Marbled Murrelet Effectiveness Monitoring
Northwest Forest Plan

2009 and 2010 Summary Report

Northwest Forest Plan Interagency Regional Monitoring Program

Gary Falxa
Marbled Murrelet Module Lead

Team Members:

Population Monitoring
Jim Baldwin, US Forest Service, Pacific Southwest Research Station
Tom Bloxton, US Forest Service, Pacific Northwest Research Station
Monique Lance, Washington Department of Fish and Wildlife
Deanna Lynch, US Fish and Wildlife Service
Sherri L. Miller, US Forest Service, Pacific Southwest Research Station
Scott F. Pearson, Washington Department of Fish and Wildlife
C.J. Ralph, US Forest Service, Pacific Southwest Research Station
Martin G. Raphael, US Forest Service, Pacific Northwest Research Station
Craig Strong, Crescent Coastal Research
Rich Young, US Fish and Wildlife Service
Gary Falxa, US Fish and Wildlife Service

Habitat Monitoring
Katie Dugger, Oregon State University
Beth Galleher, US Forest Service, Pacific Northwest Research Station
Deanna Lynch, US Fish and Wildlife Service
Sherri L. Miller, US Forest Service, Pacific Southwest Research Station
S. Kim Nelson, Oregon State University
Martin G. Raphael, US Forest Service, Pacific Northwest Research Station
Rich Young, US Fish and Wildlife Service
Gary Falxa, US Fish and Wildlife Service

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SUMMARY

This report summarizes the 2009 and 2010 activities of the Marbled Murrelet (*Brachyramphus marmoratus*) Effectiveness Monitoring Program in the area of the Northwest Forest Plan (NWFP). The purpose of the effectiveness monitoring program is to assess status and trends of murrelet populations and nesting habitat. This report includes results of the annual at-sea population surveys including a trend analysis, and an update on modeling of nesting habitat.

The objectives of the murrelet population monitoring are to estimate (1) population trends and (2) population size during the breeding season within and across five murrelet conservation zones in coastal waters adjacent to the NWFP area. The 2010 estimated population of murrelets in the NWFP target (sampling) area is 16,700 (95 percent confidence interval = 13,100 to 20,300), with the largest Zone population estimates occurring in Conservation Zone 3 (Columbia River to Coos Bay, Oregon, about 7,200) and in Conservation Zone 1 (Puget Sound and Straits of Juan de Fuca, about 4,400). At the conservation zone scale, mean murrelet at-sea density estimates in 2010 ranged from 0.78/km^2 in Zone 2 (outer Washington coast) to 4.53 birds/km^2 in Zone 3. Conservation Zone 5 was not surveyed in 2009 or 2010.

For the 5-zone area combined, trend analyses continue to show a population decline. The estimated mean rate of annual decline during the 2001 to 2010 period was 3.7 percent (95% confidence interval = -2.7 to -4.8%), which is equivalent to a total population decline over this period of about 29 percent. At the scale of individual conservation zones, we detected a decline during this same period for Zone 1, where the murrelet population is declining at an estimated rate of 7.4 percent per year. No statistically significant, zone-specific trends were detected for any of the other four conservation zones. Additional years of at-sea monitoring will be needed to reliably detect population declines in these zones. Continued monitoring will also be needed, to evaluate whether the declines observed to date continue into the future, and if so, at what rate.

In 2010 the team completed a map of baseline (1994/96) nesting habitat and estimated habitat changes since then through 2006/07, using maximum entropy (Maxent) models. We selected Maxent models based on their performance against several other modeling platforms. Maxent provided habitat suitability scores for all forested lands in the 5 conservation zones within the NWFP area (zones 1-5). We estimated 3.8 million acres of higher-suitability potential nesting habitat over all ownerships in this area at the start of the NWFP (1994/96). Most (89 percent) baseline habitat on federal lands occurred within reserved-land allocations, which include late-successional reserves established by the NWF Plan, wilderness areas, National Parks, and other areas not open to timber harvest. A substantial amount (36 percent) of baseline higher-suitability habitat occurred on non-federal lands. Focusing on losses of baseline habitat, we found a loss of about 13 percent of the baseline higher-suitability nesting habitat by 2006/07 over all lands, with losses greater on non-federal lands (about 30 percent of baseline) than on federal lands (about 3 percent). Fire has been the major cause of loss of nesting habitat on federal lands since the NWFP was implemented; timber harvest is the primary cause of loss on non-federal lands.

Publications which include recent population and habitat monitoring results in detail are in preparation or in press (see Falxa et al. 2011; Raphael et al. in press, and Miller et al. in preparation in "Recent Program Product" below).

PREFACE

This report was prepared by Gary Falxa, Deanna Lynch, and the Marbled Murrelet Monitoring Team members.

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CONTACT INFORMATION

For more information on the Marbled Murrelet Monitoring Program, contact:

Gary Falxa (Marbled Murrelet Module Lead)
Phone: 707-825-5107
Email: gary_falxa@fws.gov

For more information on the Interagency Regional Monitoring Program, contact:

Lynn Burditt (Monitoring Program Manager)
Phone: 503-808-2175
Email: lburditt@fs.fed.us

Web Site

Additional information, reports, publications, and program updates relevant to the Marbled Murrelet Effectiveness Monitoring Program (as well all other modules from the Interagency Regional Monitoring Program) can be found at http://www.reo.gov/monitoring.

SUGGESTED CITATION:

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INTRODUCTION

Regional-scale trend information can provide insights into broad-scale patterns and processes, as well as help support management strategies to achieve desired goals and objectives and to formulate new strategies (i.e., adaptive process). Evaluating population trends requires a commitment to long-term monitoring (multiple years) and consistent data collection from a target population sampled without biases (Urquhart et al. 1998).

The marbled murrelet (*Brachyramphus marmoratus*; hereafter murrelet) and northern spotted owl (*Strix occidentalis*) were the focal animal species selected to monitor and evaluate the effectiveness of the 1994 Northwest Forest Plan (NWFP). One NWFP goal is to maintain and restore marbled murrelet nesting habitat and populations throughout the range of the species within the NWFP area. A two-pronged approach is used to monitor murrelets and evaluate the success of the NWFP (Madsen et al. 1999). The first approach uses annual at-sea surveys to assess murrelet population status and trends. Status and trend information is used to assess the stability of murrelet populations within the NWFP area, and to help inform whether land-based management actions are providing for the recovery of the species. For murrelets, at-sea surveys are an accurate and direct means to monitor population trends across the range of the NWFP. Because murrelets are secretive nesters, baseline reproductive information is difficult and expensive to collect at breeding locations. At-sea population surveys offer a cost-effective method for assessing the persistence and conservation status of this species. The methods used for the at-sea surveys were published in 2007 (Raphael et al. 2007). The second approach for evaluating murrelet status within the NWFP area is to monitor the amount and trends of potential nesting habitat in the planning area. To accomplish this objective, murrelet habitat models were developed and the initial results published in 2006 (Huff et al. 2006).

The objectives of this report are to present the 2009 at-sea survey results, to present results of population trend analyses using the population data collected through 2009, and to describe habitat modeling work.

EFFECTIVENESS MONITORING QUESTIONS

The broad objectives and approach to effectiveness monitoring for the NWFP are described in Mulder et al. (1999). Effectiveness monitoring questions examine the extent to which measures of interest (e.g., strategy or initiative) have achieved intended objectives by evaluating the observed outcomes or impacts against expectations. Status questions evaluate the conditions of an indicator resource at a given moment in time, whereas trends follow changes in indicators over time and space.

The effectiveness monitoring goal for the marbled murrelet is to evaluate the success of the NWFP in maintaining and restoring murrelet populations and nesting habitat (Madsen et al. 1999). To meet that goal, the monitoring plan for murrelets identified questions to be addressed for the NWFP area, focused on (1) the predicted amount, distribution and spatial attributes of murrelet nesting habitat, and trends in those characteristics, and (2) murrelet population status

and trends. These questions are detailed in the murrelet effectiveness monitoring plan (Madsen et al. 1999).

Subsequently, Northwest Forest Plan managers identified a list of key management questions for the NWFP monitoring program. This list contains two questions directly related to murrelets:

1. What is the status and trend of Marbled Murrelet habitat and populations?
    - Identified by managers as best answered by monitoring
2. What are the relationships between marbled murrelet status and stressors, how does this affect nesting distribution, and can habitat models effectively predict where murrelets nest?
    - Identified by managers as best answered by research

METHODS

Methods for data collection and analysis of population and habitat information can be found in Huff et al. (2006) and Raphael et al. (2007). Deviations from the population survey protocol during 2009 are presented below.

Population Monitoring

Marbled murrelets are sampled from boat-based transects within 2 - 8 km of shore in Recovery Conservation Zones 1 through 5, adjacent to the NWFP area (U.S. Fish and Wildlife Service 1997; Figure 1). We conducted surveys from mid-May through late-July, the peak activity period of the murrelet nesting season. We divided each conservation zone into two or three strata based on murrelet density patterns, and created contiguous Primary Sampling Units (PSU) of approximately 20 km coastline length throughout the NWFP area (Raphael et al. 2007). Our target sample size was 30 PSU surveys per zone in most zones (60 for the larger Zone 1, 15 for Zone 5). We used program DISTANCE (Buckland et al. 2001) to generate population density estimates at the conservation zone and NWF Plan scales. The confidence intervals for individual zone population estimates were constructed using the bootstrap approach; this can result in asymmetric confidence intervals. For the population estimate for all zones combined, we constructed confidence intervals by first calculating the 5-zone standard error from the individual zone standard errors, weighting by zone area. We then constructed the 95 percent confidence intervals as plus/minus 1.96 times the 5-Zone standard error; these are symmetric. See Raphael et al. (2007) for additional details on methods.

In most zones, most or all of the shoreline is sampled at least once each year. Zone 1 (Puget Sound, San Juan Islands, Straits of Juan de Fuca) has a long complex shoreline, with 98 Primary PSUs total. At the outset of the monitoring program, a one-time stratified random sample of 30 of the 98 PSUs was selected from Zone 1, with sampling effort distributed differentially among the zone's 3 geographic strata based on relative murrelet abundance. These 30 PSUs are sampled twice annually, for a total of 60 PSU samples from Zone 1 (Raphael et al. 2007). Stratum 3 of Zone 1 includes 47 PSUs and encompasses the Puget Sound, parts of Hood Canal

and Whidbey Island, and the mainland between Puget Sound and the border with Canada. Historic data for this stratum indicated low murrelet densities; therefore the sampling design allocated relatively light effort where5 PSUs are sampled twice annually. This approach is robust with respect to detecting trends. While murrelet density and numbers are generally low within the stratum, they can be locally high at times, and density estimates for this stratum can be influenced by high murrelet density in a single PSU sample.

In 2010, we decided to exclude the 2000 results from Zones 1 and 2 from all population estimates and trend analysis. As discussed in our previous report (Falxa et al. 2009), inspection of the data set (Figure 2) suggested that the 2000 estimate may have been unusually low. The 2000 estimates from Zones 1 and 2 are particularly low relative to later estimates (Figure 3). The cause for the low 2000 estimates is not known; it may represent the true abundance that year or it may represent natural or sampling variation. However, departures from the sampling protocol occurred in Zone 2 and in Stratum 1 of Zone 1 in 2000, the first year of implementing the protocol. These departures included use of a fixed-width transect rather than an unlimited-width transect, less sampling effort compared to subsequent years, and loss of distance data for many murrelet detections. Another consideration was that Stratum 1 of Zone 1 comprises a substantial portion of the Zone 1 murrelet population. After reviewing these facts at our January 2010 team meeting, we concluded that these departures from the protocol could potentially bias population estimates using the Zone 1 or Zone 2 data from 2000, sufficiently to be unreliable. Therefore, the team decided to exclude the 2000 survey results from the population estimates for Conservation Zones 1 and 2 and from the 5-Zone trend analysis. The departures from protocol were corrected in subsequent years.

We calculated a population estimate for the entire 5-zone area by summing the estimates from each zone, for a given year. Because Zone 5 was not surveyed in 2006, 2009, or 2010, we used estimates for the missing data to allow 5-zone population estimates and trend analyses for all years. We estimated the 2006 Zone 5 density and population as the mean of the 2005 and 2007 Zone 5 estimates, and used 2008 data from Zone 5 to estimate the 2009 and 2010 Zone 5 density and population. Because the counts from Zone 5 are so low with respect to the other zones, these estimations had little effect on the overall estimated number of birds, or on the trend analyses.

Adjustments and other notes on survey methods for 2009
Due to lack of funding, Conservation Zone 5 was not surveyed in 2009.

Conservation Zone 3 experienced a 14-day period without sampling in late June and early July, as a result of unfavorable weather conditions and logistical problems. Sampling gaps of a week are expected for the outer coast zones due to weather conditions, but the 2009 gap was longer than usual. Due to logistical issues and unfavorable weather conditions survey effort in Conservation Zone 4 was also less evenly distributed than planned and first sampling was delayed until May 29. As a result of these factors, sampling was heavier during the 1st two weeks of June and during July. The 2009 gaps did not affect the sample size for either zone but the gap resulted in the samples being more clustered temporally than normal. Also, following the 2009 survey season, a minor error was found in the 2004 data used for analysis for Zone 4. Population estimates were redone for 2004, and the corrected numbers have been incorporated into Table 2 and into the trend analyses.

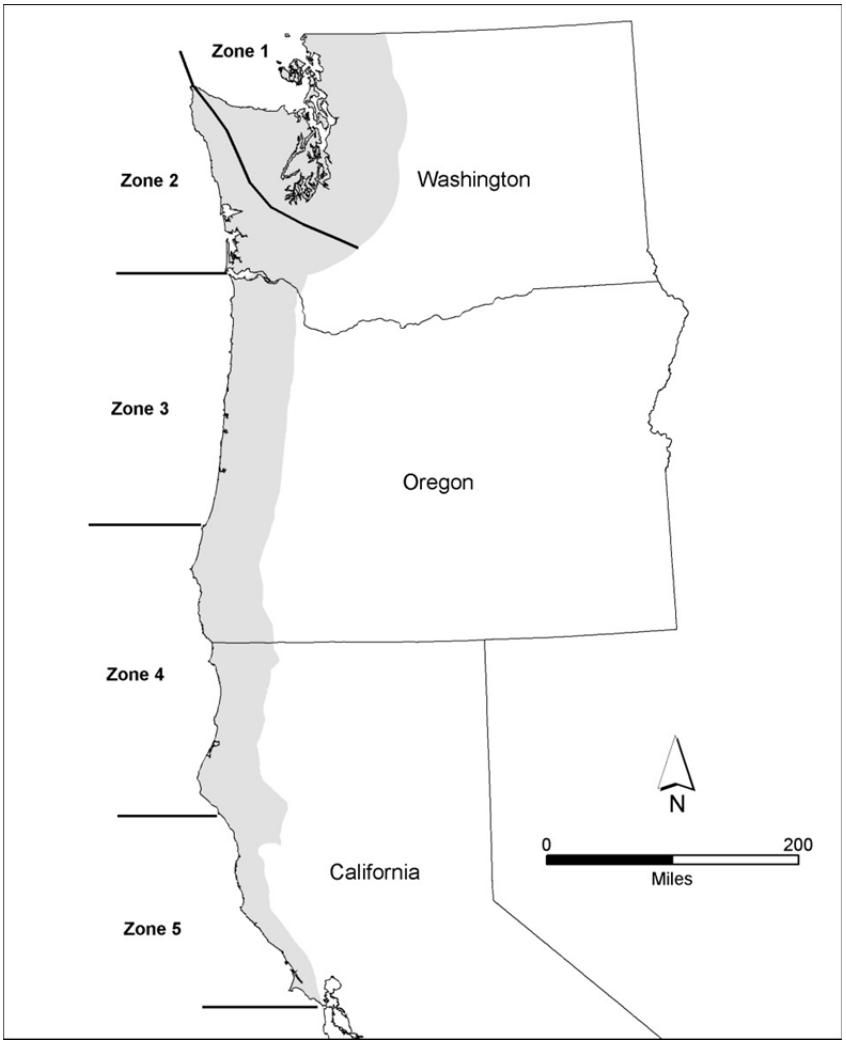

Figure 1. The five at-sea marbled murrelet survey zones adjacent to the NWFP area. Inland breeding distribution is shaded (adapted from U.S. Fish and Wildlife Service 1997).

In June 2009, the module lead accompanied the Oregon survey team from Crescent Coastal Research on murrelet surveys in Zones 3 and 4, in part to check for consistency among crews and zones in implementing the survey protocol. No major inconsistencies were identified. In 2009 we did identify a difference among crews in the treatment of murrelets first detected as flying birds. For these birds, the Oregon crew has estimated distance to the transect line from the point where the flying bird was closest to the boat, while other crews estimate this distance from where the flying bird was first detected. Upon reviewing distance sampling assumptions and consulting with the team statistician, we determined that the distance should be estimated from the point where first detected, as has been practiced by 3 of 4 crews. This will be implemented by all teams starting in 2010. Initial analysis indicates that this affected distance estimates for about 10 to 15 percent of the murrelet detections in Oregon (Zone 3 and the northern portion of Zone 4). We do not anticipate that this difference in distance estimation procedure for a small

portion of birds would affect population estimates from Oregon, but will evaluate the effect of this protocol difference once we have comparable data from the Oregon crew collected by estimating distance to flying murrelets based on the point of first detection.

Adjustments and other notes on survey methods for 2010
Due to lack of funding, Conservation Zone 5 was not surveyed in 2010.

Inclement weather conditions resulted in gaps in surveys in Conservation Zones 2, 3, and 4. This resulted in surveys being conducted later in the survey season, especially in Conservation Zone 2 stratum 2 and Conservation Zone 3. As fog played a role in poor visibility conditions in 2010, during the annual meeting, the team decided that a survey should only be conducted when surveyors can see a murrelet at 150 meters. Murrelets beyond this distance should have minor effect on density estimates, in part due to truncation. During the annual meeting, it was also re-emphasized that surveys should only conducted if sea state is Beaufort 3 or less and if greater than 25 percent of the PSU sample is collected under poor survey conditions, the entire PSU sample is discarded.

Trend Analysis

Demographic models predict a declining trend for murrelets (U.S. Fish and Wildlife Service 1997, McShane et al. 2004), and we used annual population estimates to evaluate whether or not a declining trend exists. In our program's 2008 report (Falxa et al. 2009), we tested for trends for two periods: 1) 2000 through 2008, and 2) 2001 through 2008, because of potential biases in the year 2000 data from Zone 2 and Stratum 1 of Zone 1. As discussed above, in January 2010, we decided to omit the 2000 data for Zones 1 and 2 from future trend analyses.

The statistical test for trends was conducted by fitting a regression line to the logarithm (ln) of the annual population density estimates for each of the five individual zones within the NWFP area, and for the 5-zone area combined. Because the population estimates are computed by multiplying murrelet density by the total area surveyed (which does not change from year to year), the rate of change will be identical using either the densities or the population numbers in the regression. Starting in 2010, we conducted the regression on the log of densities rather than on the simple densities. This better fits and tests the predictions of demographic models (USFWS 1997; McShane et al. 2004) which predict a population that is declining by a constant *percent* of the population size for a given year (consistent with the basic model of exponential population growth or decline; Begon et al. 2006), rather than declining by a fixed *number* of birds per year.

The statistical tests for trends were conducted as one-tailed tests for declines; significance was tested at the level of alpha (α) = 0.05. Thus, we tested the null hypothesis that the slope equals zero or greater (no change or an increase in murrelet numbers) against the alternative hypothesis of the slope being less than zero (murrelet numbers decreasing; Miller et al. 2006, page 46). Estimates for annual rates of decline were calculated by dividing the estimated annual decline for the period of analysis (the slope from the regression equation, in numbers of birds) by the mean population for the period of analysis (the average of the annual population estimates). The trend analyses are based on the period of 2001-2010 for the all-zone trend analyses. For the single-

zone trend analyses data from 2001-2010 were used for Zones 1 and 2 and data from 2000-2010 were used for the other 3 zones.

Habitat Modeling

In 2010 the team completed work initiated in 2007 to map baseline nesting habitat conditions (at the start of the NWFP in 1994), and to estimate habitat changes since then, using maximum entropy (Maxent) models. We based our nesting habitat estimates on habitat suitability models which used vegetation mapping from GNN (Gradient Nearest Neighbor; Ohmann and Gregory 2002). We used a recent modeling platform, Maxent (maximum entropy) habitat suitability software (Phillips et al. Dudík 2006), which we found to perform best based on a test of several current habitat modeling methods. Using Maxent models, we estimated the amount and distribution of potential murrelet nesting habitat during two periods: (1) baseline (1994 for California, 1996 for Oregon and Washington) and (2) 2006 (Oregon and Washington) or 2007 (California) to estimate change since the baseline. As input to the models, we used maps of the distribution of various environmental characteristics, including GNN vegetation data and climate and topographic conditions at the 30-meter pixel scale. We trained the Maxent model by using environmental conditions at 342 known murrelet nest locations and sites classified as occupied by audiovisual surveys. Model output is a map of habitat suitability, which we summarized into four classes ranging from low (class 1) to high (class 4) suitability, based on relative likelihood of murrelet presence. We used the higher two of these (classes 3 and 4) to denote potential higher suitability nesting habitat.

We used two methods to assess change in the amount and distribution of higher suitability nesting habitat: The "bookend" approach used the Maxent model to estimate habitat suitability in two periods, the baseline year and in 2006/2007; by comparing mapped habitat suitability for the two periods, we estimated net change as the balance between losses and gains of higher suitability habitat during the analysis period. This method cannot identify causes of habitat losses. Our second approach used forest disturbance data provided by LandTrendr (Landsat-based detection of Trends in Disturbance and Recovery; see Raphael et al. [in press] for details) to refine the estimates of habitat loss as determined by the bookend approach. Using LandTrendr data allowed us to identify likely causes of habitat loss, focusing on areas where bookend losses were also mapped as disturbed by LandTrendr. This second approach did not provide information on potential habitat gains.

New vegetation data and Maxent models provide more powerful and consistent results across the monitoring area than those available from the 10-year report (Huff et al. 2006). The new baseline maps and estimates replace those from the 10-year report.

RESULTS AND DISCUSSION

Population Monitoring

Table 1 summarizes the 2009 and 2010 sampling efforts and Table 2 the 2001-2010 results. The 2009 estimated murrelet population size in Conservation Zones 1 through 5 was 17,800 birds and in 2010 was 16,700 murrelets (Table 2). Among conservation zones, Zones 1 and 3 had the highest population estimates in both years and Zone 4 the highest average density (4.18 birds/km^2) in 2009, while Zone 3 had the highest average density (4.53 birds/km^2) in 2010. A summary of results for Conservation Zones 1 through 5 combined is provided in Table 2 and Figure 2. Tables 3 and 4 provide the 2009 and 2010 density and population estimates for each conservation zone and includes related estimation parameters generated by the program DISTANCE. Figure 3 provides a comparison of yearly population estimates by conservation zone, while Figure 4 provides murrelet density (birds/km^2) by zone.

The area of coastal waters sampled by the NWFP at-sea surveys in 2009 and 2010 was approximately 7,900 km^2; sampled areas vary by zone, as indicated in Table 3. This area does not include Zone 5, which was not sampled in 2009 or 2010.

The relative variation in density estimates can be measured by the coefficient of variation (CV; the standard error divided by the mean, and then multiplied by 100). For the combined 5-zone density estimate, the CV has ranged from ~8 to 13 percent since 2001, and was 10.2 percent in 2009 and 11.1 percent in 2010 (Table 2). At the scale of individual zones, CVs are typically larger, and ranged from ~18 to 22 percent in 2009 (Table 3) and from ~17 to 27 percent in 2010 (Table 4), comparable to results in previous years (Falxa et al. 2008; Falxa et al. 2009). In general, variation tended to be largest in zones and strata with low densities. However, the highest variation in 2010 was in Zone 4, which had the second-highest density estimate.

Maps that display the average estimated population density of murrelets from 2000/2001 through 2010 by primary sampling unit for each of the three States are provided in the Appendix. The information presented in the figures is provided only to illustrate general patterns of murrelet distribution within the areas sampled. The figures should not be used for other analyses because the sampling program was designed to monitor densities at the conservation zone scale and larger, and the primary sampling unit density estimates have large confidence intervals, which are not shown in the figures.

Table 1. The number of marbled murrelet population monitoring primary sampling unit (PSU) surveys completed for the Northwest Forest Plan in 2009 and 2010 by zone and the kilometers of survey transect sampled.

Zone	2009 Number of PSU Surveys	2009 Survey Effort (km)	2010 Number of PSU Surveys	2010 Survey Effort (km)
All	157	5,634	146	5433
1	60	2,230	60	2246
2	31	1,380	30	1342
3	31	1,111	30	1169
4	35	912	26	676
5	No surveys		No surveys	

Table 2. Summary of 2001-2010 murrelet density and population size estimates (rounded to nearest 100 birds) in all conservation zones combined.

Year	**Density (birds/km^2)**	**Bootstrap Standard Error (birds/km^2)**	**Coefficient of Variation of Density (%)**	**Birds**	**Birds Lower 95% CL**	**Birds Upper 95% CL**
2001	2.52	0.27	10.5	22,200	17,600	26,800
2002	2.69	0.31	11.5	23,700	18,300	29,000
2003	2.53	0.24	9.5	22,200	18,000	26,400
2004	2.43	0.25	10.5	21,400	17,000	25,800
2005	2.30	0.25	10.8	20,200	16,000	24,500
2006	2.14	0.17	8.0	18,800	15,900	21,700
2007	1.98	0.26	13.4	17,400	12,800	21,900
2008	2.03	0.18	9.1	17,800	14,600	21,000
2009	2.02	0.21	10.2	17,800	14,200	21,300
2010	1.90	0.21	11.1	16,700	13,100	20,300

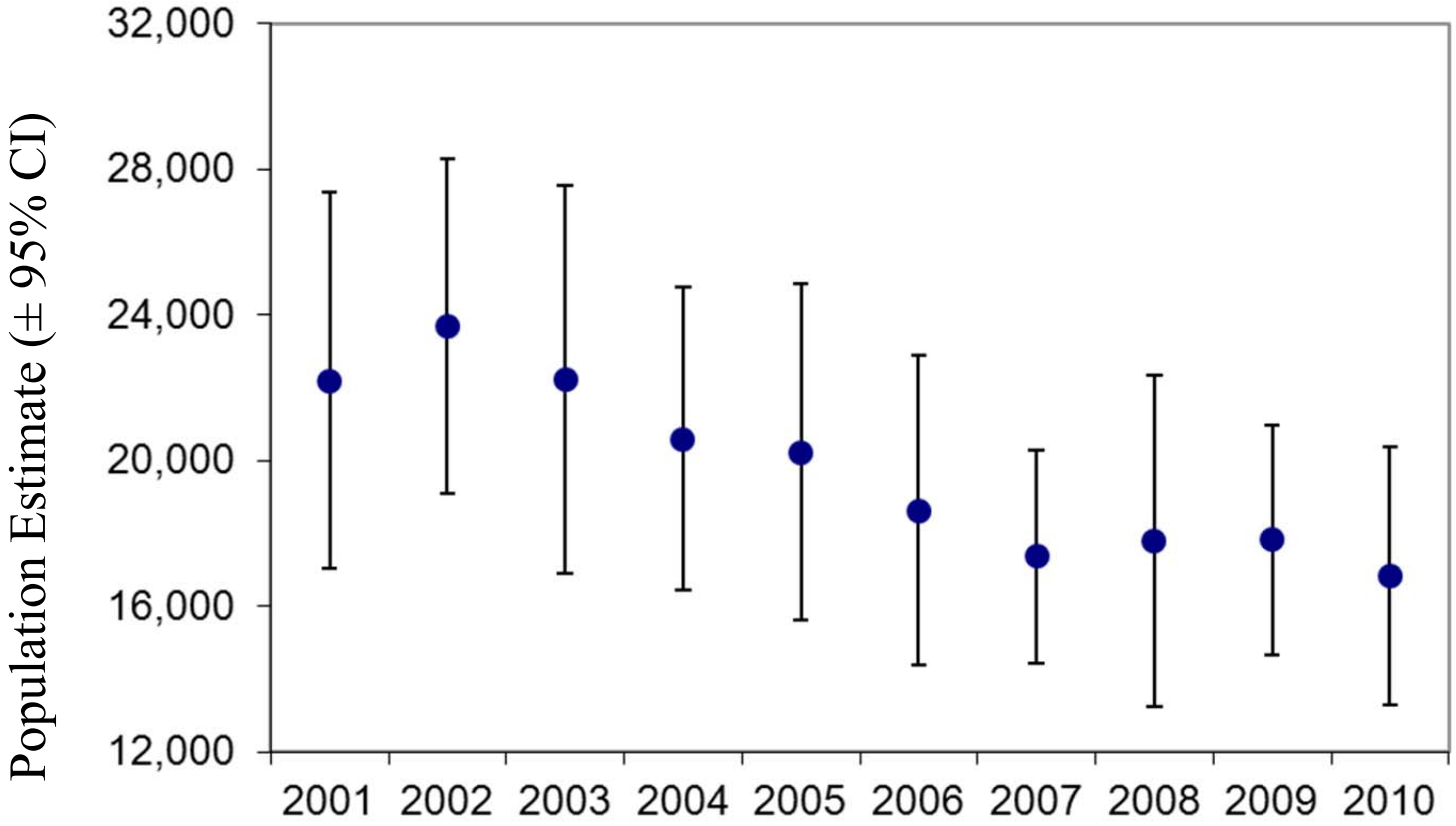

Figure 2. Annual marbled murrelet population estimates and 95 percent confidence intervals, for Conservation Zones 1 - 5 combined.

Table 3. Estimates of murrelet density and population size during the 2009 breeding season in the area of the Northwest Forest Plan. E(s), f(0), and truncation distance are parameters used by the program DISTANCE; see Raphael et al. (2007) for details. Because Zone 5 was not sampled in 2009, the "All Zone" population results use an estimated density for Zone 5 (see text for details).

Zone	Stratum	Density (birds/km^2)	Bootstrap Standard Error (birds/km^2)	Coefficient of Variation of Density (%)	Birds	Birds Lower 95% CL	Birds Upper 95% CL	Survey Area (km^2)	Total Length of Survey Transects (km)	f(0)	Std. err. of f(0)	E(s)	Std. err. of E(s)	Truncation Distance (m)	Std. err. of Truncation Distance
1	1	3.81	1.008	26.5	3,221	1,913	5,187	845							
1	2	0.69	0.177	25.7	822	482	1,299	1,194							
1	3	1.08	0.438	40.4	1,580	410	3,152	1,458							
1	**All**	**1.61**	**0.321**	**19.9**	**5,623**	**3,922**	**8,352**	**3,497**	**2,230.4**	**0.009**	**0.0008**	**1.69**	**0.110**	**254**	**15.2**
2	1	1.61	0.385	23.8	1,170	673	1,798	724							
2	2	0.10	0.065	62.3	97	--	206	926							
2	**All**	**0.77**	**0.171**	**22.3**	**1,266**	**751**	**1,881**	**1,650**	**1,379.8**	**0.009**	**0.0008**	**1.47**	**0.067**	**191**	**16.9**
3	1	0.65	0.268	41.3	429	191	867	661							
3	2	5.84	1.097	18.8	5,461	3,501	7,408	935							
3	**All**	**3.69**	**0.655**	**17.7**	**5,890**	**3,847**	**7,969**	**1,595**	**1,111.4**	**0.013**	**0.0008**	**1.69**	**0.063**	**120**	**11.4**
4	1	5.85	1.154	19.7	4,295	3,042	6,320	734							
4	2	1.31	0.806	61.7	556	254	1,441	425							
4	**All**	**4.18**	**0.791**	**18.9**	**4,851**	**3,575**	**7,153**	**1,159**	**912.4**	**0.011**	**0.0007**	**1.61**	**0.056**	**150**	**7.9**
5	**All**	**Not sampled in 2009**													
All		**2.02**	**0.206**	**10.2**	**17,751**	**14,204**	**21,298**	**8,785**							

Table 4. Estimates of murrelet density and population size during the 2010 breeding season in the area of the Northwest Forest Plan. E(s), f(0), and truncation distance are parameters used by the program DISTANCE; see Raphael et al. (2007) for details. Because Zone 5 was not sampled in 2010, the "All Zone" population results use an estimated density for Zone 5 (see text for details).

Zone	Stratum	Density (birds/km^2)	Bootstrap Standard Error (birds/km^2)	Coefficient of Variation of Density (%)	Birds	Birds Lower 95% CL	Birds Upper 95% CL	Survey Area (km^2)	Total Length of Survey Transects (km)	f(0)	Std. err. of f(0)	E(s)	Std. err. of E(s)	Truncation Distance (m)	Std. err. of Truncation Distance
1	1	2.00	0.557	27.8	1694	920	2744	845							
1	2	1.78	0.424	23.8	2128	1058	3091	1,194							
1	3	0.39	0.171	43.7	571	81	1164	1,458							
1	**All**	**1.26**	**0.256**	**20.4**	**4393**	**2689**	**6367**	**3,497**		**0.01**	**0.0012**	**1.72**	**0.078**	**200**	**9.1**
2	1	1.34	0.326	24.4	968	535	1441	724							
2	2	0.34	0.249	72.5	318	-	815	926							
2	**All**	**0.78**	**0.2**	**25.7**	**1286**	**650**	**1946**	**1,650**		**0.011**	**0.0013**	**1.58**	**0.065**	**145**	**12.8**
3	1	1.07	0.531	49.6	708	219	1376	661							
3	2	6.97	1.230	17.6	6515	3927	8521	935							
3	**All**	**4.53**	**0.764**	**16.9**	**7223**	**4605**	**9520**	**1,595**		**0.014**	**0.0020**	**1.77**	**0.069**	**160**	**30.5**
4	1	3.75	1.244	33.4	2751	1461	4939	734							
4	2	2.16	0.726	35.5	917	435	1672	425							
4	**All**	**3.16**	**0.864**	**27.3**	**3668**	**2196**	**6140**	**1,159**		**0.012**	**0.0011**	**1.63**	**0.086**	**165**	**12.4**
5	**All**	**Not sampled in 2010**													
All		**1.90**	**0.210**	**11.1**	**16,691**	**13,075**	**20,307**	**8,785**							

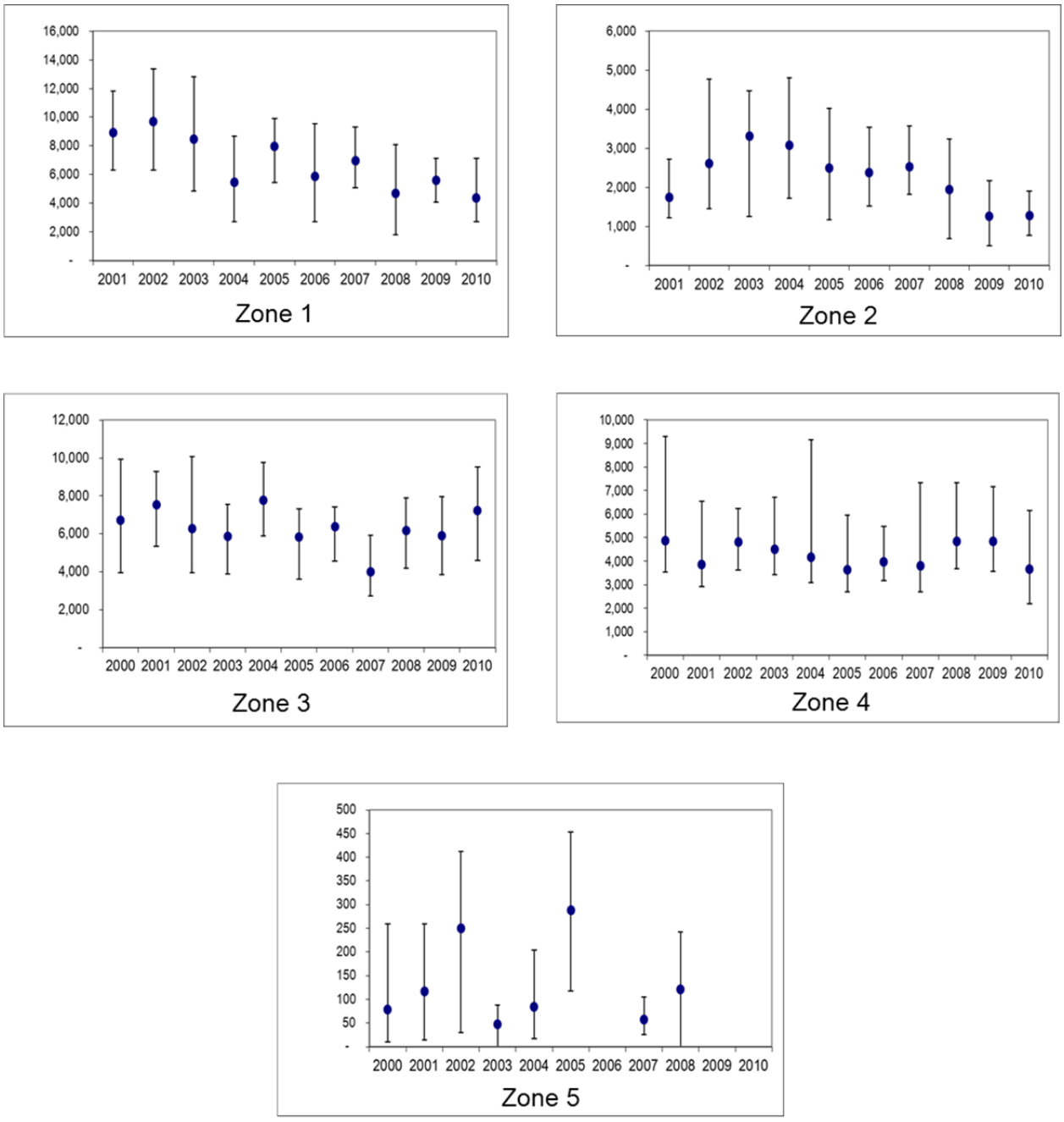

Figure 3. Annual marbled murrelet population estimates and 95 percent confidence intervals for each Conservation Zone (2001 through 2010 for Zones 1 and 2, 2000 through 2010 for Zones 3 through 5). Note that the scale of vertical axes differs among graphs, most notably for Zone 5.

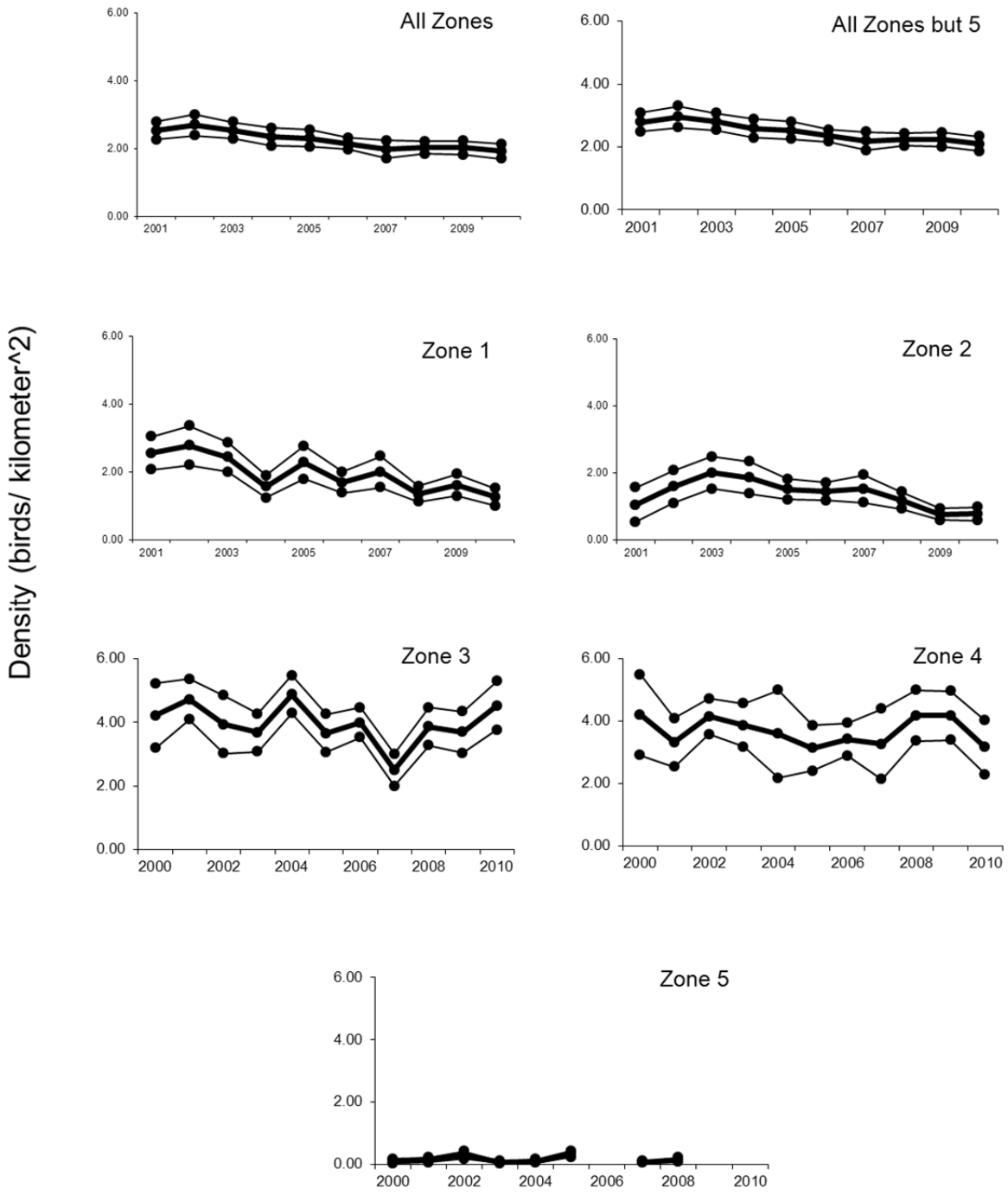

Figure 4. Estimated marbled murrelet densities (birds per square kilometer) for each Conservation Zone along with approximate 95 percent confidence intervals for years 2001 through 2010 (includes year 2000 for Zones 3, 4, and 5).

Trend Analysis

In early 2010, we conducted a new analysis of the statistical power of the sampling design to detect population changes at the single and all-zone spatial scales; this power analysis used the population data for 2001 to 2009, and updated the previous analysis published in Miller et al. (2006) which used the 2000 to 2003 data, For the population of the 5 conservation zones combined, the new power analysis estimated that with 9 years of annual sampling (the current sampling effort), an annual decrease of 3 percent could be detected with 95 percent power or greater, and that an annual decrease of 2 percent could be detected with lower (80 percent) power (Tables 5a and 5b). More years of sampling are required to detect smaller rates of decline, or to achieve greater certainty (power) of detecting an actual decline of any given magnitude. For individual zones, power to detect trends is always less. For example, in Zone 4 9 years of sampling was adequate to detect an annual decline of 7 percent or more with high confidence (Table 5b, 95 percent power); more years would be needed to detect smaller annual rates of decline.

Population demographic models predicted population declines of 3 to 7 percent per year for this area (U.S. Fish and Wildlife Service 1997; McShane et al. 2004). In 2008, we conducted an analysis for population trends and detected a significant population decline for the combined 5-zone area (Falxa et al. 2009). With the addition of 2009 and 2010 data, we have 10 to 11 years of density estimates which we can evaluate for trend over time. For the analysis based on the 2001-2010 period, the 5-zone population is estimated to be declining at a rate of 3.7 percent per year (95 percent confidence interval of -2.7 to -4.8 percent; Table 6 and Figure 5), which when compounded annually represents a total decline over this period of about 29 percent. While the estimated rate of decline has some uncertainty as indicated by the 95 percent confidence intervals (Table 6), the low *P*-value indicates a relatively high level of confidence that a declining trend exists.

We also conducted trend analyses for each individual zone (Table 6). The analysis showed a significant decline in Zone 1, with an estimated annual rate of decline of 7.4 percent (95 percent confidence interval of -3.5 to -11.2 percent). Statistically-significant ($P \leq 0.05$) trends were not detected elsewhere at the single-zone scale. However, in 2010 the *P*-value for the Zone 2 trend was 0.06, indicating that a declining trend is likely. As noted earlier, the variability in population estimates generally increases at smaller spatial scales such as zone. This decreases the statistical power to detect trends; as a result, more years of sampling are typically required to detect a trend (Tables 5a, 5b). For example, in Zone 3 the trend was not significant at the α=0.05 level, but the power analysis suggests that about 14 years of sampling would be required to detect an average decline of three percent or less with 80 percent power. Although not significant, the estimated rates of change south of Zone 1 suggest a pattern of greater declines in the northern zones (Table 6).

Table 5a. Estimate of the number of years of survey needed to detect various percentages of annual decrease in the NWFP murrelet population with 80 percent power or greater, in all Conservation Zones combined or by individual zone. Based on a power analysis conducted using 2001-2009 population results, using methods described in Huff et al. (2006; Chapter 3).

Annual Decrease Rate (%)	Zone					
	All	1	2	3	4	5
2	8	18	26	18	16	45
3	7	14	20	14	12	35
4	6	12	16	12	10	29
5	5	10	14	10	9	25
6	5	9	13	9	8	22
7	5	9	12	9	7	20
8	4	8	11	8	7	18
9	4	7	10	7	7	17
10	4	7	9	7	6	16

Table 5b. Estimate of the number of years of survey needed to detect various percentages of annual decrease in the NWFP murrelet population with 95 percent power or greater, in all Conservation Zones combined or by individual zone. Based on a power analysis conducted using 2001-2009 population results, using methods described in Huff et al. (2006; Chapter 3).

Annual Decrease Rate (%)	Zone					
	All	1	2	3	4	5
2	10	22	31	22	19	54
3	8	17	23	17	14	42
4	7	14	20	14	12	34
5	6	12	17	12	11	30
6	5	11	15	11	10	26
7	5	10	14	10	9	24
8	5	9	13	9	8	22
9	5	9	12	9	8	20
10	5	8	11	8	7	19

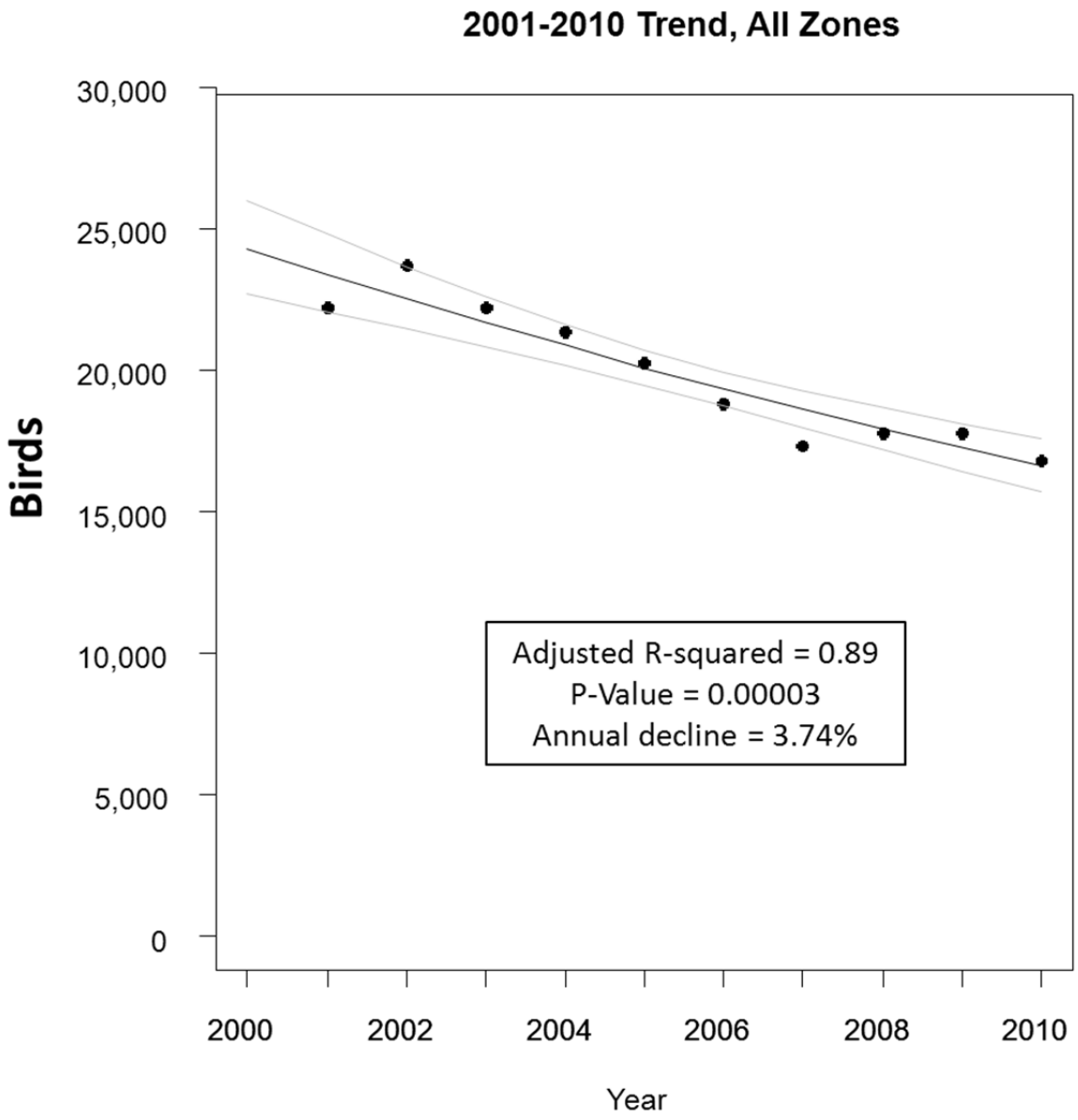

Figure 5. Results of trend analysis for Conservation Zones 1 through 5 combined for 2001-2010. Graph shows annual point estimates, the regression line and associated 95 percent confidence limits for line, and the regression equation and associated statistics.

Table 6. Estimates of average annual rate of change based on the at-sea population surveys conducted from 2000 through 2010. For 'all zones' and Zone 1 and 2, 2001-2010 was the basis for the trend analyses, while other analyses used the full data set; see text for details. Standard errors are for the estimates of percent annual change. The *P*-value is for testing whether the annual change is zero or a negative value less than zero.

Zone	Annual Rate of Change (%)		95% Conf. Limits		Adjusted R^2	*P*-value
	Estimate	Std. Err	Lower	Upper		
All Zones	-3.7	0.4	-4.8	-2.7	0.89	<0.001
1	-7.4	1.6	11.2	-3.5	0.67	0.002
2	-6.5	2.9	-13.1	0.6	0.29	0.06
3	-1.5	1.7	-5.4	2.6	0.00	0.41
4	-0.9	1.2	-3.9	2.0	0.00	0.47
5	-0.5	9.3	-21.7	26.3	0.00	0.96

Habitat Monitoring

In 2010 the team completed a map of baseline (1994/96) nesting habitat and estimated habitat changes since then through 2006/07, using maximum entropy (Maxent) models. We selected Maxent models based on their performance against several other modeling platforms. Maxent provided habitat suitability scores for all forested lands in the 5 conservation zones within the NWFP area (zones 1-5). We estimated 3.8 million acres of higher-suitability potential nesting habitat over all ownerships in this area at the start of the NWFP (1994/96). Most (89 percent) baseline habitat on federal lands occurred within reserved-land allocations, which include late-successional reserves established by the NWF Plan, wilderness areas, National Parks, and other areas not open to timber harvest. A substantial amount (36 percent) of baseline higher-suitability habitat occurred on non-federal lands. Focusing on losses of baseline habitat using the LandTrendr-informed approach, we found a loss of about 13 percent of the baseline higher-suitability nesting habitat by 2006/07 over all lands, with losses greater on non-federal lands (about 30 percent of baseline) than on federal lands (about 3 percent). Fire has been the major cause of loss of higher-suitability nesting habitat on federal lands since the NWFP was implemented; timber harvest is the primary cause of loss on non-federal lands. We also found that murrelet population size is strongly and positively correlated with the amount of nesting habitat, suggesting that conservation of remaining nesting habitat and restoration of currently unsuitable habitat is key to murrelet recovery. Raphael et al. (in press) provides the full results of this modeling effort.

MONITORING PROGRAM CONSIDERATIONS

Funding to maintain annual at-sea surveys continues to be a challenge. Surveys will be conducted in 2011. Funding continues to be a challenge for the at-sea surveys, exacerbated by reduced agency budgets. Funding surveys remains difficult for Zone 5, and has become a greater challenge in Zone 1, where the primary funding responsibility shifted in 2010 from the U.S. Forest Service PNW to the U.S. Fish and Wildlife Service.

In the near term, the Habitat and Population teams plan to bring their data together in order to investigate the relationships between nesting habitat distribution and trends, and murrelet population distribution and trends. One question is the roles of various factors on murrelet population trends; factors include past and ongoing losses of suitable nesting habitat, as well as other potential contributing factors, such as prey availability and marine conditions.

RECENT PROGRAM PRODUCTS

Earlier program products are listed in previous reports, which are available at: http://www.reo.gov/monitoring/reports/marbled-murrelet-reports-publications.shtml. The following recent publications and reports were published in association or collaboration with the Marbled Murrelet Effectiveness Monitoring Program in the last 3 years:

Falxa, G.; J. Baldwin, D. Lynch; S.K. Nelson; S.L. Miller; S.F. Pearson; C.J. Ralph; M.G. Raphael; C. Strong; T. Bloxton; B. Galleher; B. Hogoboom; M. Lance; R. Young; and M.H. Huff. 2009. Marbled murrelet effectiveness monitoring, Northwest Forest Plan: 2008 summary report. 19 pp. Available at: http://www.reo.gov/monitoring/reports/marbled-murrelet-reports-publications.shtml

Falxa, G; M. Raphael; S.L. Miller; J. Baldwin; T.D. Bloxton, Jr.; K. Dugger; B. Galleher; M.M. Lance; D. Lynch; S.K. Nelson; S.F. Pearson; C.J. Ralph; C.S. Strong; R. Young. 2011. Status and Trends of Populations and Nesting Habitat for the Marbled Murrelet. Chapter 3 *in*: Davis, R.; Falxa, G.; Grinspoon, E.; Harris, G.; Lanigan, S.H.; Moeur, M.; Mohoric, S. Northwest Forest Plan—The First 15 Years [1994-2008]: Monitoring the Northwest Forest Plan - Fifteen Year Summary of Key Findings. Tech. Paper R6-RPM-TP-XX-2011. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. Available at: http://www.reo.gov/monitoring/reports/15yr-report/summary/index.shtml

Long, L.L; S.L Miller; C.J. Ralph; E.A. Elias. 2008. Marbled murrelet abundance, distribution, and productivity along the coasts of northern California and southern Oregon, 2005-2007. Report to U.S. Fish and Wildlife Service and Bureau of Land Management, Arcata, CA. U.S. Department of Agriculture, Forest Service, Redwood Sciences Laboratory, Arcata, CA. 44 p.

Miller, S.L.; M.G. Raphael; G.A. Falxa; C. Strong; J. Baldwin; T. Bloxton; B.M. Galleher; M. Lance; D. Lynch; S.F. Pearson; C.J. Ralph; R.D. Young. In preparation. Population trends of the Marbled Murrelet in the Pacific Northwest.

Pearson, S.F.; M.G. Raphael; M.M. Lance; and T.D. Bloxton. 2010. 2009 at-sea marbled murrelet population monitoring: Research Progress Report. Washington Department of Fish and Wildlife, Wildlife Science Division, Olympia, WA. 21 pp.

Raphael, M.G.; G.A. Falxa; K.M. Dugger; B.M. Galleher; D. Lynch; S.L. Miller; S.K. Nelson and R.D. Young. in press. Northwest Forest Plan—the first 15 years (1994-2008): Status and trend of nesting habitat for the Marbled Murrelet. Gen. Tech. Rep. PNW-GTR-848. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Available at: http://www.reo.gov/monitoring/reports/15yr-report/marbled-murrelet/index.shtml

Strong, C.S. 2009. Population and productivity monitoring of marbled murrelets in Oregon during 2008. Report to the U.S. Fish and Wildlife Service, Portland, Oregon. Crescent Coastal Research, Crescent City, CA. 13 p.

Strong, C.S. 2009. Seabird abundance and distribution during summer off the Oregon and southern Washington coast. Report to National Fish & Wildlife Foundation and USFWS Columbia River Estuarine Fund. Crescent Coastal Research, Crescent City, CA. 46 p.

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Buckland, S.T.; D.R. Anderson; K.P. Burnham; J.L. Laake; D.L. Borchers; and L. Thomas. 2001. Introduction to distance sampling: Estimating abundance of biological populations. Oxford University Press, New York.

Falxa, G.; J. Baldwin; D. Lynch; S.K. Nelson; S.L. Miller; S.F. Pearson; C.J. Ralph; M.G. Raphael; C. Strong; T. Bloxton; B. Galleher; B. Hogoboom; M. Lance; R. Young; and M.H. Huff. 2008. Marbled murrelet effectiveness monitoring, Northwest Forest Plan: 2004-2007 summary report. 25 pp. Available at: http://www.reo.gov/monitoring/reports/marbled-murrelet-reports-publications.shtml

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

Miller, S.L; C.J. Ralph; M.G. Raphael; C. Strong; C.W. Thompson; J. Baldwin; M.H. Huff; and G.A. Falxa. 2006. At-sea monitoring of marbled murrelet population status and trend in the Northwest Forest Plan area. In: M.H. Huff et al., tech. coords. Northwest Forest Plan—The first 10 years (1994-2003): status and trends of populations and nesting habitat for the marbled murrelet. Gen. Tech. Rep. PNW-GTR-650. Portland, OR: US. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 31-60, Chapter 3.

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Phillips, S.J.; R.P. Anderson; and R.E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modeling 190:231-259.

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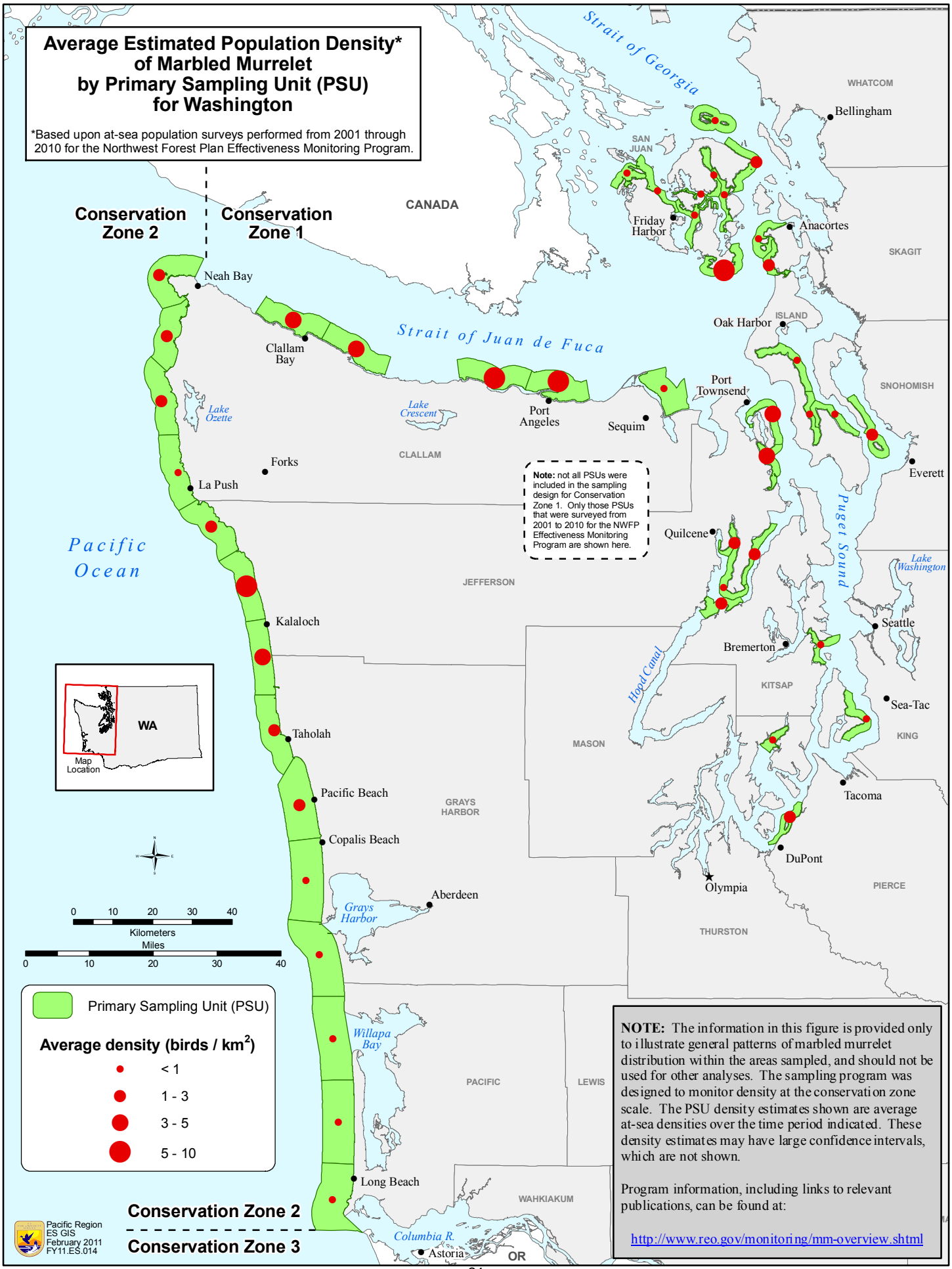
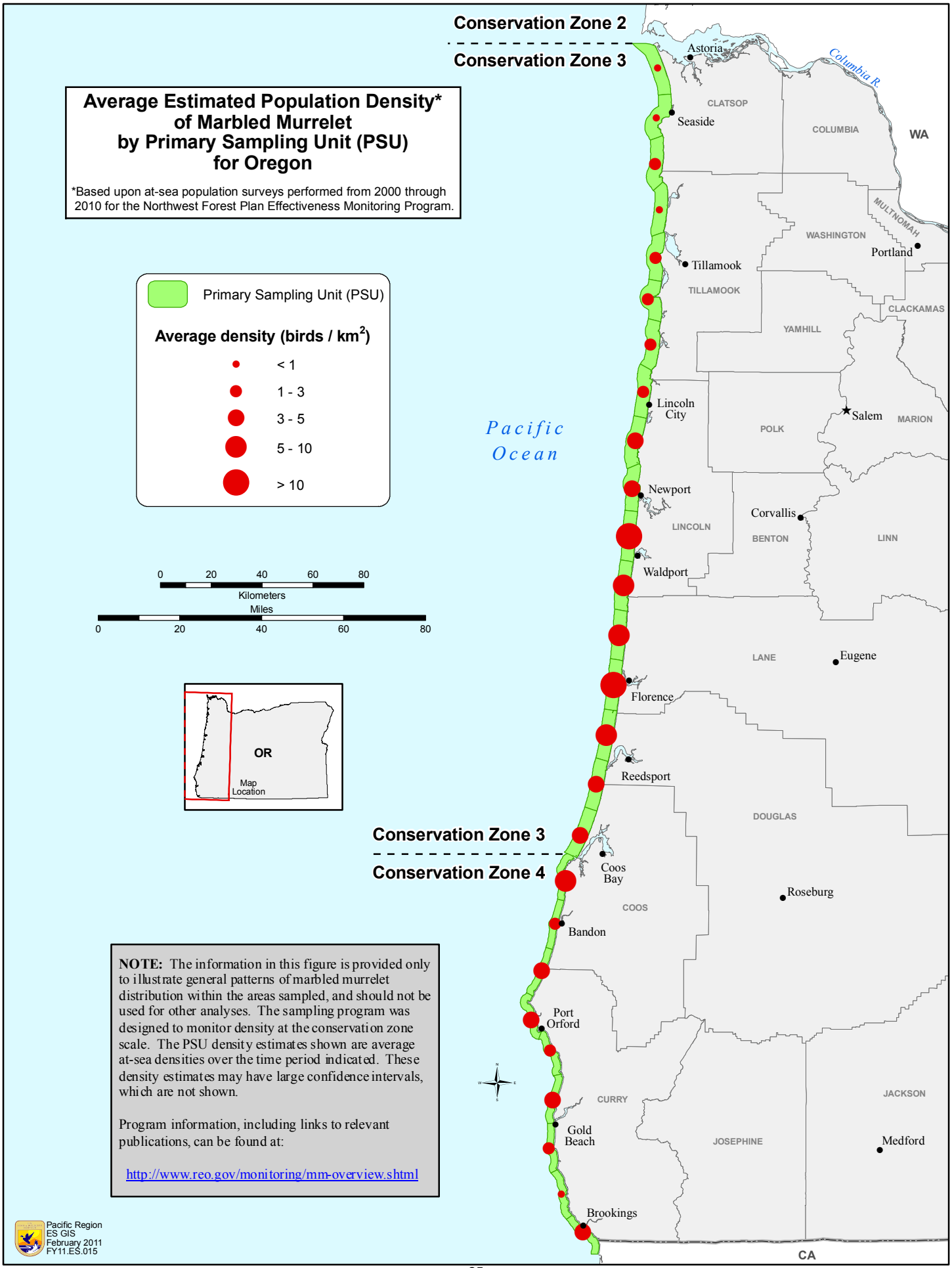
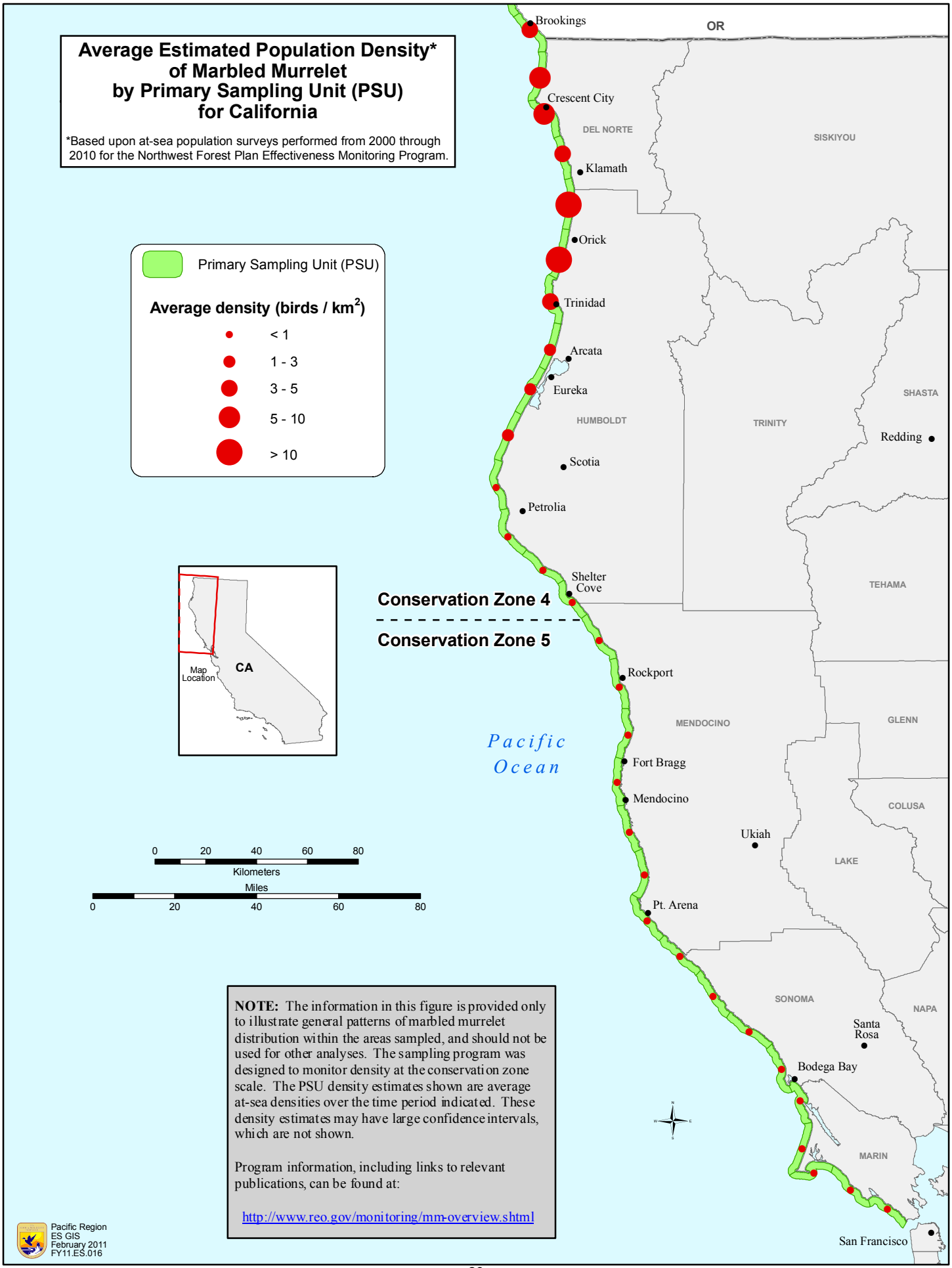
APPENDIX

MAPS OF AVERAGE MARBLED MURRELET DENSITIES AT SEA AT THE SCALE OF PRIMARY SAMPLING UNIT, FOR WASHINGTON, OREGON, AND CALIFORNIA, BASED ON 2000/2001-2010 DATA


Average Estimated Population Density* of Marbled Murrelet by Primary Sampling Unit (PSU) for Washington
*Based upon at-sea population surveys performed from 2001 through 2010 for the Northwest Forest Plan Effectiveness Monitoring Program.
Conservation Zone 2
Conservation Zone 1
CANADA
Strait of Georgia
Strait of Juan de Fuca
Pacific Ocean
Puget Sound
Hood Canal
Lake Washington
Lake Ozette
Lake Crescent
Willapa Bay
Grays Harbor
Columbia R.
WHATCOM
SAN JUAN
SKAGIT
ISLAND
SNOHOMISH
CLALLAM
JEFFERSON
KITSAP
MASON
KING
PIERCE
GRAYS HARBOR
THURSTON
PACIFIC
LEWIS
WAHKIAKUM
OR
Bellingham
Friday Harbor
Anacortes
Oak Harbor
Port Townsend
Neah Bay
Clallam Bay
Port Angeles
Sequim
Forks
La Push
Everett
Quilcene
Seattle
Bremerton
Sea-Tac
Tacoma
DuPont
Olympia
Aberdeen
Kalaloch
Taholah
Pacific Beach
Copalis Beach
Long Beach
Astoria
Note: not all PSUs were included in the sampling design for Conservation Zone 1. Only those PSUs that were surveyed from 2001 to 2010 for the NWFP Effectiveness Monitoring Program are shown here.
WA
Map Location
0 10 20 30 40
Kilometers
Miles
0 10 20 30 40
Primary Sampling Unit (PSU)
Average density (birds / km2)
< 1
1 - 3
3 - 5
5 - 10
Conservation Zone 2
Conservation Zone 3
Pacific Region ES GIS February 2011 FY11.ES.014
NOTE: The information in this figure is provided only to illustrate general patterns of marbled murrelet distribution within the areas sampled, and should not be used for other analyses. The sampling program was designed to monitor density at the conservation zone scale. The PSU density estimates shown are average at-sea densities over the time period indicated. These density estimates may have large confidence intervals, which are not shown.
Program information, including links to relevant publications, can be found at:
http://www.reo.gov/monitoring/mm-overview.shtml


Conservation Zone 2
Conservation Zone 3
Average Estimated Population Density* of Marbled Murrelet by Primary Sampling Unit (PSU) for Oregon
*Based upon at-sea population surveys performed from 2000 through 2010 for the Northwest Forest Plan Effectiveness Monitoring Program.
Primary Sampling Unit (PSU)
Average density (birds / km2)
< 1
1 - 3
3 - 5
5 - 10
> 10
0 20 40 60 80
Kilometers
Miles
0 20 40 60 80
OR
Map Location
Conservation Zone 3
Conservation Zone 4
NOTE: The information in this figure is provided only to illustrate general patterns of marbled murrelet distribution within the areas sampled, and should not be used for other analyses. The sampling program was designed to monitor density at the conservation zone scale. The PSU density estimates shown are average at-sea densities over the time period indicated. These density estimates may have large confidence intervals, which are not shown.
Program information, including links to relevant publications, can be found at:
http://www.reo.gov/monitoring/mm-overview.shtml
Pacific Region ES GIS February 2011 FY11.ES.015
Pacific Ocean
Columbia R
Astoria
Seaside
Tillamook
Lincoln City
Newport
Waldport
Florence
Reedsport
Coos Bay
Bandon
Port Orford
Gold Beach
Brookings
Portland
Salem
Corvallis
Eugene
Roseburg
Medford
CLATSOP
COLUMBIA
WASHINGTON
MULTNOMAH
TILLAMOOK
CLACKAMAS
YAMHILL
POLK
MARION
LINCOLN
BENTON
LINN
LANE
DOUGLAS
COOS
CURRY
JOSEPHINE
JACKSON
WA
CA


Average Estimated Population Density* of Marbled Murrelet by Primary Sampling Unit (PSU) for California
*Based upon at-sea population surveys performed from 2000 through 2010 for the Northwest Forest Plan Effectiveness Monitoring Program.
Primary Sampling Unit (PSU)
Average density (birds / km2)
< 1
1 - 3
3 - 5
5 - 10
> 10
Map Location
CA
Conservation Zone 4
Conservation Zone 5
Pacific Ocean
0 20 40 60 80
Kilometers
Miles
0 20 40 60 80
Brookings
OR
Crescent City
DEL NORTE
SISKIYOU
Klamath
Orick
Trinidad
Arcata
Eureka
HUMBOLDT
TRINITY
SHASTA
Redding
Scotia
Petrolia
Shelter Cove
TEHAMA
Rockport
MENDOCINO
GLENN
Fort Bragg
Mendocino
COLUSA
Ukiah
LAKE
Pt. Arena
SONOMA
NAPA
Santa Rosa
Bodega Bay
MARIN
San Francisco
NOTE: The information in this figure is provided only to illustrate general patterns of marbled murrelet distribution within the areas sampled, and should not be used for other analyses. The sampling program was designed to monitor density at the conservation zone scale. The PSU density estimates shown are average at-sea densities over the time period indicated. These density estimates may have large confidence intervals, which are not shown.
Program information, including links to relevant publications, can be found at:
http://www.reo.gov/monitoring/mm-overview.shtml
Pacific Region
ES GIS
February 2011
FY11.ES.016