Marbled Murrelet Effectiveness Monitoring
Northwest Forest Plan

2004 - 2007 Summary Report

Gary Falxa
Marbled Murrelet Module Lead (2006-current)
Mark Huff
Marbled Murrelet Module Lead (2003-2006)
Northwest Forest Plan Interagency Regional Monitoring Program

Team Members for 2004-2007:

Population Monitoring

Jim Baldwin, Statistician, US Forest Service, Pacific Southwest Research Station
Sherri Miller, Researcher, US Forest Service, Pacific Southwest Research Station
Rich Young, GIS/Database Specialist, US Fish and Wildlife Service
C.J. Ralph, Researcher, US Forest Service, Pacific Southwest Research Station
Martin G. Raphael, Researcher, US Forest Service, Pacific Northwest Research Station
Tom Bloxton, Biologist, US Forest Service, Pacific Northwest Research Station
Craig Strong, Researcher, Crescent Coastal Research
Scott Pearson, Research Scientist, Washington Department of Fish and Wildlife
Monique Lance, Wildlife Biologist, Washington Department of Fish and Wildlife
Gary Falxa, Biologist, US Fish and Wildlife Service
Deanna Lynch, Biologist, US Fish and Wildlife Service

Habitat Monitoring

Jim Baldwin, Statistician, US Forest Service, Pacific Southwest Research Station
Sherri Miller, Researcher, US Forest Service, Pacific Southwest Research Station
Martin G. Raphael, Researcher, US Forest Service, Pacific Northwest Research Station
Beth Galleher, GIS/Database, US Forest Service, Pacific Northwest Research Station
Kim Nelson, Researcher, Oregon State University
Rich Young, GIS/Database Specialist, US Fish and Wildlife Service
Gary Falxa, Biologist, US Fish and Wildlife Service
Deanna Lynch, Biologist, US Fish and Wildlife Service
Mark Huff, Ecologist, National Park Service, North Coast and Cascades Network

September 2008

SUMMARY

This report summarizes activities of the Marbled Murrelet (*Brachyramphus marmoratus*) Effectiveness Monitoring Program in the area of the Northwest Forest Plan (NWFP) during fiscal years 2004 - 2007. The purpose of the effectiveness monitoring is to assess status and trends of murrelet populations and nesting habitat. Findings for the first 10 years of the NWFP (1994-2003), including detailed analyses of the status and trends of murrelet populations and nesting habitat, are presented in the 10-year NWFP effectiveness monitoring report (Huff et al. 2006). Whereas the 10-year report did not cover the 2004-2007 period of this report, the preparation of the 10-year report by Huff and his collaborators was a primary focus during 2004-2005, and its completion a major accomplishment. Another accomplishment was a publication describing the methods of the murrelet population monitoring program (Raphael et al. 2007).

This report includes results of the annual at-sea population surveys including an initial trend analysis, and a brief update on modeling of nesting habitat. Nesting habitat analysis was not a focus of work following publication of the 10-year report, but will be for 2008-2009, for an upcoming 15-year NWFP monitoring report.

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. Conservation Zones 1 through 4 were surveyed for murrelets in all years between 2004 and 2007. Conservation Zone 5 was not surveyed in 2006. The highest total population estimate for this area (20,500 ± 4,600 birds at the 95 percent confidence interval) was in 2004. The lowest total population estimate for this area (17,400 ± 4,600 birds at the 95 percent confidence interval) was in 2007. At these confidence levels, the 2004 through 2007 population estimates broadly overlap, as well as overlapping with estimates from 2000 through 2003. During these 4 years, murrelet density (birds per km^2) was highest in Conservation Zones 3 and 4 (entire coast of Oregon to just south of Cape Mendocino, California) and lowest in Conservation Zone 5 (California coast, just south of Cape Mendocino to just north of San Francisco Bay).

For the 5 zones combined, a preliminary trend analysis indicates that a 6-to-7 percent annual decline between 2000 and 2007 is unlikely. Additional at-sea monitoring will be needed to detect population declines in the range of 2 to 5 percent with a high level of statistical power.

For the habitat monitoring component of the Effectiveness Monitoring Program, non-map and map predictive models were developed to estimate murrelet nesting habitat. Field data for the non-map model was collected from occupied and unoccupied sites across the species' range within the NWFP area. The map-models of murrelet nesting habitat were developed from spatial attributes of occupied sites based on variables that best distinguished attributes of occupied sites compared to attributes of available habitat within the range. Results from the map and non-map models were published in the 10-year interpretive report of the effectiveness monitoring program (Huff et al. 2006). In 2007, the program began to explore modifications to the existing habitat models, to evaluate model performance using the new IMAP vegetation map that is under development, and to examine the utility of resource selection function models as an alternative to Ecological Niche Factor Analysis.

PREFACE

In August 2006, Gary Falxa replaced Mark Huff as the module lead for Marbled Murrelet Effectiveness Monitoring in the area of the Northwest Forest Plan and Deanna Lynch joined the Marbled Murrelet Monitoring Team in 2007. This report was prepared by Gary Falxa, Deanna Lynch, and the Marbled Murrelet Monitoring Team members.

ACKNOWLEDGMENTS

Thank you to the many crew members who have conducted the at-sea population surveys over the years, often under difficult conditions.

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:

Shawne Mohoric (Monitoring Program Manager)
Phone: 503-808-2175
Email: smohoric@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:

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.

INTRODUCTION

Mangers responsible for resolving natural resource issues need resource trend information to develop sound management plans. Evaluating population trends requires a commitment to long-term monitoring (multiple years) and consistent data collection from a network of target sites selected without biases (Urquhart et al. 1998). 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).

The marbled murrelet (*Brachyramphus marmoratus*) (murrelet) and northern spotted owl (*Strix occidentalis*) are the only 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 in meeting that goal (Madsen et al. 1999). The first approach uses annual at-sea surveys to assess murrelet population status and trends. For murrelets, at-sea surveys are the most 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). Status and trend information is used to assess the stability of murrelet populations, and to determine whether land based management actions are providing for the recovery of the species. The second approach for evaluating murrelet status within the NWFP area is to monitor the amount and trends of potential nesting habitat in that area. To accomplish this objective, murrelet habitat models were developed and the initial results published in 2006 (Huff et al. 2006).

Huff et al. (2006) provided the status and trend of populations and nesting habitat for the murrelet for the first ten years of the NWFP, and included at-sea population monitoring results information through 2003. The objectives of this report are to present the 2004-2007 at-sea survey results, to present results of an initial population trend analysis, , and to describe habitat modeling work that has occurred since the 2006 publication.

EFFECTIVENESS MONITORING QUESTIONS

The broad objectives and approach to effectiveness monitoring of status and trends 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 how a condition of the indicator resource has changed over time at a given location.

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). This is accomplished by addressing questions on (1) the predicted amount, distribution and spatial attributes of murrelet nesting habitat, as estimated from quantitative habitat relationship models, and (2) murrelet population status and trends:

Predicted amount of marbled murrelet nesting habitat

1. What is the amount of nesting habitat in the Northwest Forest Planning area?
2. How has the predicted amount of nesting habitat changed within and outside Late-Successional Reserves (LSRs)?

Predicted distribution and size of marbled murrelet nesting habitat

1. What is the spatial distribution of nesting habitat in the Northwest Forest Planning area?
2. How has the fragmentation of nesting habitat changed within and outside LSRs?
3. How has the patch size of nesting habitat, including the proportion and amount of interior late-successional forest, changed within and outside LSRs?
4. How has the distribution of nesting habitat changed within and among LSRs and across federal land?

At-sea population status and trends during the breeding season

1. What is the population status and trend among murrelet recovery zones 1-5 and for the entire Northwest Forest Plan area?
2. What is the density status and trend among recovery zones 1-5 and for the entire Northwest Forest Plan area?

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 2004-2007 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 (USDI Fish and Wildlife Service 1997; Figure 1). At-sea surveys are conducted during the breeding season from mid-May through late-July. Each conservation zone has been divided into two or three strata based on murrelet density patterns. A target number of sampling units is designated for each stratum, however density and population size are estimated at the conservation zone and NWFP scales only. The analysis employed the program DISTANCE to generate population density estimates. See Raphael et al. (2007) for details on methods.

Adjustments in survey methods

In 2006, Conservation Zone 5 was not surveyed due to logistical and funding constraints. Zone 5 supports a small number of murrelets, about 130 (mean of estimates for years 2000-2005 and 2007), and less than one percent of the murrelet population within the 5-zone monitoring area. For these reasons, this lack of data for one year has little effect on conclusions about murrelet population size or trends for the NWFP area.

In 2007, Zone 3 experienced a 16-day period without sampling in the first half of June, due to mechanical boat problems combined with unfavorable weather conditions. Sampling gaps of a week are not uncommon for the outer coast zones due to weather conditions, but the 2007 gap was longer than usual. The 2007 gap did not affect the total sample size obtained for Zone 3, but resulted in samples that were clustered temporally around the gap. Because the gap occurred mid-season, we do not expect a bias in the population estimate due to unrepresentative sampling with respect to the birds' nesting chronology. Although it is not possible to know the effects of such a gap on population estimates, any effect is expected to be small or negligible in the context of evaluating population trends over a period which includes data from eight or more years.

Trend Analysis

Yearly population estimates for 2000 to 2007 were compared to evaluate whether a declining trend exists, as was predicted by demographic models (USDI Fish and Wildlife Service 1997, McShane et al. 2004). The statistical test for trends was conducted by fitting a regression line to the annual population estimates for each of the five zones, and then combining the individual zone results for the 5-zone NWFP area. Zone 5 in 2006 was treated as a missing value in the regressions. This analysis is preliminary, because the number of years sampled to date is at the low end of that needed to evaluate for annual declines of 4 to 6 percent for all zones combined, and is insufficient to test for smaller rates of decline (Table 6); this is based on a power analysis using the population data collected from 2000 to 2003 (Huff et al. 2006).

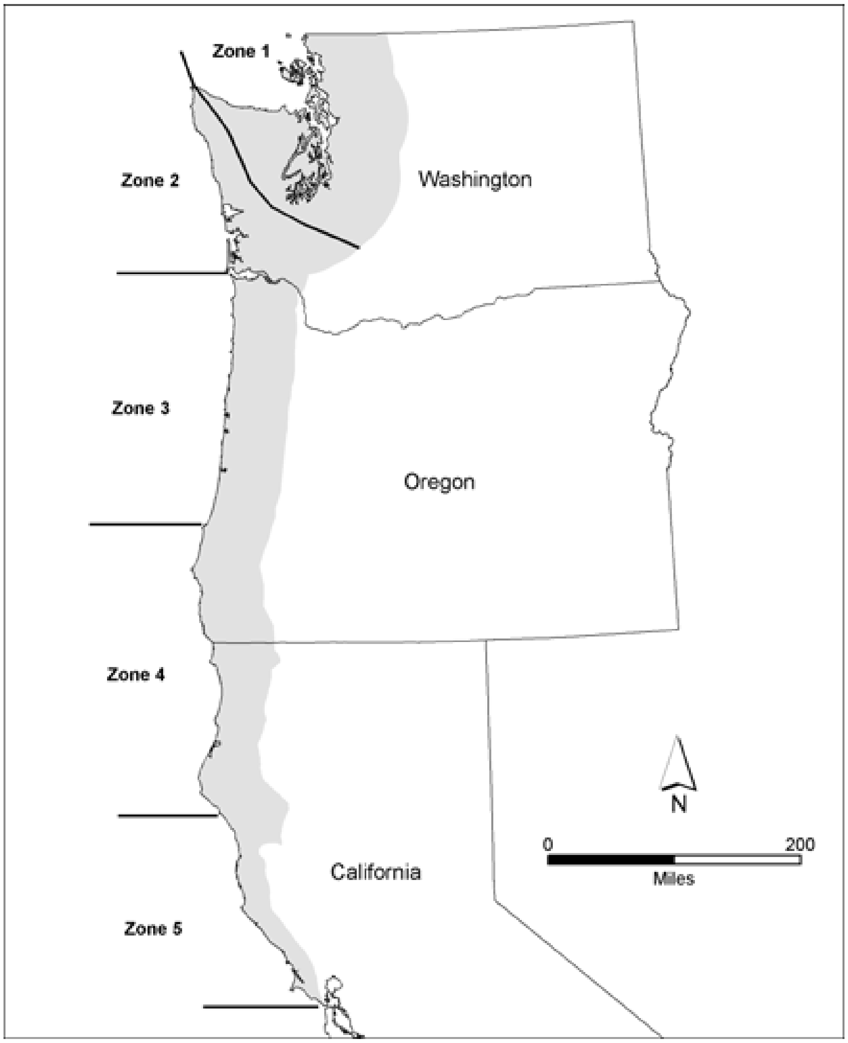


Figure 1. The five at-sea marbled murrelet survey zones adjacent to the NWFP area. Inland breeding distribution is shaded (adapted from USDI Fish and Wildlife Service 1997).

Habitat Modeling

For the habitat monitoring component of the Effectiveness Monitoring Program, predictive models, non-map and map, were developed to estimate murrelet habitat for the NWFP 10-year report. Field data for the non-map model was collected from sites occupied and unoccupied by marbled murrelets, across the range of the species in the NWFP area. Two map models of murrelet habitat were developed from spatial attributes of occupied sites based on variables that best predict known murrelet occupancy patterns. Results from the map and non-map models were published in the 2006 10-year report of the marbled murrelet effectiveness monitoring program (Chapters 4 and 5 in Huff et al., 2006). In 2007, the program began work to explore modifications to the existing models, to evaluate model performance using a new vegetation map under development, and to examine resource selection function models.

RESULTS AND DISCUSSION

Population Monitoring, 2004 - 2007

The area of coastal waters sampled by the NWFP at-sea surveys in 2004, 2005, and 2007 was approximately 8,785 km^2, of which Conservation Zones 1 to 5 cover 40, 19, 18, 13, and 10 percent of the total area surveyed respectively (i.e., 40 percent of the 8,785 km^2 sampled is in Conservation Zone 1). The total area sampled in 2006 was less, 7,902 km^2, because Conservation Zone 5 was not surveyed.

Population estimates were made for each year with and without Conservation Zone 5 because this zone was not surveyed in 2006; therefore an "All zones" summary is not available for that year. Because of Conservation Zone 5's small population of murrelets (annual estimates between 57 and 117), omission of this zone's data from the summary data has little effect on population estimates and confidence limits for the entire 5-zone survey area. A summary of survey results for Conservation Zones 1 through 4 is provided in Table 1 and Figure 2. Tables 2 through 5 provide the 2004-2007 annual density and population estimates for each conservation zone, and include related estimation parameters generated by the program DISTANCE. Figure 3 provides a comparison of yearly population estimates by conservation zone.

Between 2004 and 2007, the estimated total population of murrelets for Conservation Zones 1 through 4 ranged from about 17,300 to 20,500 (Table 1a and Figure 2). Confidence intervals are wide for all survey years and overlap broadly among years. For the 5 conservation zones combined, the highest population estimate during this 4-year period, about 20,600 birds, occurred in 2004. The 5-zone estimate declined in each subsequent year, to the low population estimate of about 17,400 birds in 2007 (Table 1b). In all years, Conservation Zone 5 had, typically by an order of magnitude or more, the lowest population and density estimates (Tables 2 through 5). The zone with the highest annual population estimate varied between Conservation Zones 1 and 3, with the highest single-zone population estimate occurring in 2005 in Zone 1 (about 8,000 birds). Standard errors and confidence intervals for single-zone population estimates tend to be larger than for the combined zone estimates, and typically overlap broadly for the Zone 1 and Zone 3 estimates. This argues for cautious interpretation of such differences at the zone scale, without accounting for the larger error surrounding the means.

Population estimates are computed multiplying the estimates of murrelet density by the extent of the survey area (square km of coastal waters). The population estimates are affected by both bird density and the size of the survey area, thus the zone with the highest murrelet density may not have the largest population estimate. Between 2004 and 2007, murrelet density estimates within the NWFP area ranged from 2.19 to 2.59 birds/km^2 (Table 1 and Figure 4). Density estimates varied among zones, being greatest in Conservation Zones 3 and 4 (4.88 birds/km^2 in 2004) and the lowest in Conservation Zone 5 (0.07 birds/km^2 in 2007). Density estimates also varied among strata within each conservation zone. This suggests that murrelet distribution and use of the coastal environment varies within the effective area of the NWFP. Over the 2004-2007 period, the relative variation in density estimates as measured by coefficient of variation (i.e., ratio of standard error to mean multiplied by 100) ranged from ~8 to 13 percent for Conservation Zones 1 – 4 combined (Table 1a), and from ~12 to 60 percent for individual zones (Tables 2 through 5). The highest variation in density estimates occurred in conservation zones which had the lowest densities of murrelets. Variation (as measured by the coefficient of variation) in density estimates was negatively correlated with bird density among zones, for the 8 years of data, thus variation tended to be largest in zones and strata with low densities.

Maps that display the average estimated population density of murrelets from 2000 through 2007 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 1a. Summary of estimates of density and population size of murrelets during the 2000-2007 breeding seasons in Conservation Zones 1 through 4 in the area of the Northwest Forest Plan. Zone 5 data are not included in this table (see text for explanation).

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**
2000	2.34	0.33	14.2	18,500	13,300	23,700
2001	2.79	0.3	10.6	22,000	17,500	26,600
2002	2.96	0.34	11.6	23,400	18,100	28,700
2003	2.81	0.27	9.6	22,200	18,000	26,300
2004	2.59	0.3	11.5	20,500	15,900	25,100
2005	2.53	0.28	10.9	19,900	15,700	24,200
2006	2.36	0.19	8.1	18,600	15,700	21,600
2007	2.19	0.29	13.4	17,300	12,700	21,900

Table 1b. Summary of 2000-2007 murrelet density and population size estimates in Conservation Zones 1 through 5 in the area of the Northwest Forest Plan. 2006 data are not included in this table because Zone 5 was not surveyed in that year.

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**
2000	2.11	0.30	14.2	18,600	13,400	23,700
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	2.34	0.27	11.5	20,600	16,000	25,200
2005	2.30	0.25	10.8	20,200	16,000	24,500
2006	NA					
2007	1.98	0.26	13.4	17,400	12,800	21,900

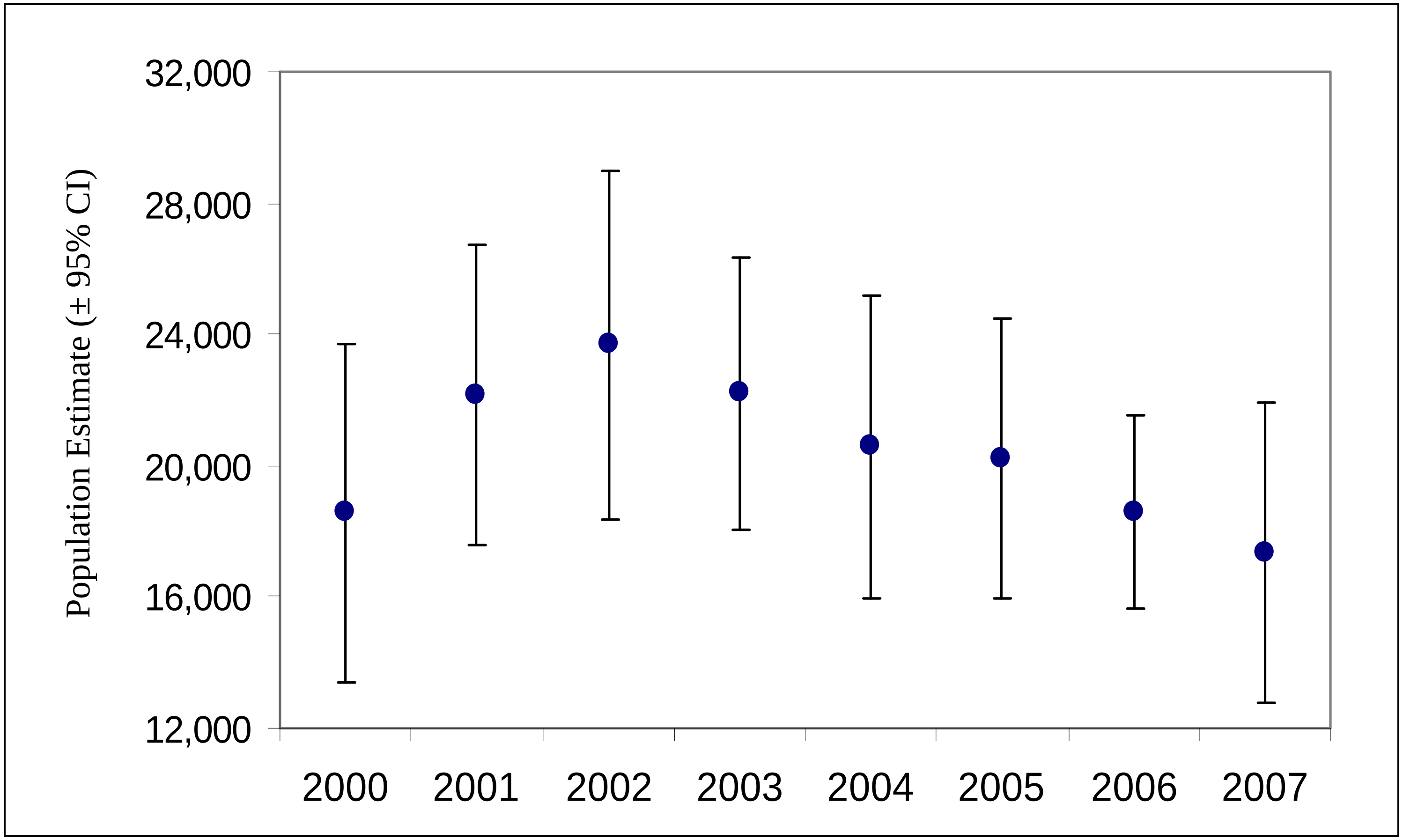


Figure 2. Annual marbled murrelet population estimates and 95 percent confidence intervals, for Conservation Zones 1 - 4 combined.

Table 2. Estimates of murrelet density and population size during the 2004 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.

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)	Transect Length	f(0)	Std. err. of f(0)	E(s)	Std. err. of E(s)	Truncation Distance (m)	Std. err. of Truncation Distance
1	1	3.83	1.12	29.2	3,241	1,368	4,876	845	320						
1	2	1.52	0.37	24.5	1,816	1,056	2,777	1,195	1,634						
1	3	0.29	0.17	59.2	417	0	721	1,458	180						
1	**All**	**1.56**	**0.33**	**21.3**	**5,473**	**2,959**	**7,438**	**3,498**		**0.011**	**0.001**	**1.79**	**0.10**	**280**	**25.0**
2	1	3.44	1.11	32.4	2,490	1,236	4,000	724	1,025						
2	2	0.63	0.16	25.0	582	330	864	926	350						
2	**All**	**1.86**	**0.48**	**25.9**	**3,071**	**1,742**	**4,596**	**1,650**		**0.012**	**0.001**	**1.40**	**0.05**	**110**	**4.5**
3	1	1.71	0.31	18.4	1,128	706	1,599	661	440						
3	2	7.12	0.98	13.8	6,653	4,833	8,443	935	705						
3	**All**	**4.88**	**0.60**	**12.2**	**7,781**	**5,885**	**9,763**	**1,595**		**0.013**	**0.001**	**1.71**	**0.05**	**120**	**7.7**
4	1	4.32	2.13	49.2	3,172	1,996	7,832	734	388						
4	2	2.34	1.10	47.0	997	598	2,448	425	366						
4	**All**	**3.60**	**1.41**	**39.2**	**4,169**	**3,084**	**9,167**	**1,159**		**0.009**	**0.001**	**1.70**	**0.07**	**200**	**20.2**
5	1	0.09	0.06	66.3	39	0	99	441	284						
5	2	0.10	0.10	95.3	45	0	136	441	128						
5	**All**	**0.10**	**0.06**	**60.3**	**84**	**18**	**204**	**883**		**0.009**	**0.001**	**1.70**	**0.07**	**200**	**20.2**
All but 5	**All**	**2.59**	**0.30**	**11.5**	**20,494**	**15,870**	**25,118**	**7,903**							
All	**All**	**2.34**	**0.27**	**11.5**	**20,578**	**15,953**	**25,203**	**8,786**							

Table 3. Estimates of murrelet density and population size during the 2005 breeding season in the area of the Northwest Forest Plan.

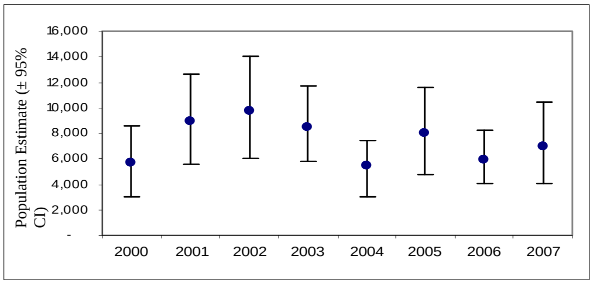
Zone	Stratum	Density (birds/km^2)	Bootstrap Standard Error (birds/km^2)	Coefficient of Variation of Density (%)	Birds	Birds Lower 95% CL	Birds Upper 95% CL	Survey Area (km^2)	Transect Length	f(0)	Std. err. of f(0)	E(s)	Std. err. of E(s)	Truncation Distance (m)	Std. err. of Truncation Distance
1	1	2.50	0.95	38.0	2,114	675	3,631	845	357						
1	2	2.43	0.65	26.9	2,895	1,145	4,328	1,194	1,676						
1	3	2.02	0.63	31.4	2,947	1,228	5,009	1,458	200						
1	**All**	**2.28**	**0.48**	**21.2**	**7,956**	**4,784**	**11,589**	**3,497**		**0.016**	**0.002**	**1.76**	**0.15**	**150**	**12.7**
2	1	2.73	0.50	18.2	1,977	1,212	2,641	724	876						
2	2	0.56	0.36	64.3	516	146	1,552	926	284						
2	**All**	**1.51**	**0.31**	**20.3**	**2,492**	**1,629**	**3,642**	**1,650**		**0.013**	**0.001**	**1.41**	**0.05**	**130**	**18.1**
3	1	0.81	0.26	31.9	537	273	943	661	513						
3	2	5.68	0.97	17.1	5,306	3,170	6,703	935	596						
3	**All**	**3.66**	**0.60**	**16.3**	**5,843**	**3,618**	**7,309**	**1,595**		**0.013**	**0.001**	**1.83**	**0.07**	**150**	**12.0**
4	1	4.45	1.12	24.8	3,267	2,249	5,407	734	421						
4	2	0.88	0.38	42.5	376	242	881	425	392						
4	**All**	**3.14**	0.73	**23.0**	**3,642**	**2,680**	**5,955**	**1,159**		**0.011**	**0.001**	**1.51**	**0.04**	**170**	**11.8**
5	1	0.27	0.12	42.9	121	0	217	441	293						
5	2	0.38	0.15	38.9	168	71	300	441	139						
5	**All**	**0.33**	0.10	**29.6**	**289**	**117**	**453**	**883**		**0.011**	**0.001**	**1.51**	**0.04**	**170**	**11.8**
All but 5	**All**	**2.52**	**0.28**	**10.9**	**19,934**	**15,673**	**24,195**	**7,902**							
All	**All**	**2.30**	**0.25**	**10.8**	**20,223**	**15,959**	**24,487**	**8,785**							

Table 4. Estimates of murrelet density and population size during the 2006 breeding season in the area of the Northwest Forest Plan. “All zone” summary not available since Zone 5 was not surveyed this year.

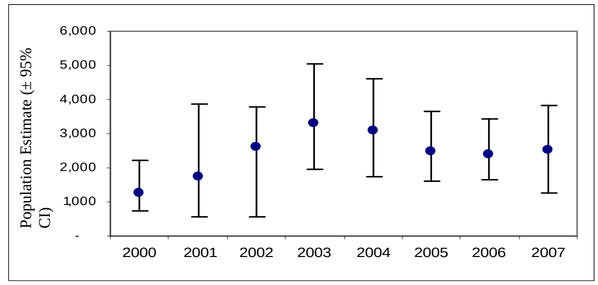
Zone	Stratum	Density (birds/km^2)	Bootstrap Standard Error (birds/km^2)	Coefficient of Variation of Density (%)	Birds	Birds Lower 95% CL	Birds Upper 95% CL	Survey Area (km^2)	Transect Length	f(0)	Std. err. of f(0)	E(s)	Std. err. of E(s)	Truncation Distance (m)	Std. err. of Truncation Distance
1	1	2.76	0.43	15.5	2,333	1,633	3,129	845	352						
1	2	1.42	0.37	26.3	1,693	756	2,493	1,194	1,678						
1	3	1.28	0.51	39.4	1,873	514	3,488	1,458	200						
1	**All**	**1.69**	**0.30**	**18.1**	**5,899**	**4,013**	**8,208**	**3,497**		**0.014**	**0.001**	**1.77**	**0.16**	**139**	**13.6**
2	1	2.26	0.48	21.1	1,638	1,009	2,413	724	1,022						
2	2	0.80	0.28	34.7	743	364	1,355	926	278						
2	**All**	**1.44**	**0.26**	**18.3**	**2,381**	**1,672**	**3,430**	**1,650**		**0.013**	**0.002**	**1.57**	**0.14**	**107**	**8.2**
3	1	1.08	0.32	29.5	715	335	1,174	661	532						
3	2	6.06	0.78	12.9	5,659	3,927	6,707	935	653						
3	**All**	**4.00**	**0.47**	**11.8**	**6,375**	**4,569**	**7,429**	**1,595**		**0.012**	**0.001**	**1.79**	**0.04**	**150**	**12.5**
4	1	4.84	0.76	15.7	3,551	2,735	4,904	734	517						
4	2	0.98	0.47	47.8	416	215	980	425	259						
4	**All**	**3.42**	**0.52**	**15.2**	**3,968**	**3,168**	**5,467**	**1,159**		**0.011**	**0.001**	**1.62**	**0.05**	**150**	**14.5**
5	1	NA													
5	2	NA													
5	**All**	**NA**													
All but 5	**All**	**2.36**	**0.19**	**8.1**	**18,622**	**15,681**	**21,563**	**7,902**							

Table 5. Estimates of murrelet density and population size during the 2007 breeding season in the area of the Northwest Forest Plan.

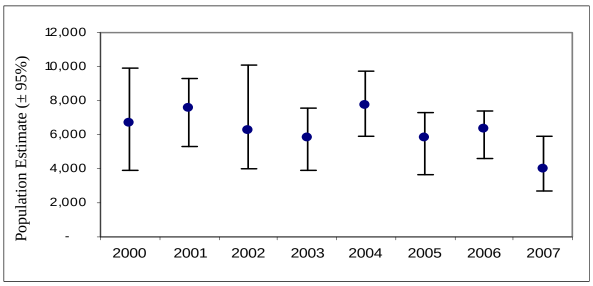
Zone	Stratum	Density (birds/km^2)	Bootstrap Standard Error (birds/km^2)	Coefficient of Variation of Density (%)	Birds	Birds Lower 95% CL	Birds Upper 95% CL	Survey Area (km^2)	Transect Length	f(0)	Std. err. of f(0)	E(s)	Std. err. of E(s)	Truncation Distance (m)	Std. err. of Truncation Distance
1	1	3.45	0.93	27.1	2,912	1,047	4,347	845	343						
1	2	1.22	0.26	21.2	1,453	764	1,994	1,194	1,670						
1	3	1.80	0.87	48.2	2,620	234	5,315	1,458	200						
1	**All**	**2.00**	**0.46**	**22.9**	**6,985**	**4,105**	**10,382**	**3,497**		**0.012**	**0.001**	**1.64**	**0.04**	**378**	**90.1**
2	1	2.84	0.92	32.4	2,056	885	3,341	724	993						
2	2	0.51	0.13	25.8	469	240	664	926	436						
2	**All**	**1.53**	**0.41**	**26.9**	**2,525**	**1,271**	**3,811**	**1,650**		**0.013**	**0.002**	**1.49**	**0.08**	**126**	**9.3**
3	1	0.52	0.30	57.3	343	21	698	661	416						
3	2	3.91	0.83	21.2	3,653	2,459	5,555	935	735						
3	**All**	**2.50**	**0.51**	**20.3**	**3,996**	**2,714**	**5,929**	**1,595**		**0.011**	**0.001**	**1.63**	**0.09**	**150**	**22.6**
4	1	4.79	1.77	37.0	3,511	2,401	7,026	734	436						
4	2	0.66	0.24	36.2	280	145	528	425	314						
4	**All**	**3.27**	**1.13**	**34.5**	**3,791**	**2,687**	**7,342**	**1,159**		**0.011**	**0.001**	**1.61**	**0.05**	**180**	**7.4**
5	1	0.13	0.05	36.6	57	26	105	441	283						
5	2	0.00	0.00					441	152						
5	**All**	**0.07**	**0.02**	**36.6**	**57**	**26**	**105**	**883**		**0.011**	**0.001**	**1.61**	**0.05**	**180**	**7.4**
All but 5	**All**	**2.19**	**0.29**	**13.4**	**17,297**	**12,743**	**21,851**	**7902**							
All	**All**	**1.98**	**0.26**	**13.4**	**17,354**	**12,800**	**21,909**	**8785**							



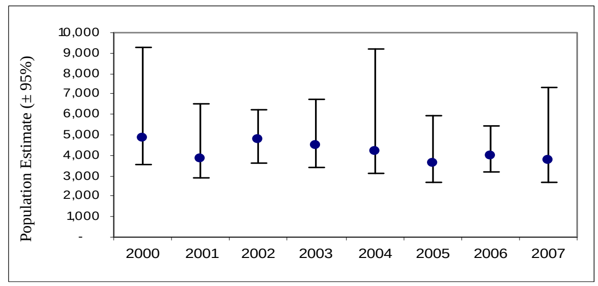
Zone 1



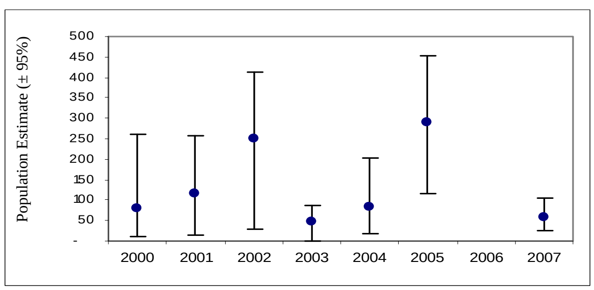
Zone 2



Zone 3



Zone 4



Zone 5

Figure 3. Annual marbled murrelet population estimates and 95 percent confidence intervals for each Conservation Zone, 2000 through 2007.

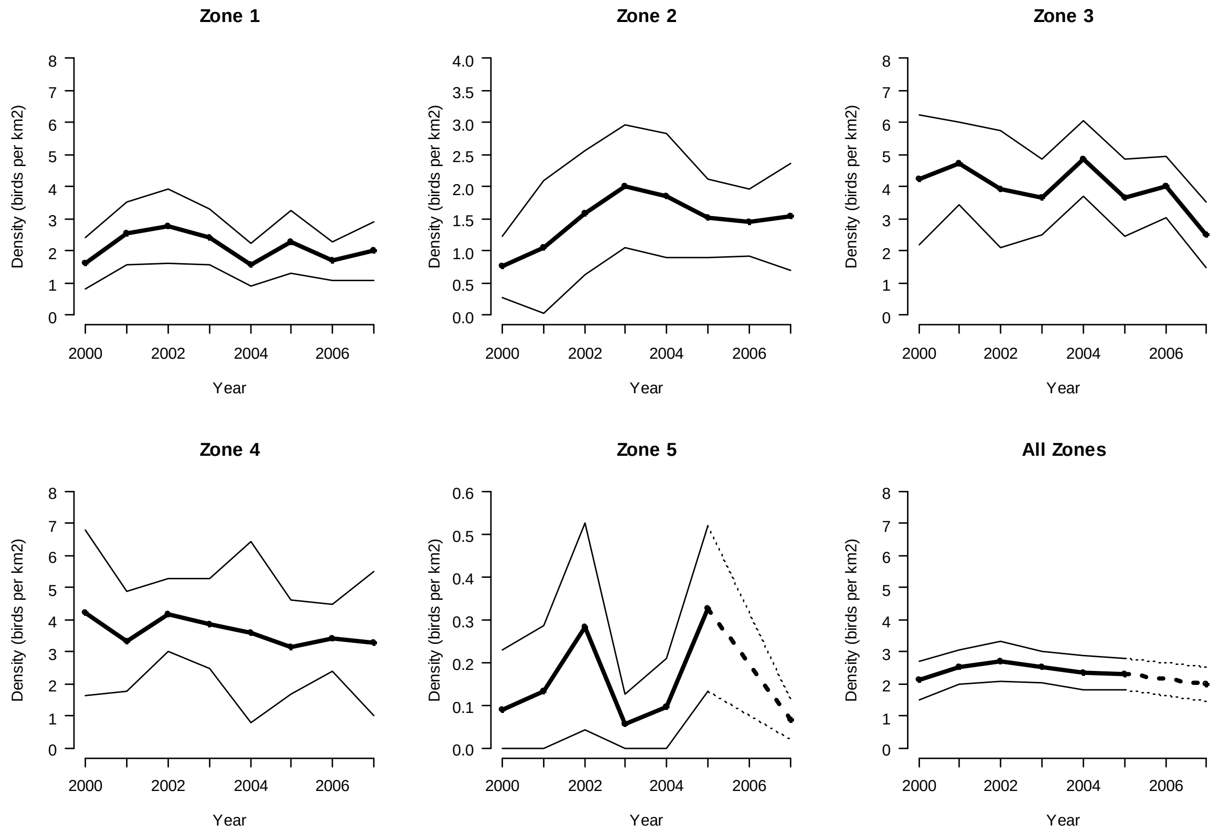


Figure 4. Marbled murrelet density estimates by Conservation Zone. Note that the vertical scale differs between graphs. Lines are dashed for Conservation Zone 5 and “All Zones” because of the missing density estimate for zone 5 in 2006.

Trend Analysis

For the population of the 5 conservation zones combined, power analyses based on data collected from 2000 to 2003 estimated that with 8 years of annual sampling (the current sampling effort), an annual decrease of 6 percent can be detected with 95 percent power or greater, and that an annual decrease of 4 percent could be detected with lower (80 percent) power (Table 6; Huff et al. 2006). 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 often less. For only 2 zones are 8 years of sampling adequate to detect an annual decline of less than 8 percent with high confidence (Table 6, 95 percent power).

Population demographic models have predicted population declines in the range of 3 to 7 percent per year for this area (USDI Fish and Wildlife Service 1997; McShane et al. 2004). In 2007, the murrelet monitoring program conducted a preliminary analysis for population trends using the 2000 through 2007 population data. We did not detect a significant trend for the combined 5-zone area during this period (Figure 5). An increasing trend is unlikely, as is an overall annual decline of 6-to-7 percent or more, and if lower (80 percent) power is acceptable, a decline of 4-5 percent is also unlikely. However, the power level of 80 percent indicates that a real decline of

4-to-5 percent would be missed about 20 percent of the time with 8 years of sampling. If greater certainty is desired, such as provided by 95 percent power, additional years of sampling would be required to detect annual population declines in the 2-to-5 percent range (Table 6b).

While no trend was detected with the 2000-2007 data, the pattern of declining population estimates for each of the past five years (Table 1 and Figure 2) is consistent with declines as predicted by demographic models (USDI Fish and Wildlife Service 1997, McShane et al. 2004). The slope of the regression line for the data represents a 2 percent annual decline (Figure 5 and Table 7); however the probability (*P*-value) for this representing a declining trend was 0.19. While not significant because of the substantial variability in the data, additional years of declining estimates could result in a *P*-value indicative of a trend (e.g., <0.05 or 0.10) over the period. This warrants future trend analyses, when more years of population data are in hand. Also, because population trends can change over time, ongoing population monitoring at some level will be needed to evaluate for trends in the future, for example, over the next 10 years.

Preliminary trend analyses were also conducted for each zone (Table 7). No trends were detected, as would be expected based on the generally low power to detect trends at the single-zone scale with 8 years of sampling. The strongest evidence of decline was for Conservation Zone 4, where the probability of the observed data not being due to chance alone (*P*-value of 0.07, or 7 percent), approached the *P*-value of 0.05, a common upper cut-off value for significance. However, as noted earlier, the variability in population estimates generally increases at smaller spatial scales such as zone, compared to estimates for all zones combined, and with only 8 years of data, the regression analysis can be sensitive to a single year of data that is above or below the regression line.

Table 6a. 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 power analysis in Huff et al. (2006; Chapter 3).

Annual Decrease Rate (%)	**Zone**					
	All	**1**	**2**	**3**	**4**	**5**
2	13	21	11	13	16	52
3	10	16	8	10	12	39
4	8	14	7	8	10	33
5	7	12	6	7	9	28
6	7	11	6	7	8	25
7	6	10	5	6	7	23
8	6	9	5	6	7	21
9	6	8	5	6	7	19
10	5	8	5	5	6	18

Table 6b. 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 power analysis in Huff et al. (2006; Chapter 3).

Annual Decrease Rate (%)	**Zone**					
	All	**1**	**2**	**3**	**4**	**5**
2	15	25	12	15	19	62
3	12	19	10	12	15	47
4	10	16	8	10	12	39
5	9	14	7	9	11	34
6	8	13	7	8	10	30
7	7	11	6	7	9	27
8	7	11	6	7	8	25
9	6	10	6	6	8	23
10	6	9	5	6	7	21

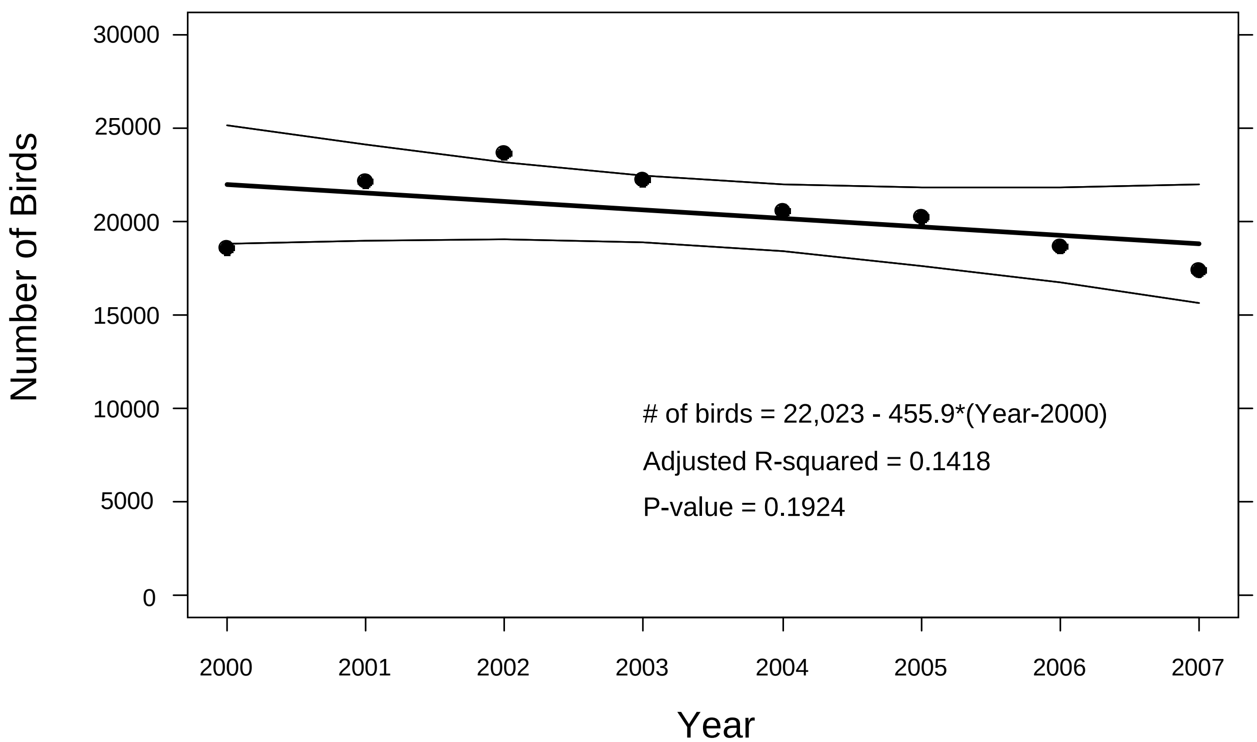


Figure 5. Results of preliminary trend analysis for Conservation Zones 1 through 5 combined, for the 2000 to 2007 period. Figure shows regression line through the annual population estimates, with 95 percent confidence limits for line, as well as regression equation and associated statistics.

Table 7. Preliminary estimates of average annual change (slope) in terms of birds and the percentage of the mean number of birds over the 2000 to 2007 at-sea surveys along with 95 percent confidence intervals for the percent annual change. The *P*-value is for testing whether the annual change is zero or a negative value less than zero.

Zone	Mean # of birds	Estimate of Annual change		95% confidence interval for annual change		*P*-value
		Birds	% of mean	Lower	Upper	
1	7,387	-167	-2.3%	-10.9%	6.4%	0.5468
2	2,424	137	5.7%	-4.0%	15.3%	0.2035
3	6,299	-289	-4.6%	-10.6%	1.5%	0.1127
4	4,201	-130	-3.1%	-6.5%	0.4%	0.0705
5	132	1	0.9%	-34.1%	35.8%	0.9526
All	**20,444**	**-448**	**-2.2%**	**-5.6%**	**1.3%**	**0.1935**

Habitat Monitoring

For the NWFP's 10-year report, covering the period 1994-2003, the amount and distribution of potential suitable murrelet nesting habitat in the NWFP area was estimated using three different modeling approaches (Huff et al. 2006). In one approach, vegetation and site occupancy data were used to derive estimates of the amount of murrelet habitat using a systematic grid sampling strategy; this approach did not produce maps showing the spatial distribution of habitat (Huff et al. 2006, Chapter 4). Vegetation data derived from satellite imagery was used to develop two other approaches to model habitat suitability: an expert judgment model and an ecological niche factor analysis which used the BioMapper software. These latter two approaches provided both estimates of habitat amount and maps of potential nesting habitat. For methods and results, see Huff et al. (2006).

In 2007, the murrelet habitat monitoring team began work to prepare for the upcoming 2008-2009 reanalysis of the amount and distribution of nesting habitat. One of the new tools that will be available for this reanalysis is initial products from the Interagency Mapping and Assessment Project (IMAP). IMAP uses data from satellite imagery, ground-based plot data from a systematic vegetation sampling scheme of forested areas, and Gradient Nearest Neighbor (GNN) to map existing forest vegetation and land cover. This approach has several potential advantages over the vegetation data used for the 10-year report: a more detailed and diverse set of forest attributes relevant to modeling murrelet habitat suitability; a standardized vegetation coverage for the entire NWFP area; and greater analytic flexibility. A pilot test of the IMAP vegetation data was conducted in 2007, for the Oregon Coast Province (the first IMAP dataset available). This test suggested the IMAP data will perform well in murrelet nesting habitat models, and represents a significant improvement over the vegetation data available for the 10-year analyses. The team also initiated tests of the performance of the BioMapper/ENFA and Resource Selection Function (RSF) models for predicting the location and quality of potential nest habitat. Additional tests comparing the 2 models and the IMAP data are planned for 2008. The habitat team also plans to continue work, started in 2007, on modifications to the habitat models used for the initial 1994-2003 analyses, to take advantage of improved data sources, including IMAP.

MONITORING PROGRAM CONSIDERATIONS

Funding to maintain annual at-sea surveys continues to be a challenge. Funding sources need to be secured each year, with budget shortfalls occurring annually and U.S. Fish and Wildlife Service field offices helping to make up shortfalls. The U.S Fish and Wildlife Service has committed to fund the at-sea surveys into the near future, beyond 2008. Refining/revising habitat models will be conducted in 2008 and 2009 for publication in the 15-year update on the NWFP.

PROGRAM PRODUCTS

The following publications and reports were published in association or collaboration with the Marbled Murrelet Effectiveness Monitoring Program:

Evans Mack, D., W.P. Ritchie, S.K. Nelson, E. Kuo-Harrison, and T.E. Hamer. 2003. Methods for surveying marbled murrelets in forests: a revised protocol for land management and research. 76 p. Pacific Seabird Group unpublished document available at http://www.pacificseabirdgroup.org.

Huff, M.H., M.G. Raphael, S.L. Miller, S.K. Nelson, and J. Baldwin, tech coords. 2006. Northwest Forest Plan – The first 10 years (1994-2003): status and trends of populations and nesting habitat for the marbled murrelet. Gen. Tech. Rep. PNW-GTR-650. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 149 p. Available online at: http://www.fs.fed.us/pnw/pubs/pnw_gtr650.pdf

Lance, M.M., and S.F. Pearson. 2005. 2005 at-sea marbled murrelet population monitoring. Washington Department of Fish and Wildlife, Olympia, WA. 12 pp.

Lance, M.M. and S.F. Pearson. 2007. 2006 at-sea marbled murrelet population monitoring: Research Progress Report. Washington Department of Fish and Wildlife, Wildlife Science Division, Olympia, WA. 14 pp.

Lance, M.M., S.F. Pearson, and M.G. Raphael. 2008. 2007 at-sea marbled murrelet population monitoring: Research Progress Report. Washington Department of Fish and Wildlife, Wildlife Science Division, Olympia, WA. 24 pp.

Meyer, C.B.; Miller, S.L.; Ralph, C.J. 2002. Multi-scale landscape and seascape patterns associated with marbled murrelet nesting areas on the U.S. west coast. Landscape Ecology 17: 95-115.

Miller, S.L.; Meyer, C.B.; and Ralph, C.J. 2002. Land and seascape patterns associated with marbled murrelet abundance offshore. Waterbirds 25(1): 100-108.

Nelson, S.K. and A.K. Wilson. 2002. Marbled murrelet habitat characteristics on state lands in western Oregon. Final Report to OR Dept. of Forestry, OR Dept. Fish and Wildlife, U.S. Fish and Wildlife Service, and National Council fir Air and Stream Improvement. 154 p.

Raphael, M.G.; Mack, D.E.; Marzluff, J.M.; Luginbuhl, J.M. 2002. Effects of forest fragmentation on populations of the marbled murrelet. Studies in Avian Biology No. 22: 221-235.

Raphael, M.G., J. Baldwin, G.A. Falxa, M.H. Huff, M. Lance, S.L. Miller, S.F. Pearson, C.J. Ralph, C. Strong, and C. Thompson. 2007. Regional population monitoring of the marbled murrelet: field and analytical methods. Gen. Tech. Rep. PNW-GTR-716. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 70 p. Available online at: http://www.fs.fed.us/pnw/pubs/pnw_gtr716.pdf

Strong, C.S. 2003. Status of marbled murrelets at sea in conservation zone 5: Mendocino, Sonoma, and Marin counties. Final Report to U.S. Fish and Wildlife Service and California Department of Fish and Game. 23 p.

Strong, C.S. 2003. Marbled murrelet abundance and reproductive indices in Oregon during 2002. Annual Report to the Oregon Department of Fish and Wildlife, and U.S. Fish and Wildlife Service. 14 p.

Strong, C.S. 2003. Decline of the marbled murrelet populations on the central Oregon coast during the 1990s. Northwest Naturalist 84:31-37.

LITERATURE CITED

Huff, M.H., M.G. Raphael, S.L. Miller, S.K. Nelson, and J. Baldwin, tech coords. 2006. Northwest Forest Plan – The first 10 years (1994-2003): status and trends of populations and nesting habitat for the marbled murrelet. Gen. Tech. Rep. PNW-GTR-650. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 149 p.

Madsen, S., D. Evans, T. Hamer, P. Henson, S. Miller, S.K. Nelson, D. Roby, and M. Stapanian. 1999. Marbled murrelet effectiveness monitoring plan for the Northwest Forest Plan. Gen. Tech. Rep. PNW-GTR-439. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR. 51 p.

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.

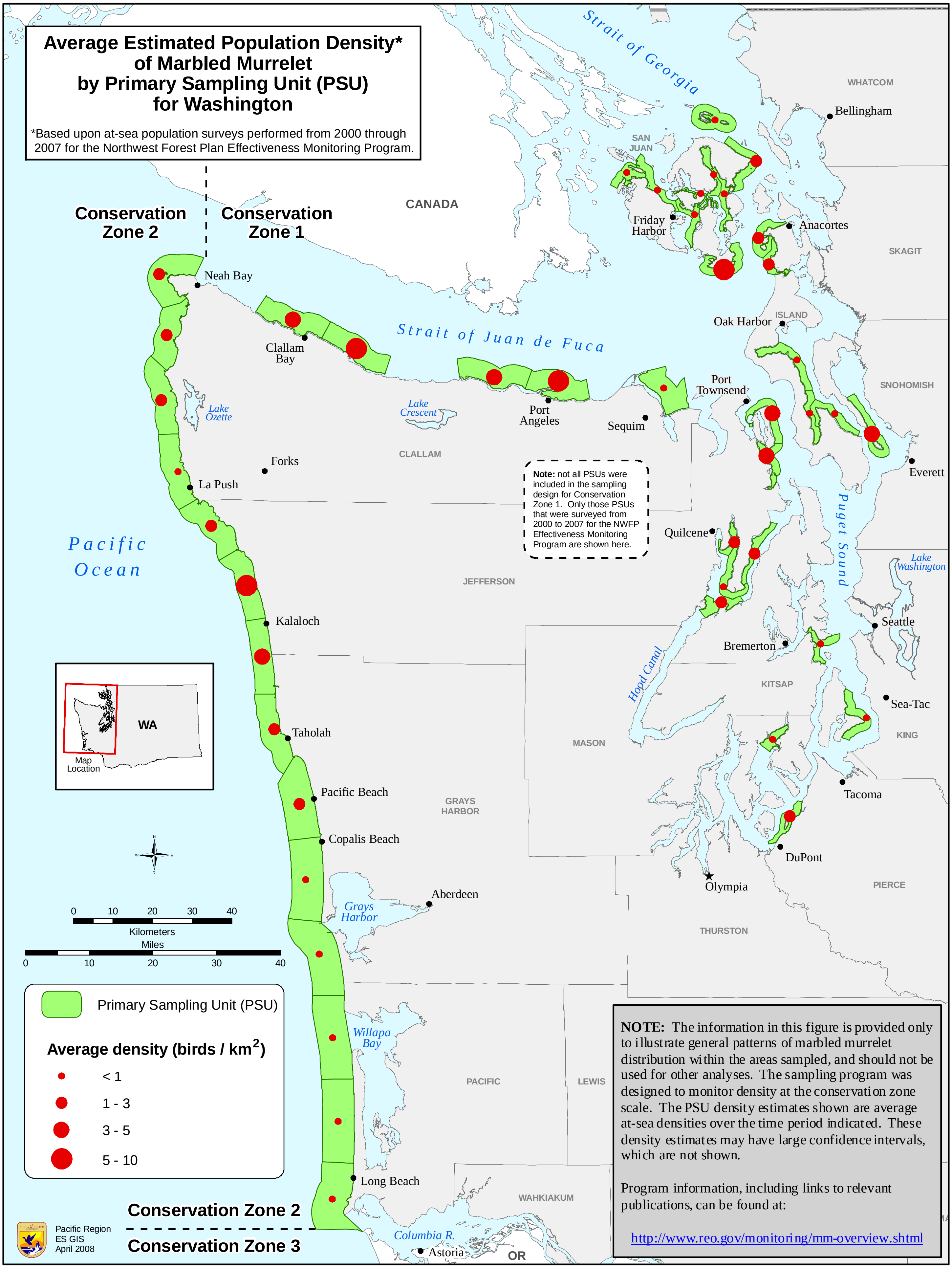
Raphael, M.G., J. Baldwin, G.A. Falxa, M.H. Huff, M. Lance, S.L. Miller, S.F. Pearson, C.J. Ralph, C. Strong, and C. Thompson. 2007. Regional population monitoring of the marbled murrelet: field and analytical methods. Gen. Tech. Rep. PNW-GTR-716. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 70 p.

Urquhart, N.S., S.G. Paulsen, and D.P. Larsen. 1998. Monitoring for policy-relevant regional trends over time. Ecological Applications 8(2): 246-257.

USDI Fish and Wildlife Service. 1997. Recovery plan for the threatened marbled murrelet *(Brachyramphus marmoratu*s) in Washington, Oregon, and California. Portland, OR. 203 p.

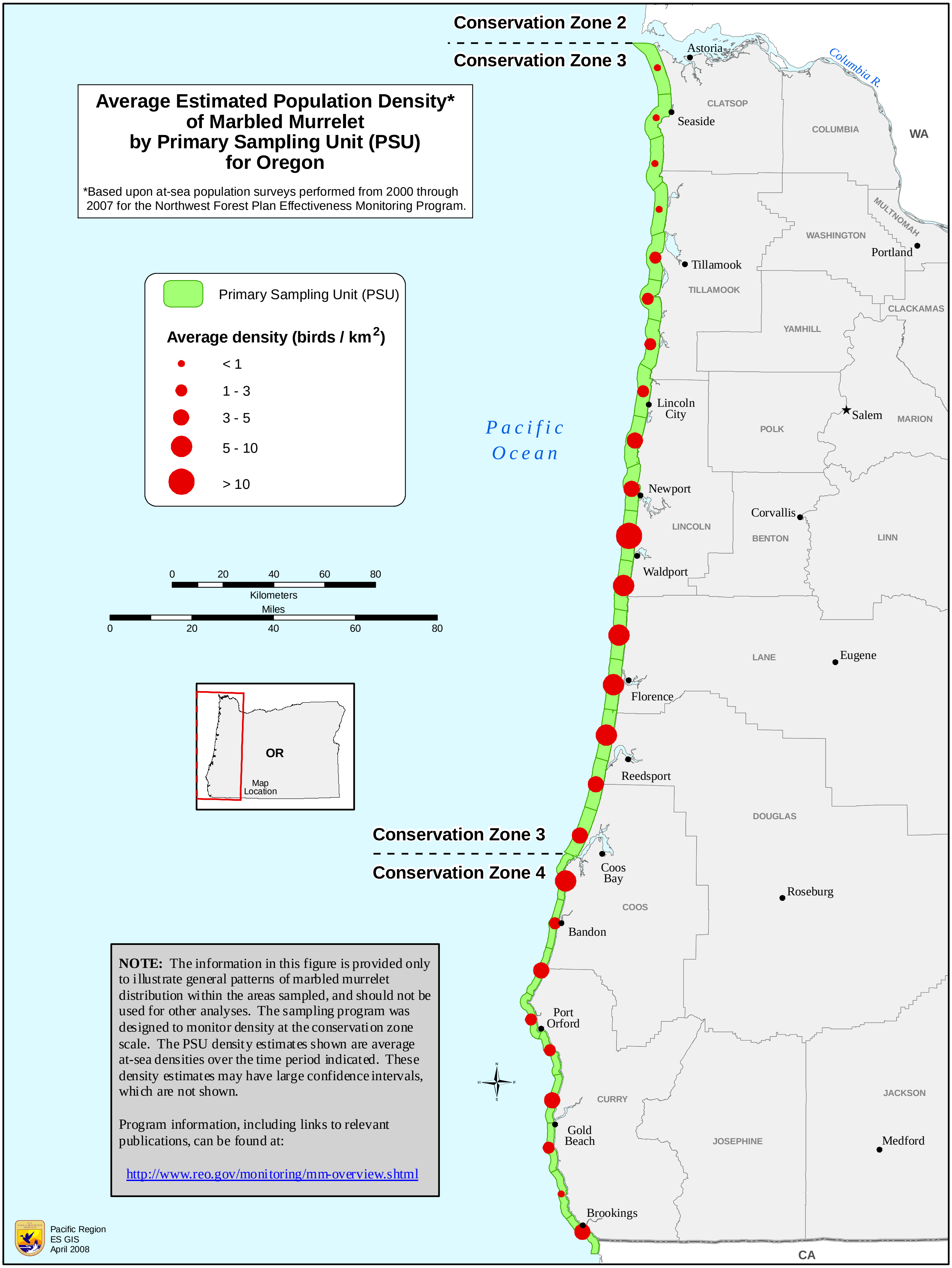
APPENDIX

MAPS OF AVERAGE MARBLED MURRELET DENSITIES AT SEA AT THE SCALE OF PRIMARY SAMPLING UNIT, FOR WASHINGTON, OREGON, AND CALIFORNIA, BASED ON 2000-2007 DATA


Average Estimated Population Density*
of Marbled Murrelet
by Primary Sampling Unit (PSU)
for Washington
*Based upon at-sea population surveys performed from 2000 through
2007 for the Northwest Forest Plan Effectiveness Monitoring Program.
Conservation
Zone 2
Conservation
Zone 1
CANADA
Strait of Georgia
WHATCOM
Bellingham
SAN
JUAN
Friday
Harbor
Anacortes
SKAGIT
Neah Bay
Clallam
Bay
Strait of Juan de Fuca
ISLAND
Oak Harbor
Port
Townsend
SNOHOMISH
Lake
Ozette
Lake
Crescent
Port
Angeles
Sequim
Everett
Forks
CLALLAM
La Push
Note: not all PSUs were included in the sampling design for Conservation Zone 1. Only those PSUs that were surveyed from 2000 to 2007 for the NWFP Effectiveness Monitoring Program are shown here.
Quilcene
Puget Sound
Pacific
Ocean
JEFFERSON
Lake
Washington
Kalaloch
Seattle
Bremerton
Hood Canal
KITSAP
Sea-Tac
WA
Map
Location
Taholah
MASON
KING
Pacific Beach
GRAYS
HARBOR
Tacoma
Copalis Beach
DuPont
Olympia
Aberdeen
Grays
Harbor
PIERCE
0 10 20 30 40
Kilometers
Miles
0 10 20 30 40
THURSTON
Primary Sampling Unit (PSU)
Average density (birds / km^2)
< 1
1 - 3
3 - 5
5 - 10
Willapa
Bay
PACIFIC
LEWIS
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
Long Beach
WAHKIAKUM
Conservation Zone 2
Conservation Zone 3
Pacific Region
ES GIS
April 2008
Columbia R.
Astoria
OR

Average Estimated Population Density* of Marbled Murrelet by Primary Sampling Unit (PSU) for Oregon

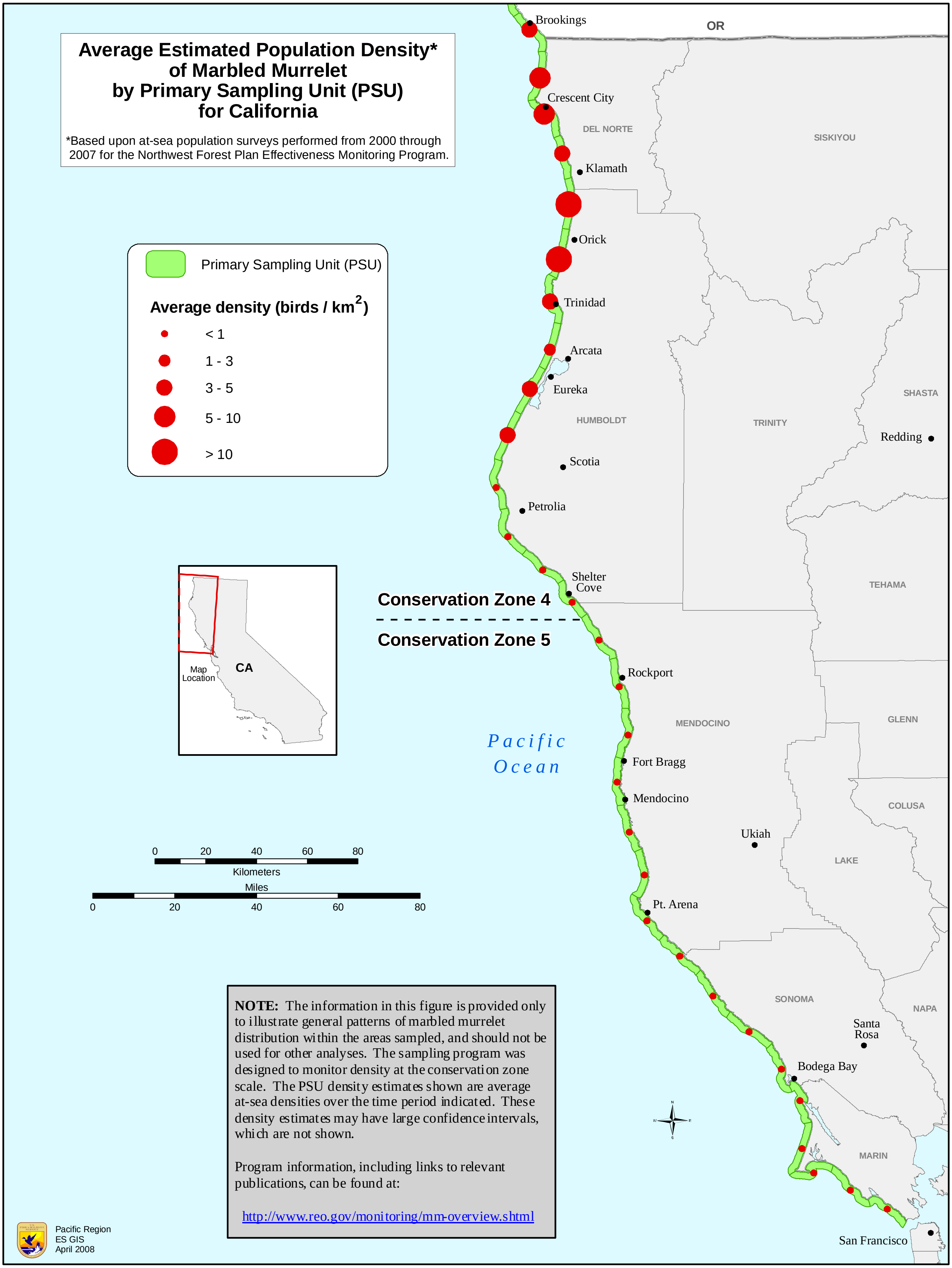
*Based upon at-sea population surveys performed from 2000 through 2007 for the Northwest Forest Plan Effectiveness Monitoring Program.



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


Average Estimated Population Density* of Marbled Murrelet by Primary Sampling Unit (PSU) for California
*Based upon at-sea population surveys performed from 2000 through 2007 for the Northwest Forest Plan Effectiveness Monitoring Program.
Primary Sampling Unit (PSU)
Average density (birds / km^2)
< 1
1 - 3
3 - 5
5 - 10
> 10
Map Location
CA
0 20 40 60 80
Kilometers
Miles
0 20 40 60 80
Conservation Zone 4
Conservation Zone 5
Pacific Ocean
OR
Brookings
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
April 2008