b; Yen et al. 2004), the degree to which our at-sea numbers reflect the local population of birds actually breeding in a given season is unknown. As a result, our at-sea abundance estimates may include locally breeding murrelets, nonbreeders, potentially postbreeding dispersers later in the survey season, and transient murrelets. The ratio of these different "groups" of birds likely changes among years depending on ocean conditions and food resources.

In waters off the Pacific coast (i.e., Conservation Zones 2 through 5), the murrelet is highly dependent upon fish and invertebrate resources of the California Current Ecosystem during the breeding and nonbreeding seasons (Burkett 1995). The California Current is part of the North Pacific gyre that spans nearly 3000 km from southern British Columbia to Baja California. In this system, cold, nutrient-rich water (upwelling) typically appears each year along the coast as warmer surface water is pushed south by seasonal equatorward winds and deflected offshore by the Coriolis force (the Earth's spin on its axis), and replaced by deep, cool, nutrient-rich water resulting in regions with high primary productivity. However, the productivity of this system is highly variable. For example, during warm-water El Niño events, upwelling is weakened, resulting in lower productivity and ultimately affecting multiple trophic levels, including the prey that seabirds depend on for successful reproduction. Large-scale ecosystem drivers such as warm-water events (Di Lorenzo and Mantua 2016) can also result in severe disruption of energy transfer from lower trophic levels to predators (von Biela et al. 2019) and can result in population-level effects to seabirds (Jones et al. 2018).

The new monitoring information included in this report (years 2014–2018) coincided with years when there were dramatic shifts in these marine-forcing mechanisms that likely exerted influence on murrelet distribution and abundance. A very large area of exceptionally high sea surface temperature, known as the "marine heatwave," moved into the nearshore environment of the California

Current Ecosystem in 2014–2016 (Bond et al. 2015, Di Lorenzo and Mantua 2016). This event featured record-high sea surface temperatures in 2015, and 2014–16 was the warmest 3-year period on record (Jacox et al. 2016). These anomalies initially compressed the zone of cold upwelled waters to the nearshore, which also concentrated the forage species into these same nearshore areas (Jones et al. 2018). However, unlike the lead-in to previous strong El Niño's, effective upwelling in the central and northern regions occurred with upwelling-related species near the coast (such as rockfish juveniles) that were still found in relatively high abundances (Leising et al. 2015). The result of this event was a system with overall, moderate productivity (depending on location), extremely high prey species diversity, and overall changes in ecosystem structure (Leising et al. 2015, Peterson et al. 2018). During 2015 and 2017, we recorded our greatest densities (above the 95 percent confidence limits for the conservation zone) of murrelets, in Conservation Zone 4 (table 2). Again, when birds choose not to breed or failed to breed, we would expect more birds on the water because fewer birds would be inland incubating eggs or feeding chicks. Furthermore, when murrelets and other small alcids are no longer anchored to their nests, they are more likely to move to where food resources are more available (see Adams et al. 2004).

The exceptionally high sea surface temperature anomalies reached maximum values in spring/summer 2016 and declined thereafter, but there was considerable variation at smaller spatial scales (Thompson et al. 2018, Wells et al. 2017). Anomalously strong downwelling occurred in the winter of 2015–16 (typical of El Niño winters). From January to May 2017, sea surface temperature anomalies north of 42 ˚N (California-Oregon border) were near the long-term average (Thompson et al. 2018, Wells et al. 2017), and upwelling was close to normal throughout most of the California Current System in 2017 and 2018. Although the strength of upwelling was close to normal, its onset was delayed in 2017 resulting in poor forage conditions until June (Thompson et al. 2018). Throughout the period that the marine heatwave affected the California Current, the copepod composition off Newport, Oregon (Conservation Zone 3) remained in a warm-water phase with a high diversity of southern copepod species, but with lower caloric value than forage fish prey (Peterson et al. 2018). In May and June of 2017, there was an abrupt and late period of upwelling, and the copepod community switched back to larger, fewer species associated with boreal cold-water conditions and generally better feeding conditions for predators of forage fish (salmon and seabirds) (Hooff and Peterson 2006, Peterson et al. 2018).

These warm-water events can have both short- and long-term influences on marine resources and ultimately on species, such as the murrelet, that depend upon them for survival (Becker et al. 2007). Weak or delayed upwelling for a given season has strong influence on productivity within that season and may influence murrelet reproduction. However, there can also be lag effects associated with large-scale ecosystem perturbations such as the 2015–2016 marine heat wave, which can have longer term influences on murrelet populations. For example, reduced spawning biomass of forage taxa in a year of poor upwelling can have carryover affects into subsequent years because there are fewer animals available to spawn even if spawning conditions are favorable. It will be several years before these ecosystem-scale influences on murrelet populations are more fully understood. Climate change is expected to increase the number of anomalous events and the variability of the California Current (Sydeman et al. 2018). With our alternating-year sampling of conservation zones, and the likelihood of bird movements between conservation zones, we have difficulty in relating murrelet densities to marine heatwave events.

Increases in the South

In Conservation Zone 4, which includes southern Oregon and northern California, the at-sea abundance trend estimate was positive for the 2000 to 2017 period. Similarly, the at-sea abundance trend estimate for Oregon was positive. Potential mechanisms for the increase in at-sea abundance of murrelets include an increase in local recruitment (i.e., maturation of chicks from the local population), lack of local breeding or early breeding such that more adult murrelets are on the water during surveys, dispersal of breeding or nonbreeding individuals from areas north of this conservation zone, or a combination of factors. Because murrelets have delayed sexual maturity, produce a single chick per breeding pair per year, and have low reproductive success, the relatively large and rapid increases in at-sea abundance in recent years in this region are unlikely due solely to local demographic recovery. Local recruitment could be improving if there were more nesting habitat available. Based on the results from monitoring nesting habitat (Lorenz et al. 2021), there does not seem to be a strong correlation between the amount of nesting habitat and at-sea abundance of murrelets, but there is some evidence of a correlation between trends in abundance at sea and change in amount of nesting habitat. Consequently, we suspect that processes of dispersal and immigration as well as changes in amount of nesting habitat likely contribute to the abundance trend in Conservation Zone 4.

Research examining the mechanisms responsible for changes in at-sea abundance in Conservation Zone 6 (central California) may provide some insights into this apparent increasing trend in Conservation Zone 4. Previous research into changes in the central California murrelet abundance suggested that at-sea population increases were driven by birds dispersing into this region, largely by temporary influxes of nonbreeding individuals (Hall et al. 2009, Peery et al. 2004), and a more recent study linking genetic information with abundance at sea suggested that the rapid population increase following the 2007–2008 decline was likely driven by the initial dispersal of resident birds out of the area and the subsequent return of those resident birds (Vásquez-Carrillo et al. 2013). This pattern was consistent with murrelets abandoning breeding activities locally and moving out of the region, followed by a return of those same resident birds to their usual breeding areas. Understanding the mechanisms responsible for the apparent increase in murrelet abundance at sea in Conservation Zone 4 would require a similar analysis to disentangle the relative influence of short-term movements of resident birds, permanent immigration, and local reproduction. However, our recent change to surveying every other conservation zone every other year complicates our ability to examine potential drivers because some conservation zone-scale changes could be the result of interannual movements of birds between conservation zones, which are not apparent when adjacent conservation zones are not surveyed in the same year.

Most of the forest habitat for the murrelet in Conservation Zone 4 is contained in Redwood National and State Parks (RNSP). Since 2011, RNSP management has included infrastructure and visitor education to curtail human supplemental feeding of wildlife, which artificially enhances their populations over their undisturbed numbers (RNSP 2018). These efforts were directed specifically to reduce corvid numbers around campgrounds with the intent that this would reduce predation pressure on murrelets. Also, in 2010 and 2011, an effort was made to train Steller's jays (*Cyanocitta stelleri*) to avoid murrelet eggs via taste aversion of placed eggs (Gabriel and Golightly 2011). Although there is no feasible way to test for an effect of these management actions on murrelet predation rates (but see Strong 2013), there is evidence of reduced corvid numbers at RNSP campgrounds (RNSP 2018). Considering that campground areas are a tiny fraction of the available habitat to murrelets, it is unlikely that any improvement of nesting success resulting from these actions could account for the recent observed increase in murrelet numbers in Conservation Zone 4.

The exceptionally high at-sea abundance estimate for Conservation Zone 5 in 2017 (table 2) relative to prior years may exemplify temporary relocation of resident birds during a single year, as considered for Conservation Zone 6 by Vásquez-Carrillo et al. (2013). There was evidence of very poor prey availability north of Cape Mendocino in 2017 (Peterson et al. 2017, Schneider 2019, Suryan et al. 2017, Thompson et al. 2018). For example, within Conservation Zone 3, upwelling was below normal with a strong downwelling in May and June resulting in increased sea surface temperatures and hypoxic conditions that resulted in poor forage conditions (Thompson et al. 2018). In addition, there was an abundance of forage fish in the Gulf of the Farallones region, particularly of anchovy (*Engraulis mordax*) (Strong 2018, Thompson et al. 2018). Further, most murrelet sampling in Conservation Zone 5 occurred late in the sampling period in 2017. It is possible that some murrelets from locations to the north may have temporarily immigrated into Conservation Zone 5 following failed breeding attempts or earlier-than-normal breeding. Unfortunately, our infrequent sampling of Conservation Zone 5 makes it difficult to describe the 2017 results as an anomaly or part of a larger shift in relative abundance. Conservation Zone 5 sampling is next planned for 2021. This delay in sampling is particularly problematic to our overall sampling strategy, for if murrelet abundance in Conservation Zone 5 continues to increase, it will be critical to increase the frequency of its sampling.

Decreases to the North

Our results indicate that murrelet abundance at sea is continuing to decline in the U.S. portion of the Salish Sea (Conservation Zone 1). Results from monitoring trend in nesting habitat show a net decrease in total amount of nesting habitat from 1993 to 2017 in Conservation Zone 1 (Lorenz et al. 2021). We do not have enough information to establish a cause/effect relationship between the at-sea abundance trend and the terrestrial habitat trend, but the results from Lorenz et al. (2021) do indicate the possibility that decreasing habitat is contributing to a decline in abundance at sea within Conservation Zone 1.

A very similar fall-through-spring survey effort funded by the U.S. Navy was conducted between 2013 and 2018 using the identical line transect survey methodology reported here and some of the same primary sampling units (plus others not sampled as part of this effort) primarily in central to northern Puget Sound. Results indicated greater annual decline of -16.5 percent (95 percent confidence interval: -2.6 percent to -28.5 percent, $r^2 = 0.66$) (Pearson and Lance 2018). Similarly, Lorenz and Raphael (2018) found the spring through early summer murrelet density at sea near the San Juan Islands (the region of the Salish Sea with highest murrelet densities) declined from 11.16 to 5.76 murrelets per square kilometer between 1995 and 2012. Despite this consistent decline in overall murrelet density, the density of juvenile murrelets and murrelet productivity ratio (juveniles:adults) did not decline during this time period (Lorenz and Raphael 2018). Lorenz and Raphael (2018) concluded that the declining density of murrelets in the San Juan Islands was due to declines in adult murrelets only, not juveniles.

If adult murrelets are leaving Conservation Zone 1 to breed elsewhere, we would expect numbers to be increasing in adjacent areas such as British Columbia or the Washington coast. Although not significant, the abundance at sea off Washington is declining, and there is evidence for a coast-wide decline of about 1.6 percent per year in British Columbia between 1996 and 2013, based on radar detections of murrelets flying inland, with the steepest declines in conservation regions bordering the Salish Sea (Bertram et al. 2015, Burger 2002). Alternatively, birds could be moving from Washington to areas off Oregon and California where we are seeing evidence for increasing numbers in recent years; however, we have insufficient evidence to support or refute this possibility.

Some additional evidence indicates that unique factors associated with Conservation Zone 1 may be contributing to this long-term local decline at sea. Lorenz et al. (2017) examined movement patterns and reproduction of murrelets in the Salish Sea between 2004 and 2008 and found that they had low breeding propensity, large marine ranges, and long nest-sea commutes, compared with results found in similar studies conducted in other parts of the murrelet's range (Hébert and Golightly 2008). In particular, the long commutes to foraging areas suggested poor-quality marine/foraging habitat in Washington compared to other parts of the murrelet's range. They also found some indication that murrelet movements were shorter in cooler waters (Lorenz et al. 2017), indicating that cooler water may provide greater prey abundance or availability, similar to what some past studies indicated (Barrett 2008).

Previously, we evaluated the relative influence of marine and terrestrial factors on the distribution and abundance of murrelets throughout the NWFP area (Raphael et al. 2015, 2016b). We also evaluated the relative influence on the distribution and abundance in Conservation Zone 1 only and found that changes in amount of higher suitability nesting habitat was the best predictor of changes in murrelet abundance and distribution. However, unlike all the other conservation zones, the next best predictor was the marine human footprint, which could reflect more intense vessel traffic, fishing pressure, and pollution in that conservation zone compared with the outer Pacific Northwest coast where the influence of the marine human footprint was much less important. Again, the factors contributing to changes in the abundance and distribution of murrelets in this inland marine habitat appear to be different than in more coastal environments.

Our results from the other fish-eating alcid-species certainly do not indicate a broader decline throughout the Salish Sea, but instead suggest unique population drivers among species. For the murrelet, it may be the combination of dependence on older forests for nesting and rapidly changing marine ecosystem. In contrast to nesting within forests, both the rhinoceros auklet and pigeon guillemot are burrow and crevice nesters, often nesting on offshore islands without mammalian predators, which may make their eggs and chicks less vulnerable to predation. Many Salish Sea-nesting rhinoceros auklets move to offshore waters of the northeastern Pacific during the nonbreeding season (Hipfner et al. n.d.) and are therefore not exposed to the same factors as the murrelet. The pigeon guillemot lays two eggs compared to the one-egg clutch of the murrelet, which may give it a reproductive advantage. In addition, guillemots primarily feed their chicks demersal fish from very nearshore environments (Bishop et al. 2016) in contrast to the more coastal pelagic fish diet fed to murrelet chicks (Nelson and Hamer 1995). A growing body of evidence suggests that several forage fish species are declining in the Salish Sea (e.g., Greene et al. 2015), but we do not have evidence for a similar decline in nearshore demersal fish.

Conclusions and Management Implications

This monitoring program provides population information on the status of murrelets at sea adjacent to the NWFP area. A conservation goal of the NWFP is to stabilize and increase murrelet populations by maintaining and increasing nesting habitat. In this report, we address a primary question for evaluating the plan's effectiveness in achieving this goal during the first 25 years of NWFP implementation: "Is the murrelet population stable or increasing?" Our findings based on at-sea abundance indicate that the answers to this question are "yes and no." The murrelet abundance at sea adjacent to the NWFP area is not stable or increasing in Washington but seems to be increasing in Oregon and California. We believe that the magnitude of the decline observed for Washington state and its two conservation zones, based on the 2001 to 2018 period, is sufficient to cause concern, and merits a review of potential management implications and responses. In addition, we think the current every-other-year sampling design is inadequate for detecting within-season or interannual movements of murrelets among conservation zones. The every-other-year sampling approach also limits our ability to evaluate annual variation in murrelet abundance within and between years within conservation zones. For example, a dramatic increase in Conservation Zone 5 density in 2017 indicates the importance of surveying this conservation zone more frequently than every 4 years.

Management implications of results from the murrelet effectiveness monitoring program from 2000 through 2013 were provided in detail in Raphael et al. (2016b). Similar to what was found in that report, trend patterns reported here (2000 through 2018) are of concern, particularly for Washington, where the murrelet abundance at sea has not stabilized. Both the NWFP (FEMAT 1993) and the species' recovery plan (USFWS 1997) anticipated a challenge in maintaining murrelet populations for 50 to 200 years, until new nesting habitat develops. In light of observed trends in at-sea abundance, our findings underscore the importance of the goal to maintain existing nesting habitat. Long-term monitoring of murrelet populations and their environment, including nesting habitat and abundances at sea should reveal whether the NWFP meets its conservation goal of stabilizing and ultimately increasing murrelet populations by maintaining and increasing nesting habitat. With long-term monitoring, we may also better understand the mechanisms underlying population change, and the degree to which population changes are due to nesting habitat conditions on the lands managed under the NWFP (see Lorenz et al. 2021). Additional research on local recruitment, within season dispersal, and breeding phenology could help disentangle long-term population change from short term shifts associated with post-breeding or failed breeding movements. Finally, we intend to explore how a variety of physical forcing factors (e.g., Pacific Decadal Oscillation, El Niño, upwelling), either independently or synergistically, might be influencing murrelet abundance trends in a nonlinear fashion.

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