Northwest Forest Plan
Marbled Murrelet Effectiveness Monitoring
2000 Annual Report

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Summary

Marbled murrelets (*Brachyramphus marmoratus*) range from Alaska to California and are federally listed as threatened in Washington, Oregon, and California. Throughout the listed range of the species, the Northwest Forest Plan (Forest Plan) Federal land-base and standards and guides are expected to make substantial contributions towards conservation and recovery.

Specific monitoring requirements have been outlined to ensure the Forest Plan is effective in maintaining and recovering this species over the long term. This report represents the results and the status of the Marbled Murrelet Effectiveness Monitoring Program to date. The Program has two distinct components, one designed to monitor population trends and the other to define and monitor nesting habitat. Each component was developed by separate interagency teams.

Population Monitoring
The population team developed a new sampling design and standardized survey methods to be implemented throughout the Forest Plan area. The sampling design was implemented during the 2000 field season, and its results represent the first year of murrelet population data for the entire Plan area. The population of marbled murrelets in the range of the NFP is estimated to be18,097, with a 95% confidence interval ranging from 12,991 to 23,202 birds. This report describes the sampling design and the survey and analysis methods; it also identifies future steps for the monitoring program. We emphasize that this is the first year of sampling that used a consistent protocol applied throughout the majority of the murrelet's listed range. Because these methods have not been used before, comparing the results with past population estimates is not valid.

Nesting Habitat Monitoring
The nesting-habitat team developed two approaches to assess the nesting habitat baseline for murrelets: a map created from satellite images, and a quantitative estimate of nesting habitat based on vegetation data collected from ground plots. The team also updated and reconfigured murrelet data sets so that they can be analyzed for this effort. This report describes the team's approach, outlines progress to date, and identifies future steps.

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Introduction

The marbled murrelet (*Brachyramphus marmoratus*) is federally listed as threatened in Washington, Oregon, and California. The Northwest Forest Plan (Forest Plan) land base and standards and guides for land management activities are expected to result in substantial contributions towards conserving and recovering this species and its habitat over the long term. Specific monitoring requirements have been outlined to aid conservation of this species.

Madsen et al. (1999) developed an approach to effectiveness monitoring for the murrelet under the Forest Plan; the approach recommends assessing population trends at sea under a unified sampling design with standardized survey methods. Inland, the goal is to establish a credible nesting-habitat baseline. Trends in population abundance and nesting habitat would be tracked over time. The ultimate goal is to assess the relationship between population trends and quality and quantity of nesting habitat. If a strong relationship exists between these two attributes, then habitat monitoring may serve as a surrogate for population monitoring over the long term.

In 1998, the US Fish and Wildlife Service Module Leader convened two teams to design monitoring methods for murrelet populations and nesting habitat. This report provides an overview of population and nesting habitat monitoring efforts to date. Members of the population team are

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Population Monitoring

Overview

It has proven difficult to assess populations of marbled murrelets at there nest sites, which, throughout much of their range, are located far above-ground in complex, multi-storied forest stands. Instead, marbled murrelet populations are best assessed in their foraging habitat, which is nearshore marine waters. Therefore, the population monitoring team identified the target population as those birds in the nearshore waters (within 2 - 8 km of shore) from the Canadian border to San Francisco Bay, the area associated with the Forest Plan. We subdivided the target population into the Marbled Murrelet Conservation Zones identified in the Marbled Murrelet Recovery Plan (USFWS 1997; Figure 1). During the 1998 and 1999 field seasons, we tested methods allowing the team to reach consensus on the methods and the sampling design for a pilot project in the 2000 field season. Following, we describe the sampling design and the population monitoring program.

Sampling Design

An overview of the sampling design for population monitoring is shown in Table 1, which appears near the end of this section. Details are discussed below.

Spatial Target Population

The target population is of murrelets are those birds within the Marbled Murrelet Recovery Plan Conservation Zones (US Fish and Wildlife Service 1997; Figure 1). The northern boundary is the Canadian border and the southern boundary is near the northern end of San Francisco Bay. In this area, we targeted birds in "nearshore" waters (i.e., ≤ 8 km from shore) for surveying. The inshore boundary was defined by the closest possible distance to shore, yet away from the surf, rocks, and kelp, that was considered to be safe for navigation. This distance was roughly estimated for each zone and for each stratum within each zone. The offshore boundary varied among and, in some instances, even within zones. The offshore boundary was set to coincide with the decline in murrelet density that typically occurs with distance from shore. This boundary varied by zone and, occasionally, even within zones. More details on zone-specific boundaries are presented in the separate zone sections of this report. If ongoing data collection suggests annual changes in murrelet distribution in relation to distance from shore, we will then revisit the offshore boundary determination.

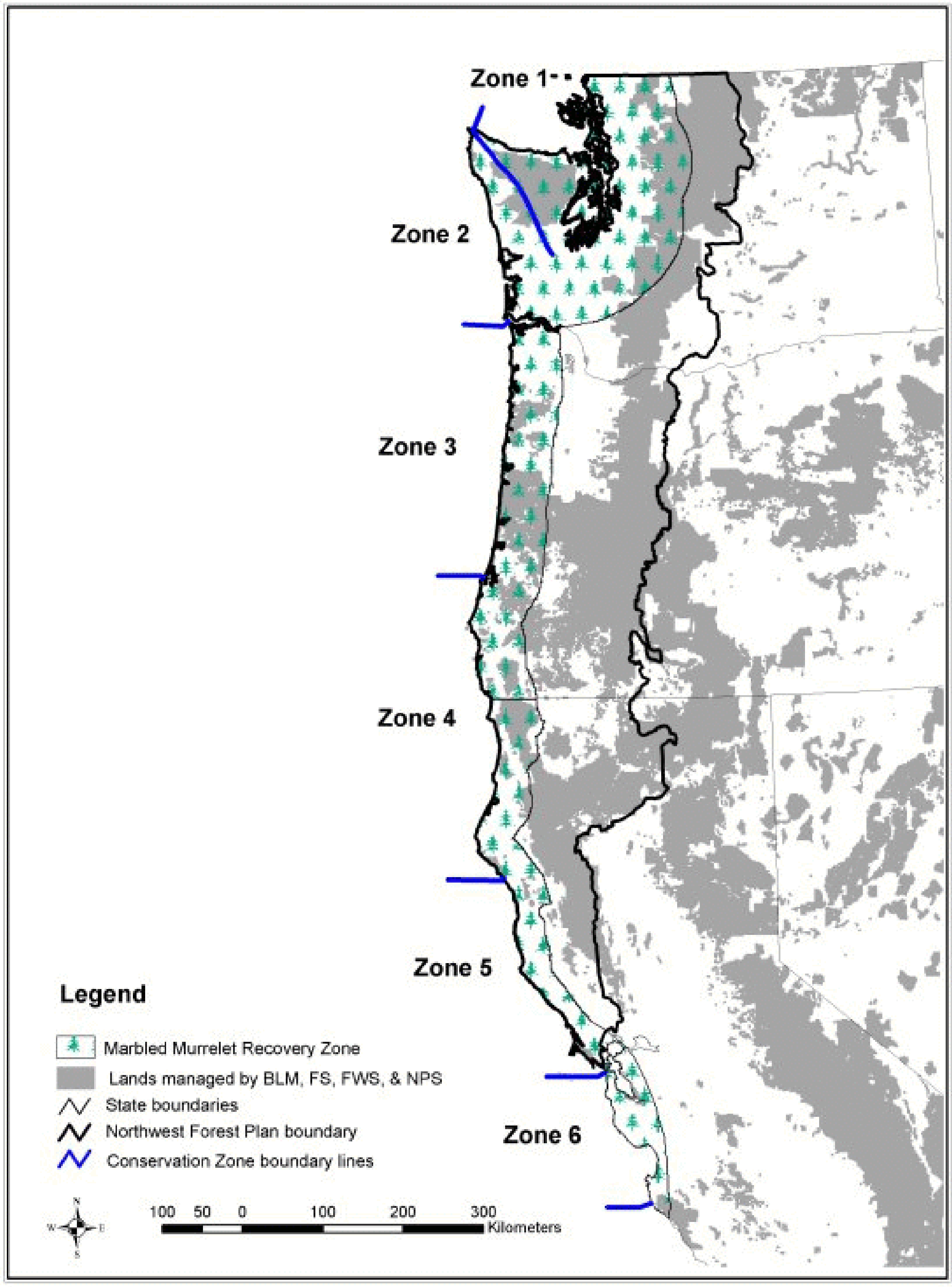

Figure 1. Northwest Forest Plan and Marbled Murrelet Recovery Plan conservation zones.

Temporal Target Population

Mid-May through mid- or late-July is when breeding birds at sea are likely to be associated with inland nesting habitat in the Forest Plan area. We established 15 May - 31 July as our sampling period for population monitoring.

Stratification

The Marbled Murrelet Recovery Plan (US Fish and Wildlife Service 1997) identified six conservation zones, five of which occur in the Forest Plan area. The Recovery Plan states that when populations in four of the six zones have stable or increasing numbers, murrelets may have reached recovery status. For this reason and because it was logistically and financially most feasible, we developed a sampling design that would result in separate population estimates for each zone as well as a total population estimate for all five zones. In each zone, researchers also identified two or three areas along the coast (hereafter referred to as strata) where densities of murrelets appeared to be similar within the area but substantially different from adjoining areas. We sampled in each stratum, but did not estimate murrelet density or population separately for each strata. In general, strata with low densities of murrelets received less sampling effort, strata with high densities received greater sampling effort, and all the data collected in a zone were used to obtain the zone population estimate. This sampling design was implemented to reduce error rates associated with density and population estimates.

If additional sampling was conducted (i.e., sampling efforts greater than currently employed), separate density estimates could be obtained for each geographic stratum in the zones. This additional sampling could help refine information about the relationship at-sea populations and the amount and distribution of inland habitat at scales smaller than an entire conservation zone. Our budgets did not allow for this extra sampling during the pilot year except in Zone 4. In Zone 4, the Pacific Lumber Company implemented a habitat conservation plan under the Endangered Species Act that included a murrelet monitoring component. Additional funding allowed 30 surveys to be completed in the Sampling Units in the southern portion of Zone 4. We then calculated one population estimate for the entire zone, and a separate estimate for the southern portion.

Primary Sampling Units

Spatial definition of a primary sampling unit (Sampling Unit). A Sampling Unit is a roughly rectangular area along about 20 km of coast line. Its width is the distance between the inshore and offshore boundaries (Figure 2) and this width varied by zone and stratum. The Sampling Units meet end to end along the shore, with no gaps. Each Sampling Unit consists of one inshore and one offshore subunit which are divided by the "centerline".

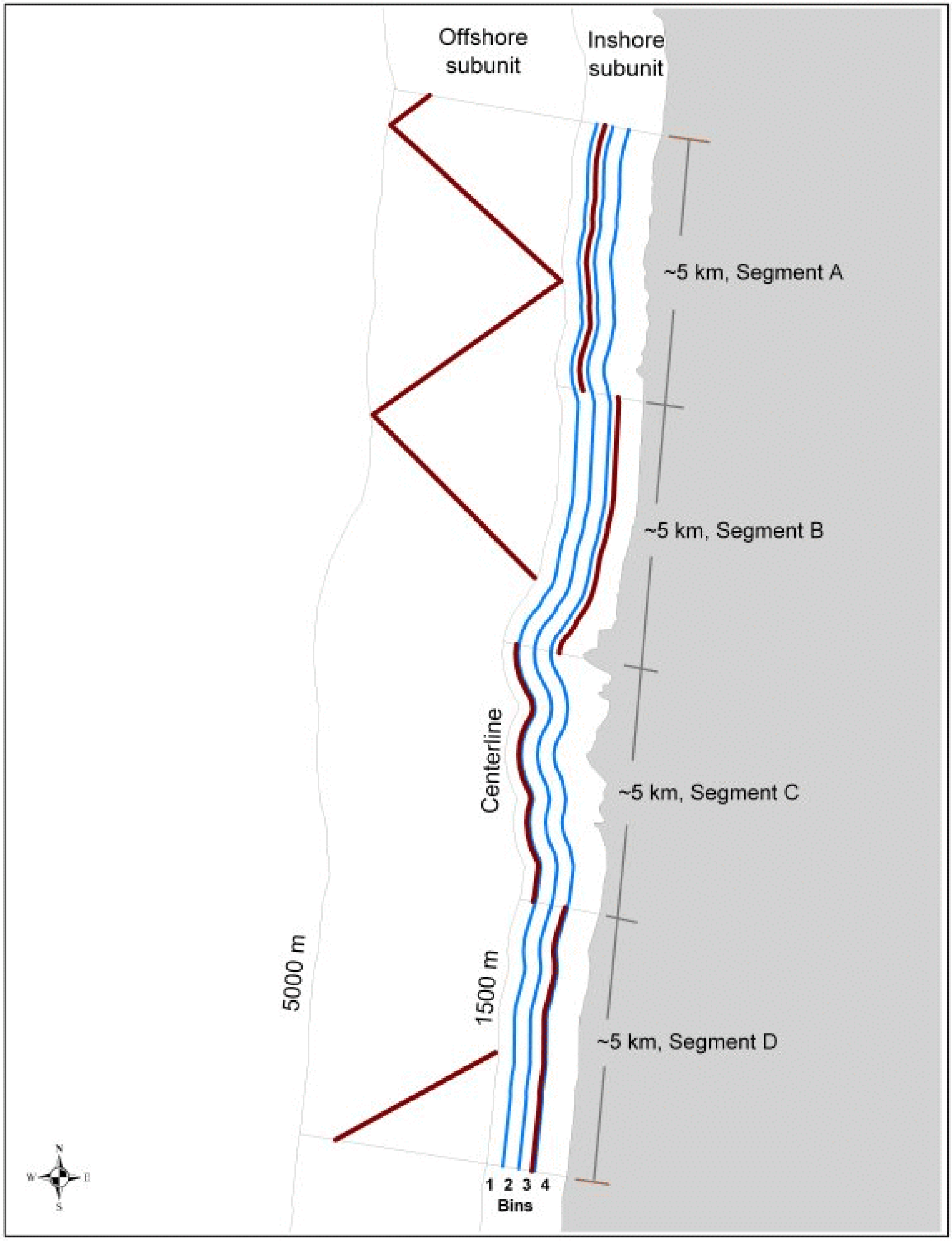

Figure 2. Marbled murrelet primary sampling unit with inshore and offshore subunits, showing parallel and zigzag transects. The inshore subunit is divided into four equal-length segments (about 5 km each) and four equal-width bins (bands parallel to and at increasing distances from the shore). One bin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

The inshore boundary, adjacent to the coast, was defined by the physical features of the shore line that affected navigation. In some Sampling Units, these physical features are permanent obstructions such as islands or submerged rocks. In others, the features are not permanent (e.g., kelp beds that shrink or expand depending on storm conditions or sea otter activity). Tidal fluctuations also affect navigation. Some areas that can be surveyed during high tides may be inaccessible during low tides. Although boats stayed a safe distance from shore, observers were able to survey a portion of the area within about 50 m of the boat; thus, the area of inference (i.e., the marine area from which we calculated densities and population estimates) extends 50 m beyond the transect lines.

Temporal definition of a primary sampling unit. We elected to use only Sampling Unit surveys completed in one day. In many areas, increased afternoon winds would make navigation unsafe, causing survey efforts to be discontinued. In these situations, we decided not to use partial surveys for analyses. If a boat completed more than one Sampling Unit in a day, all of the surveys were used for analysis.

Sample size per zone. Each conservation zone had a target sample-size of 30 Sampling Unit surveys. We based our target on analyses that demonstrated reasonably low coefficients of variation as total transect length approached 600 km (30 x 20 km; Raphael et al. unpublished data available from the authors). The target was usually met, but because of logistical problems, only 16 Sampling Units in Zone 2 were completed in the 2000 field season.

Method of selecting Sampling Units. The Sampling Units were generally selected randomly without replacement, that is, once they were selected they were not available again until all other Sampling Units were selected. The surveys were spread temporally over the field season. To help reduce variability in population estimates, more samples were completed in geographic strata where research has found high murrelet densities. In these areas, Sampling Units were sampled in random order many times during the field season. In low-density strata, we randomly selected fewer Sampling Units, and each one selected was sampled only once.

Although initially the Sampling Units were selected randomly, sampling was subject to logistic constraints, such as the location of ports, weather, and mechanical difficulties. These logistics resulted in clustered samples. We conducted a bootstrap analysis to estimate the variance of our density estimates (see Analysis section).

Over the long term, the Sampling Units selected during the pilot year will form the basis of the monitoring program. The same randomly selected Sampling Units will be sampled each year to reduce variance in annual population estimates.

Sampling Unit Transect Layout. We used both parallel and zigzag transects to survey the Sampling Units. Parallel transects in the inshore subunit and, generally, zigzag transects in the offshore subunit (Figure 2). Strata 2 and 3 in Zone 1 were the exceptions; there, parallel transects were used in the offshore subunit. Transects were always placed to avoid overlapping sampling close to the centerline between the two subunits.

In the inshore subunit, the length of the Sampling Unit (about 20 km) was divided into four transect segments of about 5-km and parallel to shore. The width of the subunit was divided into four bins of equal size and parallel to shore. One transect was placed in each randomly selected (without replacement) bin, ensuring that transects were distributed spatially at different distances from shore (Figure 2). In the bins, the transect segments were selected in increments of 100 m distance from the shore.

In the offshore subunit, a zigzag transect traversed the entire width of the subunit (Figure 2) and a portion of the Sampling Unit's length or, sometimes its entire length. The transect trajectory was determined from a random selection point. The length of the zigzag transect in each zone was roughly calculated from a formula based on the total inshore and offshore subunit areas and murrelet densities (from previous data) as follows: each Sampling Unit consists of two subunits, with areas (km^2) inshore, a_1, and offshore, a_2. We assumed that the number of birds observed in each collection of subunit transects followed a Poisson distribution, with mean densities λ_1 and λ_2 (in birds per km^2). Therefore, the optimal ratio (r) of inshore to offshore transect length is given by:

$$r = \frac{a_1}{a_2} \cdot \sqrt{\frac{\lambda_1}{\lambda_2}}$$

which is simply the product of the area ratio and the square-root of the density ratio.

Details regarding methods pertaining to the use of GIS to develop and implement the population sampling design appear in Appendix 1.

Line Transect Sampling

The line transect sampling method was used to estimate murrelet density (number of murrelets per unit area), and ultimately, population size. We recorded the perpendicular distance of each murrelet observation from the transect line; by using Distance software (Buckland et al. 1993, version 3.5), we selected a mathematical function that described the effect of distance on number of birds detected (see Analysis section for density estimation methods).

This method makes some important assumptions, including that objects near the line are not missed by the surveyors or that birds have not moved away from the line in response to the observer before being detected. If objects are missed or move away from the line, density will be underestimated. Brennan (2000) tested the assumption that all murrelets on or near the transect are detected. She found that, on average, birds moved before detection by the observer, but not large distances ($\bar{x} \leq 10$ m) and that some birds were missed because they dove or flew away. Mack et al. (2002) evaluated the effects of observers, the number of observers, and other covariates on the likelihood of detecting birds on the transect line, and they showed that some proportion of birds on the transect are missed and each of these covariates has some effect on detection rates. We are continuing to examine the potential effect of these behaviors on our estimates.

Table 1. Population sampling design overview.

Recovery zone	1	2	3	4	5
Target population (Figure 1)	Nearshore ($\leq$ 8 km) marine waters of Zones 1 - 5				
Geographic strata	1. Strait of Juan de Fuca 2. San Juan Islands and selected portions of Puget Sound 3. The remainder of San Juan Islands and Puget Sound	1. WA North Coast 2. WA South Coast 3. Grays Harbor, Willapa Bay, and Columbia River	1. North portion of zone 2. South portion of zone	1. North portion of zone 2. South portion of zone	1. North portion of zone 2. South portion of zone
Primary sampling unit (Sampling Unit) (Figures 2 and 3)	~20 km section of coast line with inshore and offshore subunits				
Area of inference by geographic stratum	1. 300-5000 m 2. 100-2000 m 3. 100-2000 m	1. 300-5000 m 2. 300-8000 m	1. 300-5000 m 2. 300-5000 m	1. 350-3000 m 2. 350-3000 m	1. 350-3000 m 2. 350-3000 m
Sampling Unit selection	Random selection (without replacement) in each geographic stratum and spread over time and space to the maximum extent logistically feasible				

Total Sampling Units in zone Stratum 1 Stratum 2 Stratum 3	 **98** 9 42 47	 **17** 8 6 3	 **17** 7 10 NA	 **22** 14 8 NA	 **16** 8 8 NA
Total no. sampling units sampled Stratum 1 Stratum 2 Stratum 3	 **31** 6 20 5	 **16** 8 6 0	 **24** 10 14 NA	 **57** 23 34 NA	 **29** 24 5 NA
Total area of zone Km^2 Stratum 1 Stratum 2 Stratum 3	**3,494** 840 1,196 1,459	**1,688** 727 961 NA	**1,804** 696 1,109 NA	**1,165** 739 426 NA	**884** 442 442 NA
Time of Year	Mid-May to mid-July	Mid-May to end of July			
Sampling Unit Subsampling (Figure 2)	Four 5-Km parallel transects in inshore subunit; parallel and zigzag offshore	Four 5-km parallel transects in inshore shore subunit; zigzag offshore			

Sampling Unit = primary sampling unit, an area of ~20 km in length along the coast and 2000 m, 3000 m, 5000 m, or 8000 m in width off the coast.

Program DISTANCE also assumes that the distance of objects from the transect is accurately estimated. Raphael et al.(1999; http://www.reo.gov/monitoring/murrelet/pdf/pnw_atsea.pdf) tested this assumption in the 1999 field season by driving a boat through a field of fixed buoys and recording the observer's estimates of either perpendicular distance or radial distance and sighting angle to the buoys and the “true” distance measured with a laser rangefinder. They found no significant difference in distances when observers estimated a direct perpendicular distance, compared with the radial distance from the object to the boat and the angle of the object from the transect line (using a trigonomic calculation to obtain the distance). Although estimates were found to be biased, the direct estimate of perpendicular distance was more precise.

See the Raphael/Laake document on the web site (http://www.reo.gov/monitoring/murrelet)for further information on using the Distance 3.5 Program with this sampling design.

Observer Methods

Two observers surveyed 90˚ arcs on either side of the boat starting from the bow. Observers scanned continually, slowing their pace slightly at the bow of the boat. More effort was expended watching for birds close to the line ahead of the boat (within 45˚ of the line). A complete scan of 90˚ takes about 5 to 7 seconds. Observers estimated the perpendicular distance of murrelets from the transect line; they used binoculars for species verification, but not for sighting birds. For most surveys, observers recorded information into tape recorders for transcription to survey forms. One exception was the crew in Zone 1, Stratum 1, and Zone 2, where observations were relayed by headsets to a person in the boat cabin who entered the data directly onto a computer. Appendix 3 is the survey form with the common data fields.

Analysis

Overview

The team produced statistically defensible estimates of average marbled murrelet densities (average numbers of birds per square km for the target period) for the target population, with associated defensible estimates of precision. This was done for each zone, separately, and also for the entire target population consisting of all zones combined. This estimation required a process integrating design, implementation, and analysis. Briefly, the sampling design was stratified: estimates were required for zones (subpopulations), and for the entire population consisting of all zones. Here, we describe the analytical methods of data analysis required to produce the desired estimates.

In general terms, an estimate of average density, with an associated estimate of precision, was produced separately in each geographic stratum. All zones had two or three strata. Estimates of precision were produced by using a complex application of bootstrap resampling methods. Estimates for zones and for the entire target population were produced by using standard methods for stratified sampling. First, density (i.e., numbers of birds per square km) was estimated in each strata. Density estimates, and the associated estimates of precision, were then expanded, by using standard methods based on total area within each stratum, to estimate the average total number of birds by zone and for all zones combined for the target period, with associated estimates of precision. The details of these various procedures are documented in the rest of this section.

Estimates of Density in Strata

Estimating density within a stratum required

- Accounting for some non-random selection of Sampling Units in space and time; and
- Specifying parameters to be used in the Distance 3.5 program.

Selection of Sampling Units was non-random for two reasons. First, the long distances between points where boats could access the water, required sampling neighboring Sampling Units either on the same day or on successive days. Second, sea conditions were not always conducive to adequate sampling or the conditions posed safety hazards for the boat crews. This problem resulted in non-random selection of days in the season, and some Sampling Units with adequate sampling conditions were selected more often than originally expected.

Two requirements for using the Distance 3.5 program for summarizing the data were

- Specifications for truncating data; and
- Selecting the method for determining which detection function was used.

For truncating data, we determined the distance at which 5% of the observed distances over all strata in the zone were exceeded. Specifically, if we made *n* distance observations, then we chose the distance associated with the *k*-th observation, where *k* is the nearest integer to *n* multiplied by 0.95, with the data set sorted from lowest to highest distance. That distance was set as the truncation distance in the program Distance 3.5. This truncation rule was used because, when the Distance 3.5 parameter that removes a proportion of the observations was used, that same proportion is removed from each stratum. Because so few observations were made in some of the strata, we removed only 5% of the largest distances irrespective of strata. Doing so required setting a specific truncation distance.

The other major parameter specified in Distance 3.5 was the detection function curve to be selected using the lowest AIC (Akaike's Information Criteria) value from three model types: half-normal, uniform, and hazard rate.

Outputs From Program Distance 3.5

From Distance 3.5, we obtained estimates of the probability of detection on the line ($f(0)$, in units of m^{-1}), and the mean number of birds per group ($E(s)$), along with the observed encounter rate (ER = number of groups of birds observed per km of transect) for each Sampling Unit's subunit (inshore and offshore) survey. Density (birds/km^2) for each subunit survey was estimated with the following formula:

$$\hat{d} = 1{,}000 \cdot \hat{f}(0) \cdot \hat{E}(s) \cdot ER \, / \, 2$$

with the "hats" over the letters representing estimates. Estimates of Sampling Unit density were constructed as a weighted average of the subunit densities with the weights being the areas of the subunits.

Estimates of Precision Within Strata

Estimating precision in a stratum also required accounting for the non-random selection of Sampling Units in space and time. In general, bootstrap resampling methods were used to estimate precision. Bootstrapping allowed for adjusting for sources of non-random selection, as well as incorporating a component of variance associated with the model in model-assisted estimation.

To adjust for the non-random selection of Sampling Units in space and time, we performed a bootstrap procedure where "clusters" in space and time were identified and randomly selected with replacement. Then Sampling Units in each selected cluster were randomly selected with replacement. Both levels of resampling were used to produce one bootstrap replicate sample. The resulting bootstrap sample was then analyzed by the Distance 3.5 program, by using all the same methods we described in the preceding section.

The bootstrap procedure incorporated the program 'PSU Variance' which Laake and Raphael developed to account appropriately for the pairing of the inshore and the offshore subunits for both estimating density and estimating the variance of that estimator.

Estimates of precision were based on 1,000 bootstrap replications (as described above). We used SAS (Version 8, 2000) to select the bootstrap replicate samples: run Distance 3.5, calculate the density estimates, and summarize the bootstrap results.

Variants in Estimation Procedures

Estimation procedures differed slightly for Zones 1, 2, 4, and 5.

- Zone 1. Because not all detection distances were available for Stratum 1 but were available for Strata 2 and 3, a subset with all distances available was used to estimate density for Strata 2 and 3 and $f(0)$ and $E(s)$. Then, a second bootstrap sample from all data from Stratum 1 was used to estimate the encounter rate, which was then combined with the estimates of $f(0)$ and $E(s)$ to produce an estimate of density for Stratum 1. Finally a weighted average of the stratum densities was used as the estimate for the zone density.

- Zone 2. Because many of the detection distances were missing, we assumed no loss of detections out to 100 m and a fixed-width transect estimate was calculated.

- Zones 4 and 5. Because Zones 4 and 5 used the same crews and detections were so few in Zone 5, the data from the two zones were used to estimate common values of $f(0)$

and $E(s)$. Then, separate estimates for each zone were calculated.

Zone and Population Estimates

Because of the potential of both spatial and temporal non-randomness, a model-assisted approach for estimating density was developed and considered for use. If both spatial and temporal non-randomness existed, then the output from Distance 3.5 would be used to estimate density for each Sampling Unit-day combination in the sample. Then, the density at each Sampling Unit-day combination in the zone would be estimated by fitting the following linear model:

$$d_{Day,PSU} = \alpha + \beta_{Day} \cdot Day + \beta_{PSU} \cdot PSU + \beta_{DayxPSU} \cdot Day \cdot PSU + error$$

where PSU = Primary Sampling Unit.
Then a weighted average of predicted densities (with weights being the Sampling Unit areas) for each stratum would be constructed.

Despite the known deviations from a completely random selection of days, however, the data did not suggest any temporal trends during this year. Because any indications of temporal trends for this year's data were lacking, we performed no temporal adjustment of estimates for strata.

Once estimates of mean density and their associated estimates of precision were produced for each stratum, these stratum-scale estimates were combined by using standard methods for stratified sampling. This method produced estimates of mean density with associated estimates of precision for each zone and for the entire target population of all zones combined. Standard methods for stratified sampling, as described in Cochran (1977), require proper weighting of stratum-scale estimates based on the areas in each stratum. These methods apply to producing estimates of mean density and mean total number of birds for zones or for the entire population for the target period, as well as for producing associated estimates of precision.

Constructing Confidence Intervals for Numbers of Birds

For each zone, a 95% confidence interval for the total number of birds was constructed by using the percentile confidence interval method (Efron 1992). For each of the 1,000 bootstrap replications, we estimated the number of birds in the zone by multiplying the estimate of density (birds per km^2) by the total area in the zone. These estimates were sorted from lowest to highest and the 25th-ranked and the 975th-ranked estimates were taken as the 95% confidence interval limits.

For the 95% confidence interval for the total number of birds in all zones, we calculated an estimate of the standard error and then added and subtracted 1.96 times that standard error from the estimate of the total number of birds for the confidence interval limits.

Power Analysis

One of the measures for assessing this monitoring program is the power to detect changes of interest in the mean density (and mean number) of murrelets over time. This ability requires specifying a variety of items:

(1) A summary statistic to estimate the change in mean density;
(2) A plausible model of change over time;
(3) A plausible model characterizing the sources of variability;
(4) An assessment of the consequences for both claiming there is a change when no change occurred (a Type I error) and not detecting a change when a change has occurred (a Type II error); and,
(5) A decision process for applying the results of the data collection and analysis that incorporates the above items.

Standard approaches to items (1) and (2) consist of an estimate of slope for a linear trend over time. Items (4) and (5) are not discussed here.

Item (3) requires two things, one is knowledge of the precision of the estimator of change for a single year and the second is year to year variability of the actual mean density independent of trend information. The bootstrap estimates of precision give us an idea of the precision for the summer 2000 estimate for the zone. But because only a single year's data have been collected, year-to-year variability cannot be estimated based solely on the data collected so far. Data are available from other surveys, however, and they can give us initial estimates of the magnitude of year-to-year variability.

Because of the tentative nature of the available estimates of the postulated two sources of variability, this section will document the estimates of variability, describe the process of estimating power to be used when additional years' information has been collected, and provide examples based on available estimates of precision.

Estimates of Sources of Variability. Washington data from previous years were examined for Zone 1 (Stratum 1 only) and Zone 2 (Strata 1 and 2). The data were confined to the same months as described for the temporal aspect of the population (May, June, and July). Densities of marbled murrelets (birds per km^2) were estimated by using a fixed-width transect with a width of 200 m. The summary statistics for the density estimates associated with the transects from previous Washington data are shown in Table 2. The mean density of murrelets by year is shown in Figure 3.

As Figure 3 shows, larger means tend to be associated with larger standard deviations and the Zone 2 strata have smaller densities and less variability than the single Zone 1 stratum.

Table 2. Mean marbled murrelet densities (birds/km^2) recorded on marine surveys in recovery plan zones 1 and 2, Washington, 1995-1999.

Year	Zone	Stratum	No. of Transects	Mean density	Standard deviation
1995	1	1	3	1.81	1.77
1996	1	1	20	1.78	2.13
1997	1	1	24	2.45	2.84
1998	1	1	71	20.02	21.47
1999	1	1	18	11.06	10.82
1996	2	1	35	2.43	8.09
1997	2	1	40	2.31	2.16
1998	2	1	23	1.38	1.77
1999	2	1	4	0.75	0.76
1996	2	2	26	0.71	0.94
1997	2	2	14	0.16	0.24
1998	2	2	37	0.30	0.36
1999	2	2	4	0.11	0.15

Fitting a linear change model (see Appendix 2 for SAS code) allowing for different variances per year and year-to-year variation did not result in a significant year-to-year variance component for any of the strata. Further, a plot of the mean density vs. standard deviation of density estimates over all strata showed a linear relation between the two variables (Figure 4). This relation suggested that the variability can be represented by a constant coefficient of variation for all years and strata.

What this means for the monitoring program is that initial estimates of power could be based on the observed coefficients of variation associated with the estimates of density. This procedure will undoubtedly overestimate power because the lack of an indication of year-to-year variability once trends were removed is likely to be due to the few years available for each zone-stratum combination.

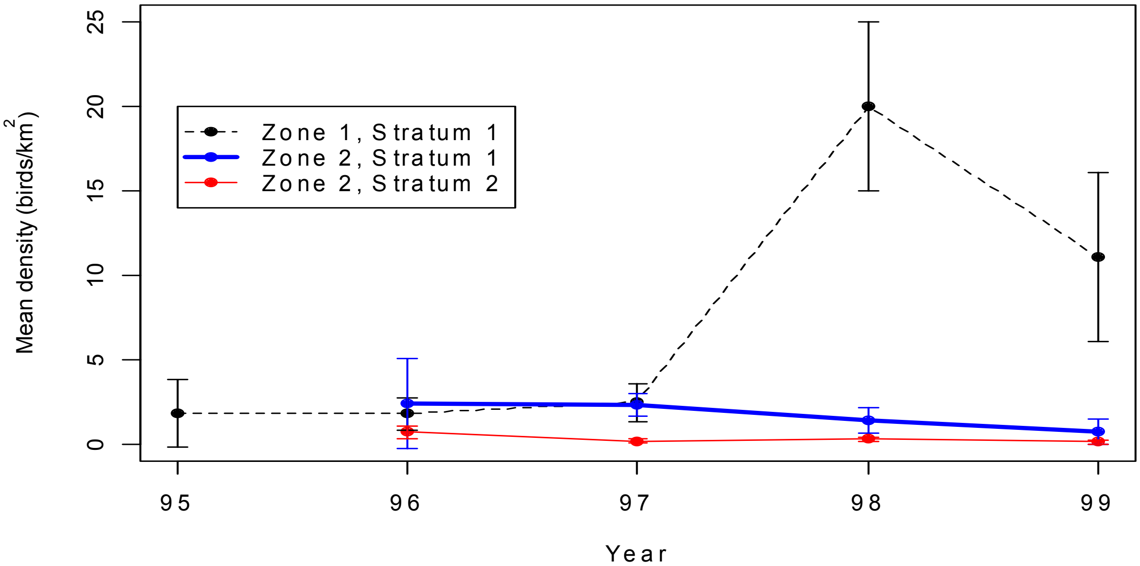

Figure 3. Plot of mean marbled murrelet density estimate vs. year for Washington data. Error bars represent 1.96 times the standard deviation of the individual density estimates. No attempt was made to adjust for differences in transect length.

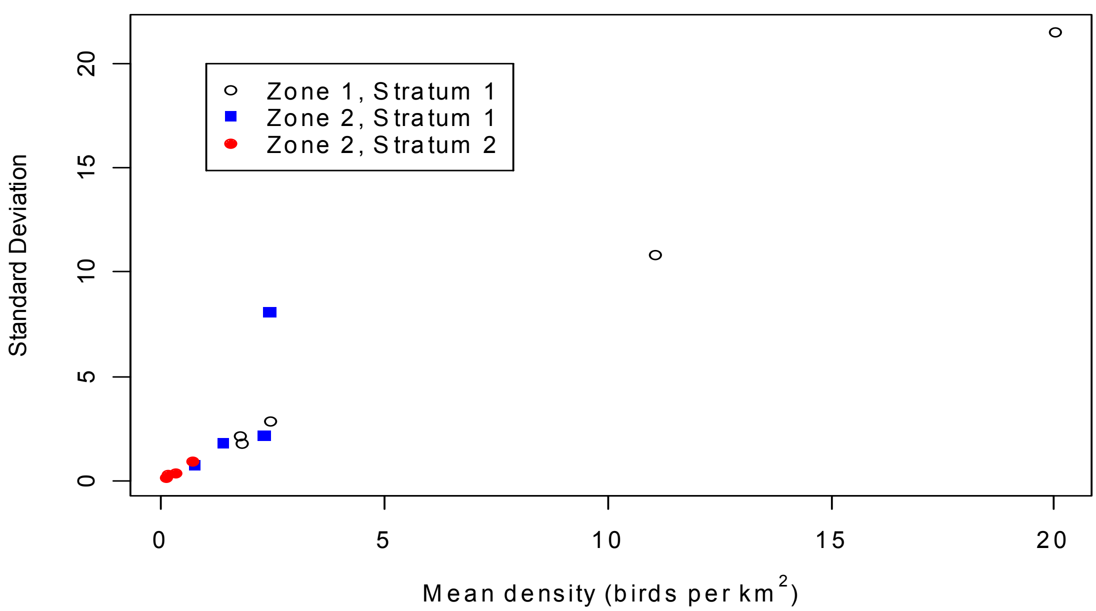

Figure 4. Plot of mean marbled murrelet transect density vs. transect standard deviation for each year and zone-stratum combination for surveys conducted in Washington, May - July.

Process for Estimating Power. The program TRENDS (Gerrodette 1987,1991) was used to estimate power because of its flexibility, widespread availability, and published documentation. To estimate power or required number of years to detect a specified trend, we need to supply several variables (Table 3). The list was modified from the TRENDS manual.

Table 3. Variables need to estimate power to detect population trends of marbled murrelts.

Variable	Value(s) specified for this monitoring program	Description
n	10 years	*n* is the minimum number of years needed at the given error rates
r	5% and 10% decline	*r* is the minimum annual rate of change that can be detected at the given error rates
CV	Zone CV from the first year's summary	*CV* is the maximum permitted CV (minimum required precision) for the initial sample at the given error rates
a	0.05 and 0.10	*a* is the probability of obtaining a significant trend (slope ≠ 0) falsely (Type I error)
Power	0.95 and 0.90	Power is the probability of obtaining a significant trend (slope ≠ 0) correctly (= 1-*b*, where *b* is the probability of a Type II error)

Other attributes that must be defined include the type of change that occurs over time (linear or exponential model) and how the coefficient of variation depends on the mean density. Further details can be found at the TRENDS web site (see Reference section).

Examples of Power Estimation. Assuming the coefficient of variation associated with the estimate of zone density is the only characterization of variability necessary, several scenarios are possible for estimating power and thus the number of years required to detect trends of different magnitudes. Below, we assume that $\alpha = 0.05$ or 0.10, a one-tailed test, an exponential decrease over time, and that the coefficient of variation remains constant for density (Tables 4 and 5).

Table 4. Power to detect annual decreases in abundance (r =- 5% and r = -10%) power = 0.95 along with the required number of years to achieve a power of 0.95 for annual decreases of 5% and 10%. Significance levels are set to $\alpha = 0.05$ and the CV's are assumed to be constant throughout all years.

		Power		**Number of Years**	
Zone	**CV**	$\alpha = 0.05$ $n = 10$ $r = -10\%$	$\alpha = 0.05$ $n = 10$ $r = -5\%$	$\alpha = 0.05$ Power = 0.95 $r = -10\%$	$\alpha = 0.05$ Power = 0.95 $r = -5\%$
1	24.1%	0.98	0.56	10	15
2	19.4%	1.00	0.71	9	13
3	28.9%	0.92	0.44	11	17
4	21.6%	1.00	0.64	9	14
5	54.3%	0.53	0.21	16	24
All	14.4%	1.00	0.89	8	11

n = number of years
r = annual percent decline from previous year

Table 5. Power to detect annual decreases in abundance (r =- 5% and r = -10%) power = 0.90 along with the required number of years to achieve a power of 0.90 for annual decreases of 5% and 10%. Significance levels are set to $\alpha = 0.05$ and the CV's are assumed to be constant throughout all years.

		Power		**Number of Years**	
Zone	**CV**	$\alpha = 0.10$ $n = 10$ $r = -10\%$	$\alpha = 0.10$ $n = 10$ $r = -5\%$	$\alpha = 0.10$ Power = 0.90 $r = -10\%$	$\alpha = 0.10$ Power = 0.90 $r = -5\%$
1	24.1%	1.00	0.72	8	13
2	19.4%	1.00	0.84	7	11
3	28.9%	0.97	0.61	9	14
4	21.6%	1.00	0.78	8	12
5	54.3%	0.69	0.34	13	21
All	14.9%	1.00	0.95	6	10

Discussion of power to detect trends continues in the population summary section.

Zone Results and Sampling Narratives

Zone 1: Strait of Juan de Fuca and Puget Sound

Martin G. Raphael, Diane Evans Mack, and Chris Thompson
USDA Forest Service, Pacific Northwest Research Station, Strata 2 and 3 (MGR and DEM).
Washington Department of Fish and Wildlife, Stratum 1 (CT)

Description and Justification

Strata in Each Zone. Zone 1 was divided into three strata (Figure 5), corresponding to geographic areas of varying marbled murrelet densities identified from previous surveys (PNW, unpublished marine survey data; WDFW, unpublished boat and aerial surveys). Stratum 1 was the Strait of Juan de Fuca. Stratum 2 included the San Juan Islands, the coastline of Fidalgo Island from Anacortes to Deception Pass, the waters between the eastern coastline of central and southern Whidbey Island and Camano Island (Saratoga Passage and Holmes Harbor), and northern Hood Canal from Port Townsend to the Duckabush River (Figure 6). Stratum 3 included all other areas of Puget Sound from the Canadian border to Olympia, and the southern portion of Hood Canal.

Sampling effort was higher in areas of higher densities of marbled murrelets. Based on expected densities and size of a stratum, the intended distribution of Sampling Units sampled in Zone 1 was 5 in Stratum 1, 20 in Stratum 2, and 5 in Stratum 3, all randomly selected from the total Sampling Units available.

Sampling Regime per Stratum.
Stratum 1. Six Sampling Units were completed in the 2000 field season (Table 6). The target number of Sampling Units to be surveyed (n = 5) was randomly selected from the total number available (n = 9). The order in which these Sampling Units were surveyed was constrained by the ports out of which we operated (Neah Bay, Sekui, and Port Angeles). Therefore, sampling was in a geographical order logistically most efficient and resulted in some clustering of samples. Because we planned to survey all Sampling Units at least once on the outer coast, we had hoped to survey the additional four Sampling Units along the Strait of Juan de Fuca that were not part of the five randomly chosen ones. Unfortunately, we succeeded in surveying only six Sampling Units total, (that is, one "extra" Sampling Unit). The 20-km Sampling Units were divided into four 5-km segments, and into inshore and offshore subunits. In the inshore subunit, 5-km transects were parallel to shore, each run at a different distance from shore, with the distance selected randomly (without replacement) from 100-m intervals from 350 to 1450 m. In the offshore subunit, we used zig-zag transects.

Stratum 2. We divided the 20-km Sampling Units into four 5-km segments, and into inshore and offshore subunits. Transects were parallel to shore in both subunits, and each transect (a 5-km segment-subunit combination) in each Sampling Unit was run at a different distance from shore, with the

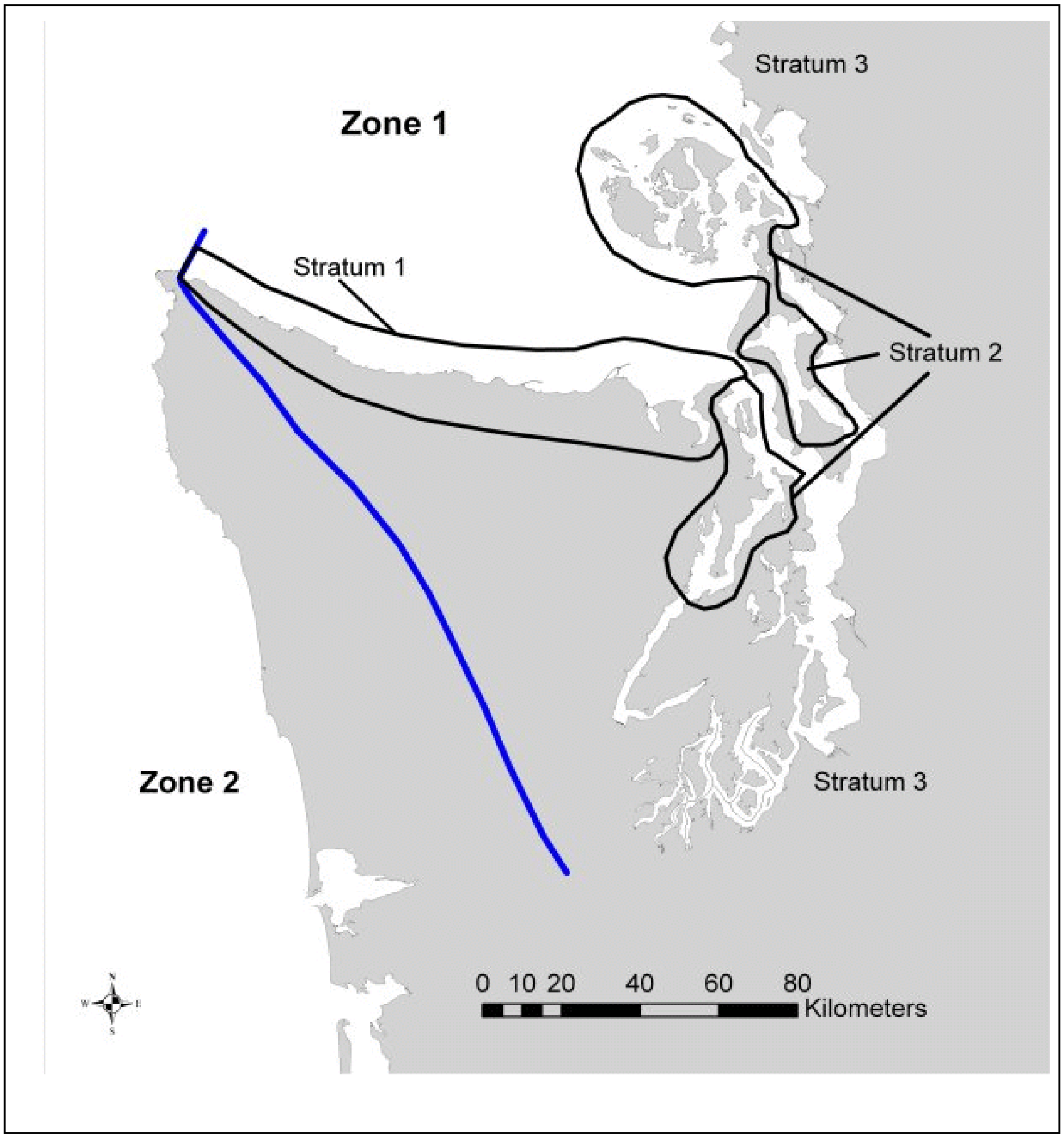

Figure 5. Marbled Murrelet Conservation Zone 1 with Strata 1 and 2 circled. Stratum 3 is the remaining area in Zone 1.

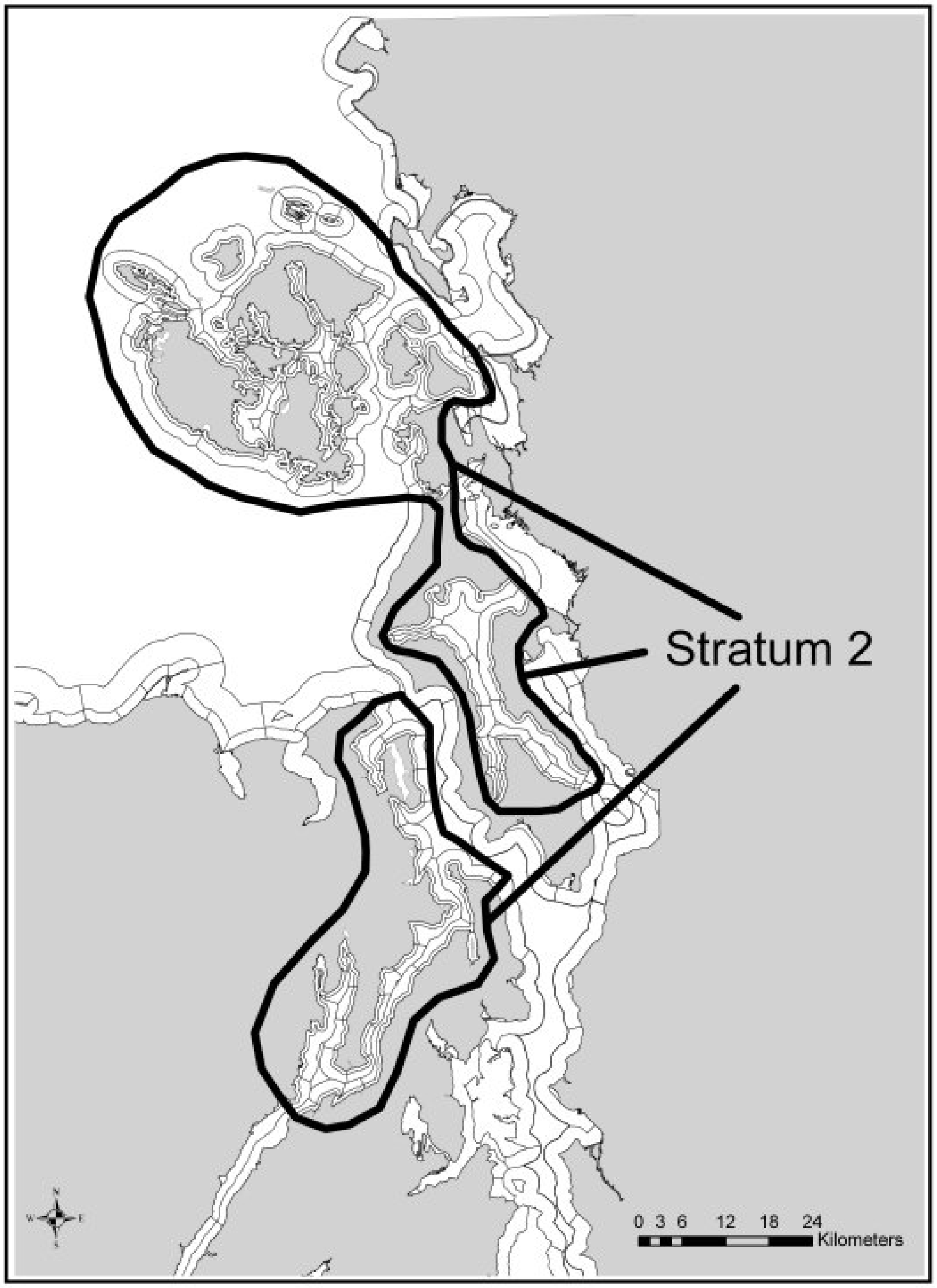

Figure 6. Marbled Murrelet Conservation Zone 1 enlargement of Stratum 2.

distance selected randomly (with replacement), from 100-m intervals.[1] We selected inshore transects first, by Sampling Unit, with distances selected at 150, 250, 350, or 450 m. Transects in the offshore subunit were selected from 15 distances, extending 550-1950 m from shore. Because not all shorelines could be buffered out to 2000 m, the 'universe' (pool of available distances) was defined uniquely for each offshore subunit segment (A, B, C, or D) of each Sampling Unit. The order in which transects were selected was random (not paired with the inshore subunit counterpart during selection and not done for one complete Sampling Unit before moving onto the next Sampling Unit). All possible offshore segment-distance combinations were put into the pool to begin the random selection. Once selected, that transect's distance was subtracted from 300 km (total effort in the offshore subunit) until our transects totaled, as closely as possible but not exceeding, 300 km. Because the random selection was by the segment, not by the Sampling Unit level (that is, we did not select the four transects for Sampling Unit 1 and then move on to the next Sampling Unit), distances could be repeated within a Sampling Unit. We reached 300 km before all offshore segments had been selected. Thus, each selected Sampling Unit generally had eight 5-km transects: four in the inshore subunit and usually four in the offshore subunit. Several had fewer than four transects in the offshore subunit (Figure 2), however. We surveyed 20 units in Stratum 2 (Table 6).

Stratum 3. As above, 20-km Sampling Units were divided into four 5-km segments, but they had no inshore-offshore division or centerline. Thus, each Sampling Unit had four transects parallel to shore. Distance from shore for each transect was randomly selected (with replacement) from available distances (150 to a maximum of 1950 m from shore). We surveyed five units in stratum 3 (Table 6).

Inshore Boundary. The inshore boundaries were set at 300 m (represented by a 350-m transect line) in Stratum 1 and 100 m (150-m transect line) in Strata 2 and 3 because our boats could not safely navigate closer to shore in most areas.

Offshore Boundary. The offshore boundary for sampling was 5000 m from shore in Stratum 1. Previous empirical at-sea survey data from Stratum 1 indicated that at least 95% of murrelets are found within 5000 m of shore; thus, we chose that distance as the outer boundary. For strata 2 and 3, we selected an offshore boundary of 2000 m from shore. The 2000-m limit was based on significantly lower densities of murrelets at distances 2000-4000 m from shore compared with 0-500 and 500-2000 m from shore (PNW, unpublished marine survey data). Densities beyond 2 km were 10 times lower (0.16 birds/km^2) than the 0.5-2 km zone (1.67 birds/km^2).

Centerline. The transition between nearshore and offshore subunits was set at 1500 m from shore in Stratum 1. Previous empirical at-sea survey data indicated that at least 75% of the murrelets are found within 1500 m of shore in Stratum 1. Thus, 1500 meters was chosen as the centerline between the inshore and offshore subunits. The centerline was 500 m in Stratum 2, which corresponded to a 10-fold change in density (from 10.61 birds/km^2 in the 0- to 500-m

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[1] Contrary to the direction in the Draft Monitoring Program, we selected with replacement rather than without. This choice resulted in some distances from shore being repeated in a Sampling Unit. (Example: Segment A at 250, B at 450, C at 450, D at 150.) This technicality was an oversight and will be corrected in future years.

zone to 1.67 birds/km^2 between 500 and 2000 m from shore; PNW, unpublished marine survey data). We did not distinguish inshore and offshore subunits in Stratum 3 because of low bird density throughout that stratum.

Allocation of Effort in Subunits. For Strata 1 and 2, sampling effort was greater in the inshore than the offshore subunits.

Stratum 1. We used a "zig-zag" transect across the entire width and at least a portion of the length of each offshore subunit. The length of the transect was roughly calculated from a formula based on stratum area and murrelet densities.

Stratum 2. To calculate the effort needed in the offshore subunit of Stratum 2, we first calculated the percentage effort needed nearshore from the equation:

$$\text{percentage effort in a1} = a1(\sqrt{d1})/(a1(\sqrt{d1}) + a2(\sqrt{d2})),$$

where
a1 = nearshore area (calculated from GIS layer based on length and width of Sampling Units[2])
a2 = offshore area (calculated from GIS layer based on length and width of Sampling Units)
d1 = density of murrelets in nearshore area (from previous surveys); and
d2 = density of murrelets in offshore area (from previous surveys).

Because the inshore effort of Stratum 2 had already been set at 400 km (20 Sampling Units in Stratum 2 x 20 km long), we used the result of the above equation and known inshore length to calculate the total length for the stratum, and then subtracted 400 km from the total to arrive at the number of kilometers needed in the offshore subunit. For example, we calculated that 58% of the effort should be spent in the inshore subunit, based on area and density of birds. Given the total inshore transect length of 400 km, the total length for the stratum was 690 km, leaving 290 km in the offshore subunit. Because of the lack of precision in the designation of 400 km for the inshore subunit (not all Sampling Units were exactly 20 km long), we rounded the offshore effort to 300 km.

Equipment

Stratum 1. To collect data during at-sea surveys, the Washington Department of Fish and Wildlife (WDFW) uses a software program called DLOG (for datalog, developed by R.G. Ford, Inc., Portland, OR) loaded onto a laptop computer. The program interfaces with a geographic positioning system (GPS) and geographic information system (GIS) overlays of the Washington shoreline and adjacent bathymetry, and uses them to record GPS coordinates, perpendicular distance to shore, and water depth at time intervals defined by the operator (such as every 30 seconds). Transect-survey length is calculated from the GPS trackline (location points recorded along the transect line during surveys) recorded in DLOG. Other data such as weather and sea

[2] Note: The area used in this calculation included 0-100 m from shore. This analysis was completed before the decision was made by the team to exclude areas not 'surveyable' from density analyses.

conditions, on or off the transect, and names of observers are also recorded manually in DLOG. One of our survey crew manually entered bird observation data (species, number, and behavior [such as flying, on water, diving], and perpendicular distances of murrelets from the transect line) in real time into the laptop as relayed from both the port and starboard observers through audio-headphones. In summer 2000, murrelet observations were recorded by using line-transect methods, but only birds observed in a strip of 100 m on either side of the boat (transect line) were recorded. In addition, because of an unknown user error, perpendicular distance estimates for many murrelet observations were not recorded by our software. As a result, we had to calculate murrelet densities based on our transect-strip width of 200 meters (100 meters on either side of the transect line) rather than as line-transect data. Beginning in 2001, murrelet observations will be collected at all distances to which they can be identified. Since 1995, WDFW has used many boats to conduct at-sea surveys for murrelets. Boats have ranged from 26 to 56 feet long, inboard to outboard, and single to twin engine. In 2000, we used two vessels, the twin-outboard 26-foot WDFW vessel, *Harlequin*, and a 36-foot twin inboard commercial fishing vessel, *Seasport*. Platforms were about 1.5 to 2 m high, putting the observer eye-height at about 3.5 to 4 m.

Strata 2 and 3. All surveys were conducted from 17-foot Boston Whalers with center consoles. Platform height was 0.5 m, putting observer eye-height at 2 m above the water line. The boats were equipped with a Garmin 215-d GPS with real-time differential correction and G-chart. Before the field season, latitude and longitude of the end points of each transect segment were converted in Garmin PCX5 V2.09 from NAD27 (the datum of the underlying coast layer) to WGS84 (to correspond to the G-charts in our GPS units) and uploaded to the GPS unit. On the water, the GPS was used to navigate to the beginning of a transect segment. When this point was reached, the Furuno radar unit was set to the actual distance from shore. The radar was used to stay on the transect at this distance until the end point of the transect segment was close, at which time the GPS was used to hit the end point. Boats were equipped with Apelco 'fish finders' to record depth and water temperature. Laser rangefinders were used in training and testing distance estimates.

Training

Stratum 1. All observers had extensive at-sea seabird survey experience before 2000, although not with murrelets. We spent a week training observers to identify seabird species, to use line transect methods, and to use DLOG to collect real-time data. The draft protocol we developed for counting murrelets at sea specifies that perpendicular distances of murrelets from the transect line be estimated directly (rather than by using radial distance and angle to calculate perpendicular distance). As a result, during the training period, each morning we towed a buoy at various distances behind our vessel (at slow speed) to help observers gain an accurate sense of relative distance of objects from the vessel. Then, each afternoon, we tested observers in a similar manner. For the rest of the season, we repeated this exercise at least once a week.

Strata 2 and 3. Observers were trained in seabird identification, murrelet age classification, and distance estimation during a two-week session before surveys began and periodically tested throughout the survey season. Distance estimation trials involved driving the boat slowly through an array of stationary buoys, having the observer estimate perpendicular distance to a target, and measuring actual perpendicular distance with a laser rangefinder when the target came abeam of the boat. This system provided fairly immediate feedback to the observer so that he or she could look at the target again with the known distance in mind. We obtained 155-197 estimates per observer, with about 50% of those before surveys, and the remaining 50% from two follow-up trials during the survey period. In addition, a 100-m line marked with knots at 5 m and buoys at 25 m was trailed from the stern of the boat for more frequent (daily or weekly) distance calibration.

Unique Zone Aspects

Because of the convoluted shoreline and narrow passages in Strata 2 and 3, not all Sampling Units could extend to the outer boundary of 2000 m before meeting the outer boundary extending from the opposite shore (Figure 7). This constrained the available distances from shore that we could select. Many areas of Stratum 3 were shallow for a substantial distance from shore. We established a new shoreline ("safe" shoreline) in our GIS layer, using this new line as our zero distance from shore and generating 100-m-distance bands from it.

Data Analysis and Results

We surveyed a total of 31 Sampling Units in Zone which resulted in over 1,800 km of transects and an area surveyed of ca. 3,500 km^2 (Table 6). All Sampling Units in Strata 2 and 3 were surveyed twice during the sampling period. The first survey was from 23 May to 19 June, the second was from 20 June to 19 July. Both estimated murrelet density and population for Zone 1. Although the number of transects was doubled, the corresponding effort also doubled, so no bias was added in density estimates. The number of murrelets observed per 20 km varied across the survey season (Figure 8).

In Stratum 1, murrelets observed in flight would have been recorded if they were within 100 m of the transect line. In summer 2000, however, we did not observe any murrelets in flight in 100 m of the transect line; therefore, flying birds did not contribute to density estimates. In Strata 2 and 3, murrelets detected in flight were included in total counts, but they represented <5% of total detections included in the final density analyses.

We estimated that the density of murrelets in Zone 1 was 1.613 $\pm$ 0.389 birds/km^2 (Table 7). This resulted in a population estimate of 5,635 birds (95% CI of 3,198 - 8,453) for zone 1.

Table 6. Summary of analysis statistics for marbled murrelets in Zone 1.

Analysis parameter	Total	Stratum 1	Stratum 2	Stratum 3
Number of km surveyed	1,810.7	209.9	1,403.6 [d]	197.2 [d]
Number of Sampling Units sampled	31	6	20 [d]	5 [d]
Number of murrelets	552	176	339	37
Area of zone (km^2)	3,494.4	840.1	1,195.6	1,458.6
Truncation point	5%[a]	-[b]	-	-
Probability of detection on the line–f(0)	0.012[c]	-	-	-
Average cluster size–E(S)	1.53[c]	-	-	-
Encounter rate (number of birds/km)[e]	0.247	0.506	0.179	0.167

[a] Equated to a 179-m truncation.
[b] Dashes indicate that global estimates were calculated; estimates are not available by stratum.
[c] Taken from distance-project output.
[d] Each Sampling Unit was sampled twice, so that the actual number of surveys and length of surveys are double the numbers shown.
[e] Encounter rate = (no. murrelet groups observed within truncation zone / total transect length) * E(S)

Table 7. Summary of marbled murrelet population statistics in Zone 1.

Population parameter	Total
Population estimate	5,635
95% confidence interval on population estimate	3,198 - 8,453
Density (number of birds/km^2)	1.613
Standard error of density estimate	0.389
Coefficient of variation of density	24.1

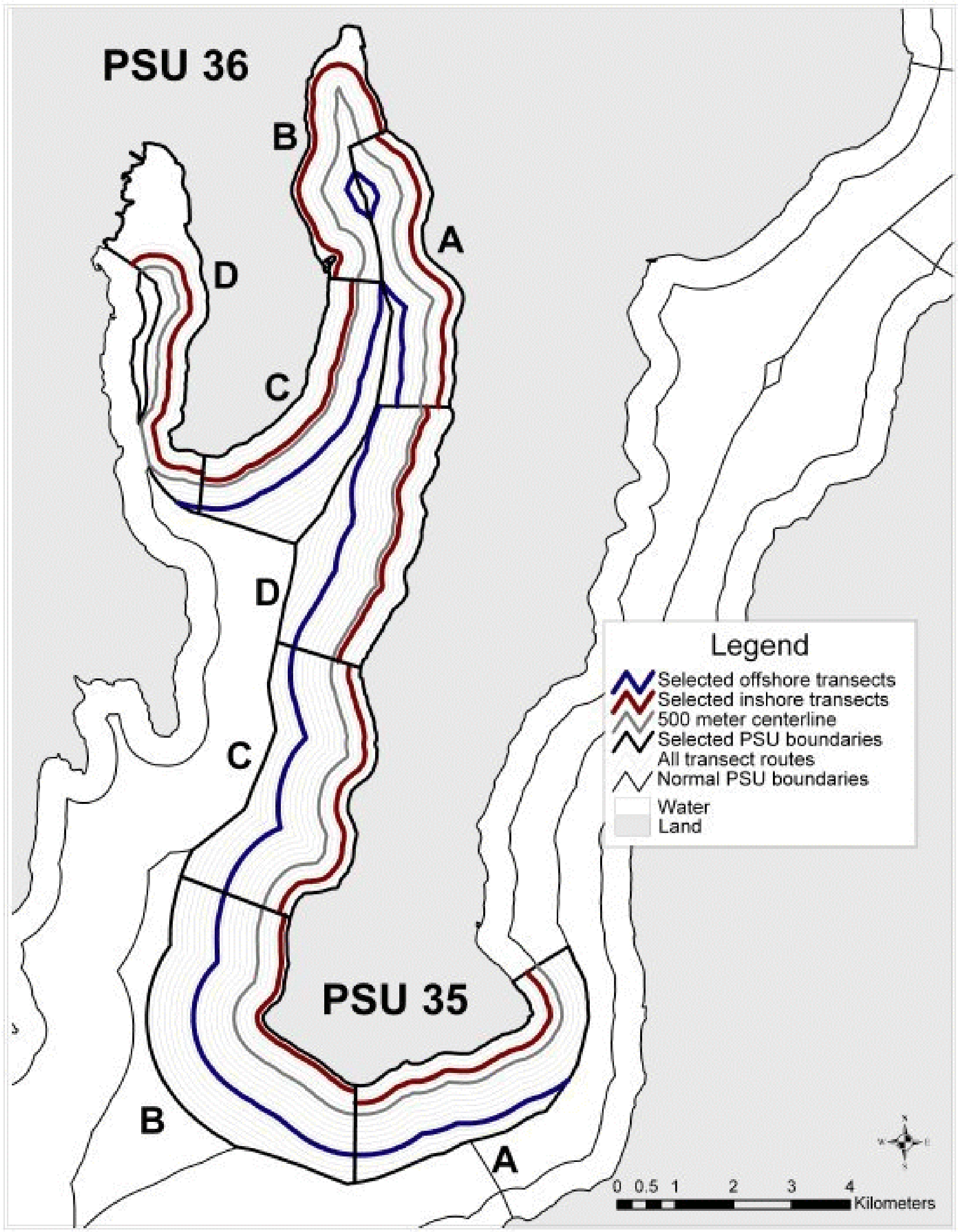

Figure 7. Primary sample unit example for Zone 1, Stratum 2, showing shore-to-shore distances <4000 m limiting the maximum width of the offshore subunit.

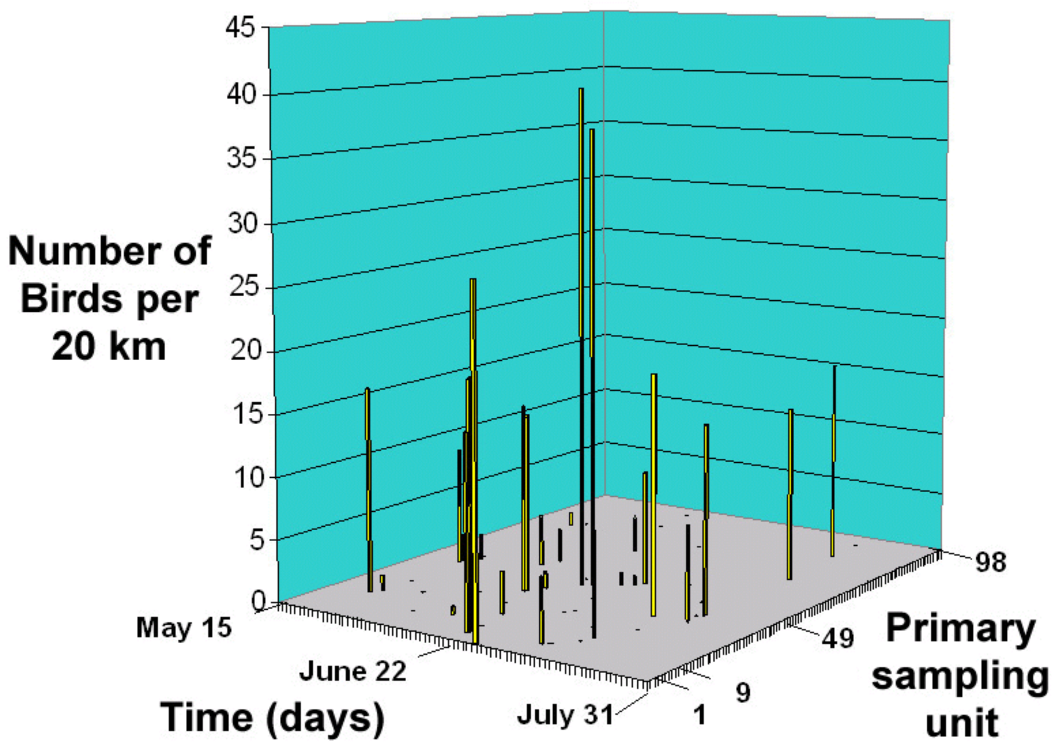

Figure 8. Marbled murrelets per 20 km in each primary sampling unit sampled in Zone 1.

Zone 2: Outer Coast of Washington

Chris Thompson
Washington Department of Fish and Wildlife

Description and justification

Strata in each zone. Zone 2 was divided into three strata (Table 1, Figure 9), based on known differences in the abundance and distribution of murrelets among them (Thompson 1997 a,b; 1999; 2000). Stratum 1 ("north coast") ranges from the northernmost limit of Zone 1 at the northwest tip of Washington south to the mouth of Grays Harbor. This stratum is characterized by a rocky shoreline and ocean floor, and a fairly rapid increase in water depth with increasing distance from shore. Stratum 2 ("south coast") ranges from the mouth of Grays Harbor south to the mouth of the Columbia River. This stratum is characterized by a sandy shoreline and ocean floor, and a relatively slow increase in water depth with increasing distance from shore. Stratum 3 ("rivers and bays") includes Grays Harbor, Willapa Bay, and the Columbia River.

Sampling regime per stratum. The sampling design for Zone 2 called for sampling 33 Sampling Units: three replicates of all eight Sampling Units in Stratum 1 (north coast), temporally distributed across the season from 15 May through 31 July, and one replicate of each of the six Sampling Units in Stratum 2 (south coast), and three Sampling Units in Stratum 3. Unfortunately, because of a variety of personnel, vessel, and weather problems, we completed surveys of only 16 Sampling Units in Zone 2 (Table 8). To analyze Sampling Unit surveys as independent samples, each one must be sampled temporally and spatially independently; that is, ideally, the Sampling Units must be sampled in random order in time and space. Following this sampling design was logistically and financially impractical, however. The outer coast of Washington has only five ports; from north to south: Neah Bay, La Push, Gray's Harbor (Westport), Willapa Bay (Tokeland), and the Columbia River (Ilwaco). As a result, each week we worked out of one or, at most, two ports, and sampled Sampling Units within commuting distance of that port; thus, our sampling was neither temporally nor spatially random. The potential effects of these deviations from our sampling design on estimates of mean density and its variance were corrected by bootstrap analysis.

Inshore Boundary. We selected an average inshore boundary of 350 m from shore. Although we can often survey this close to shore, many sites had kelp, rocks, or surf extending further out from shore than 350 m, requiring that we extend our inshore boundary to a greater distance. The location of the rocks is permanent, but kelp abundance and distribution differs from year to year, depending on weather and other factors in the preceding year. Within years, abundance and distribution of kelp depend on the time of year (less kelp in May than in July) and tide (less kelp at high tide compared to low tide). In 2001, we plan to map the inshore boundary of Zone 2.

Offshore Boundary. Previous empirical at-sea survey data from Strata 1 and 2 show that at least 95% of the murrelets are sighted within 3000 m Zone 1 of shore in Stratum 1 and 8000 m in Stratum 2; thus,

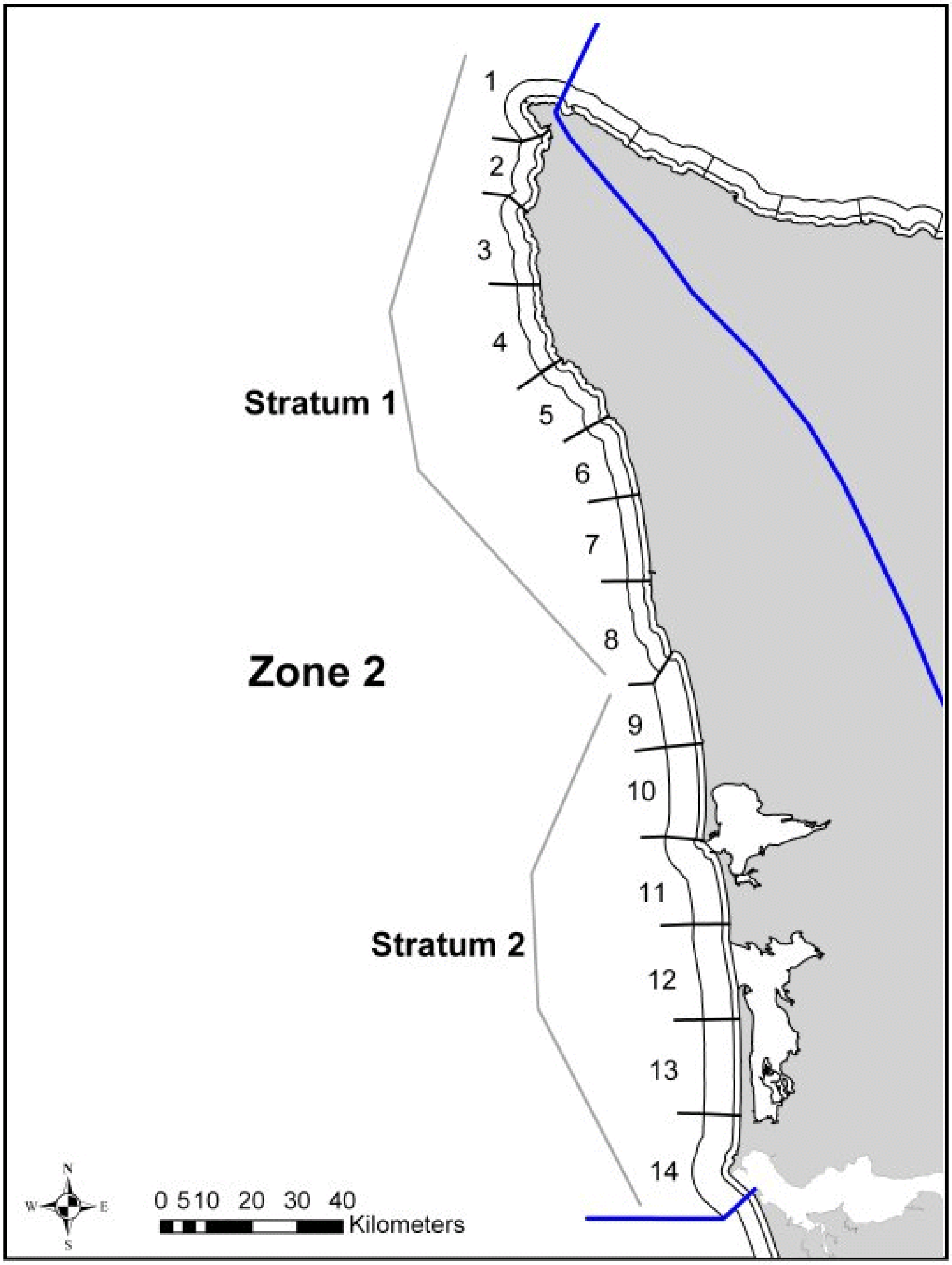

Figure 9. Marbled Murrelet Conservation Zone 2, Strata 1 and 2.

we chose these distances as the offshore boundaries for these zones (Thompson 1997a; unpublished data).

Centerline. Previous empirical at-sea survey data from both Strata 1 and 2 show that at least 75% of the murrelets are sighted within 1500 m from shore. Thus, 1500 m was chosen as the centerline between the inshore and offshore subunits in both strata.

Allocation of Effort in Subunits. A zig-zag transect in the offshore subunit traversed the entire width and at least a portion of the length of each Sampling Unit. The transect length was roughly calculated from a formula based on stratum area and murrelet densities. In Stratum 2, our offshore boundary was 8000 m, so the areas of the offshore subunits of the Sampling Units in Zone 2 were large and the calculated transect length to survey in the offshore subunit was about 70 km. After sampling the inshore subunit, we often could not also survey the offshore subunit of the same Sampling Unit within a half day, as required by our temporal definition of a Sampling Unit. As a result, we reduced the transect length in our offshore subunits to between 20 and 30 km.

Equipment

To collect data during at-sea surveys, the Washington Department of Fish and Wildlife uses a software program called DLOG loaded onto a laptop computer (see Zone 1, Stratum 1 for details of data collection and vessels).

Training

All observers had extensive at-sea seabird survey experience before 2000, although not with murrelets (see Zone 1, Stratum 1 for training details).

Unique Zone Aspects

Some nearshore areas in Strata 1 and 2 are not accessible because of kelp, rocks, islands, or shallow water that produces breaking waves. Specifically, in Stratum 1, these structures are within 1500 m of shore and prevent surveying close to them. In Stratum 2, the mouths of Grays Harbor, Willapa Bay, and the Columbia River are often have extremely treacherous for boats, requiring that we survey at considerable distances offshore from them. These distances vary considerably depending on tidal stage and weather.

Data Analysis and Results

We surveyed a total of 13 Sampling Units in Zone which resulted in ca.550 km of transects and an area surveyed of ca. 1,690 km^2 (Table 8). We would have recorded murrelets in flight if we had seen them, but in summer 2000 we saw no murrelets in flight within 100 m of the transect line. Thus, our density estimates did not include flying birds. The number of murrelets seen per 20 km by Sampling Unit survey day varied across the monitoring season (Figure 10). We estimated that the density of murrelets in Zone 2 was 0.455 $\pm$ 0.088 birds/km^2 (Table 9). This resulted in a population estimate of 769 birds (95% CI of 500 - 1,100) for zone 2.

Table 8. Summary of analysis statistics for marbled murrelets for Conservation Zone 2.

Analysis parameter	Total	Stratum 1	Stratum 2	Stratum 3
km surveyed	558.3	301.4	256.9	0
Number of Sampling Units sampled	13	7	6	0
Number of murrelets	69	51	18	-
Area of zone (km^2)	1687.8	727.0	960.9	713.7*
Truncation point	100 m	-	-	-

*Note the area in Zone 2, Stratum 3, was not used for density calculations.

Table 9. Summary of marbled murrelet population statistics for Conservation Zone 2.

Population parameters	Total
Population estimate	769
95% confidence interval on population estimate	500 - 1,100
Density (number of birds/km^2)	0.455
Standard error of density estimate	0.088
Coefficient of variation of density estimate	19.4

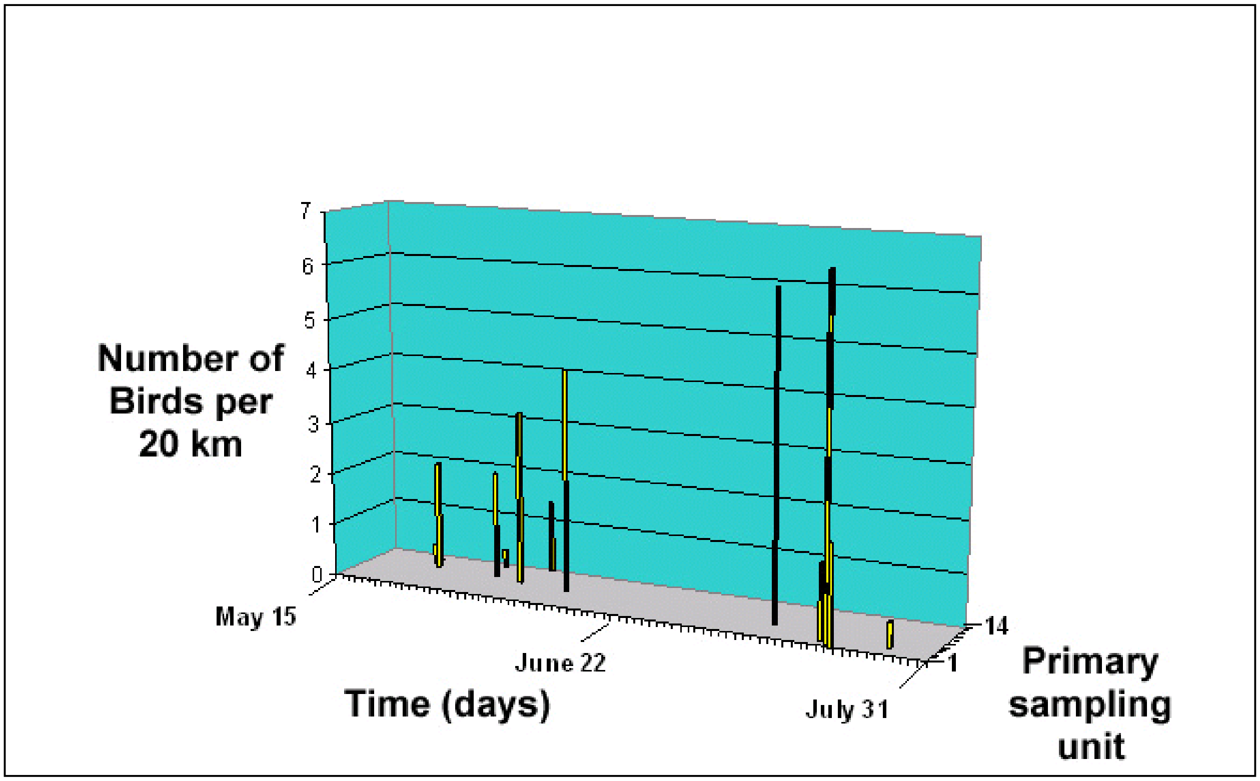

Figure 10. Number of marbled murrelets per 20 km in each primary sampling unit sampled in Zone 2.

Zone 3: Columbia River to Coos Bay, Oregon

Craig Strong
Crescent Coastal Research

Description and justification

Strata in Each Zone. Zone 3 was divided into a northern stratum with a characteristically low density of murrelets and a southern stratum with a high density (Figure 11; Strong et al. 1995, Strong and Carten 2000).

Sampling Regime per Strata. Of the 30 Sampling Unit sampling goal, we targeted 20 samples in the southern stratum (two replicates surveying all ten Sampling Units in the stratum), and ten in the north (two replicates surveying five of the seven Sampling Units in each replicate). The first replicate was to be completed in June, the second in July. Before the survey season, we developed a strategy to survey in a randomized spatial and temporal format, while limiting logistic inefficiency. The intent was to randomly select survey excursions corresponding to a 2- to 3-day field trip to one part of the coast (one or two port-access points), resulting in clumped temporal and spatial sets of Sampling Units. This clumped sampling was accommodated by using the bootstrap analysis.

Inshore Boundary. A distance of 350 m from shore was generally representative of the navigable waters close to shore in Zone 3.

Offshore Boundary. In all parts of their range on the open coast of the contiguous United States, marbled murrelets concentrate in nearshore waters and decrease in frequency out over the shelf waters (Nelson 1997). The actual shape of this distribution differs by region and year (Rachowicz and Beissinger 1999). To select the offshore boundary of the sampled population in Zone 3, I used samples of the offshore distribution from 1992 to 1999, which consisted of 4-km transects set at increasing distance from shore, usually in 500-m increments. These data are difficult to summarize because sampling effort was empirically driven; when no murrelets were detected for one or two transects, the effort was stopped for the day. During 83 sampling days, we completed 21 surveys beyond 3000 m from shore, and only 3 (3.6%) beyond 5000 m, where observers saw only six birds (0.1% of 5,922 birds seen). Years in which we surveyed beyond 5000 m were those with low primary productivity (1993, 1996). The birds may have been increasing their foraging range in those years. I considered a 5000-m offshore Sampling Unit boundary conservative for including 95% of the population, even considering annual variability. During the 2000 season (a year of high primary productivity), only one murrelet was seen more than 3000 m offshore.

Centerline. To determine the boundary between the high-density inshore subunit and the low-density offshore subunit, I examined the area where I found peak densities in the 83 samples of offshore distribution from 1992-1999. Peak density was at 500 m in 49 cases, at 1000 m in 20

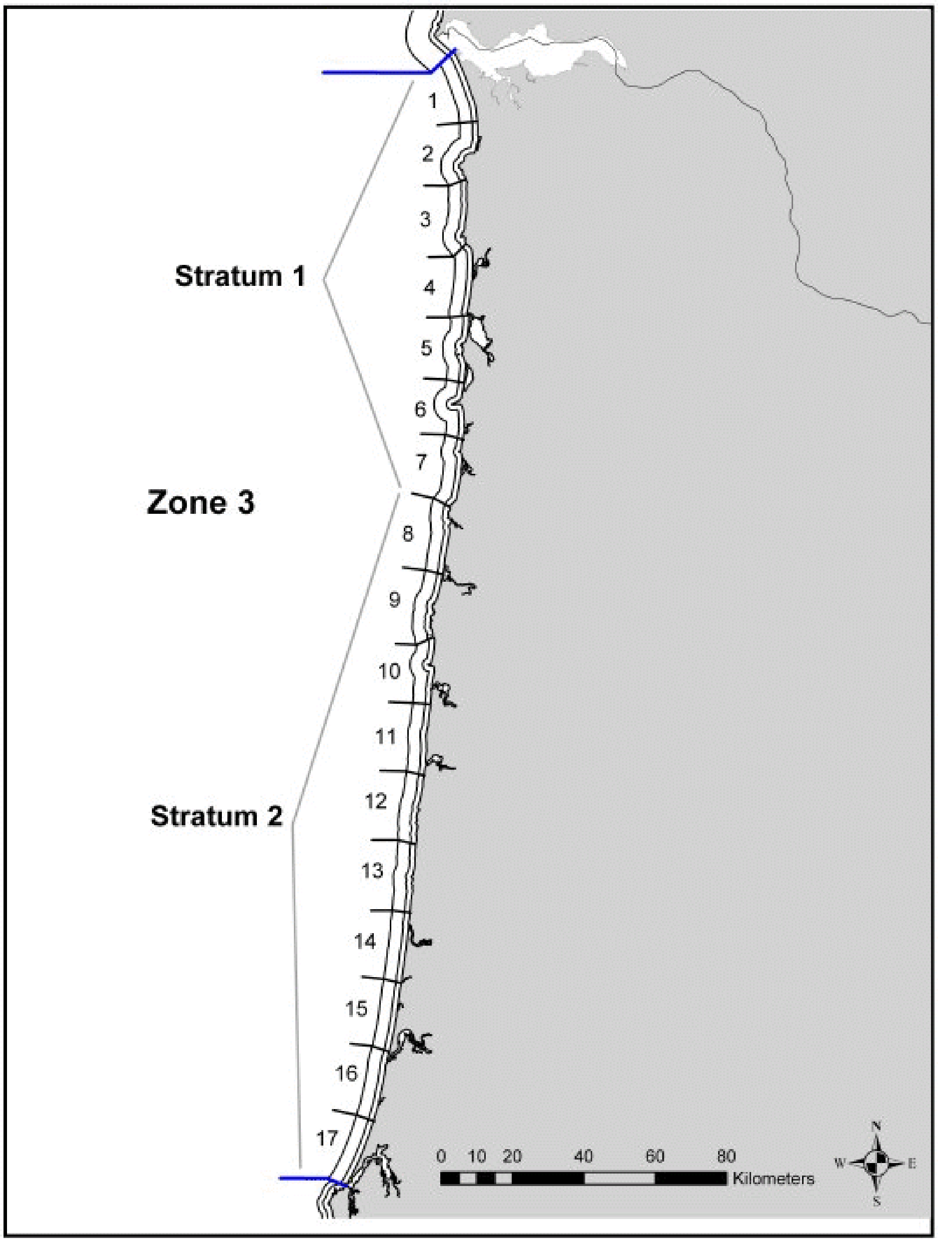

Figure 11. Marbled murrelet conservation Zone 3 with Strata 1 and 2.

cases, at 1500 m in 12 cases, and at 2000 m only twice (2.2%). I selected 1500 m as capturing the area of high density to avoid 'diluting' density estimates in the area of peak occurrence with the generally lower values found offshore, while still maintaining some room for annual variability.

Allocation of effort in subunits. We used densities of murrelets from prior surveys, and the formula for allocating survey effort between inshore and offshore subunits described in the sampling-design section. With an inshore transect length set at 20 km, we computed an offshore transect length of 24.6 km in Stratum 1 and 17.2 km in Stratum 2. During the first part of the season, some offshore subunit transect lengths were greater than intended because of GIS and waypoint entry error. The small differences, and the general lack of murrelets in the offshore subunit were not expected to have an effect on calculated densities, however.

Equipment

Our survey vessel during 2000 was a 21-foot Reinell. Observers stood on the port and center of the boat, behind the cutty cabin and windscreen, with the driver on the starboard side. The deck was about 10 cm above the waterline, put the view of a standing observer looking over the windscreen at about 2 m above the sea. Vessel speed was maintained at 10 knots, slightly less at beaufort sea state of 3 (about 9 knots), and up to 11 knots in calm waters with excellent viewing conditions. Data were all recorded on microcassettes held by each observer, later transcribed to data forms, and then entered into computer database files.

Training

All observers were trained in survey protocol during initial surveys each year, in the company of the project leader. All observers were experienced with seabird identification and had reviewed methods before the season began. At a minimum, observers had a cumulative total of 3 years experience surveying marbled murrelets (one observer had 2+ years' experience and one had 1+). In 2000, one observer had 3 years' experience, one had 1 year, and one was new to the crew. The observers and driver were interchangeable in position, and sometimes rotated. Although the driver (who had the same view as observers) was not responsible for making bird observations, he often watched for murrelets and pointed out those that may have been missed by observers. Detections made by the driver were recorded in the data to show the contribution of the 'third observer'. Communication among the crew was an important part of the survey, to ensure all birds were reported, and without duplication of birds close to the transect line where both observers were watching.

Distance estimates were calibrated by towing a measured buoy at varying distances from the boat, 5 to 120 m away. First, distances were told to observers to gain familiarity with estimating them; then, a series of distances were estimated where the buoy operator did not tell the true distance until others had made their estimates. When all observers were consistently estimating distances within 5 m of the measured value when the buoy was within 60 m of the boat, and within 10 m when it was farther away, they were considered qualified. Buoy distances were estimated at the start of the season and about every two weeks thereafter. Distance estimates between observers were compared daily when on transect in estimating birds' distance from the transect line, and if large or consistent discrepancies were found, we again deployed buoys at the first opportunity to make corrections. A formal test of estimation accuracy completed by Becker and Beissinger (1999) showed our crews to average within 8% of the true distance with no bias toward higher or lower estimation. During 2001, a laser rangefinder will be used to calibrate our distance estimation more precisely than we were able to do this year.

Unique Zone Aspects

Assisted by GIS routes entered on portable GPS units, sampling the inshore subunit by using the 20-km-long Sampling Unit format proved very workable, but we encountered two difficulties in following prescribed GIS-generated routes. First, on days where swell size caused breakers, we could not always safely follow the transect line closest to shore. For the seven times this problem was encountered, we moved to the nearest distance offshore where safe navigation was possible. Second, GPS-generated routes led us into islands or reefs, or were consistently offset from the intended distance from shore. We had this offset problem twice in northern Oregon, where the coastline had changed significantly since the 1927 datum was developed (in Sampling Unit 1 and the northern portion of Sampling Unit 2, along Clatsop Spit). These problems can be corrected with communication between GIS and field personnel and the base map adjusted to include the small islets and reefs. Because we did not compare our GPS-generated tracklines with the GIS routes, navigation error may also have caused some minor differences from planned routes.

Data Analysis and Results

We surveyed a total of 24 Sampling Units in Zone 3, which resulted in ca. 1,000 km of transects and an area surveyed of ca. 1,600 km^2 (Table 10). Only birds first detected on the water were included in the density analysis. Flying birds comprised 11.2% of the 908 detections in Zone 3 (all data), but their contribution to the density estimates would be minimal because most of the flying birds were farther from the transect line. In our previous research, only 40% of the flying birds were within 50 m of the transect line, where 78.5% of birds detected were on the water. Thus, if flying birds were included in a 50-m fixed-width strip analysis of the data, the estimate would have increased by about 4.5% (0.112*0.4). For line-transect analysis, the change would be less, because the density is based on f(0), the detection rate at and very near the line. Including or omitting flying birds will be standardized between all zones in coming years.

From 8 June to 31 July, 26 Sampling Units were surveyed in Zone 3 (Table 10), but two were discarded as incomplete (due to weather), leaving ten in Stratum 1 and 14 in Stratum 2. The shortfall from the targeted 30 samples was due to starting late in the season, an extended period of foul weather in mid-June, and two mechanical repairs in July. The randomized clustering of surveys was not completed in the same order as originally designed because of weather and other logistic constraints, but we arbitrarily selected Sampling Unit clusters distributed through the season and along the coast.

We estimated that the density of murrelets in Zone 3 was 4.269 $\pm$ 1.235 birds/km^2 (Table 11). This results in population estimate of 6,738 birds (95% CI of 3,940 - 11,707) for zone 3. The number of murrelets observed per 20 km by Sampling Unit survey-day varied across the monitoring season (Figure 12).

Table 10. Summary of analysis statistics for Marbled Murrelet Conservation Zone 3.

Analysis parameter	Total	Stratum 1	Stratum 2
km surveyed	1000.5	439.0	561.5
Number of Sampling Units sampled	24	10	14
Number of murrelets recorded	398	63	335
Area of zone (km^2)	1578.5	644.6	933.9
Truncation point	5% [a]	- [b]	-
Probability of detection on the line–f(0)	0.019 [c]	-	-
Average cluster size–E(S)	1.639 [c]	-	-
Encounter rate (number of birds/km)	0.438	0.144	0.628

[a] Equated to an 85-m truncation distance.
[b] Dashes indicate that global estimates were calculated; estimates are not available by stratum.
[c] Taken from Distance project output.
[e] Encounter rate = (no. murrelet groups observed within truncation zone / total transect length) * E(S).

Table 11. Summary of marbled murrelet population statistics for Conservation Zone 3.

Population parameter	Total
Population estimate	6,738
95% confidence interval on population estimate	3,940 - 11,007
Density (number of birds/km^2)	4.268
Standard error	1.236
Coefficient of variation of density estimate	28.9

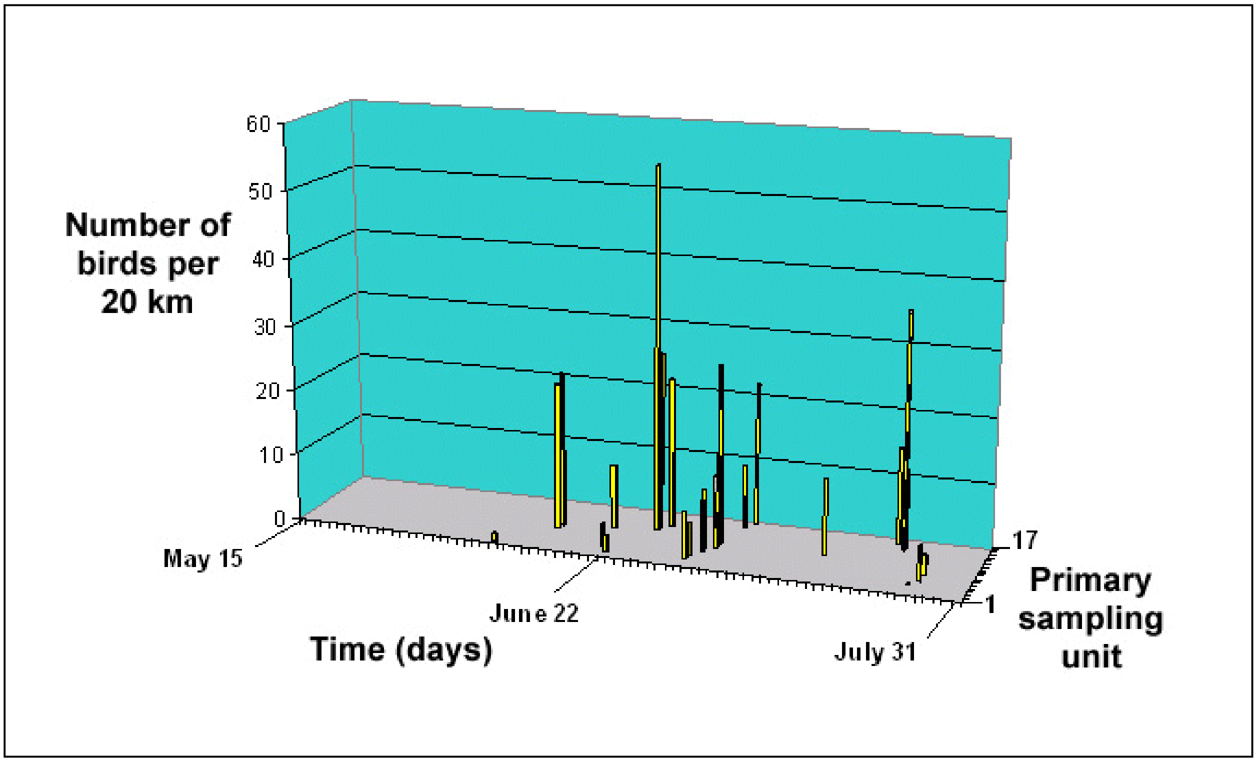

Figure 12. Number of marbled murrelets per 20 km in each primary sampling unit in Zone 3.

Zones 4 and 5: Coos Bay, Oregon, to Humboldt/Mendocino County Line, California, and from Humboldt/Mendocino County Line to San Francisco Bay

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The 2000 monitoring effort in both Zones 4 and 5 (Figures 13 and 14) was coordinated by Redwood Sciences Laboratory. These Zones, thus, have many things in common, so the two zone chapters were merged into one.

Zones 4 and 5: Description and Justification

Inshore, Offshore, and Centerline Boundaries. We used murrelet observations from our 1989 through 1999 surveys of the California and Oregon coasts to assist with our decisions on inshore and offshore Sampling Unit boundaries in Zones 4 and 5. Using computer simulations, we reproduced the observed distribution to place a 'population' of birds from the shoreline to about 5 km offshore. The distribution out from shore was based on what we call our "Intensive Surveys," conducted from several parallel transects systematically placed at increasing distances from the shore on 10 sections of the northern California and southern Oregon coasts. The distribution along the coasts of California and Oregon was based on birds observed during our "Extensive Surveys," conducted from transects at 800 and 1400 m from the shore in all of Zones 4 and 5.

The computer simulations resulted in a calculated population averaging 260 birds between 400 m and 2000 m from shore in a 20-km section of coast, and about 40 birds between 2000 m and 3000 m. We then compared the percentages of birds included inshore and offshore of a parallel line drawn at different distances from the shoreline. The inshore and offshore subunit boundaries were selected based on the distribution of our entire population of simulated birds. Boundaries of 400 m inshore and 3000 m offshore included 95% of the simulated bird population. We selected a centerline (the division between the inshore and offshore subunits) of 2000 m, which allowed most of the survey effort to be apportioned to the inshore subunit, where most of the birds were found. With a centerline of 1200 m, the subunit contained 50% of the population; with a line at 1500 m, the subunit contained 33%, and at 2000 m, 13%.

Allocation of Effort in Subunits. Using the methods described earlier for assigning survey effort to the subunits,

$$r \approx \sqrt{\frac{1600 \cdot 20}{1000 \cdot 20} \cdot \frac{260}{40}} = \sqrt{\frac{16}{10} \cdot \frac{26}{4}} \approx 3.2249 \approx \frac{\text{length of inner transect}}{\text{length of outer transect}} \approx \frac{20\,\text{km}}{6.2017\,\text{km}},$$

and the 2000-m boundary required 6 km of offshore subunit transect, and 20 km of transect in the inshore subunit.

Equipment

We surveyed from five open boats about 5 to 7.5 m long, with console steering. Observers stood or sat where they had unobstructed views, with eye level at about 1.5 to 2.5 m above the water's surface. Cassette tapes were used to record observations and data were later transcribed to forms for computer data entry. Voice-activated radio headsets were used to communicate with the driver and between observers to avoid missing or double-counting birds near the line. Global positioning system (GPS) units and computer generated-maps were used for navigation. The GPS was also used to record the boat's position at 30-second intervals, and the trackline was transferred to the computer at the laboratory. A depth and fish finder was also used to assist with navigation and safety. Visibility and sea conditions, depth, and temperature were recorded at the beginning and end of each 5- or 6-km segment.

Training

Over the 12 years we have conducted line-transect seabird surveys, we have developed a training program to help observers learn and maintain the skills needed to record accurate information. New observers spend two to four weeks with an experienced trainer learning techniques for identifying birds, estimating distance, scanning, navigating, and following safe procedures. Returning observers spend one to two weeks working with the trainer to renew their skills. To assure safety of the crews all observers must learn safe boat-handling and maintenance. Our protocol for safety contains instructions and reminders for assessing weather and sea condition assessment, handling boats, properly maintaining boats and safety gear, rescuing techniques, and using emergency procedures. The trainer and observers surveyed simultaneously to help reduce observer variation. Results were compared and surveys repeated until results were similar for both observers. Each observer must successfully complete a series of assessment drills to test her or his survey, boating and safety skills and knowledge.

Accurate estimates of the perpendicular distance from the transect line to birds detected from the boat is key to using line-transect methods to estimate densities. Observers were first trained in distance estimation on land, then on the water. Laser rangefinders were used for training and for calibration and testing of observers' distance estimates before each survey. Distances to stationary buoys, crab-pot markers, or a small float towed behind the boat were estimated by the observer, and the distance then measured with the rangefinder when the boat was perpendicular to the object.

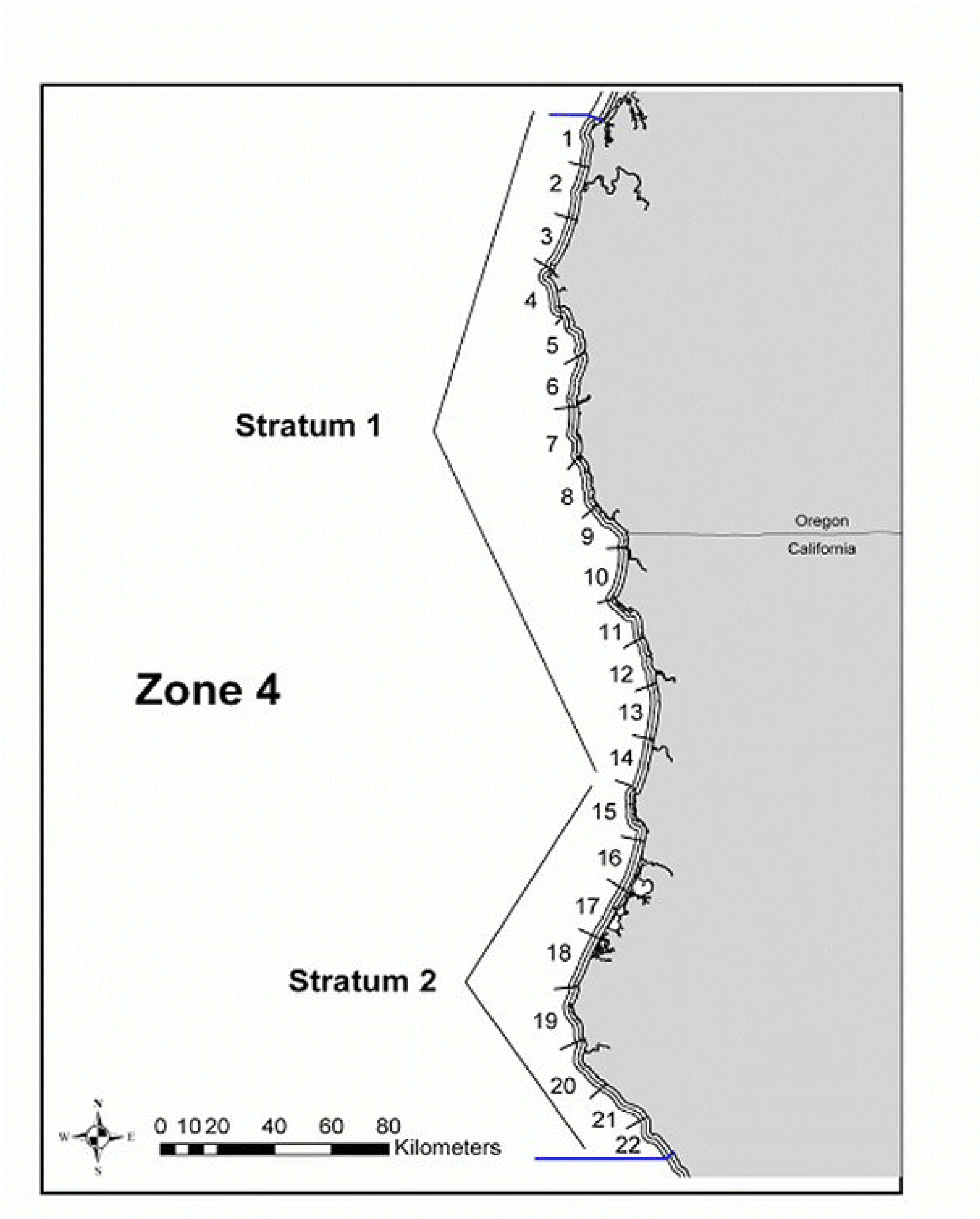

Figure 13. Marbled murrelet conservation Zone 4 with Strata 1 and 2.

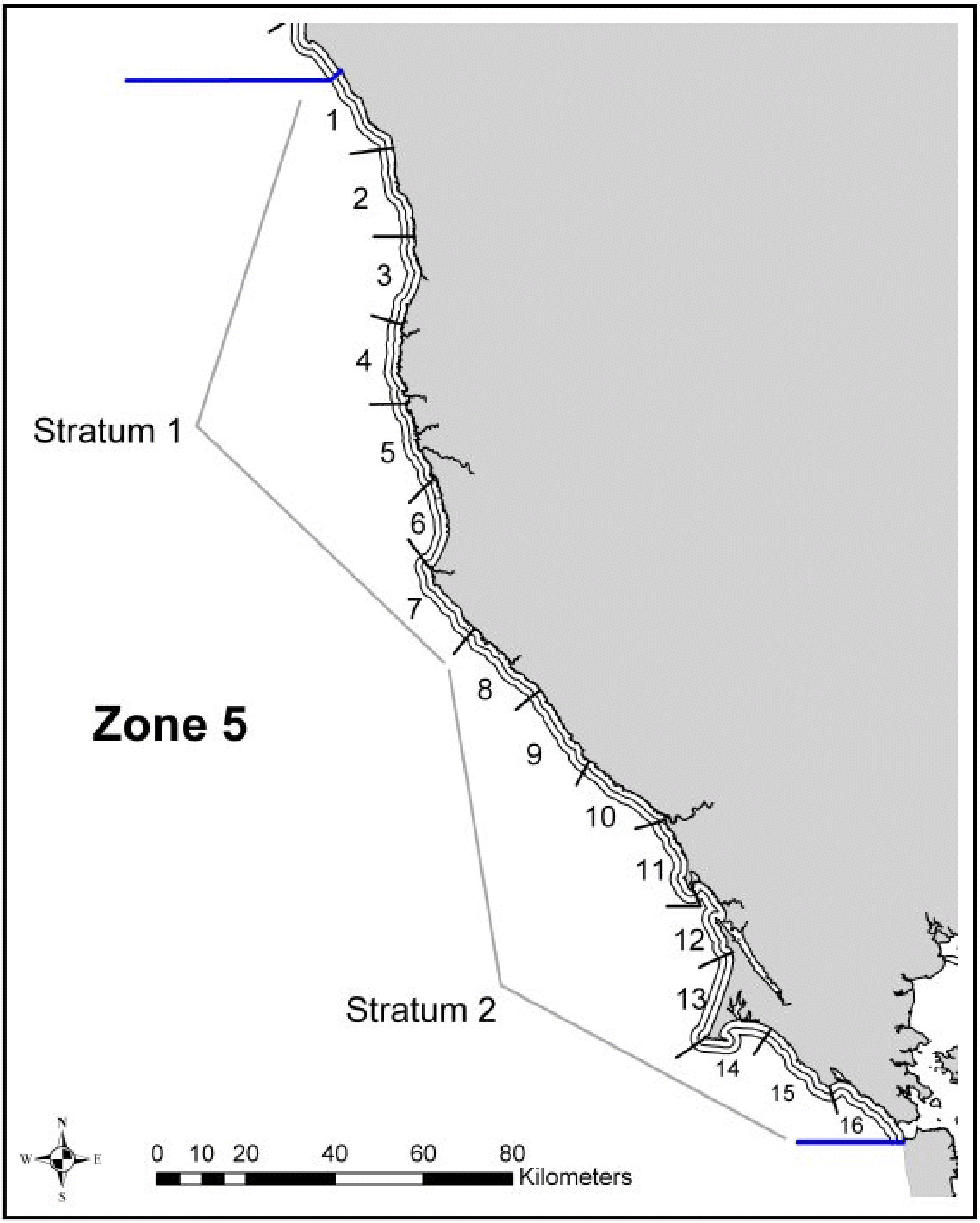

Figure 14. Marbled murrelet conservation Zone 5 with Strata 1 and 2.

Unique Zone Aspects

Some portions of the Sampling Units in Zone 4 and 5 were inaccessible to the boats because of shallow water or rocks. When a randomly selected 5-km segment was determined by a crew to be unsafe to survey, the survey was moved to the nearest safe transect distance. Shallow, sandy beaches in many areas cause the swells to build or the surf to break beyond 400 m from shore. Both of these conditions are unsafe for the boats and crews. In addition, rocks near or just under the water's surface, at any distance, can be unsafe under some wave conditions. The segments at 400 m were the most likely to require an alternative transect. Of 15 randomly selected 400-m transects, 12 were repositioned to an alternative distance. We will continue to monitor for these sites in recognition of any bias they may create in our estimates.

The southernmost Sampling Units (13-16) in Zone 5 were not surveyed. Access to them is difficult and undependable at best. Few murrelets have been observed in this area on all past surveys, with no detections, to our knowledge, in the small and infrequent adjacent forest habitats. These Sampling Units will remain in the pool for possible random selection, however; in some years, they may not be surveyed because crew safety must always be the first priority.

Data Analysis

In Zones 4 and 5, flying birds were included in the analyses. About 10% (146) of the observations were of flying birds.

Zone 4 Description and Justification of Strata and Sampling Regime per Stratum

Zone 4 included 452 km of coastline; the zone was divided into two strata. The north stratum included Sampling Units 1 – 14, from Coos Bay, Oregon, south to Big Lagoon (12). This section of coast was offshore from National Forest, State and National Redwood Park lands, and private timberlands in southern Oregon and northern California. The southern Humboldt stratum of the zone, Sampling Units 15 – 22, from Big Lagoon to Shelter Cove is offshore of state lands, including Grizzly Creek and Humboldt Redwoods State Parks, and the Owl Creek Reserve; federally managed lands, including the recently acquired Headwaters Forest; and private timberlands, most notably, the potential murrelet nesting habitat of the Pacific Lumber Company.

The federal and state purchases of Headwaters Forest and Owl Creek stands from Pacific Lumber Company were acquisitions to preserve three of the largest old-growth stands remaining in private ownership. Associated with the purchases was approval of the Company's Habitat Conservation Plan, which includes additional large stands identified as “Marbled Murrelet Conservation Areas.” The Company is required to monitor the population of murrelets offshore of the Conservation Areas to help assess their effectiveness in contributing toward maintaining the population of murrelets in southern Humboldt County. The southern Humboldt stratum of Zone 4 was established to meet the needs of monitoring the murrelet population nesting in this complex of state, federal, and private lands. Murrelets have been observed traveling up to 100 km from their nest sites to forage, but more commonly travel 20 to 40 km (P. Jodice, pers.

comm., Wildlife Research Cooperative Unit, Oregon State University, Corvallis, Oregon; F. Cooke pers. comm., Simon Fraser University, Burnaby, B.C., Canada). The boundaries we used for the southern Humboldt stratum were about 40 km from the northern and southern extent of the larger stands of potential nesting habitat in the region.

Zone 4 Results

In Zone 4, we completed 57 Sampling Unit surveys between 15 May and 31 July, 23 in the north stratum and 34 in the southern Humboldt stratum (Table 12). We completed 26 Sampling Unit surveys between 1 August and 2 September, when plumage data were collected to estimate juvenile-to-adult ratios, a measure of annual reproductive success. We surveyed 1,797 km of transect in Zone 4, 807 in the north stratum and 990 in the southern Humboldt stratum. We recorded 1,547 murrelet observations of one or more birds. In the north stratum, we recorded 2,259 birds; in the southern Humboldt stratum, 488 birds. We estimated that the density of murrelets in Zone 4 was 4.185 $\pm$ 0.904 birds/km^2 (Table 13). This results in a population estimate of 4,876 birds (95% CI of 4,135 - 8,100) for zone 4. The number of murrelets observed per 20 km by Sampling Unit survey-day varied across the monitoring season (Figure 15).

Table 12. Summary of analysis statistics for marbled murrelet for Conservation Zone 4.

Analysis parameter	Total	Stratum 1	Stratum 2
km surveyed	1,797	807	990
Number of Sampling Units sampled	57	23	34
Number of murrelets	2,747	2,259	488
Area of zone (km^2)	1,165.3	738.6	426.7
Truncation point	5%[a]	-[b]	-
Probability of detection on the line – f(0)	0.01[c]	-	-
Average cluster size - E(S)	1.73[c]	-	-
Encounter rate (number of birds/km)	0.869	1.242	0.226

[a] Equated to a 180-m truncation distance.
[b] Dashes indicate that global estimates were calculated; estimates are not available by stratum.
[c] Taken from Distance program output.
[e] Encounter rate = (no. murrelet groups observed within truncation zone / total transect length) * E(S).

Table 13. Summary of marbled murrelet population statistics for Conservation Zone 4.

Population parameter	Total
Population estimate	4,876
95% confidence interval (population estimate)	4,135 – 8,100
Density (number of birds/km^2)	4.185
Standard error of density estimate	0.904
Coefficient of variation of density estimate	21.6

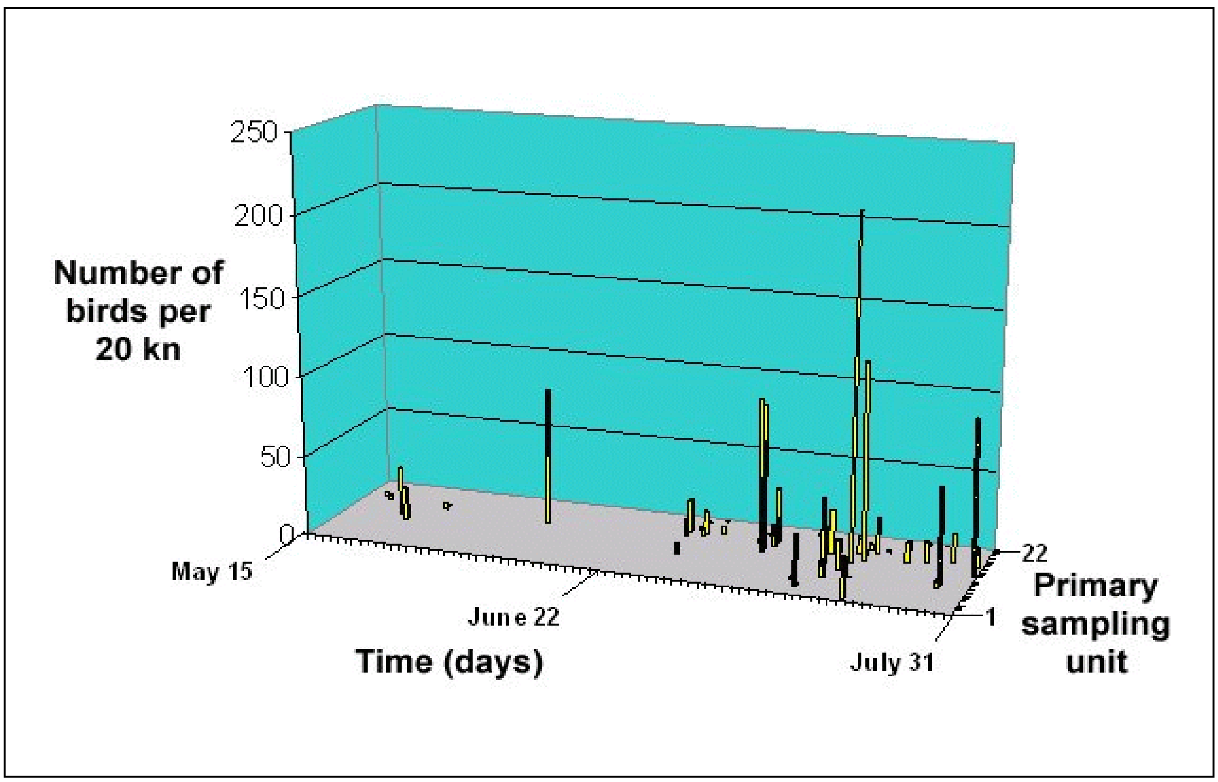

Figure 15. Numbers of marbled murrelets per 20 km in each primary sampling unit in Zone 4.

Zone 5 Description and Justification of Strata and Sampling Regime per Stratum

Zone 5 included 353 km of northern California coastline and was divided into two strata. The north stratum included Sampling Units 1 – 8, from Shelter Cove to Stewart's Point (Figure 14). This section of coast is offshore of the King Range National Conservation Area, several small state-owned redwood and coastal parks, and small, fragmented potential nesting habitat on private lands. A few murrelets have been detected in some of the forest habitat adjacent to the north stratum. One known nesting site is adjacent to Point Arena on timber-company lands. The south stratum of Zone 5, -- Sampling Units 9 – 16, from Stewart's Point to San Francisco Bay -- is adjacent to small, fragmented old-growth forest, that, to our knowledge, has had no murrelet detections. Because evidence that murrelets nest inland from the south stratum is lacking and the rare observations of murrelets at sea here, we elected to reduce the proportion of surveys in this stratum.

Zone 5 Results

In Zone 5, we completed 29 Sampling Unit surveys between 15 May and 31 July, 24 in the north stratum and 5 in the south stratum (Table 14). We surveyed 775 km of transect in Zone 5, about 155 in the south stratum, and 620 in the north stratum. We recorded only 25 murrelets in this zone from observations of 13 individuals or groups of birds. Fifteen birds were near Point Arena and 10 birds were near the King Range National Conservation Area. We estimated that the density of murrelets in Zone 5 was 0.089 ± 0.048 birds/km^2 (Table 15). This results in a population estimate of 78 birds (95% CI of 9 -173) for zone 5. The number of murrelets observed per 20 km by Sampling Unit survey-day varied across the monitoring season (Figure 16).

Acknowledgments. Surveys were conducted by Redwood Sciences Laboratory, US Fish and Wildlife Service, and Crescent Coastal Research. Funds were contributed by the USDA Forest Service, Pacific Southwest Research Station, the US Fish and Wildlife Service, the Pacific Lumber and Simpson Timber Companies, and the California Department of Fish and Game.

Table 14. Summary of analysis statistics for marbled murrelet for Conservation Zone 5.

Analysis parameter	Total	Stratum 1	Stratum 2
km surveyed	775	620	155
Number of Sampling Units sampled	29	24	5
Number of murrelets	25	25	0
Area of zone (km^2)	883.7	441.8	441.9
Truncation point	5%[a]	-[b]	-
Probability of detection on the line – f(0)	0.01[c]	-	-
Average cluster size - E(S)	1.73[c]	-	-
Encounter rate (number of birds/km)[e]	0.019	0.037	0.0

[a] Equated to a 180-m truncation distance.
[b] Dashes indicate that global estimates were calculated; estimates are not available by stratum.
[c] Taken from Distance project output.
[e] Encounter rate = (no. murrelet groups observed within truncation zone / total transect length) * E(S).

Table 15. Summary of marbled murrelet population statistics for Conservation Zone 5.

Population parameter	Total
Population Estimate	78
95% Confidence Interval on population estimate	9 – 173
Density (number of birds/km^2)	0.089
Standard Error of Density Estimate	0.048
Coefficient of Variation	53.6

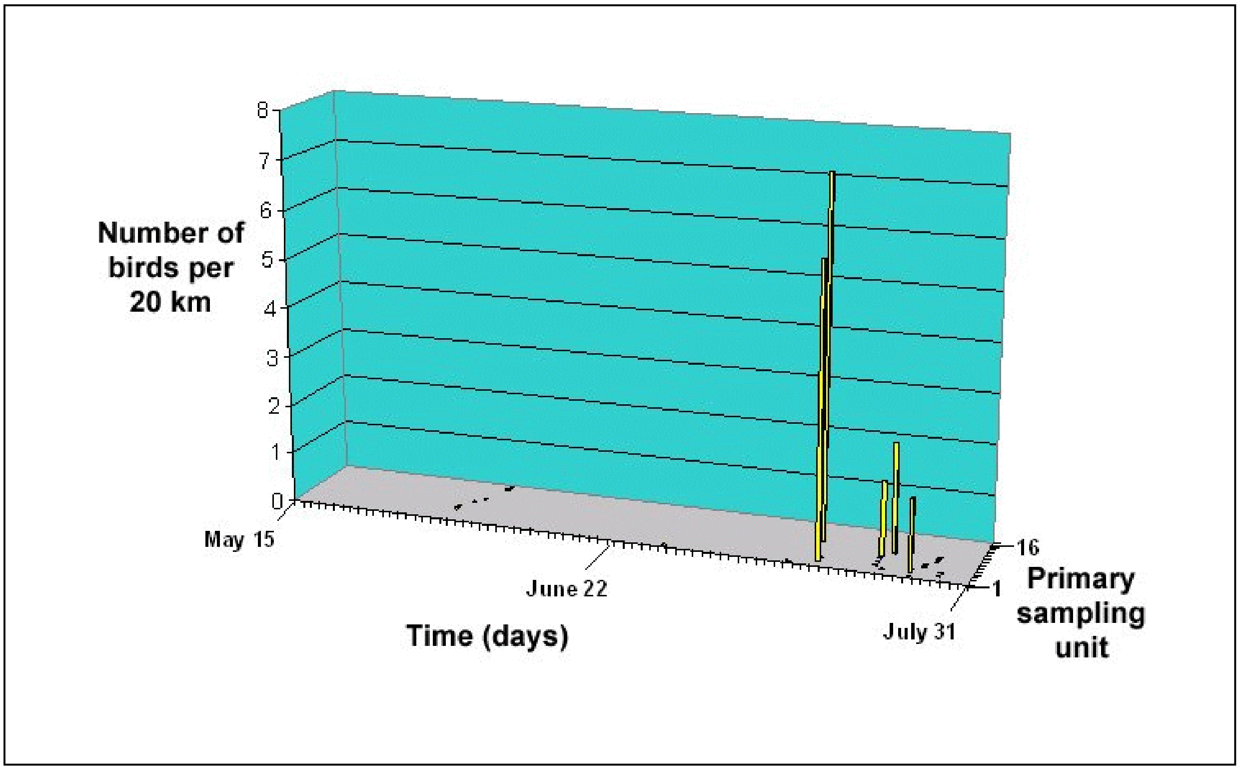

Figure 16. Number of Marbled murrelets per 20 km in each primary sampling unit in Zone 5.

Population Summary for Marbled Murrelets in the Northwest Forest Plan Area

Population Estimates

The year 2000 was the first of a coordinated and comprehensive population estimate throughout this area. These numbers thus represent the first year of marbled murrelet population and density data for the Forest Plan's monitoring program. The total population estimate for the Forest Plan area during the 2000 field season is estimated to be about 18,097 murrelets with a 95% confidence interval of 12,991 to 23,202 (Table 16). Individual zone estimates are also provided.

Table 16. Summary population statistics for conservation zones associated with the Northwest Forest Plan area.

Zone	Density (n/km^2)	Bootstrap estimate of standard error	Bootstrap estimate of coefficient of variation[1]	Population estimate	95% confidence interval
1	1.613	0.389	24.1%	5,635	3,198 - 8,453
2	0.455	0.088	19.4%	769	500 - 1,100
3	4.269	1.236	28.9%	6,738	3,940 - 11,707
4	4.185	0.904	21.6%	4,876	4,135 - 8,100
5	0.089	0.048	54.3%	78	13 - 168
All zones (1-5)	2.054	0.296	14.4%	18,097	12,991 - 23,202

[1] Coefficient of variation = 100 * (SE of density/estimate of density).

Variance Estimates and Power Analyses

Encounter rates of birds on the transect line by far represented the greatest source of variability in the variance estimates, because the distribution of the birds on the water is far from uniform. Because we have only one year of data, we do not know the extent of the year-to-year variance under this design.

We made a preliminary assessment of year-to-year variance by looking at one data set from Washington that was collected over a 5-year period. These data were collected under a different sampling regime and evaluated to assess year-to-year variance only. These data did not demonstrate much year-to-year variance, however, perhaps because few years of data were available or because little year-to-year variance occurs. If year-to-year variation is found to be greater in the long-term monitoring data than what we saw in the Washington data, our actual power to detect trends will be less than the estimates given below and trends will take longer to detect.

If we have little year-to-year variability in future years, we will have the power to detect annual exponential declines of -5% in 9 years or -10% in 6 years, if we look at the entire population associated with the Forest Plan (Tables 4 and 5). If we have high year-to-year variability, detecting trends will take longer. Our ability to detect trends of the same magnitude in individual zones ranges from 7 to 20 years.

We considered $\alpha = 0.10$ with a power of 0.90 appropriate to this study; it means we accept the risk one out of ten times of erroneously detecting a negative trend. Or put another way, we think we will be correct nine out of ten times if we assert the population is declining. Accepting this level of risk of incorrectly asserting a negative trend exists (Type 1 error) reduces the number of years to detect a trend. Alternatively, we could be more stringent about being correct in detecting a negative trend, and the species could be in a serious state of decline before we realize it (Type II error). Tables 4 and 5 illustrates this concept of the different amounts of time needed to detect different exponential trends (-10% or -5% annual declines) with different levels of power (0.95 or 0.90).

Another way to reduce the time to detect a trend is to substantially increase the sample size. Doubling the number of samples reduces the coefficients of variation for sample estimates by about 30%, while increasing the sample size four fold reduces CVs by about half. Therefore, there is a diminishing rate of return on increasing precision with increasing sample size.

Allocation of Effort

As part of the monitoring design, greater sampling effort was allotted to areas of higher densities of birds in an effort to reduce variability in the population estimates. Along shore, large geographic strata were identified where more Sampling Units were selected in higher density areas. Within Sampling Units, densities tend to be higher closer to shore and to taper off with distance from shore (although these distributions shift in different years, possibly associated with different prey abundance). Therefore, more transect length per unit area in the Sampling Units was sampled in the generally smaller inshore subunits than in the larger offshore subunit. These design decisions were made before implementing the pilot project in the 2000 field season, based on previous data collected under different sampling designs. Table 17 shows this general trend held true in the 2000 field season data. (Also keep in mind that Sampling Unit sizes and inshore/offshore subunit areas are different in different zones.)

Table 17. Mean density estimates in the inshore and offshore subunits of each zone.

Zone	Inshore density	Offshore density	Zone density
1	2.05	1.08	1.61
2	0.80	0.37	0.46
3	12.62	1.32	4.27
4	5.68	1.69	4.18
5	0.10	0.06	0.09
All	3.39	0.92	2.05

Future Steps

The 2001 field season will proceed with few changes in the sampling design or methods. In a few instances, the amount of transect allocated to the inshore or offshore subunit may change. In Zone 1, we will use a zig-zag layout of transects in the offshore subunits of strata 2 and 3, rather than the parallel layout used in this year's sampling. In the future, the team will continue to address certain issues, such as birds moving on the water before they are detected. A standardized training booklet will be produced and used to train observers and boat operators. Also, a centralized data base will be formalized.

This effort represents an important step for the murrelet monitoring program, but more effort is needed. Ultimately, the hope is create a tie to the species' inland use of the Forest Plan land base where management decisions affect inland nesting habitat. Radar may be a possible tool to help gain an understanding of the general distribution of murrelets on the landscape (Raphael et al., 2002).

Nesting Habitat Monitoring

Overview

The Marbled Murrelet Effectiveness Monitoring Plan (Madsen et al. 1999) for the Northwest Forest Plan includes determining the amount and distribution of nesting habitat on federal lands currently, and over time. The general strategy for monitoring the Forest Plan (Mulder et al. 1999) is to develop habitat maps using vegetation classifications derived from satellite images as a cost-effective tool. These maps will be updated periodically to assess changes in habitat that may reflect the effects of federal land-management policies in mature and old-growth forests.

This document represents the nesting habitat team's approach to this goal, an approach still in progress. In general, the team -- biologists, statisticians, and computer specialists -- has agreed to develop four statistical models. Two of these models will result in maps, and two will result in more mathematically accurate estimates of the amount of habitat and be applicable on a more site-specific scale. Table 18 (due its large size, Table 18 appears out of sequence and at the end of this section) provides an overview and comparison of the different models.

We expect our map models will not be highly accurate because the source vegetation maps derived from satellite images are not highly accurate. We expect higher accuracy associated with estimates of the amount of habitat derived from non-map models. We hope to attain this higher accuracy by associating variables at murrelet occupancy sites with variables from ground-based vegetation plots currently maintained in a random grid pattern across both public and private lands. Ultimately, we would like to connect the non-map model to the satellite vegetation map models, if possible.

Our objectives are to:

- Develop and test for accuracy four models of murrelet forest-nesting habitat on federal lands in the Northwest Forest Plan Area in Washington, Oregon, and northern California.
- Use two of the models and satellite-derived vegetation classifications to map potential nesting habitat in the three states, with a selected probability of murrelet occupancy.
- Use two of the models to develop more accurate estimates of the amount of habitat and to assess habitat at a more site-specific scale.
- Conduct bird surveys to validate models.
- Integrate the non-map and map models.
- Repeat the process periodically when new vegetation classifications are developed to gain a relative comparison of habitat changes over time.

Methods – Map Models

Murrelet Forest Surveys

Because we wish to determine habitat associations for nesting murrelets, the response variable for analyses will be occupancy, or observations of occupied behaviors thought to be indicative of nearby nest locations (Singer et al. 1995). We are therefore using station surveys that meet the criteria of the Pacific Seabird Group's Marbled Murrelet Forest Survey Protocol (Ralph et al. 1994, and subsequent revisions). This protocol was specifically intended for use in suitable murrelet habitat in advance of activities that might alter habitat at a particular site (patch or stand of forest of up to 120 acres). According to the protocol, to determine if a site is occupied by murrelets, the site should be surveyed four times during a portion of the breeding season, mid-April through early August, for two consecutive years. We will therefore include data from sites beginning with the year 1994 and later (1995, 1996, and so on) as long as it meets the requirements of having eight station visits during two years with a minimum of three visits in one year.

A site is considered “occupied,” if occupancy is found in any of the survey stations at the site. If murrelets were not detected, the station's status was determined to be unoccupied or an “absence” site. For our monitoring purposes, presence detections will not be used because of the concern about whether they can be associated with a particular site on the landscape. Station locations will be digitized into a GIS coverage and assigned the appropriate status.

To date, the nesting habitat team has invested substantial time in preparing existing bird data sets to use in these analyses. These data were gathered for another purpose, however, and need to be examined carefully before they can be used in modeling.

The Washington Department of Fish and Wildlife maintains a centralized murrelet data base. The data was previously stored so that grouping the bird detections representing a site surveyed for two years according to the Pacific Seabird Group's protocol took considerable time.

The Oregon Department of Fish and Wildlife ceased maintaining a centralized data base as of 1994. Therefore, team members searched extensively for both electronic and paper survey data sets, which almost always meant going back to original land managers and requiring careful review to determine which sites were surveyed according to protocol.

In California, other complications to the bird data sets exist because large landscapes, rather than individual sites, were often surveyed. Many large, contiguous areas were surveyed in a grid pattern, so it is challenging to break down the areas into comparable sites -- that is, sites that still maintain sufficient bird-survey effort to determine the dependent variables: occupancy or absence.

Vegetation Data Bases

Vegetation classifications for Washington and Oregon are being produced by the Northwest Forest Plan monitoring effort. The Interagency Vegetation Mapping Project is producing one physiographic province map at a time (Figure 17). The time lines for completing areas in the range of murrelets are as follows:

Oregon Coast Range – completed end of July 2000;
Western Oregon Cascades – review copy available as of March 15;
Olympic – review copy available as of March 15;
Western Washington Cascades – due September 2001;
Western Washington Lowlands – due June 2001; and
Klamath Mountains – due February 2002.

Maps for California have been produced by the US Forest Service, Region 5 remote-sensing laboratory by using wildlife habitat relationships. The team has concerns about accuracy associated with the satellite maps of the three states.

Spatial and Temporal Scale

The vegetation GIS coverages and the murrelet survey coverages will be combined. We will use computer GIS capabilities to center circular analyses plots on occupied sites by using the geometric mean of survey-station locations (even if only one station location is known). Where station locations are missing but polygon information exists, we will use polygons.

Although a single station covers an area of about 12.5 ha, and a site is usually an area of about 50 ha, the surrounding landscape is also likely to affect murrelet behavior at the stations. The team therefore selected two circle sizes, one with a radius of 300 m and one with an 800 m radius, as representing a stand (300 m radius = 27 ha), and a stand with some of the surrounding landscape (800 m radius = 192 ha). This choice doesn't preclude analyzing other circle sizes in the future, however.

Murrelet survey data used for the modeling must correspond to the period when the satellite images were recorded, or be in sites that have not been altered in the selected spatial scale.

Developing a Logistic Regression Model

The first steps in developing the model include identifying the dependent and independent variables. The dependent variables are occupancy or absence. For the independent variables, we will make a complete list of candidate variables (see Table 18). Knowing whether variables are continuous or categorical is important. For categorical variables, we will identify the number of levels. The team will begin to reduce the list of independent variables, based on our current knowledge of the biology of murrelets. We will agree on a process for this reduction and the number of candidate variables we should retain.

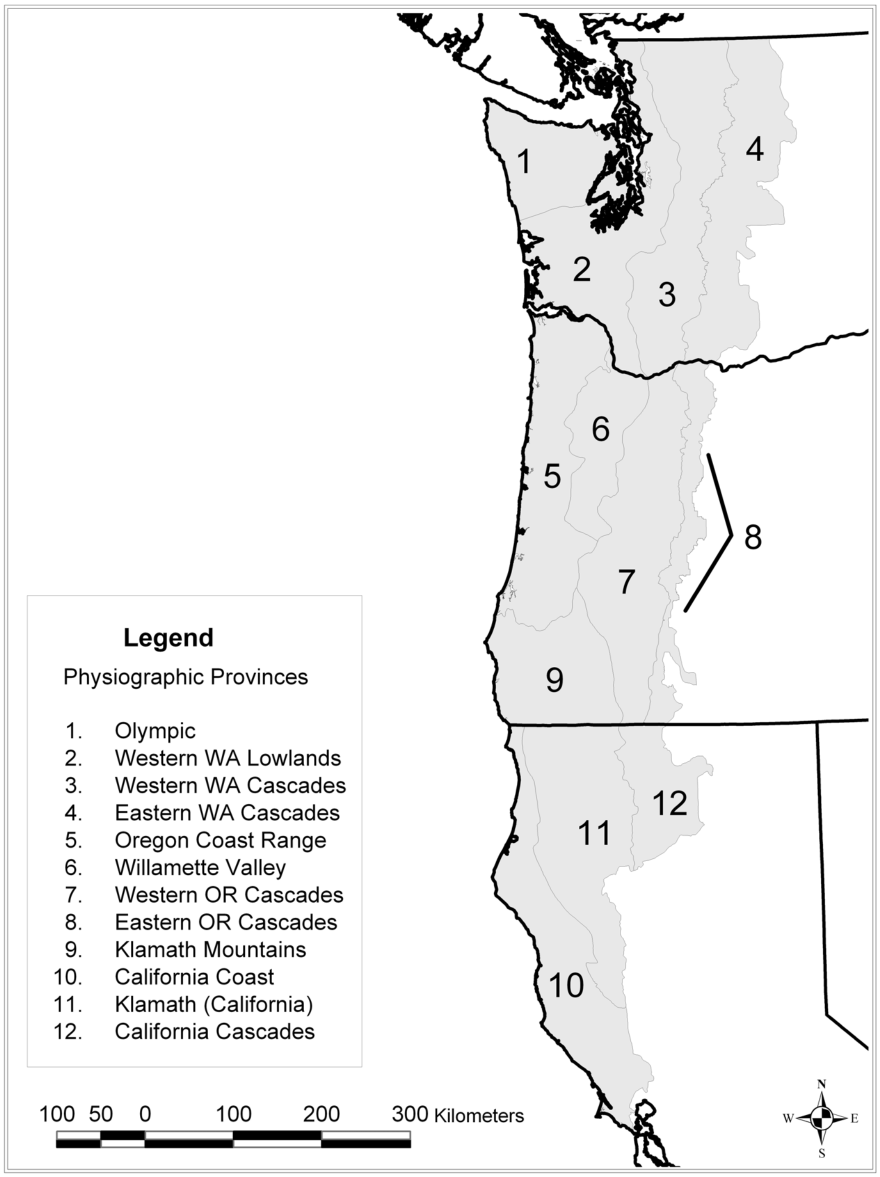

Figure 17. The Northwest Forest Plan physiographic provinces.

Next, we will determine the candidate models. The team will agree on the maximum number of variables we will consider fitting to the available data. Further, we will agree about how to deal with interaction terms, on the first order only and on all possible first-order interactions. We will determine if interaction terms depend on whether variables are continuous or categorical. By doing this, we will identify a set of candidate models. Using a model that includes all possible combinations of the independent variables up to the maximum number of variables the team specified may be most appropriate. Or we may chose a more limited subset of models. We will agree whether any variables should be guaranteed inclusion in the model.

The team will decide on what statistics or other diagnostics to use that will best help us fit candidate models and compare fits. The group has agreed to use Akaike's Information Criterion (AIC), a tool used for model selection. This criterion will help us select the final model or models. We will agree how to make this final selection. Finally, we will assess model quality by using cross-validation techniques to get improved estimates of prediction error.

Habitat Mapping

Once models are selected, the team will apply the vegetation data base and map potential habitat. To validate the models, we have several choices. We can reserve a portion of sites from the modeling exercise for validation. Or we can use all sites for modeling and do a cross-validation method, which removes one site at a time and runs the model repeatedly to determine how well it works. Finally, depending on how well the model works according to one of those methods, we may need to conduct murrelet forest surveys to validate the models.

Methods – Non-map Models

Murrelet Forest Surveys

See text on map models.

Vegetation Plots

During the 2001 field season, the team will collect vegetation data at occupancy, absence, and random sites to develop non-map models. Random sites will be chosen from state and federal lands supporting old-growth, mature or younger stands with a residual or old-tree component (that is, areas that would need to be surveyed in advance of activities that might alter habitat). Plot data are also available from a variety of murrelet studies and may be useful to this effort.

The team has identified the variables below (also see Table 19). On a large plot, we will gather data on larger trees ≥50 cm (20 inches). On a small plot, we will gather data on smaller trees 25-50 cm (10-20 inches). The number of vegetation plots per site will be constant.

Table 19. Examples of vegetation plot variables collected during ground surveys of habitat.

Tree scale	Site scale
Platform density – For trees ≥50 cm, number of trees with platforms (any structure ≥10 cm in diameter and ≥10 m above the ground). For trees ≥50 cm, number of trees with >1 platform. We will also record platforms 15 cm in diameter and whether 10 - 15 m or >15 m above the ground	Slope – obtain from GIS
Mean platform diameter	Aspect – obtain from GIS
Tree species	Elevation – obtain from GIS
Diameter at breast height	Distance to ocean – obtain from GIS
Crown diameter	Distance to nearest stream – obtain from GIS and aerial photographs
Moss, %	Distance to openings (natural and manmade) – obtain from GIS and aerial photographs
Lichens, %	Canopy cover – field technicians taught in a standard method to obtain gross ocular estimate per canopy layer
Mistletoe, %	Number of canopy layers – keep to two categories

In addition, the Forest Service and Bureau of Land Management gather vegetation data at plots on a large-scale, systematic basis across both federal and nonfederal lands. Generally, the current vegetation surveys are on federal lands and the forest inventory analysis plots are on nonfederal lands. Both groups have begun to collect data on two murrelet habitat variables in the species' range, percentage of moss and platform abundance. These data sources should provide good estimates of the amount of nesting habitat because they are derived from systematic random samples in a grid pattern across the landscape.

Spatial Scale

Field crews will gather vegetation from occupancy, absence, and random sites at two plot sizes. The non-map model will be derived from studies and plots of different scales, for example a forest inventory analysis plot is <1, a murrelet station covers about 12.5 ha, and an occupancy site can be 50 ha. The independent variables will be put on a per-unit basis, however.

Developing a Logistic Regression Model

See text on map models. We will develop one model for the combined area of Washington, Oregon, and California. Modeling will be iterative among the team members and guided by the two team statisticians, Tim Max and Jim Baldwin.

Habitat Models

These models will also need validation. If additional bird survey and vegetation plot data are needed, they will be obtained as much as possible in conjunction with the data gathered for the validation of the map models.

Summary

Satellite vegetation maps have few variables, and accuracy assessments are not very high, but they still may be the most cost-effective tool for gaining a relative assessment of the distribution of murrelet nesting habitat on a large, landscape scale. Ground -based vegetation plots at occupancy or absence sites may help us ascertain the amounts of habitat with greater accuracy. Ultimately, we will try to link these efforts.

Table 18. Overview of nesting habitat models.

	Map model		Non-map model	
Definition	Use vs. availability	Use vs. non-use	Use vs. availability	Use vs. non-use
Dependent variables	Occupied analyzed separate from known nest sites OR Model built with occupancy and reserve nest sites for a partial validation	Occupied vs. absence (only those done to protocol)	Occupied analyzed separate from known nest sites OR Model built with occupancy and reserve nest sites for a partial validation	Occupied vs. absence Nest vs. non-nest
Basic model form	Logistic regression for occupancy and nest sites			
Clear expectations of what is possible for models	Produce a "probability of occupancy" map with a clear understanding of precision and level of confidence (e.g., an area has a low, medium, or high probability of occupancy with a 90% confidence interval ± 5%) *Deferred some of this discussion		Predict the best "probability of occupancy" by a site (knowing something about a particular site) Examine other models for the biological meaning of variables and attempt to find surrogate measurements that are cheaper or more readily available	Predict the best "probability of occupancy" by site (knowing something about a particular site)

Definition	Use vs. availability	Use vs. non-use	Use vs. availability	Use vs. non-use
Potential uses of the model	Graphic depiction of habitat distribution, abundance, and degree of fragmentation with known precision at any given point on the map Compare relative changes in habitat configuration over time		Estimate habitat quantities Tracking changes in habitat amounts over time Determine likelihood of murrelet occupancy (maybe a useful tool for watershed-scale planning) May obviate the need for surveys at a site (Model evaluation will reflect on its appropriateness for these uses)	Estimate habitat quantities.
Independent variables	Quadratic mean diameter for the dominants and co-dominants Cover, % (conifer canopy) Topographic variables such as slope, aspect, elevation, distance to ocean, distance to fresh water Site size (as determined by number of stations assumed to be 30 acres, unless the actual is known)		Tree scale: platform density mean platform diameter tree species dbh crown diameter? % moss % lichens? % mistletoe Site scale: slope	

Definition	Use vs. availability	Use vs. non-use	Use vs. availability	Use vs. non-use
	*Deferred discussion on distance to nearest similar habitat (how do you characterize "similar," and how do you decide the nearest distance"…) * Deferred Fragstat statistics: patch size, spatial patterns, distance to nearest similar habitat, etc.		aspect elevation distance to ocean distance to nearest stream distance to openings (natural and manmade) canopy cover number of canopy layers	
Issues of scale	Circles with radii of 300 m and 800 m centered at the geometric mean of the stations		Two plot sizes, 25 m and 13 m radii, independent variables on a per-unit basis.	
Combining scale and independent variables	About 800 pixels per site Quadratic mean diameter for the dominants and co-dominants: (e.g., mean % of pixels ≥ some undetermined value [50 or 70 cm], or cluster sizes of 1, 5, or 10 pixels with ≥ 50 [or 70 cm]) Cover % (conifer canopy), (for example, mean % of pixels ≥ some undetermined value [10%, 50%, or 80%]) Topographic variables such as slope, aspect, elevation, distance to ocean, distance to fresh water (e.g., mean % of pixels with slope ≤ some undetermined value [5% or 10%]) * Deferred Fragstat statistics: patch size, spatial patterns, distance to nearest similar habitat, etc.		N/A	

Definition	Use vs. availability	Use vs. non-use	Use vs. availability	Use vs. non-use
Reference population	Temporal: Using 1994 to the present (as long as it met our required two-year survey, eight visits, three visits in one year) Also date of stand exam data Spatial: Split WA & OR from CA because of the different approaches used in FS R5 and FS R6 to develop vegetation classification systems from satellite images		Temporal: Using 1994 to the present (as long as it met our required two-year survey, eight visits, three visits in one year) Also date of stand exam data Spatial: One area throughout WA, OR and CA	
Variable selection	All possible subsets using Akaike's Information Criterion (AIC) with a screening process built in			
Model evaluation	A statistical, mathematical evaluation, without ground data (no new information). First answer: What is the model supposed to do? How well does it need to perform that function?			
Further model development	Will likely need to go back and fill information gaps; could also happen during the model development			
Model validation	Obtain more data or save some portion of the data set (nest sites) to help validate. May need to get both habitat and bird-use. Surveys may be the best method because it gives info about the bird use (occupancy). Problem is that some sites may not show birds because of biological reasons. Need to have a large enough sample size to capture the important combinations of the independent variables		Additional data will very likely be necessary.	

Acknowledgments
We thank several people and agencies for contributing to murrelet monitoring. Steve Beissinger participated as a member of the population monitoring team and provided comments on the chosen sampling design. Jeff Laake developed the "PSU Variance" program to help analyze population data under our sampling design and provided many helpful comments to the population team. Beth Galleher (PNW) and Bill Hogoboom (PSW) provided GIS assistance. Population monitoring is funded by USDA Forest Service, Pacific Northwest and Pacific Southwest Research Stations, US Fish and Wildlife Service, Washington Department of Natural Resources, Washington Department of Fish and Wildlife, Oregon Department of Fish and Wildlife, and the Marbled Murrelet Trust Fund. Nesting habitat monitoring is funded by the Bureau of Land Management, USDA Forest Service Pacific, Northwest and Pacific Southwest Research Stations, and the US Fish and Wildlife Service.

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Appendix 1

Geographical information systems methods

The population team relied heavily upon geographic information system (GIS) technology to develop and implement the population sampling design. GIS software played an important role in defining and creating both primary sample units (PSU) and at-sea survey transects. The spatial functionality of the GIS allowed for a consistent computer-based orientation and navigational tool to define survey transect routes. We used GIS to produce a series of field maps which illustrated the transect route, PSU boundary, physical land features, and navigational way-point coordinates. These coordinates were then inputted into global positioning system (GPS) devises and used by the survey teams.

The basic GIS functions performed for the pilot-year project were

- Sampling Unit delineation;
- Sampling Unit-subunit breakdown (inshore versus offshore, segments, and bins);
- Parallel transect survey routes;
- Zig-zag transect survey routes;
- Calculation of navigation waypoint coordinates (latitude and longitude);
- Sampling Unit area calculation; and
- Various field maps: field-survey transect-layout maps, zone maps, and other visual aids.

The north and south boundaries of each conservation zone are identified in the Marbled Murrelet Recovery Plan (U.S. Fish and Wildlife Service 1997). In each conservation zone, the population team members collectively agreed on the Sampling Unit parameters. GIS provided the mechanism to spatially define individual Sampling Unit boundaries. We used three 1:24,000 USGS base GIS data sets: California Coastline, Oregon and Washington Coastline, and Puget Sound/Hood Canal/San Juan Island Coastline of Northwestern Washington.

Primary GIS Personnel

GIS specialist	Beth Galleher	Bill Hogoboom	Ken Ostrom
Agency	USDA, PNW Forest Service	USDA, PSW Forest Service	USDI, Fish & Wildlife Service
Location	Olympia, WA	Arcata, CA	Portland, OR
Zones	Zone 1, Strata 2 and 3	All of Zones 4 & 5	Zone 1, Strata 1; All of Zones 2 & 3

All offices used Environmental Systems Research Institute, Inc GIS software. The US Forest Service offices provided ARC/INFO Version 7.2.1 (©1982-1998) and ArcView 3.2. The US Fish and Wildlife Service use ArcInfo 8.12 (©1998-2001) and ArcView 3.2. Peripheral programs included MS Access 2000 and MS Excel 2000 assisted with maintaining and organizing waypoints files.

Conceptual Delineation of Sampling Units

Ideally, all Sampling Units in each stratum would have the same length measured from a predetermined buffered line 1500 m off the coast, referred to as the "coast buffer." A weed tolerance of 5 m was used to generate a less convoluted coast buffer.

The ideal Sampling Unit length is 20 km, but the actual length was determined by taking the total length of the coast buffer for each zone or stratum and dividing it by 20 km. This number was then rounded to the nearest whole number to determine the number of Sampling Units. The final length was determined by dividing the length of the coast buffer by the number of Sampling Units.

The offshore boundary was defined by buffering the coastline to a specified distance – ranging from 3000 to 8000 m, depending on the zone or stratum.

GIS Methods Used

The Dynamic Segmentation module in Arc/Info was used to designate Sampling Unit break points. The procedure calculated the length of the stratum or zone coast buffer, divided this number by 20 km, and rounded to the nearest whole number to establish the number of Sampling Units. The break points were adjusted to create equal Sampling Unit lengths, and the individual Sampling Unit north and south boundaries were delineated perpendicular to the coast at these points. The inshore and offshore boundaries of the Sampling Units were defined with lines buffered from the coastline at specified distances. The inshore boundary ranged from 100 to 400 m, and the offshore from 3000 to 8000 m, depending on zone. Several Arc Macro Language programs were developed to automate most of the Sampling Unit delineation for all the conservation zones.

The inshore and offshore boundaries of the Sampling Units were defined with lines created by buffering the coastline at specified distances by conservation zone. The following information pertains to all of the conservation zones except for stratums 2 and 3 of conservation zone 1 (Puget Sound area) which is outlined in the following paragraph. The inshore boundary ranged from the approximately the 'breaker zone' which ranges from 300 to 400 m from shore out to centerline. The centerline was defined at different distances off-shore parallel to coast by conservation zone and ranged between 1500 and 2000 m. The offshore boundary began at the centerline and extended out 3000 to 8000 m, depending on zone. Several Arc Macro Language programs were developed to automate most of the Sampling Unit delineation for all the conservation zones.

Sampling Unit Components (Inshore and Offshore Subunits, and Bins).

Inshore and offshore. In each Sampling Unit, several subunit divisions were created using the buffer function in Arc/Info. The first subdivision divided the Sampling Unit along the centerline to defined the inshore and offshore subunits.

Segments. Segments are subdivisions in the inshore subunit of the Sampling Unit. Four segments, about 5 km long and parallel to the coastline, were delineated in each inshore subunit (Figure 2).

Bins. A bin is a cluster of near-shore transects to be randomly selected from. Within each near-shore sub-psu, all of the transects are grouped into 4 bins beginning from the closest transect to shore and extending to the furthest. Each bin contains the same number of transects and the number of transects per bin is calculated by taking the total number of transects and dividing by four. The first bin contains the transect closest to shore (usually 350 or 400 m depending upon zone) and the next two sequentially located transects (if 12 total transects exist across the sub-psu). Each bin is numbered beginning from the nearest to the coastline at increasing distances from shore. For each Sampling Unit survey, one bin is selected for each 5-km segment in the inshore subunit. Once a bin has been randomly selected for a segment, the entire bin is not available for selection in another segment (sampling without replacement).

Tracks. Tracks are 100 m-wide adjacent bands, parallel to the coast. Each bin contains four tracks. One of the four possible tracks within each selected bin is randomly selected and surveyed.

Sampling Unit Configuration of the Inshore Subunit by Zone

The total number of segments varied by zone or stratum. Zone 1, Stratum 3, did not have a centerline, and segments crossed the entire width of the Sampling Units. The results are shown in the following table.

Conservation zone	**Stratum**	**Centerline**	**Closest segment to shore**	**Farthest segment from shore**	**Number of Sampling Units**
1	1	1500 m	350 m	1450 m	12
1	2	500 m	150 m	450 m	4
1	3	-	150 m	1950 m	19
2	1 & 2	1500 m	350 m	1450 m	12
3	1 & 2	1500 m	350 m	1450 m	12
4	1 & 2	2000 m	400 m	1900 m	22
5	1 & 2	2000 m	400 m	1900 m	16

Zig and Zig-zag Survey Transect Routes.

All transects completed a "cross gradient" or "zig" portion of the survey, positioned at an angle to the coastline. Each zig-zag transect segment begins at a random starting point on each survey. The points were placed along the centerline at 100m increments and numbered sequentially, south to north, from 1 to about 200. The total number of possible starting positions depended on the width of the offshore subunit and the total Sampling Unit length.

When a zig exceeded the PSU end boundary before completing an entire cross gradient pass, the remaining portion of the transect was resumed at the opposite end of the PSU at the same distance from shore that had been reached when it was broken. Each strata within conservation zones calculated the offshore subunit survey effort and some zones instigated a zig-zag survey pattern to meet the calculated survey effort length.

Arc Macro Language programs were developed to automate procedures to spatially define offshore zig-zag transects. The table below lists the specifics of these zig-zag transects.

Conservation zone	**Stratum**	**r**	**Offshore transect length**	**Number of cycles or zigs**	**Cycle or zig length**
1	1	1.25	15.709 km	3	5.164 km
2	1	0.82	23.462 km	5	4.692 km
2	2	0.28	75.775 km*	10**	7.576 km
3	1	0.425	47.154 km*	10**	4.715 km
3	2	1.166	17.185 km	4	4.296 km
4	1 & 2	3.224	6 km***	1	6 km
5	1 & 2	3.224	6 km***	1	6 km

* The calculated survey distance was too far to survey in one day.
** The number of cycles was reduced to five, resetting the survey effort to 50% of the calculated transect distance.
***The calculated 6.207 km was rounded to 6 km.

Navigation Waypoint Coordinates (Latitude and Longitude)

After transects were defined by GIS, a series of navigation points and their coordinates were identified. These coordinates, in conventional decimal-degree format (latitude and longitude projection), were saved into several formats and downloaded into handheld GPS receivers as waypoints for navigation. The accuracy of the calculated coordinates was tested by field crews, and was found to be approximately +/- 20m.

Sampling Unit Area Calculation.

Areas were calculated for all Sampling Units and their subunits to determine bird densities. Islands and rocks >1 ha were subtracted from the area calculation. These physical features were sporadic and more frequent along Zones 4 and 5.

Map and Visual Aids Generated for the Project.

Sampling Unit survey transect layouts. The field maps were developed to show the area of survey, Sampling Unit components, the location and number of the waypoints, and a general outline of the transect route. Some maps were supplemented with waypoint coordinate printouts.

Classic area or vicinity maps. A variety of maps have been created at different scales and map extents for planning and information sharing.

Miscellaneous visual aids. Many graphics have been created to insert as visual aids in various documents, technical presentations, and web pages; GIS can convert a map view or map layout into many different electronic formats (such as the maps shown in this document).

Summary

Geographic information systems played an important role in developing and implementing the pilot-year population-sampling design. It allowed for detailed planning before fieldwork began. The GIS specialists working with these projects faced challenges developing consistent procedures across conservation zones, but the technology provided researchers with a practical tool to help test and implement the at-sea transect surveys.

Appendix 2.

Below is the SAS code for fitting the linear change model.

```
* Get data in Excel document;
  proc import out=chris
    datafile="c:\windows\profiles\jbaldwin\desktop\power\mmalldat.xls"
    dbms=excel2000 replace;
    getnames=yes;
    range = "B$";
    run;

* Add in a copy of the year variable so that a class variable and a continuous
  variable representing year can be used in PROC MIXED;
  data chris;
    set chris;
    if year ne .;
    yr = year;

* Sort by zone and stratum;
  proc sort data=chris out=chris;
    by zone stratum;

* Perform the analysis for each zone and stratum combination;
  proc mixed data=chris covtest;
    by zone stratum;
    class yr;
    model mamu_density = year / ddfm=satterth s; * Fit a simple linear model;
    random yr;  * This term represents the year-to-year variability;
    repeated / group=yr; * This term represents the measurement error;
    run;
```

Appendix 3.

Offshore Marbled Murrelet Survey Form
Instructions

Header

Zone	1 digit
Strata	1 digit
Sampling Unit	2 digits
Vessel	first 4 letters of boat name
Observer Height	eye height **(m)** above water where observer is standing
Skipper	initials of boat navigator
Observer 1	3 letters initials of observer
Observer 2	3 letters initials of observer
Date	6 digits date (mo-dy-yr)
Notes	any pertinent info specific to survey. Example inshore obstructions to surveys.

Main Form

Subunit	1 letter, N or O, for Inshore or Offshore
Distance	4 digits **(m)** for parallel transect distance from shore. Example 1250 m
Segment	1 letter A, B, C, or D for segment along shore
Seg length	2 digits for actual length traveled on parallel transect (**km** to nearest 0.1km). Example 5.2 km
Z Start A	3 digit code **(m)** for zigzag starting point along shore. This is a distance beginning from left side of the Sampling Unit (looking out from shore). Example 120 m
Z Start O	4 digit code **(m)** for zigzag starting point offshore. Example 1500 m
Z End A	3 digit code **(m)** for zigzag ending point along shore
Z End O	4 digit code **(m)** for zigzag ending point offshore
Z Length	3 digits for actual length traveled (**km** to nearest 0.1km). Example 15.2 km.
Time	4 digit code, military time. Taken at start of every segment and to show breaks (murrelets opt)
Depth	4 digits bottom depth **(ft)**. Read from depth sonar (fish finder) at beginning of every segment and at murrelets
Clouds	% cloud cover; ocular estimate
Precip	1 letter code for precipitation (N=none, D=drizzle, S=Shower, L=light rain, R=steady rain, F=fog)
Visibility	4 digit or 1 letter horizontal distance of clear visibility **(m)**; 'U' for unlimited
Glare	3 digits for % glare or reflection that is hindering view of the water.
Swell Dir	1 to 3 letter code for direction of swells (N=north, NNW=north northwest, etc.)
Swell Ht	height **(m)** of average swell from crest to trough (to nearest 0.1 m)
Swell Time	average time (sec) between swells (crest to crest or trough to trough)
Wave Dir	1 to 3 letter code for direction of wind waves or wavelets (N=north, NW=northwest, etc.)
Wave Ht	height **(cm)** of average wavelet
Wind Speed	2 digits **(mph)** measured from anemometer
Beaufort Scale	1 digit code for Beaufort Sea conditions
Wind Dir	1 to 3 letter code for wind direction
White Caps	average distance **(m)** between whitecaps on different swells
P,S,B	1 letter code for side of boat of detection (Port, Starboard, Bow)
Species	4 letter species code for observation based on common name. First 2 letters of first word, first 2 letters of last word, or first letters of each word in common name. Example: White-winged Scoter=WWSC. For those identified only to genus, use first 4 letters of common generic name. Example: TERN or LOON
Number	group size of detection

Distance — perpendicular distance **(m)** of bird from transect line (use center of a group of birds)

Behavior — 1-letter code for behavior of murrelets
S=swimming F=flying T=taking flight H=holding fish
D=foraging dive A=avoidance dive V=vocalization

Plumage Class — number of murrelets from total group in each of 7 plumage classes recorded as definite or probable
1= brown bird, very little to no molt, entirely in alternate plumage
2= obvious body and/or flight feather molt but >50% alternate (brown)
3= <50% brown but still distinguishable from juvenile by some brown on back, breast, and neck and/or presence of flight feather molt
4= black and white bird (basic plumage) - known adult
5= black and white bird but confirmed HY
6= unknown black and white bird
7= unknown

Plumage Notes — additional information on plumage - as much detail is needed to support classification

Note: Page numbers of the forms are not variables, but should be entered as follows: 1 of 2, 2 of 2, etc.