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Regional Population Monitoring of the Marbled Murrelet: Field and Analytical Methods

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The marbled murrelet (*Brachyramphus marmoratus*) ranges from Alaska to California and is listed under the Endangered Species Act as a threatened species in Washington, Oregon, and California. Marbled murrelet recovery depends, in large part, on conservation and restoration of breeding habitat on federally managed lands. A major objective of the Northwest Forest Plan (the Plan) is to conserve and restore nesting habitat that will sustain a viable marbled murrelet population. Under the Plan, monitoring is an essential component and is designed to help managers understand the degree to which the Plan is meeting this objective. This report describes methods used to assess the status and trend of marbled murrelet populations under the Plan.

Our monitoring plan is specifically designed to estimate marbled murrelet density, population size, and population trend in each of five geographic areas (conservation zones) between the northern tip of Washington state and San Francisco, California. Within each zone, we defined an offshore boundary denoting the extent of the target population. We then divided the shoreline into 20-km segments (primary sample units, denoted as PSUs) and drew a stratified random sample of about 30 PSUs for each zone. For each PSU survey, observers in small boats followed a prescribed at-sea transect line and recorded perpendicular distances to all murrelets observed from mid-May to the end of July when murrelets detected on the water are most likely locally breeding birds. We use distance sampling methods to compute density and population estimates for the target population each year. This sampling design was implemented during the 2000 field season and sampling has continued each year thereafter. This report describes our sampling design, survey methods and analysis methods. To help illustrate our methods, we present results from the 2005 field season. The total population estimate that year was approximately 20,200 murrelets with a 95 percent confidence interval ranging from 16,000 to 24,500 murrelets. We emphasize that this is the first systematic sampling protocol applied throughout the murrelet's listed range. Because these methods have not been used in the past, our current population estimates are not directly comparable to past estimates from other researchers.

Keywords: *Brachyramphus marmoratus*, distance sampling, line transect, marbled murrelet, Northwest Forest Plan, population monitoring.

Introduction

Marbled murrelets (*Brachyramphus marmoratus*) range from Alaska to California and are federally listed under the U.S. Endangered Species Act as threatened in Washington, Oregon, and California (USFWS 1997). Recovery of the murrelet depends, in large part, on conservation and restoration of breeding habitat on federally managed lands. Conservation of murrelet nesting habitat was one of the major objectives of the Northwest Forest Plan (hereafter the Plan). Under the Plan, the goal was to conserve and restore nesting habitat on federally administered lands that will sustain a viable murrelet population (FEMAT 1993). Monitoring is an essential component of the Plan and is meant to help managers understand the degree to which the Plan is meeting this objective. This report describes the methods used to assess the status and trend of the marbled murrelet in the portion of its range covered by the Plan.

Madsen et al. (1999) developed an approach for marbled murrelet effectiveness monitoring under the Plan that recommended assessing population trends at sea under a unified sampling design and standardized survey methods. Inland, the goal was to establish a baseline estimate of suitable nesting habitat. The trends in population abundance and nesting habitat would be tracked over time. The ultimate goal was to model population trends based on the amount and distribution of nesting habitat. If that modeling effort is successful, then managers might monitor nesting habitat as a surrogate to monitoring murrelet populations over the long term. However, until this relationship is established, population monitoring will be the primary murrelet monitoring tool. This report provides an overview and application of current population monitoring methods.

In 1998, the U.S. Fish and Wildlife Service named a team leader and assembled a team of experts to design and implement a population monitoring protocol. The population team members were Naomi Bentivoglio, Team Lead, U.S. Department of the Interior, Fish and Wildlife Service; Steven R. Beissinger, professor, University of California, Berkeley; Jim Baldwin, statistician, U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Tim Max, statistician, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; Sherri L. Miller, wildlife biologist, U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station; Ken Ostrom, GIS/database specialist, U.S. Department of the Interior, Fish and Wildlife Service; C.J. Ralph, research wildlife biologist, U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station; Martin G. Raphael, research wildlife biologist, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; Craig

Strong, consulting biologist, Crescent Coastal Research; and Chris Thompson, research scientist, Washington Department of Fish and Wildlife.

Because of the murrelet's crepuscular activity and cryptic nature in its nesting habitat high in forest canopies throughout much of its range, there is general consensus that populations are best assessed at sea (Becker and Beissinger 1999, Becker et al. 1997, Madsen et al. 1999, Huff et al. 2006). Members of the population team identified the target population for monitoring as those birds in the nearshore waters (generally within 8 km of shore) from the Canadian border to San Francisco Bay, the area associated with the Plan. The team divided the target population into the marbled murrelet conservation zones identified in the marbled murrelet Recovery Plan (USFWS 1997, fig. 1). The isolated subpopulation found in San Mateo and Santa Cruz Counties (Conservation Zone 6) was not included in monitoring as no federal lands associated with the Plan are found there.

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Methodological tests (e.g., evaluation of distance estimation techniques, efficacy of single versus double observers) were conducted during the 1998 and 1999 field seasons. Those baseline data, as well as data on the offshore distribution of murrelets obtained from earlier surveys, permitted the team to reach consensus on the methods and sampling design for a pilot project in the 2000 field season. Table 1 and the following discussion describe the agreed-upon sampling design and the population monitoring program. This report is an expansion of an earlier publication (Miller et al. 2006) and is intended to provide additional detail to more fully describe our methods and analytical procedures. Miller et al. (2006) provided results of our population surveys for the years 2000 through 2003.

Sampling Design

Spatial Target Population

The marbled murrelet Recovery Plan (USFWS 1997) identified six conservation zones, five within the Plan area. The recovery plan states that when populations within four of six zones have stable or increasing numbers, murrelets may have reached recovery status. For this reason, we designed our sampling frame to permit a separate population trend estimate for each of the five zones. The target population is contained within Conservation Zones 1 through 5 (fig. 1). The northern boundary is the U.S.-Canada border and the southern boundary is approximately San Francisco Bay. Within this area, we targeted the "nearshore" waters, 8 km or less from shore. The inshore boundary was defined by the closest possible navigable distance from the shore outside the surf zone (i.e., away from the surf, rocks, and kelp). The offshore boundary varied within and among

Table 1—Population sampling design overview

Attribute	Stratum	Conservation zone 1	2	3	4	5
Area of inference (m from shore)	1	300–5000	350–5000	350–5000	350–3000	350–3000
	2	100–2000	350-8000	350-5000	350-3000	350-3000
	3	100–2000				
Centerline distance (m from shore)	1	1500	1500	1500	2000	2000
	2	500	1500	1500	2000	2000
	3	NA[d]				
Total PSUs[a] available	1	9	8	7	14	8
	2	42	6	10	8	8
	3	47				
Total		98	14	17	22	16
Number of unique PSUs sampled[b]	1	5	8	7	14	7
	2	20	5	10	7	5
	3	5				
Total		30	13	17	21	12
Total PSUs sampled[b c]	1	10	21	`12	16	10
	2	40	5	16	15	5
	3	10				
Total		60	26	28	31	15
Total km surveyed[b]	1	105	299	438	602	653
	2	1398	354	564	891	139
	3	197				
Total		1700	653	1002	1493	792
Total area of zone (km^2)[b]	1	840	724	661	739	442
	2	1196	926	935	427	442
	3	1459				
Total		3494	1650	1596	1165	885

[a] PSU = primary sample 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.
[b] Sample sizes refer to the 2005 field season; sample sizes in other years vary slightly.
[c] Total number of PSUs sampled, including repeated samples from the same PSU.
[d] In Stratum 3 of Zone 1, we do not distinguish the inshore and offshore subunits and follow a zigzag transect throughout each PSU.

conservation zones and portions of zones. This distance was approximated for each zone or for each stratum (geographic areas with different densities of murrelets—see below) within the zones by using available data on the relative abundance of murrelets in relation to distance from shore. We do not foresee a consistent long-term increase of birds beyond our offshore boundaries. However, if evidence from other studies suggests a change in distribution further offshore, extending the offshore boundary may be necessary.

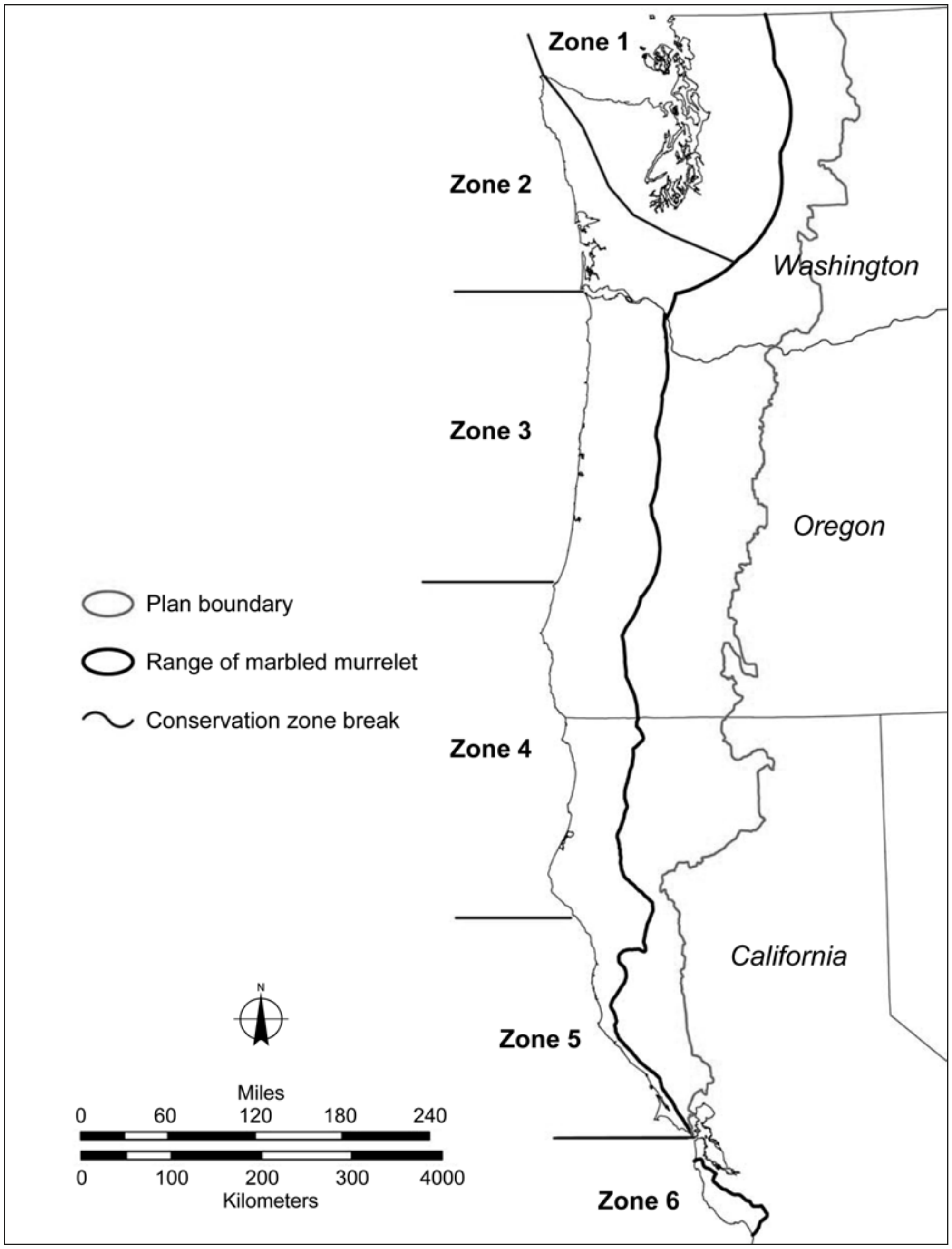

Figure 1—Forest Plan and marbled murrelet recovery plan conservation zones.

Temporal Target Population

Mid-May through mid- or late-July is the time of year when breeding birds at sea are likely to be associated with inland nesting habitat in the Plan area (Nelson 1997). As a result, we established 15 May through 31 July as our population sampling period.

Stratification

Within each zone, researchers identified large geographic areas along the coast, designated as strata. See fig. 2 for an example and Miller et al. (2006) for a more detailed map of each stratum within each zone. In Zone 1, Stratum 1 is the Strait of Juan de Fuca, Stratum 2 is the San Juan Islands and selected portions of Puget Sound, and Stratum 3 is the remainder of Puget Sound. In the other zones, Stratum 1 is the northern portion of the zone and Stratum 2 is the southern portion. Strata were selected to distinguish areas of coast with differing densities of murrelets (based on available data from previous surveys or existing literature). Sampling

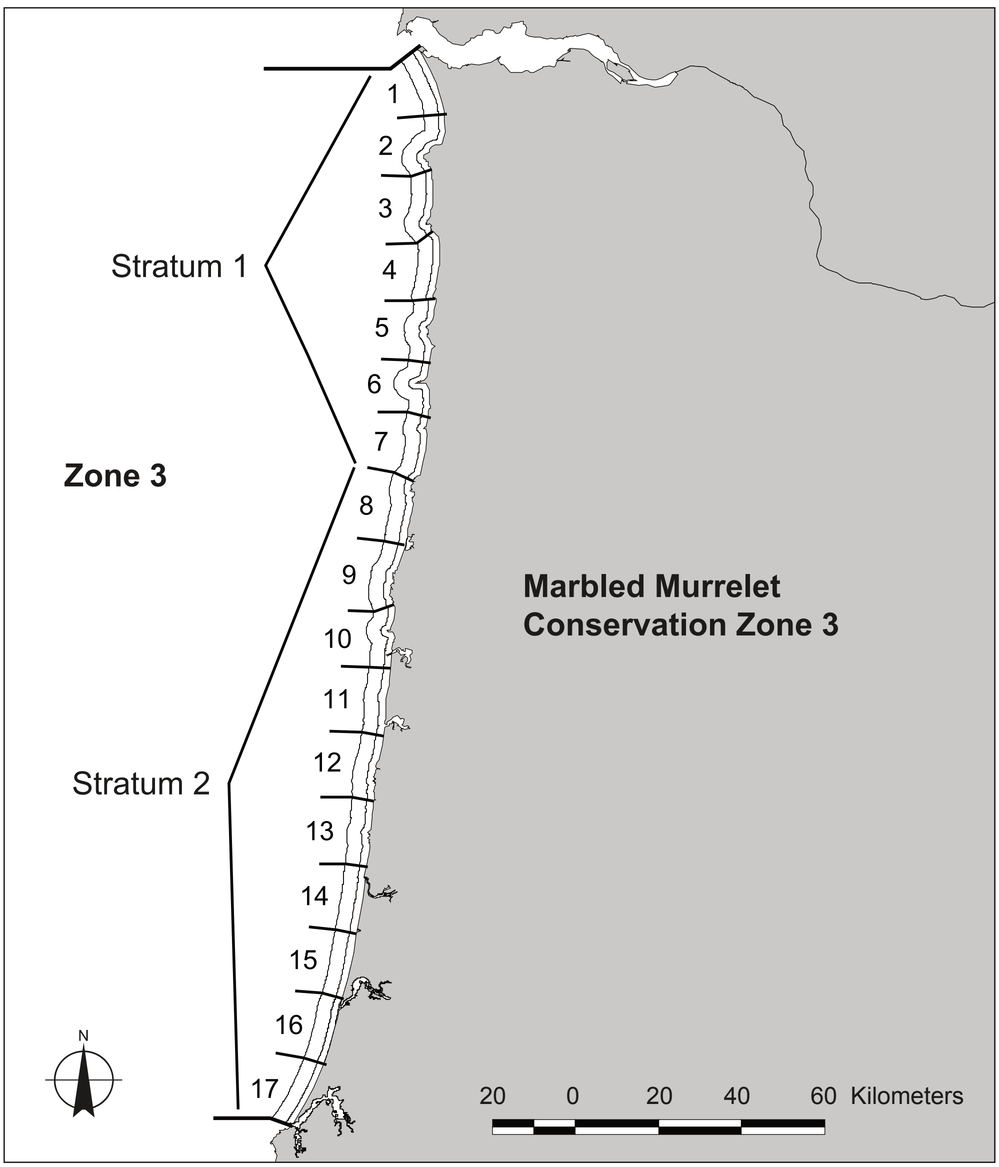

Figure 2—Sample layout of strata and primary sample units, numbered 1–17, for one conservation zone.

occurred within each geographic stratum; however, a separate population estimate was not made for each of these strata. In general, strata with low densities of murrelets received less sampling effort, strata with high densities received greater sampling effort, and all those data within a zone were used to obtain the population estimate for that zone. In this way, greater precision and lower variance in population estimates would be achieved for the strata with higher murrelet density.

With additional sampling, separate density estimates with adequate precision could be obtained for a geographic stratum within a zone. This could help refine information about 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 during the pilot year (2000) with the exception of 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 (Pacific Lumber Company 1999). This funded additional surveys and a separate population estimate in the southern portion of that zone for the years 2000 to 2003 (Miller et al. 2006).

Primary Sample Unit

A primary sample unit (PSU) is a roughly rectangular area along approximately 20 km of coastline.

A primary sample unit (PSU) is a roughly rectangular area along approximately 20 km of coastline. The width of the PSU is the distance between the inshore and offshore boundaries (fig. 3); width varied by zone and stratum. The PSUs meet end to end along shore without any gaps. Each PSU consists of one inshore and one offshore subunit (divided by the "centerline"), and we sampled approximately 30 PSUs per zone, totaling 93 selected from a total of 167 PSUs over all zones (see below).

The inshore boundary, adjacent to the coast, was defined by the physical features of the shoreline that affected navigation. In some PSUs, these physical features are permanent obstructions, such as submerged rocks or islands. In other PSUs, these features are not permanent, such as kelp beds that shrink or expand depending on storm conditions or other environmental factors. Tidal fluctuations and swell height also affect navigation, especially near shore. 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 thoroughly survey the area within about 50 m of the boat. Therefore, the area of inference (from which we calculated densities and population estimates) extends up to 50 m inshore of the transect lines.

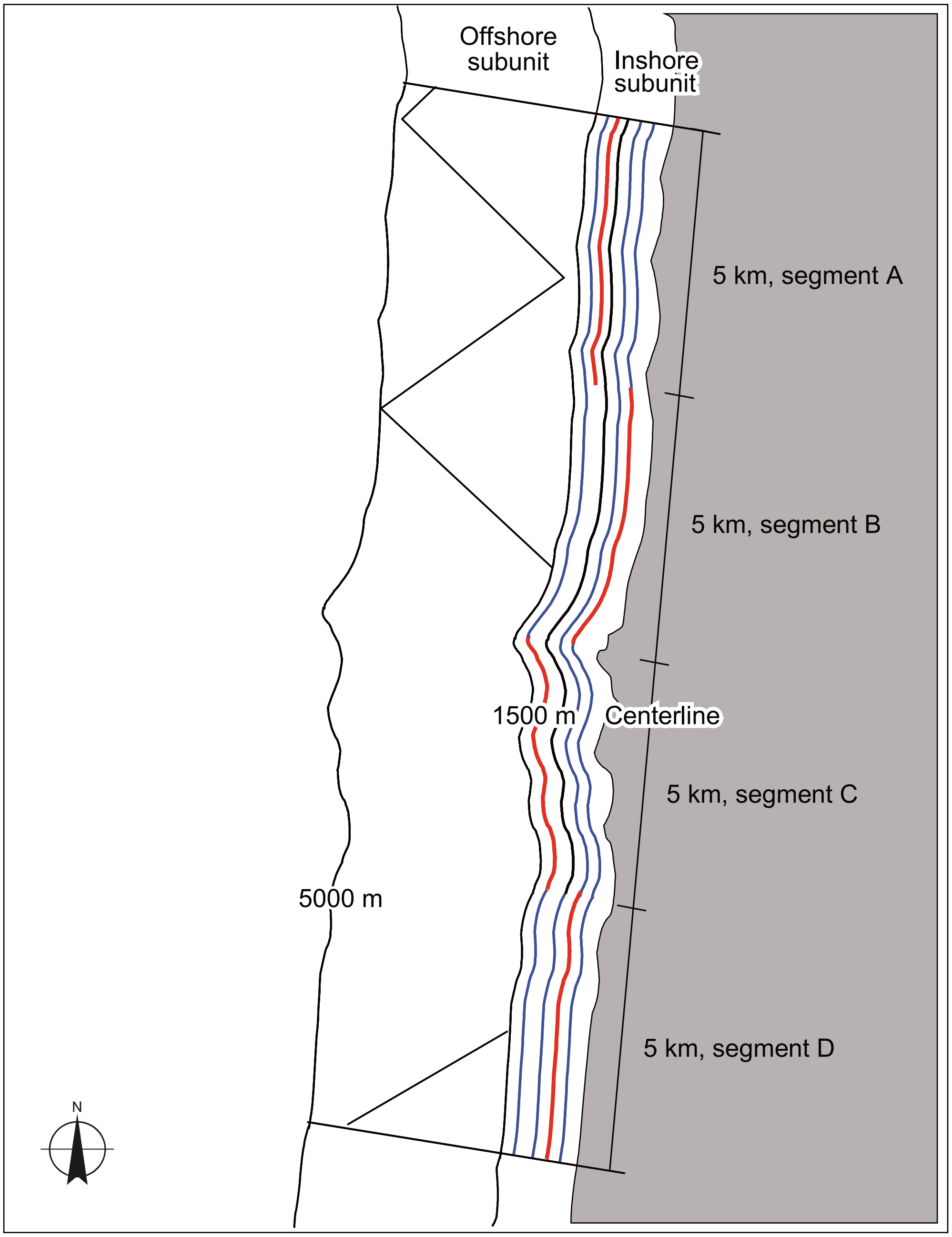

Figure 3—Marbled murrelet primary sample unit with inshore and offshore subunits showing parallel and zigzag transects. The inshore subunit is divided into four equal-length segments (approximately 5 km each) and four equal-width bins (bands parallel to and at increasing distances from the shore). One bin is selected without replacement (depicted in red) for each segment of transect.

Temporal definition of PSU—

We only used PSU surveys completed in 1 day. In many areas, afternoon winds increase in intensity and make it impossible to continue surveys. Partial surveys (where less than 75 percent of the transect length was completed) were not used for analysis. If a crew completed more than one PSU in a day, all survey data were used in analyses.

Sample size per zone—

Each conservation zone had a target sample size of 30 PSU surveys. We based this target on an analysis that demonstrated reasonably low coefficients of variation as total transect length approached 600 km (fig. 4), and 30 PSU surveys resulted in a total shoreline length of about 600 km.

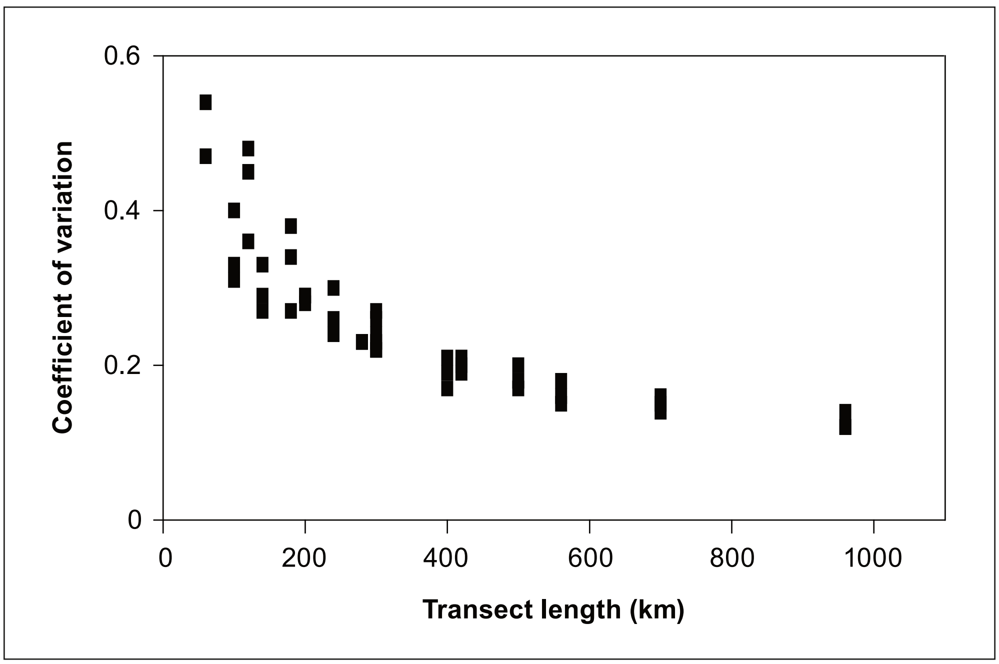

Figure 4—Coefficient of variation in encounter rate of marbled murrelets in relation to transect length.

Method of selecting PSUs—

We segmented the entire coastline into approximately 20-km PSUs (n = 167, table 1). Within each zone, we randomly selected a sample of PSUs. Some PSUs were selected more than once to achieve the desired sample size (about 30). Although the selection of PSUs was initially random, field sampling was subject to logistic constraints, such as location of ports, weather, mechanical difficulties, etc. These logistics sometimes resulted in some temporal and spatial clustering. We conducted a bootstrap analysis, accounting for these clustered observations, to estimate the variance (and 95 percent confidence intervals) of our density estimates (see "Analysis" section for details).

The set of PSUs that we selected during the initial (year 2000) field season was and will continue to be resampled each year. Resampling selected PSUs will reduce variance in our estimate of population trend. Of 167 PSUs available throughout the target area, we sampled 93 PSUs. As mentioned above, this total includes some individual PSUs that might be sampled two or more times (table 1); total numbers of PSUs that we sampled each year from 2000 to 2005, including these repeated samples, varied from 160 to 198 (see table 1 for an example of sample sizes of unique and repeated PSUs from the 2005 field season).

We used parallel transects for the inshore subunit to take advantage of the higher density of murrelets in that area and thus to increase the encounter rate. We used zigzag transects in the offshore subunit to cut across the gradient of declining murrelet density in that subunit while giving all areas of that subunit an equal probability of being included in the sample.

Transect layout within PSUs—
We used georeferenced parallel and zigzag transects to sample PSUs: parallel transects were used in the inshore subunit and zigzag transects were used in the offshore subunit (fig. 3). We used parallel transects for the inshore subunit to take advantage of the higher density of murrelets in that area and thus to increase the encounter rate. We used zigzag transects in the offshore subunit to cut across the gradient of declining murrelet density in that subunit while giving all areas of that subunit an equal probability of being included in the sample. In all cases, we placed transects to avoid overlapping sampling effort close to the centerline between the two subunits. See appendix 1 for a detailed description of methods used to lay out transect lines.

Within the inshore subunit, we divided the length of the PSU (approximately 20 km) into four segments that were approximately 5 km long and parallel to shore. We then divided the width of each subunit into four bins parallel to shore and of equal size. One transect was randomly placed within each bin (without replacement) ensuring that transects were distributed spatially at different distances from shore (fig. 3). Within the bins, we selected the transect segments in increments of 100-m distances from shore (app. 1).

Within the offshore subunit, we delineated a zigzag transect so that it traversed the entire width of the subunit (fig. 3) and a portion of the PSU's length, or in some cases the entire length. Length of the zigzag was calculated to be proportional to the average density of murrelets in the offshore versus inshore subunits. We determined a zigzag transect's starting point from a random point. We approximated the length of the zigzag transect in each zone from a formula based on the total area of inshore and offshore subunits and murrelet densities (from previous data; also see Rachowicz and Beissinger 1999) as follows: Each PSU consists of two subunits labeled inshore and offshore with areas (km^2) a_1 and a_2, respectively. We assumed that the number of birds observed in each collection of subunit transects followed a Poisson distribution with mean densities d_1 and d_2 (in birds per km^2). Therefore, the ratio (r) of inshore to offshore transect length is given by:

$$r = \frac{a_1}{a_2} \times \sqrt{\frac{d_1}{d_2}}$$

This ratio (r) is simply the product of the area ratio and the square root of the density ratio. Given a 20-km transect in the inshore subunit, this equation was solved for the length of the transect within the offshore subunit within each stratum of each zone (see app. 1 for additional details).

Line Transect Sampling

The line transect sampling method was used to estimate murrelet density (number of murrelets per unit area per day), and ultimately, population size. We recorded the perpendicular distance of each murrelet observation (or group of murrelets) from the transect line for use in the software program DISTANCE (Buckland et al. 2001, versions 3.5 and later 4.1), which selects a mathematical function to describe the effect of distance on numbers of groups of birds detected.

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

Another important assumption of the transect method is that the distance of objects from a transect line is accurately estimated. Raphael et al. 1999 (http://www.reo.gov/monitoring/murrelet/pdf/pnw_atsea.pdf) tested this assumption during 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 that overall there was no significant difference in distances when observers estimated (1) a direct perpendicular distance, versus (2) the radial distance from the object to the boat and the angle of the object from the transect line (by using a trigonomic calculation to obtain the distance). Although estimates were found to be negatively biased, the direct estimate of perpendicular distance was more precise.

Raphael and Laake (2000, available from the senior author on request) documented the full set of steps necessary to configure program DISTANCE for analysis of data to compute a detectability function using this design.

Observer Methods

We conducted a number of tests to determine whether to use one or two observers to record murrelet observations (http://www.reo.gov/monitoring/murrelet/pdf/pnw_atsea.pdf, Evans Mack et al. 2002). We obtained more accurate results from two observers than from one observer, especially when bird density was high and in wind conditions that generated wind wavelets. Under these conditions, single observers missed a higher proportion of birds close to the line than two observers. After having evaluated the results from these experiments, we decided to use two observers at all times.

During surveys, each of the two observers surveyed 90° arcs on their side of the boat starting from the bow. Observers scanned continually, but more effort was expended watching for birds close to the line ahead of the boat (within 45° of line) to reduce the risk of missing birds located close to the transect line. Observers estimated the perpendicular distance of each murrelet (or the center of a group of murrelets) from the transect line (see app. 3 for training methods). Binoculars were used for species verification, but not for sighting birds. For most surveys, observers recorded information into tape recorders for subsequent transcription to survey forms. In surveys conducted in Zone 2, observations were relayed by headset to a person in the boat cabin who entered those data directly onto a laptop computer. Appendix 2 describes the data fields and codes we used in these surveys.

Observer Training

New observers spend 2 to 4 weeks with an experienced trainer learning techniques for bird identification, distance estimation and scanning, as well as navigation and boat safety procedures (app. 3). Returning or experienced observers spend 1 to 2 weeks working with the trainer to renew their skills. Simultaneous surveys are conducted by the trainer and observers to help reduce observer variation. Results are compared and surveys repeated until results are similar for the two observers. Each observer must successfully complete a series of assessment drills to test their survey, boating, and safety skills and knowledge. To assure safety of the crews, all observers must learn safe boat handling and maintenance. In Zone 1, new crew members are given a 1-day course taught by the Coast Guard auxiliary or equivalent organization. In Zone 2, there is a dedicated boat operator who has a marine operator's license and is Coast Guard certified. In all zones, safety protocols for all crew members include instructions and reminders for weather and sea condition assessment, boat handling, proper maintenance of the boat and safety gear, rescue techniques, and emergency procedures.

Accurate estimates of the perpendicular distance from the transect line to birds detected from the boat are key to density estimates made by using line transect methods.

Accurate estimates of the perpendicular distance from the transect line to birds detected from the boat are key to density estimates made by using line transect methods (Buckland et al. 2001). Training in distance estimation is conducted first on land, then on the water. Laser rangefinders are used for training and for calibration and testing of observers' distance estimates before or during each survey. Distances to stationary buoys, crab pot markers, or a small float towed behind the boat are estimated by the observer and the distance then measured with the rangefinder when the boat reaches the position perpendicular to the object. Each observer completed a minimum of 80 distance estimates during training.

Quality assurance tests were repeated daily or weekly throughout the entire survey period where each observer was tested on their ability to accurately estimate distances. Observers made a set of 5 to 10 estimates of perpendicular distance to targets and the actual perpendicular distance was measured with a laser rangefinder. After the first set of estimates, the observer's results were assessed. If estimates were within 15 percent of the actual distance, the trial was complete for that observer. If estimates were not within 15 percent of actual or if observer estimates showed consistent bias, the observer continued to estimate distances until error and bias were less than 15 percent. In addition, one of the project leads accompanied the survey crew and observed their overall performance and ability to detect murrelets three times during the survey season and completed an audit form created by the Murrelet Monitoring Program (Huff 2003, http://www.reo.gov/monitoring/murrelet/docs-pubs/MAMU02rptfinalver2__9_23_03.pdf). The results of the audit were shared with the observers after the survey day was completed for feedback and discussion. See appendix 2 for an example of our field training protocol.

Zone-Specific Sampling Details

Detailed descriptions of the locations of strata, equipment used, and technical issues specific to each zone are beyond the scope of this report, but details can be found in the 2000 monitoring report, available at http://www.reo.gov/monitoring/murrelet/docs-pubs/MAMU_EM_00report.pdf.

Analysis

Overview

Statistically defensible estimates of average marbled murrelet density (average daily counts of birds/km^2 for the target time period) for the target population, with associated estimates of precision, were produced for each conservation zone separately and also for the entire target population consisting of all zones combined. The estimation process integrated design, implementation, and analysis. The sampling design was a stratified design, described above. This section describes the analytical methods required to produce the desired estimates.

An estimate of average daily density, with an associated estimate of precision, was produced separately within each geographic stratum for each breeding season. All zones had two or three strata (table 1). Estimates of precision were produced by using bootstrap resampling methods. Estimates for zones and overall estimates for the entire target population were produced by using standard methods for stratified sampling (Cochran 1977, Sokal and Rohlf 1981). We used standard methods based on total area within each stratum to expand density estimates, and associated estimates of precision, to calculate the average total numbers of birds by zone and for all zones combined for the target period. The details of these various procedures are documented in the remainder of this section.

Estimates of Density Within Strata

Estimating density within a stratum required:

- Accounting for some nonrandom selection of PSUs in space and time.
- Specifying parameters to be used in the DISTANCE program.

Nonrandom selection of PSUs occurred for two reasons. First, the long distances between boat launch sites necessitated sampling neighboring PSUs either on the same day or on successive days. Second, sea conditions were sometimes too rough to allow adequate sampling, or those conditions posed safety hazards for the boat crews. Both situations resulted in a nonrandom selection of days in the season, and some PSUs that were available with adequate sampling conditions were selected more often than originally expected.

Two main parameters were required for using the DISTANCE program for summarizing the data:

- Specifications for truncating data at large distances from the transect line.
- Selecting the method for determining which detection function was used.

We truncated extreme observations (those beyond some maximum distance from the transect) because they have negligible effect on density estimates and can cause unnecessarily complex models of the detection function. For truncating data, we eliminated the 5 percent of all observations in each zone that were the greatest distance from the boat. Specifically, if there were *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. This truncation rule was used because when using the DISTANCE parameter that removes a proportion of the observations, that same proportion is removed from each stratum. Because there were so few observations in some of the strata, we removed only 5 percent of the largest distances irrespective of strata.

We used AIC (Akaike Information Criteria) (Akaike 1973, Burnham and Anderson 2002) in DISTANCE to select the detection function curve from two model types: half-normal and uniform (see app. 4 for a discussion of our selection of models).

Outputs From the Program DISTANCE

From DISTANCE we obtained estimates of the probability of a bird that is present being detected on the transect line ($f(0)$), 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 PSU subunit (inshore and offshore) survey. Density (birds/km^2) for each PSU subunit survey was estimated with the following formula:

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

with the “hats” over the letters designating estimates. The constant 1,000 was used to convert units to birds/km^2, and the constant 2 was used to account for the fact that we count numbers of birds on both sides of the transect line. Estimates of PSU density were constructed as a weighted average of the PSU subunit densities with weights being areas of the PSU subunits.

Estimates of Precision Within Strata

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

Our sampling universe is the array of PSU×Day combinations and it is the mean of the PSU×Day densities that we use to characterize the density within a zone during the sampling season. As such, our sampling scheme has both a spatial and a temporal dimension.

We divided each zone into two or three strata and in theory we would randomly select PSU×Day combinations to survey. But because of the limited travel range of boats from their varying starting locations during the season, some PSUs near each other needed to be sampled very close in time (usually the same day or within a few days) resulting in a lack of independence of PSU×Day selections.

In an attempt to adjust for the lack of complete independence for estimating the precision of the estimates of zone density, we delineated clusters of PSU×Day combinations that were close in both space and time. It was then assumed that these clusters more closely represented independent selections. That was our justification for using bootstrapping methods based on resampling the delineated clusters. In addition, during the bootstrap process we randomly selected PSU×Day combinations within a cluster. Both levels of resampling were used to produce one bootstrap replicate sample. The resulting bootstrap sample was then analyzed by the DISTANCE program, using all the same methods as described in the preceding section.

In an attempt to adjust for the lack of complete independence for estimating the precision of the estimates of zone density, we delineated clusters of PSU×Day combinations that were close in both space and time.

Note that some PSUs had multiple observations and some days had multiple observations. To account for some PSUs being sampled more than others (in some instances because of deliberate unequal sampling), we calculated the PSU means and then constructed a weighted mean of those PSU means with the weights being the area of the associated PSU. In all strata in all zones (except Strata 2 and 3 in Zone 1) nearly all of the PSUs were sampled each year, so we believe that using the mean of the means for PSUs removed most of any selection bias.

The bootstrap procedure incorporated the program PSU Variance (Laake and Raphael 2000, available from Raphael on request) developed to account appropriately for the pairing of the inshore and the offshore PSU subunits for both estimation of density and estimation of 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 bootstrap replicate samples, run DISTANCE, calculate the density estimates, and summarize bootstrap results (see app. 5).

Variants in Estimation Procedures

During the initial year (2000), we encountered some sampling problems that required special analytical procedures affecting Zone 1 Stratum 1, and Zone 2 Strata 1 and 2. Most of the distances to observed groups of birds throughout that season were lost in these strata owing to a malfunctioning recording device. Because complete information was available for Strata 2 and 3 in Zone 1, which was not the case for Zone 2, different estimation approaches were used in the two zones.

Zone 1:

(1) All observations with valid distances (and all observations with no birds) from strata 1, 2, and 3 were used to estimate $f(0)$ and the densities for strata 2 and 3.

(2) For Stratum 1, the following process was used:

   (a) The missing distances in Stratum 1 were filled in from random selections of the observed distances (this is just to get DISTANCE to run).

   (b) DISTANCE (with the same settings as other estimations—remove the largest 5 percent of the distance observations, same detection functions, etc.) was run to estimate the encounter rate and $E(s)$ just using the observations from stratum 1 (a separate Excel spreadsheet was created).

   (c) Using the estimates of $f(0)$ from step 1 and the estimates of the mean encounter rate and $E(s)$ from 2b, the estimate of density was constructed (for the raw data and for each bootstrap run).

Zone 2:

(1) To get DISTANCE to run and produce estimates of the encounter rate and $E(s)$, the missing distances were filled in at random.

(2) DISTANCE was run by using the usual settings.

(3) The estimate of $f(0)$ for the raw data was taken as the average of the estimates of $f(0)$ for the years 2001, 2002, and 2003 where there were no malfunctioning recording devices. For the 1,000 bootstrap runs for 2000, one thousand random selections were taken without replacement from the complete collection of 2001, 2002, and 2003 bootstrap values of $f(0)$. That effectively results in approximately equal numbers of $f(0)$ from each of the years 2001, 2002, and 2003. Year 2004 values were not included, as these were from a different crew.

   - 2002: Zone 2 Stratum 1. The sub-PSUs in PSUs 1 and 2 were not always surveyed near in time:

PSU	Sub-PSU	New label	Survey date(s)
1	Near-shore	50	6/18/2002, 7/4/2002
	Far-shore	51	5/31/2002, 7/5/2002
2	Near-shore	52	6/18/2002
	Far-shore	53	5/30/2002, 7/3/2002

To account for this, those four sub-PSUs were considered to be separate PSUs and relabeled as shown in the above tabulation just for the 2002 season.

Zone and Population Level 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 would be used to estimate density for each PSU×Day combination in the sample. Then the density at each PSU×Day combination in the zone would be estimated by fitting the following linear model, and a weighted average of predicted densities (with weights being the PSU areas) for each stratum would be constructed:

$$d_{Day,PSU} = \alpha + (\beta_{Day} \times Day) + (\beta_{PSU} \times PSU) + (\beta_{Day \times PSU} \times Day \times PSU) + error$$

However, despite the known deviations from a completely random selection of days, examination of data did not suggest any temporal trends. Because of the lack of any indications of temporal trends, 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-level estimates were combined by using standard methods for stratified sampling. The methods, as described in Cochran (1977), involve proper weighting of stratum-level estimates by using the areas in each stratum. This produced estimates of mean density with associated estimates of precision for each zone and for the entire target population consisting of all zones combined. Precision was estimated from the standard deviation of the results of the individual bootstrap iterations. Confidence intervals for density estimates were constructed from the central 95 percent of the bootstrap results (also known as the percentile method).

Construction of Confidence Intervals for Numbers of Birds

For each zone, a 95 percent 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/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 percent confidence interval limits.

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 to estimate 95 percent confidence interval limits for birds in all zones as follows:

a_i Area of zone *i*

d_i Estimate of density for zone *i*

$\hat{\sigma}_i^2$ Estimate of the variance for zone *i*

$\bar{d}$ Overall estimate of density for the 5 zones:

$$\bar{d} = \sum_{i=1}^{5} a_i d_i \ / \sum_{i=1}^{5} a$$

$\hat{\sigma}^2$ Estimate of variance for average density for all 5 zones ($\bar{d}$):

$$\hat{\sigma}^2 = \sum_{i=1}^{5} a_i^2 \hat{\sigma}_i^2 \ / \left(\sum_{i-1}^{5} a_i^2 \right)$$

$$\mathrm{SE} = \sqrt{\hat{\sigma}^2}$$

Power Analysis

One of the measures for assessing this monitoring program is the power to detect changes of interest with respect to the mean density (and mean number) of murrelets over time. A full description of our methods to estimate power and an example of the analysis for the years 2000 to 2003 are given by Miller et al. (2006). For example, given the variability in year-to-year population estimates, we estimate 13 years of sampling would be needed to have 80 percent power to detect a 2 percent annual rate of decline and 7 years to detect a 5 percent annual rate of decline. For 95 percent power, we estimate 15 and 9 years to detect 2 percent and 5 percent annual declines, respectively.

The total population estimate for the Plan area during the 2005 field season was approximately 20,200 murrelets with a 95 percent confidence interval of 16,000 to 24,500.

Population Summary Across All Zones

Population Estimates

We present population estimates from the 2005 field season to illustrate the application of the methods described above. Results from years 2000 through 2003 are given by Miller et al. (2006). The total population estimate for the Plan area during the 2005 field season was approximately 20,200 murrelets with a 95 percent confidence interval of 16,000 to 24,500 (table 2).

Table 2—Estimates of density and population size of marbled murrelets during the 2005 breeding season in the area of the Northwest Forest Plan

Zone	Stratum	Density	Bootstrap standard error	Coefficient of variation of density	Birds[a]	Birds lower 95% confidence interval[a]	Birds upper 95% confidence interval[a]	Survey area	Transect length	Probability of detection f(0)	Standard error of f(0)	Mean number of birds per group E(s)	Standard error of E(s)	Truncation distance	Standard error of truncation distance
		- - *Birds/km*^{2} - -		*Percent*				*km*^{2}	*km*					- - *Meters* - -	
1	1	2.5014	0.9507	38.0	2,100	700	3,600	845	420						
1	2	2.4255	.6523	26.9	2,900	1,100	4,300	1,194	2,807						
1	3	2.0209	.6336	31.4	2,900	1,200	5,000	1,458	394						
	All	2.2751	.4820	21.2	8,000	4,800	11,600	3,497	3,621	0.0156	0.0021	1.76	0.149	150	12.7
2	1	2.7283	.4965	18.2	2,000	1,200	2,600	724	301						
2	2	.5568	.3579	64.3	500	100	1,600	926	257						
	All	1.5100	.3069	2.3	2,500	1,600	3,600	1,650	558	.0134	.0014	1.41	.052	130	18.1
3	1	.8123	.2594	31.9	500	300	900	661	439						
3	2	5.6780	.9715	17.1	5,300	3,200	6,700	935	562						
	All	3.6624	.5973	16.3	5,800	3,600	7,300	1,595	1,001	.0126	.0012	1.83	.074	150	12.0
4	1	4.4524	1.1175	24.8	3,300	2,200	5,400	734	807						
4	2	.8827	.3762	42.5	400	200	900	425	990						
	All	3.1423	.7316	23.0	3,600	2,700	6,000	1,159	1,797	.0107	.0011	1.51	.040	170	11.8
5	1	.2733	.1201	42.9	100	0	200	441	620						
5	2	.3807	.1482	38.9	200	100	300	441	155						
	All	.3270	.0970	29.6	300	100	500	883	775	.0107	.0011	1.51	.040	170	11.8
All	—	2.3020	.2476	1.8	20,200	16,000	24,500	8,785	7,822						

[a] Numbers rounded to the nearest 100 birds.

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 PSUs were selected within higher density areas. Within PSUs, densities tend to be higher closer to shore and taper off with distance from shore (although these distributions shift in different years, possibly associated with different prey conditions). Therefore, within PSUs, more transect length per unit area was sampled in the generally smaller inshore subunits than in the larger offshore subunit. These design decisions were made prior to implementation of the pilot project in the 2000 field season based on previous data collected under different sampling designs. On average, density of marbled murrelets in the inshore subunit was 6.5 times that in offshore subunits (table 3).

Table 3—Mean density estimates in the inshore and offshore subunits and zones, 2000–2005

Zone	Inshore density	Offshore density	Ratio in/off
	- - - - *Murrelets/km²* - - - -		
1	4.55	0.90	5.1
2	2.61	1.42	1.8
3	13.84	.83	16.7
4	5.41	.92	5.9
5	.22	.01	22.0

Future Steps

The 2001 and subsequent field seasons proceeded with very few changes in the sampling design or methods. In a few instances, the amount of transect allocated to the inshore or offshore subunit was changed. In Zone 1, we implemented a zigzag layout of transects in the offshore subunits of Strata 2 and 3 rather than the parallel layout used in the year 2000 sampling. As the work continues, we expect to further modify procedures as we gain further experience and as new issues are encountered. We have developed a centralized database to archive each year's observations, survey effort, and maps of transect lines.

This effort represents an important step for the murrelet monitoring program, but more is needed. Ultimately the hope is to understand how at-sea population size is influenced by the amount and distribution of inland nesting habitat. Efforts continue to develop a map of potential nesting habitat and to evaluate how habitat affects population size and productivity (Raphael et al. 2006). Radar (Raphael et al. 2002) and land- and seascape analyses (Miller et al. 2002, Raphael 2006) may be possible tools to help gain an understanding of linkages between murrelet populations and habitat conditions, and we are continuing to explore this possibility.

Acknowledgments

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English Equivalents

1 kilometer = 2. 47 acres
1 meter = 3.28 feet

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Appendix 1: Geographic Information System Methods[1]

Geographic information system (GIS) technology was used to assist the population team in developing and implementing the population sampling design. The team used GIS as a computer-based orientation and navigation tool to define the extent of the primary sample units (PSUs), to generate survey transects within each PSU, and to produce hardcopy field maps and field navigation coordinate tables for use by the population survey crews. Using GIS facilitated the implementation of the new sampling design.

The GIS personnel for the study included Rich Young, USDI Fish and Wildlife Service, Beth M. Galleher, USDA Forest Service Pacific Northwest Research Station, and Bill Hogoboom, USDA Forest Service, Arcata, California. The GIS software from the Environmental Systems Research Institute (ESRI) was used at all locations, including ArcInfo 7, ArcGIS 8, and ArcView 3.1.[2] Our spatial data were in Universal Transverse Mercator (UTM), Zone 10N, NAD27, unless otherwise specified.

The basic GIS tasks performed for the project included:

- PSU delineation.
- PSU subunit breakdown (inshore versus offshore, and inshore segments).
- Generation of inshore parallel transect survey routes.
- Generation of offshore zig and zigzag survey transect routes.
- Random transect selection.
- Generation of navigation waypoint coordinates (latitude and longitude).
- PSU area calculation.
- PSU transect length calculation.
- Hardcopy maps (field survey transect layout maps, zone maps, and other visual aids).

PSU delineation

Within each of the five conservation zones, the team members collectively agreed upon the PSU boundaries (table 1). The GIS provided the mechanism to spatially define the individual PSU boundaries. We used digital data sets (1:24,000 scale) from the U.S. Geological Survey (http://gos2.geodata.gov/wps/portal/gos/) to define the coastline for the entire study area. After receiving feedback from field

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[1] Appendix 1 was developed by Rich Young, GIS analyst, U.S. Fish and Wildlife Service, 911 NE 11th Avenue, Portland, OR 97232, and Beth M. Galleher, GIS analyst, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 3625 93rd Avenue SW, Olympia, WA 98512-9193.

[2] Use of trade or firm names in this publication is for user information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

survey crews during the first 2 years of the project, we modified these data sets by using hand-drawn maps of islands, large rocks, and shallow beach bars that were digitized in GIS to exclude nonnavigable areas from the study area. These modifications were in place for the 2002 field season.

Ideally, all PSUs would be a standard length of 20 km, as determined by the team. To most closely approximate this standard by using real world data, however, the actual PSU length was determined by stratum within each conservation zone. We used the dynamic segmentation feature of ArcInfo to automatically determine PSU breakpoints resulting in standardized PSUs within each stratum that are as close to 20 km in length as possible. Boundaries between PSUs were generated perpendicular to the coast at these breakpoints.

We created the offshore boundary, or outer extent of the PSU, by buffering the coastline to a specified distance, ranging from 2000 to 8000 meters, depending on the zone or stratum as determined by the team (table 1). An exception to this exists in Zone 1 Strata 2 and 3 where topography sometimes limited the ability to get the full distance from shore. An example is two opposing coastlines that are closer together than twice the specified PSU width. In these cases, the channel was split and the offshore boundary for the adjacent PSUs was created halfway between the two coastlines.

PSU Subunit Breakdown

Within each PSU, we used GIS to create the necessary subdivisions, as illustrated in figure 3. We created the centerline, the boundary between the inshore and offshore subunits, in all strata except Zone 1 Stratum 3, by buffering the coastline to a specified distance based on zone and stratum (table 1). Additionally, we divided the inshore subunit into four equal segments, labeled A through D, each approximately 5 km in length (fig. 3). This was accomplished in much the same manner as the creation of the PSUs.

Our overall objective was to define transect routes so that any point within a subunit of any PSU had an equal probability of being included in a survey.

Generation of Inshore Parallel Transect Survey Routes

Our overall objective was to define transect routes so that any point within a subunit of any PSU had an equal probability of being included in a survey. Inshore transect lines were generated by buffering the coastline in 100-m increments beginning 50 m beyond the extent of the designated surf zone (table 1) and ending 50 m before the centerline. We used 100-m increments based on pilot surveys showing that observers detected nearly all birds within 50 m from each side of a transect line. Each transect was attributed with its distance (in meters) from the coastline. Transects were then overlain on the PSU segment polygons resulting in

~5-km transect lines in segments A through D. This process was performed once during the pilot study, and then modifications were made prior to the 2002 field season based upon survey crew feedback. A random selection of these parallel transects has been used in subsequent surveys. This selection is accomplished in Zone 1 by use of a random number table, and in all other zones by using the RANDOM function of ArcGIS.

Generation of Offshore Zig and Zigzag Transect Routes

Surveys in the offshore subunit followed either a zig (Zones 4 and 5 only) or a zigzag pattern (fig. 3). Zig pattern surveys consisted of one transect line oriented at an angle between the centerline and the offshore boundary, whereas zigzag surveys were two or more contiguous transect lines or "legs" that angle away from and then toward the shore. Starting points for transects were based upon randomly selected points along the centerline for each PSU. For each zone and stratum, the team selected a target length for the offshore transect, and a number of "legs" (zigs or zigs plus zags). These parameters, along with the width of the offshore subunit, determined the orientation of each transect.

To construct the zigzag transects, we used several GIS functions. First, we buffered a randomly selected starting point along the centerline to create a circular polygon with a radius equal to the leg size (total transect length / number of legs). We then intersected this circle with the offshore polygon and drew a straight line between the starting point and the outer PSU boundary. This point of intersection became the new starting point for the next leg in the transect, the zag, which heads back toward the centerline. We repeated this process until all legs were constructed. Partial transect legs that became truncated owing to an intersection with the PSU boundary were continued at the opposite end of the PSU.

Owing to topographic constraints, such as convoluted coastlines, we modified the method for constructing zigzag transects in Zone 1. The starting point, selected from a set of points covering the entire offshore area and spaced 100 m apart, and initial direction of the transect from the starting point, were randomly selected for each PSU and repetition by using a Visual Basic script, randomizer.exe, written by K. Ostrom. Transects in this zone differed in length, and we made one or more adjustments in orientation to maintain the overall objective of traversing the area between centerline and outer boundary.

For all zones, except Zone 1, the offshore transect routes were generated each year for that year's survey season based upon new randomly selected starting points. For the pilot year, parallel transects were used to survey Zone 1 Strata 2 and 3. In 2001, the design was modified to employ zigzag transects in these strata;

however, owing to the complexities involved in constructing transect routes in and around Puget Sound and the San Juan Islands, the offshore routes for Zone 1 were generated once and then reused in subsequent survey years with the order of use randomly selected each year from a random number table.

Random Transect Selection

For strata where inshore surveys were performed (all except Zone 1 Stratum 3), we chose parallel transects to be surveyed each year by using the random number generator in ArcInfo or ArcGIS. Within each PSU, we grouped the parallel transects into four bins, each representing a quarter of the total number of transects (fig. 3). Random selection without replacement of bins and transect lines produced a survey route for each PSU with one ~5-km transect in each of the four segments and each bin surveyed only once. This ensured a more even distribution of survey effort across the inshore subunit.

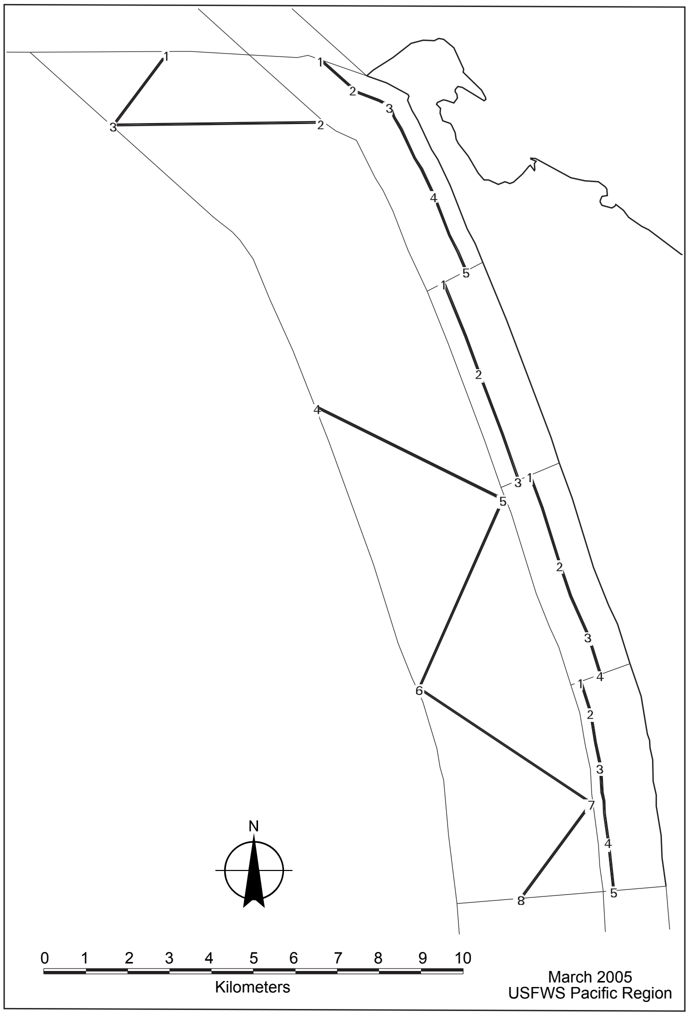
Selection of offshore transects, except in Zone 1 as previously described, involved randomly identifying a starting point along the centerline to begin construction of the route. Possible starting points were initially generated for each PSU and were evenly spaced at 10-m intervals along the centerline. The first starting point was positioned along an extrapolated centerline that extended beyond the end of the PSU so that no portion of the offshore subunit was excluded from the possibility of being selected to be surveyed.

Generation of Navigation Waypoint Coordinates

As transect routes were selected or newly constructed, beginning points, endpoints, and internal vertices were captured as coordinate points in UTM meters. These were then converted to a geographic coordinate system (latitude/longitude) and provided to the field survey crews for entering into their onboard global positioning system (GPS) units as waypoints for navigation (see fig. 5 for an example map and set of coordinates). Originally, these coordinates were provided in hardcopy format and manually entered into the GPS by field survey personnel. In recent years, digital files containing the waypoint coordinates have been created in a format that can be easily uploaded to the GPS units.

PSU Area Calculation

We used ESRI GIS software to calculate the area, in km^2, of the inshore and offshore subunits of each PSU. We did this by using a digital coverage in a UTM, Zone 10, NAD27 projection. We provided the area calculations to the team statistician for use in generating population estimates.



2005 MAMU Field Survey Way-Point Map
Zone 3, Strata 1, PSU 01

Row A, Selected Transect 450m from Bin 1, length = 6348m
- WayPoint 1, Latitude 46 13.954, Longitude - 124 2.279
- WayPoint 2, Latitude 46 13.589, Longitude - 124 1.672
- WayPoint 3, Latitude 46 13.372, Longitude - 124 0.983
- WayPoint 4, Latitude 46 12.230, Longitude - 124 0.145
- WayPoint 5, Latitude 46 11.264, Longitude - 123 59.530

Row B, Selected Transect 1050m from Bin 3, length = 5039m
- WayPoint 1, Latitude 46 11.109, Longitude - 123 59.942
- WayPoint 2, Latitude 46 9.958, Longitude - 123 59.267
- WayPoint 3, Latitude 46 8.577, Longitude - 123 58.511

Row C, Selected Transect 750m from Bin 2, length = 5042m
- WayPoint 1, Latitude 46 8.643, Longitude - 123 58.296
- WayPoint 2, Latitude 46 7.501, Longitude - 123 57.727
- WayPoint 3, Latitude 46 6.588, Longitude - 123 57.186
- WayPoint 4, Latitude 46 6.090, Longitude - 123 56.949

Row D, Selected Transect 1250m from Bin 4, length = 5068m
- WayPoint 1, Latitude 46 5.996, Longitude - 123 57.313
- WayPoint 2, Latitude 46 5.603, Longitude - 123 57.127
- WayPoint 3, Latitude 46 4.901, Longitude - 123 56.928
- WayPoint 4, Latitude 46 3.941, Longitude - 123 56.767
- WayPoint 5, Latitude 46 3.309, Longitude - 123 56.660

ZigZag Transect 235, Each 'Leg' Length 4936m, Total Length 24681m
- WayPoint 1, Latitude 46 14.006, Longitude - 124 5.135
- WayPoint 2, Latitude 46 13.151, Longitude - 124 2.260
- WayPoint 3, Latitude 46 13.082, Longitude - 124 6.105
- WayPoint 4, Latitude 46 9.480, Longitude - 124 2.252
- WayPoint 5, Latitude 46 8.330, Longitude - 123 58.796
- WayPoint 6, Latitude 46 5.882, Longitude - 124 0.304
- WayPoint 7, Latitude 46 4.435, Longitude - 123 57.092
- WayPoint 8, Latitude 46 3.197, Longitude - 123 58.368

Figure 5—Sample layout of inshore and offshore subunits for one primary sample unit in Zone 3, along with the coordinates used to navigate to each waypoint along the transect lines. Similar maps and coordinates are provided to each field crew at the start of each day's marbled murrelet survey.

PSU Transect Length Calculation

The team used the length of a transect to calculate encounter rates for density estimates. Transect lengths were recorded by using tracklines produced by GPS units during surveys and compared with lengths of transects as mapped by using ESRI GIS software. The two measures were similar and we found no bias in any differences between recorded and mapped transect lengths. Therefore, we used the GIS estimates in most cases. The GPS tracklines were used to measure transect length when the actual course deviated significantly from the planned course.

Hardcopy Maps

Maps of each PSU displaying selected transect routes and waypoint coordinates were generated in GIS and provided to the field crews for use in planning and executing surveys. The waypoint coordinates were output in the same projection as the base maps (UTM, Zone 10, NAD27) to a text file. The PCX5 software (Garmin 1993–1997) was used to convert the UTM coordinates to latitude-longitude decimal degrees, WGS84. PCX5 produces a file that can be directly uploaded into the GPS units. Hardcopy listings of the coordinates were also provided to field crews as backup. Although the points were provided at submeter precision, the ability to locate these points accurately in the field was limited by equipment and terrain.

Appendix 2: Offshore Marbled Murrelet Survey Form Instructions

Header

Zone	1 digit
Strata	1 digit
PSU	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-digit date (mo-dy-yr)
Notes	Any pertinent info specific to survey (e.g., inshore obstructions to surveys)

Main form

Subunit	1 letter, N or O, for near shore 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 0.1 km). 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 PSU (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 0.1 km). Example 15.2 km
Time	4-digit code, military time. Taken at start of every segment and to show breaks
Depth	4 digits bottom depth (**ft**). Read from depth sonar (fish finder) at beginning of every segment and at murrelets
Clouds	Percentage 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 = unlimited
Glare	3 digits for percentage of 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 (visually estimated 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 (visual estimate)
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 percent alternate (brown) 3 = <50 percent 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 (juvenile) 6 = Unknown black and white bird 7 = Unknown
Plumage Notes	Additional information on plumage—as much detail as 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.

Appendix 3: Field Training Protocol

Background

- The marbled murrelet (*Brachyramphus marmoratus*) is federally listed as threatened in Washington, Oregon, and California. Throughout the listed range of the species, the Northwest Forest Plan (the Plan) land base standards and guidelines are expected to make substantial contributions towards conservation and recovery. Specific monitoring requirements have been outlined to ensure the Plan is effective in maintaining and recovering this species long term.
- Marbled murrelet effectiveness monitoring under the Plan recommended assessing population trends **at sea** because of the cryptic nature of murrelets in their nesting habitat. There is also an inland component, whose goal is to establish a credible nesting habitat baseline. The ultimate goal is to track over time, both the at-sea population abundance and nesting habitat and show a strong correlation between population trends and nesting habitat so that nesting habitat can be monitored as a surrogate for the species population over the long term.
- A population team of state and federal representatives has developed the new sampling design and standardized survey methods to be implemented throughout the Plan area. These survey methods were employed beginning in 2000 and were developed to facilitate comparisons of data among studies in different geographic areas and to examine long-term population trends at sea.

Sampling Design

Target population

- Marbled murrelets from the Canadian border to San Francisco Bay (Northwest Forest Plan)—see map
- Inshore boundary: Closest navigable waters adjacent to the coast (between 100 and 400 m out to sea)
- Offshore boundary: Varies based on available marbled murrelet distribution data in each zone, from 2 to 8 km from shore

Sampling period

- Mid May to end of July
- Time of year when breeding birds at sea are likely to be associated with land nesting habitat in the Plan area

Conservation zones

- Six conservation zones along the west coast and within Puget Sound (five of six occur within the Plan area):
    - Zone 1—inland waters of Puget Sound
    - Zone 2—outer coast of Washington—Cape Flattery to Columbia River
    - Zone 3—northern to southern Oregon coast
    - Zone 4—southern Oregon coast to northern California coast
    - Zone 5—northern to central California coast south to San Francisco
- Mean at-sea density and population trend estimates of marbled murrelets are calculated separately for each zone

Strata within zones

- Sampling effort based on marbled murrelet density→Strata 1 (northern Washington coast) more replicates than Strata 2 (southern Washington coast)

Primary sample unit (PSU)

- Rectangular "unit" along 20 km of coastline
- Each "unit" consists of one inshore and one offshore subunit; width differs by zone and stratum
- Subunits have a density component
- Inshore subunit consists of four approximately 5-km segments parallel to shore at increments of 100 m from shore
- Offshore subunit consists of a zigzag transect that traverses the entire width of the subunit and a portion (or all) of the PSU length
- PSU specifics for Zone 2 (outer Washington coast): Inshore boundary 350 m, centerline boundary 1500 m, offshore boundary for Stratum 1 is 5000 m and for Stratum 2 is 8000 m; offshore transect length is 20 to 30 km. Specifics for other zones are listed in table 1.

Overall sampling methodology (note: this example is from Zone 2; training methods are similar for crews in other zones, except that data are recorded into portable tape players in other zones.

- Each conservation zone has a target sample size of 30 PSU surveys.
- High-density PSUs are sampled numerous times throughout the field season in random order (Zone 2 Stratum 1: 3 replicates of eight PSUs).
- Low-density PSUs are sampled only once (Zone 2 Stratum 2: 1 replicate of eight PSUs).

- Selection of PSUs is completed prior to the beginning of the field season. PSUs are generally selected randomly without replacement, and sampling should be spread evenly over the field season.
- Port location and weather will constrain random PSU selection, but effort should be made to avoid “clustered” surveys (PSUs that are completed on the same or adjacent days for logistical reasons).
- All four inshore subunits and offshore zigzag of a PSU must be surveyed on the same day.
- If unable to survey 25 percent or more of the transect line owing to obstacles (e.g., reef or breakers), survey the next possible transect line moving away from shore in 100-m increments. Document why the line was moved.
- Partial surveys occur when less than 75 percent of the transect is complete, and these are not used for analysis.
- Ensure that actual transect length (meters) is recorded for each of the four inshore subunits and offshore zigzag transect by the global positioning system in the DLOG2 program.
- Record depth by using depth finder at the beginning and end of each transect and at each murrelet record.
- A “break” of 100 m should be maintained when offshore zigzag transect legs cross and when inshore and offshore transects abut at the centerline—keep 100 m between adjacent lines or points.
- Stratum 3 (Grays Harbor, Willapa Bay and mouth of the Columbia River) has been surveyed in previous years. These data have not been used for population monitoring, and the monitoring team has decided that no surveys are to be completed in 2005 in these coastal estuaries.

Line Transect Distance Sampling

Used to estimate murrelet density (number of murrelets per unit area), which is then used to estimate population size.

Uses perpendicular distance to each murrelet observation (or group of murrelets) from the transect line and uses DISTANCE software (Buckland et al. 2001, program DISTANCE version 3.5, 4.1) to select a mathematical function that describes the effect of distance on numbers of groups of birds detected.

Important assumptions:

1. Murrelets near the line are not missed or they have not moved away from the line (in response to the observer) prior to being detected. If murrelets are missed or move, density will be underestimated.
2. Distance of murrelets from the transect line is accurately estimated.

Measurement Quality Objectives

For long-term murrelet population monitoring, quality assurance ultimately depends on the population estimate, which is composed of **density** and **area**. The density value is dependent on data collected both in the field and data used in or derived from analyses for density in the program DISTANCE.

Data collected during surveys that affect marbled murrelet density:

- Number of groups observed: Need communication between observers to minimize missed detections (DISTANCE does not require that all groups will be detected)
- Group size: A "group" is a collection of birds separated by 2 m or less at first detection and moving together or, if greater than 2 m, the birds are exhibiting behavior reflective of birds together.
- Distance: Estimate and record a distance to every murrelet group observed during surveys, regardless of distance from the line.
- Transect length: Actual distances traveled by the boat along the predescribed transect line, minus any deviations to get a better look at a bird or avoid large obstacles.

Survey Protocol

- Two observers scan from 0° off the bow to 90° abeam of the vessel.
- More effort is expended watching for murrelets close to the transect line ahead of the boat (within 45° of line). The program used to analyze the survey data assumes that birds close to the transect line are not missed.
- Observers should scan continuously, not staring in one direction, with a complete scan taking about 4 to 8 seconds. An observer focusing beyond 100 m is likely to miss some birds that are closer, thus observers should vary their focus from close to far in scanning within the 90° arc on each side of the boat.
- Scan far ahead of the boat for birds that may flush or dive in response to the boat. The intent is to record distance before the birds respond to the boat and move away.

- Scan with the naked eye and use binoculars only to verify species or plumage. Binoculars should not be used to scan.
- To maintain effective transect width, birds detected with binoculars that would not otherwise have been detected with the naked eye, are recorded in the comments field as “off transect.”
- Record group size at first detection. Record the midpoint distance for a group of birds if greater than 2 m apart.
- Estimate the perpendicular distance from the transect line of each group of murrelets as far as the eye can see in front of and to the side of the vessel. Generally, detections can be made to at least 200 m perpendicular distance (depending on sea conditions), but all distances, even those further than 200 m should be recorded. The program used to analyze the survey data assumes that distance of murrelets from the transect line is accurately estimated.
- Observers should communicate on birds close to the transect line to avoid double counting.
- Avoid “lumping” distances at 0 m (e.g., use exact distance: 2 m, 7 m), and at >10 m. Record the exact distance at first detection as accurately as possible.
- Distance to flying murrelets should equal the perpendicular distance from the transect line if the bird is roughly parallel to the boat, or the distance at first detection if its flight path is not parallel.
- Record behavior at first detection (on-water, flying, etc.). The intent is to record behavior before the birds respond to the boat.
- Record plumage class for each individual murrelet (see key below). The boat should be stopped to confirm identification if necessary and to confirm plumage class. The boat can leave the transect line to approach murrelets for a closer look if necessary and then resume the transect line at the point of departure.
- Data are recorded for all seabirds and marine mammals encountered; however, collecting marbled murrelet data is the primary focus of these surveys.
- If a large group of birds (>200) of any species is encountered, the boat may stop to allow the observers to scan and estimate numbers for each species. Estimating the percentage of the entire group for each species is an efficient way to do this.
- Survey speed is maintained at 8 to 12 knots, depending on sea conditions. The observers should set the survey speed within range according to their perceived ability to cover their survey area.

- Environmental data (Beaufort, glare, swell height, etc.) are recorded directly onto field forms at the beginning of each survey and updated as conditions change.
- Survey effort is ended if glare is code 2 or greater (glare 2 = missing 2/3 of birds).
- Survey effort is ended if Beaufort scale is 3 or greater (see table 4).
- If fatigue begins, take a short break at the end of a subunit or zigzag. Do not compromise data collection.

Table 4—Beaufort Wind Scale developed in 1805 by Sir Francis Beaufort of England (0 = calm to 12 = hurricane)

Force	Wind (knots)	Classification	Appearance of wind effects on the water	Appearance of wind effects on land	Notes specific to on-water seabird observations[a]
0	< 1	Calm	Sea surface smooth and mirror like	Calm, smoke rises vertically	Excellent conditions, no wind, small or very smooth swell. You have the impression you could see anything.
1	1–3	Light air	Scaly ripples, no foam crests	Smoke drift indicates wind direction, still wind vanes	Very good conditions, surface could be glassy (Beaufort 0), but with some lumpy swell or reflection from forests, glare, etc.
2	4–6	Light breeze	Small wavelets, crests glassy, no breaking	Wind felt on face, leaves rustle, vanes begin to move	Good conditions, no whitecaps, texture/lighting contrast of water make murrelets hard to see. Surface could also be glassy or have small ripples, but with a short, lumpy swell, thick fog, etc.
3	7–10	Gentle breeze	Large wavelets, crests beginning to break, scattered whitecaps	Leaves and small twigs constantly moving, light flags extended	Fair conditions, scattered whitecaps present, detection of murrelets definitely compromised, a hit-or-miss chance of seeing them owing to water choppiness and high contrast. This could also occur at lesser wind with a very short wavelength, choppy swell.
4	11–16	Moderate breeze	Small waves 0.3 to 1.1 m becoming longer, numerous whitecaps	Dust, leaves, and loose paper lifted, small tree branches move	Poor conditions, end surveys, whitecaps abundant, sea chop bouncing the boat around, etc. If you were nearly done with a survey and running with the wind, you could survey somewhat effectively in these conditions (but shouldn't).
5	17–21	Fresh breeze	Moderate waves 1.1 to 2.0 m taking longer form, many whitecaps, some spray	Small trees begin to sway	

[a] Source: Strong 1998.

Distance Quality Assurance/Quality Control

Estimates of distance from the transect line are a critical part of the data collected; therefore, substantial time is spent practicing the technique prior to the survey season and followed by quality assurance tests during the survey season.

Presurvey distance tests

- Stationary targets are selected at a range of distances in front and to the side of the boat.
- Compare individual's direct estimate of perpendicular distance to that recorded by a range finder.
- Provide immediate feedback and visual calibration between estimated distance and actual distance.
- Conduct 60 to 100 estimates per person.

During survey distance tests

- Test every 3 survey days for distance calibration and record on test form (provided).
- Completed prior to or during the survey day (e.g., use targets encountered on water).
- Observers make five estimates of perpendicular distance to five different targets; if all five are within 15 percent of the actual distances, the trial is complete. If not, the observer continues in sets of five until all five distances are within 15 percent of the actual distances.
- Observers are given feedback on potential bias (consistently over, or under).

External audits

- Someone not part of the daily survey crew will make at least three visits to each crew during the survey period to verify the survey protocol is being implemented correctly and complete audit form (Huff 2003).

Key to Aging Marbled Murrelets At Sea

In the field, marbled murrelets (*Brachyramphus marmoratus*) are classified into seven age/plumage categories. Classes 1 through 4 are from Strong 1998; class 5 was added to represent known juveniles, and two “unknown” categories were added to represent unknown age. Basic plumage is the black and white plumage seen in fall and winter. Alternate plumage is the brown mottled breeding plumage.

CLASS 1	Very little or no molt. Entirely in alternate plumage; bird appears brown.
CLASS 2	Obvious body molt but estimated at less than 50 percent of alternate plumage lost or replaced. Breast and neck obviously lighter than back.
CLASS 3	Over 50 percent of alternate plumage lost or replaced, but still clearly distinguishable from HY (juvenile) birds by brown alternate plumage feathers on back, breast, and belly. Molting birds placed in this class if throat and neck appeared whitish overall in color.
CLASS 4	Appears to be in basic plumage (black and white) from a distance. By definition, birds in this class require closer examination to distinguish between after hatch year (AHY, adult) and hatch year (HY, juvenile) murrelets. **For this protocol, birds recorded as class 4 (after close examination) are assumed to be adult birds in advanced molt. Otherwise, they would be recorded as class 5 or “unknown.”
CLASS 5	Entirely in basic plumage—confirmed HY bird.
UNKNOWN	Unknown age, black and white bird (HY or AHY cannot be reliably determined).
UNKNOWN-B/W	Plumage classification cannot be determined (inadequate viewing time, etc.)

These classes are intended for observations made throughout the summer and early fall, before adults have completed prebasic molt. Juveniles can begin to appear in mid to late June, but they can be distinguished from adults at this time. It becomes more difficult to distinguish juveniles and adults once class 4 birds begin to appear. For Puget Sound, this generally occurs by late July, and class 4 birds become increasingly more numerous through August.

Appendix 4: Estimation of the Detection Function[1]

An important aspect of the line transect method is the estimation of the detection function. The detection function describes the probability of detecting an object in relation to its distance from a random line or point. In analyzing the data from 2000 through 2005, the DISTANCE program (Version 4, Release 1, Buckland et al. 2001) was used to estimate the detection function. The individual perpendicular distances to an observed group of birds were used to fit the half-normal, hazard-rate, and uniform key functions with up to a five-parameter cosine series multiplier. This provided additional flexibility but only allowed parameters that result in a strictly nonincreasing detection probability with distance. The curve form was selected that had the smallest Akaike's Information Criterion (AIC) value that was corrected for a finite sample size bias (AICc). AIC is a method for assessing the fitness of a model (i.e., a small deviation from observed data or large likelihood), taking into account the number and order of model parameters. This process is automated in DISTANCE.

The detection function describes the probability of detecting an object in relation to its distance from a random line or point.

Estimated Detection Functions for the 2002 Zones 4 and 5 Surveys

Following the 2002 field season, we reevaluated our analysis of the detectability. Using the 2002 data as an example, we found evidence that the hazard-rate model might give spurious results, depending on the shape of the detection function. Therefore, we did a more thorough evaluation of the various options for model selection, and results are described in this appendix. Figure 6 shows the best AICc half-normal, hazard-rate, and uniform detection function estimates for the 2002 data from Zones 4 and 5. There are 730 observations (i.e., 730 individual perpendicular distances to groups of birds), with a large relative frequency of counts near zero perpendicular distance. Histograms (using 25 equally spaced nonoverlapping intervals) are superimposed over each detection function such that the area under the histogram equals the area under the detection function out to the maximum distance. For this example, the maximum distance is 175 m. The histogram plot in figure 6 shows the number of observations for each histogram bar. The detection functions all have similar curve forms estimated for effective strip half-widths

[1] Appendix 4 was developed by Jim Baldwin, U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, P.O. Box 245, Berkeley, CA 94701.

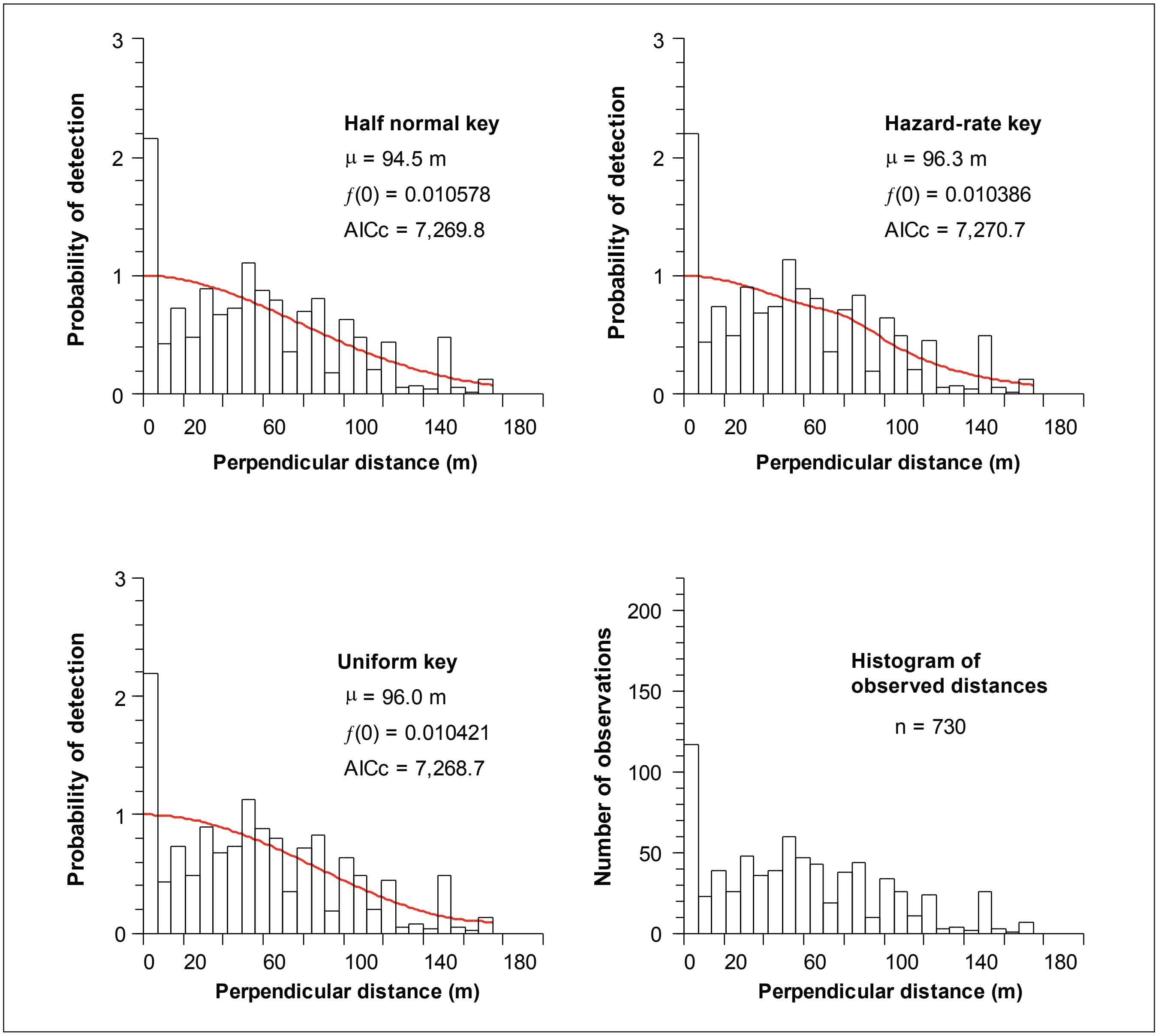


Figure 6—Estimates of detection functions along with the display of the histogram of the counts in each of 25 categories for the observed data in the 2002 Zones 4 and 5 surveys.

(μ = 94.5, 96.3, and 96.0 m for the half-normal, hazard-rate, and uniform detection functions, respectively) and similar estimates of the detection function probability, $f(0)$. The uniform key is chosen because of having the lowest AICc value. Effective strip half-width can be thought of as the width of a strip on one side of the transect over which essentially all of the objects (murrelets) are detected and is equal to the inverse of $f(0)$.

Some Problems Estimating Detection Functions

Under the above settings for the estimation of a detection function, different estimates for the curve occur occasionally for some particular bootstrap samples. The estimated effective strip half-widths (μ = 92.5, 14.4, and 9.1 m for the half-normal, hazard-rate, and uniform detection functions, respectively) differ considerably for the bootstrap sample shown in figure 7. (The bootstrap is a method for estimating the distribution of an estimator by simulated resampling of data with replacement). The estimate for the hazard-rate key has an extremely small estimate

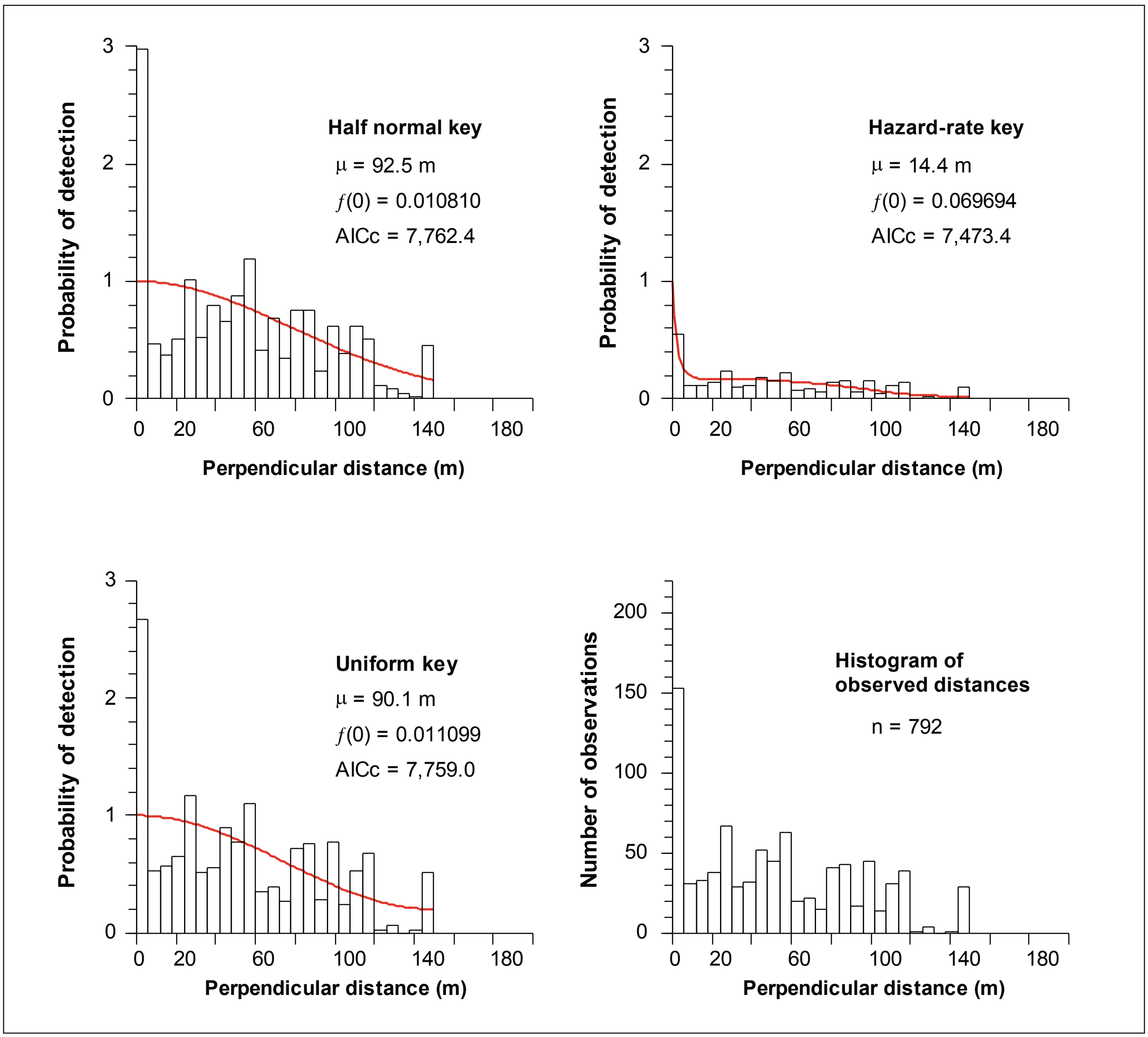


Figure 7—Estimates of detection functions along with the display of the histogram of the counts in each of 25 categories for a particular bootstrap sample from 2002 Zones 4 and 5 surveys.

of the effective strip half-width, which corresponds to a very large estimate of $f(0)$. The problem arises when certain predictors produce unreasonable outcomes for individual bootstrap samples. The effects of this are seen, for example, at 20 m for the hazard-rate estimate, which predicted a probability of less than .20 to observe a group of murrelets for this distance. This type of lack of fit for the hazard-rate function occurred in about 10 to 20 of the 1,000 bootstrap samples of the 2002 Zones 4 and 5 surveys, resulting in very large estimates of $f(0)$ and density estimates with large standard errors. Although data with large standard errors are plausible, the ones observed with the standard hazard-rate key are spurious because of the unjustifiable estimates of $f(0)$. Although removal of the hazard-rate key function is defensible, unfortunately none of the key functions fit the histograms very well as shown by the large number of observations near zero meters.

The estimates of the detection functions for the 2002 at-sea surveys and the scaled histogram of the observations for each zone are shown in figure 8. Scaling has the effect of making area under the histogram equivalent and the area under the detection function ≤1. Zone 1 shows a "spike" of observations near zero meters, as do Zones 4 and 5. This is characteristic of the condition called "guarding the centerline." One approach to reduce this effect after the fact is to group data into intervals and then use the grouped data to estimate the detection functions. Using the 2002 Zones 4 and 5 survey data as an example, the estimated detection functions for all three key functions in figure 9 appear to fit better than that of the ungrouped data shown in figure 7; and, the estimates of $f(0)$ differ little between the grouped and ungrouped data. Refitting of the extreme bootstrap of ungrouped data shown in figure 7 with the distances grouped at every 20 m shown in figure 10 gives a much more reasonable estimate of the effective half-strip width for the hazard-rate key function. However, even after grouping the data, up to 10 bootstrap samples from the 2002 Zone 4 and 5 surveys result in extreme estimates of $f(0)$ and associated detection function that are unsuitable.

Adjustments to Analysis Methods

To eliminate the inappropriate estimates of $f(0)$ and the associated detection functions, data were grouped into seven intervals after truncating 5 percent of the most extreme distances from all observations in a zone. An alternative method where the grouping is selected from a data-driven process, as recommended by Barabesi et al. (2002) will be investigated as this is not yet a feature of DISTANCE. Based on the current data, an interval of 20 m seems appropriate. As more data are gathered with the future monitoring, additional investigation will be done on selecting the appropriate intervals.

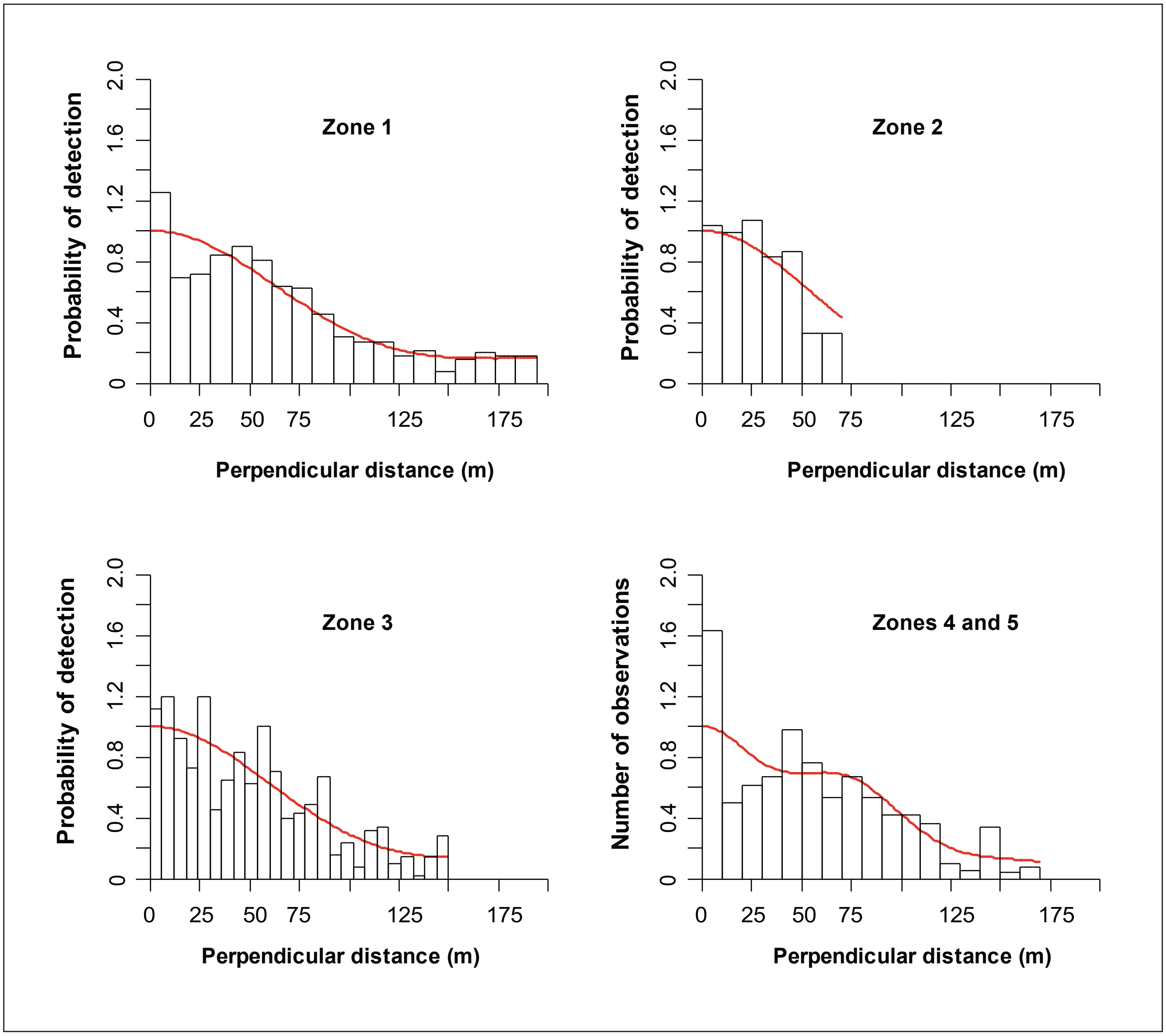


Figure 8—Estimated detection functions for at-sea surveys taken 2002 for each zone along with the scaled histograms. Note that, until 2002 in Zone 2, observers were instructed to record observations out to only 100 m (this instruction was eliminated in subsequent years).

The hazard-rate key function has been dropped from the marbled murrelet population analyses because of the unrealistic *ƒ*(0) estimates encountered from Zones 4 and 5. Similar problems have occurred with this function in other studies with somewhat spiked data. Buckland et al. (2001) reported that the hazard-rate function can give density estimates with large positive bias, especially when the data spikes are an artifact of data rounding.

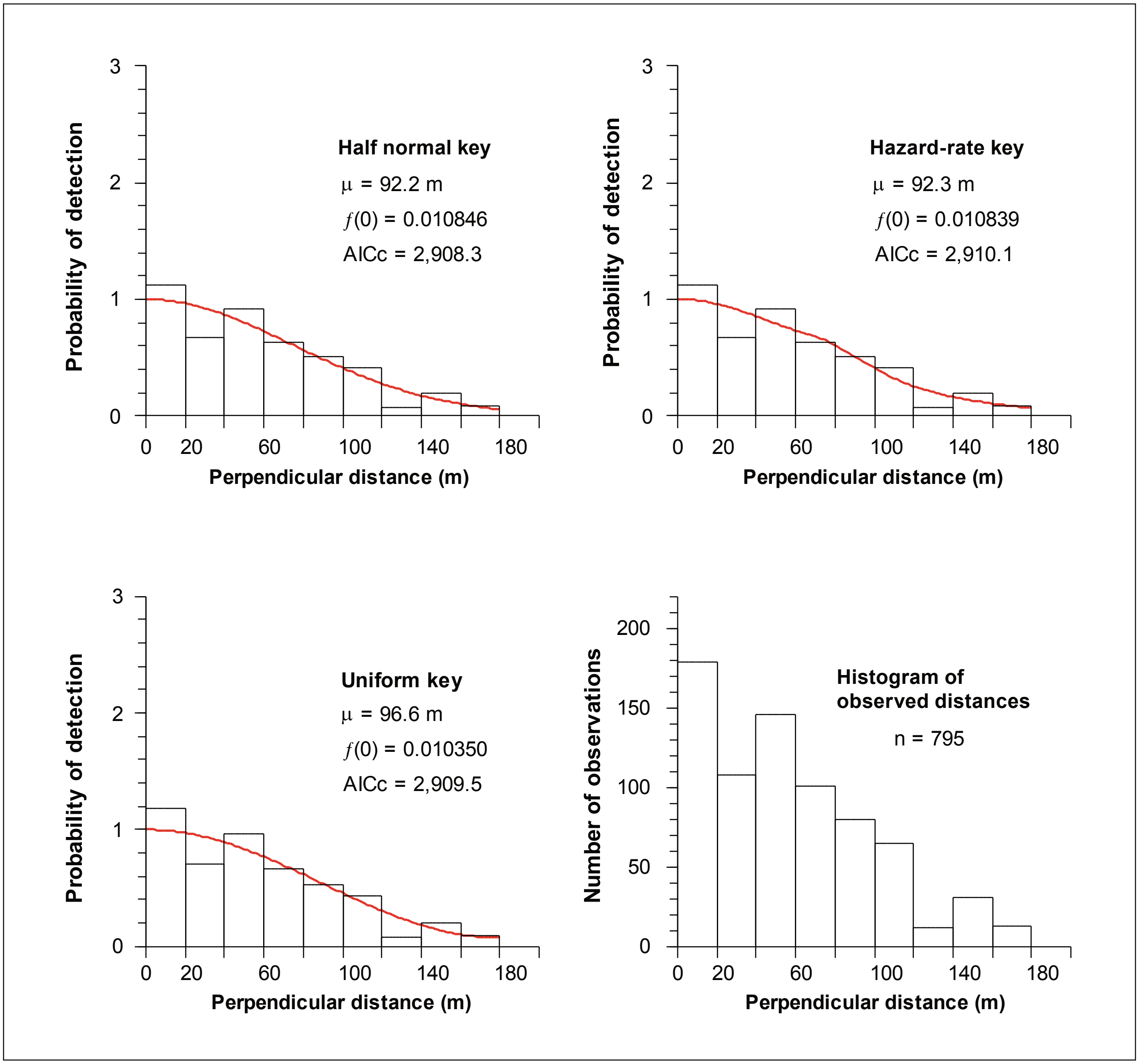


Figure 9—Detection functions for the observed data in 2002, Zones 4 and 5, fit with distances grouped at every 20 m.

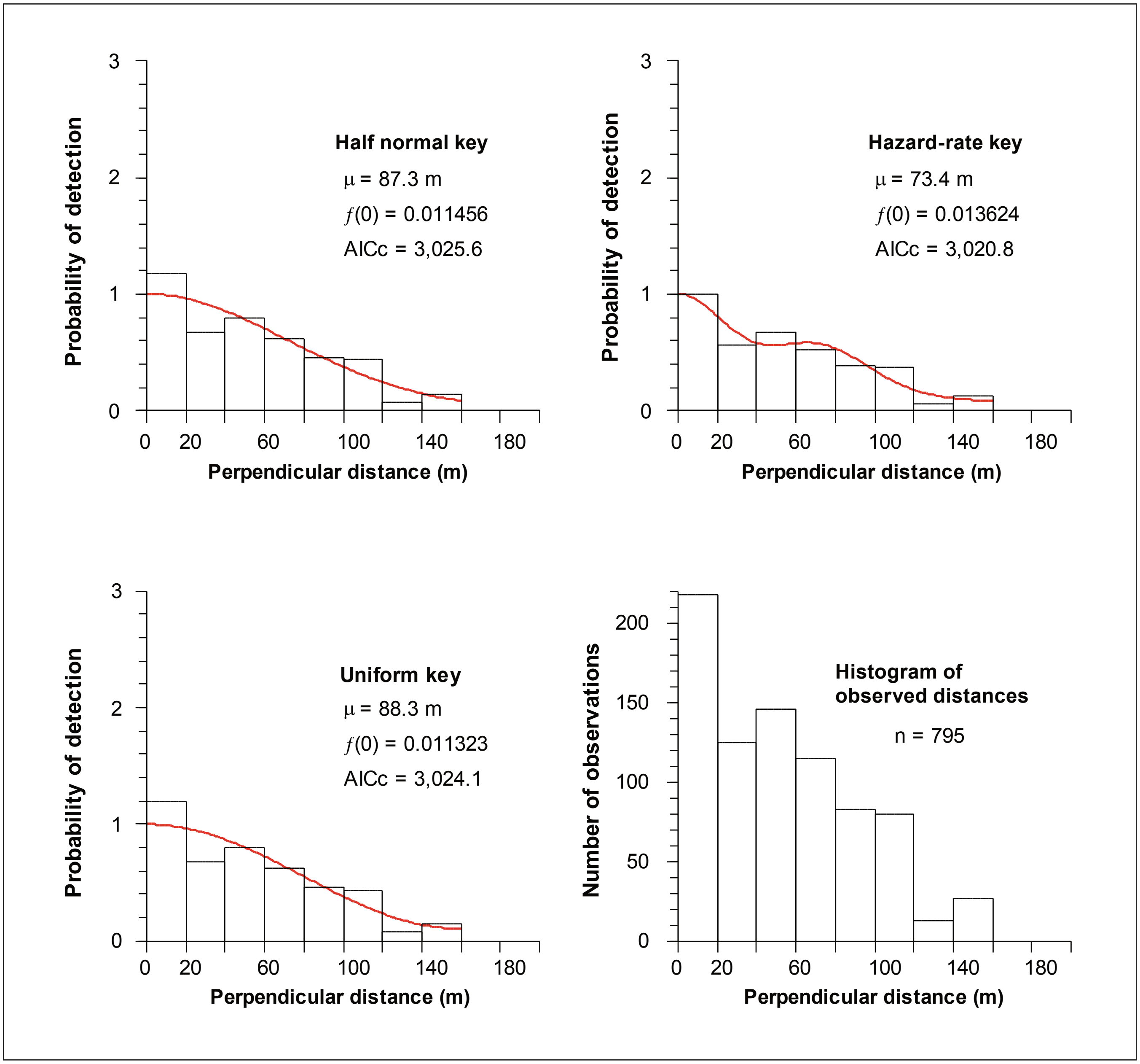


Figure 10—Detection functions for an “extreme” bootstrap sample from the 2002 Zones 4 and 5 data fit with distances grouped at every 20 m.

Appendix 5: An Example of SAS Code for Performing Bootstrap Analysis[1]

```
* Get density estimates for all Zones;

* Include SAS macros;
  option spool nomprint;
  %include "c:\Docume~1\jbaldwin\mydocu~1\mamu\atseamacros.sas";

* Set season dates:  starting month, day, year and ending month, day, year;
  %SetSeason(5,15,2005,7,31,2005)

   * Zone 1;
  %FileLocations(c:\Docume~1\jbaldwin\mydocu~1\mamu\2005\z1\,
                 c:\progra~1\distan~1\)
  %analysis(zone1_2005,1000,3,0);

* Zone 2;
  %FileLocations(c:\Docume~1\jbaldwin\mydocu~1\mamu\2005\z2\,
                 c:\progra~1\distan~1\)
  %analysis(zone2_2005,500,3,0);

 * Zone 3;
  %FileLocations(c:\Docume~1\jbaldwin\mydocu~1\mamu\2005\z3\,
                 c:\progra~1\distan~1\)
  %analysis(zone3_2005,500,3,0);

* Zones 4 and 5;
  options mprint;
  %FileLocations(c:\Docume~1\jbaldwin\mydocu~1\mamu\2005\z45\,
                 c:\progra~1\distan~1\)
  %analysis(zone45_2005,250,3,0);

  run;
* AtSeaMacros.sas;

* Contains macros used in the bootstrap process;

* Version 1.0, February 2, 2001;
* Jim Baldwin, Pacific Southwest Research Station;

%macro analysis(filename,nbootstraps,noModelAssist,FixedWidth);

  * Main analysis routine for obtaining estimates;

  /*
     Parameters           Description
     filename            Name of Excel data file (mamu3, mamu45, etc.) (Don't put in
     .xls extension)
     nbootstraps          Number of bootstrap runs (1,000 takes about 3 hours)
     noModelAssist        3 for no model assisted estimation
     FixedWidth           0 => line transect estimation.  Any positive number is
     interpreted as the transect halfwidth for fixed-width transect estimation
  */

  * First, set some of the constants that will rarely be changed;
    %global maxC maxPSU maxStrata TruncateP maxf0;
```

[1]Appendix 5 was developed by Jim Baldwin, U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, P.O. Box 245, Berkeley, CA 94701.

```
    %let maxC = 100;              * Maximum number of clusters in a stratum;
    %let maxPSU = 100;            * Maximum number of PSUs within a cluster;
    %let maxStrata = 4;           * Maximum number of strata per zone;
    %let TruncateP = .05;         * Truncation proportion;
    %let maxf0 = 1;               * Maximum value of f0 allowed;
    %if &FixedWidth > 0 %then %let TruncateP = .00;

  * Estimate density (without the bootstrap);
    data summary; run;
    %settings(nobootstraps=1,nbootstraps=1,nomodelassist=&noModelAssist,
              notempfiledelete=0,FixedW=&FixedWidth)
    %boot(&filename..xls)
    data raw; set summary;

  * Bootstrap runs (if any);
    %if &nbootstraps > 0 %then %do;

        * Discard all log output to get ready for bootstrap runs;
          filename logout dummy;
          proc printto log=logout;

        data summary; run; * Initialize summary file;
        %settings(nobootstraps=0,nbootstraps=&nbootstraps,nomodelassist=&noModelAssist,
                  notempfiledelete=0,FixedW=&FixedWidth)
        %boot(&filename..xls)
        data bootstraps; set summary;
        %summarize(bootstraps)
    %end;

  * Restart log output;
    proc printto;

  * Output all of the results to a text file that can be directly imported into Excel;
    %summarize(raw)
    data;
      set raw %if &nbootstraps > 0 %then bootstraps;;
      file "&datadir.summary_&filename..csv";

      if _n_ = 1 then put
         "Type,f0,Es,TruncateDistance,zone,density1,density2,density3,density4,"
         "stratumarea1,stratumarea2,stratumarea3,stratumarea4,"
         "birds1,birds2,birds3,birds4,"
         "zonedensity,zonebirds,zonearea";

      put type "," f0 "," Es "," TruncateDistance "," zone ","
          density1 "," density2 "," density3 "," density4 ","
          stratumarea1 "," stratumarea2 "," stratumarea3 "," stratumarea4 ","
          birds1 "," birds2 "," birds3 "," birds4 ","
          zonedensity "," zonebirds "," zonearea;
      run;

%mend analysis;

%macro SetSeason(ssmonth,ssday,ssyear,eemonth,eeday,eeyear);
  * Sets the beginning and ending dates for the season.  Observations outside of these
    dates are not used in the analysis;

  %global smonth sday syear emonth eday eyear;

  * Starting date of season;
    %let smonth = &ssmonth;
```

```
    %let sday = &ssday;
    %let syear = &ssyear;
  * Ending date of season;
    %let emonth = &eemonth;
    %let eday = &eeday;
    %let eyear = &eeyear;

%mend SetSeason;

%macro summarize(summary);

  * Summarizes results;

  * Remove the first record as it just contains missing values and add in
    estimates of the number of birds;
  data xsummary;
    set &summary;

  data &summary;
    set &summary;
    drop z5area1 z5area2 z5density1 z5density2;

    if "&summary" = "raw" then type = "Raw "; else type = "Boot";

    * Skip lines that contain missing values for Zone;
      if zone = . then delete;

    * Separate Zones 4 and 5;
    if zone = 45 then do;
       zone = 4;
       z5area1 = stratumarea3;
       z5area2 = stratumarea4;
       z5density1 = density3;
       z5density2 = density4;
       stratumarea3 = .;
       stratumarea4 = .;
       density3 = .;
       density4 = .;
       zonedensity = (stratumarea1*density1+stratumarea2*density2)/
(stratumarea1+stratumarea2);
       zonearea = stratumarea1 + stratumarea2;
       output;
       zone = 5;
       stratumarea1 = z5area1;
       stratumarea2 = z5area2;
       density1 = z5density1;
       density2 = z5density2;
       zonedensity = (stratumarea1*density1+stratumarea2*density2)/
(stratumarea1+stratumarea2);
       zonearea = stratumarea1 + stratumarea2; output; end;
    else output;

  data &summary;
    set &summary;
    if stratumarea1 ne . then birds1 = density1*stratumarea1; else birds1 = .;
    if stratumarea2 ne . then birds2 = density2*stratumarea2; else birds2 = .;
    if stratumarea3 ne . then birds3 = density3*stratumarea3; else birds3 = .;
    if stratumarea4 ne . then birds4 = density4*stratumarea4; else birds4 = .;
    zonebirds  = zonedensity*zonearea;
  proc sort data=&summary out=&summary;
    by zone;
```

```
  proc means data=&summary mean stddev n;
    by zone;
    run;

%mend summarize;

%macro FileLocations(data,prog);

  * Sets the data file and program file directories;

  %global datadir distdir;

  %let datadir = &data;
  %let distdir = &prog;

%mend FileLocations;

%macro settings(nobootstraps,nbootstraps,nomodelassist,notempfiledelete,fixedW);

  * Sets common settings;

  %global noboot nboot noassist nodelete FixedWidthOnly TransectHalfWidth;

  %let noboot = &nobootstraps;
  %let nboot = &nbootstraps;
  %let noassist = &nomodelassist;
  %let nodelete = &notempfiledelete;
  %let TransectHalfWidth = &fixedW;
  %if &fixedW = 0 %then %let FixedWidthOnly = 0; %else %let FixedWidthOnly = 1;
  %put “FixedWidthOnly = &FixedWidthOnly”;

%mend settings;

%macro MakeDen;
* Create Distance batch file for densities (first analysis from Laake and Raphael);
data;
  file “&datadir.mamu1.txt”;
  put “out1.txt”;
  put “log1.txt”;
  put “densitystats.txt”;
  put “boot1.txt”;
  put “plot1.txt”;
  put “Options;”;
  put “  Type=Line;”;
  put “  Length /Measure=’Kilometers’ /Units=’Kilometers’;”;
  put “  Distance=Perp /Measure=’Meters’ /Units=’Meters’;”;
  put “  Area /Units=’Sq. kilometers’;”;
  put “  Object=Cluster;”;
  put “  SF=1;”;
  put “  Selection=Sequential;”;
  put “  PValue=.150;”;
  put “  Lookahead=1;”;
  put “  Maxterms=5;”;
  put “  Bootstraps=999;”;
  put “  Seed=0;”;
  put “  Confidence=95;”;
  put “  Print=Selection;”;
  put “End;”;
  put “Data /Structure=Flat;”;
  put “  Fields=STR_LABEL, STR_AREA, SMP_LABEL, SMP_EFFORT, DISTANCE, SIZE;”;
  put “  Infile=’&datadir.mamu.dat’;”;
```

```
  put “End;”;
  put “Estimate;”;
  put “  Distance /Nclass=7 /Width=&TruncateDistance /Left=0;”;
  /* put “  Distance /Intervals=0,20,40,60,80,100,120,140,160,180,200,210,220,240,260 /
Width=&TruncateDistance /Left=0;”; */
  /* put “  Distance /Nclass=9 /Width=180 /Left=0;”; */
  put “  Density=All;”;
  put “  Density=Stratum /Design=Strata /Weight=Area;”;
  put “  Encounter=Stratum;”;
  put “  Detection=All;”;
  put “  Size=All;”;
  put “  Estimator /Key=HN /Adjust=CO /Criterion=AIC;”;
  /* put “  Estimator /Key=HA /Adjust=CO /Criterion=AIC;”; */
  put “  Estimator /Key=UN /Adjust=CO /Criterion=AIC;”;
  put “  Monotone=Strict;”;
  put “  Pick=AIC;”;
  put “  GOF;”;
  put “  Cluster /Bias=GXLOG /Test=.15;”;
  put “  VarN=Empirical;”;
  put “End;”;
  run;
%mend MakeDen;

%macro MakeER;

* Create Distance batch file for encounter rates
  (second analysis from Laake and Raphael);
data;
  file “&datadir.mamu2.txt”;
  put “out2.txt”;
  put “log2.txt”;
  put “erstats.txt”;
  put “boot2.txt”;
  put “plot2.txt”;
  put “Options;”;
  put “  Type=Line;”;
  put “  Length /Measure=’Kilometers’ /Units=’Kilometers’;”;
  put “  Distance=Perp /Measure=’Meters’ /Units=’Meters’;”;
  put “  Area /Units=’Sq. kilometers’;”;
  put “  Object=Cluster;”;
  put “  SF=1;”;
  put “  Selection=Sequential;”;
  put “  PValue=.150;”;
  put “  Lookahead=1;”;
  put “  Maxterms=5;”;
  put “  Bootstraps=999;”;
  put “  Seed=0;”;
  put “  Confidence=95;”;
  put “  Print=Selection;”;
  put “End;”;
  put “Data /Structure=Flat;”;
  put “  Fields=STR_LABEL, STR_AREA, SMP_LABEL, SMP_EFFORT, DISTANCE, SIZE;”;
  put “  Infile=’&datadir.mamu.dat’;”;
  put “End;”;
  put “Estimate;”;
  put “  Distance /Width=&TruncateDistance;”;
  /* put “  Distance /Intervals=0,20,40,60,80,100,120,140,160,180,200,220,240,260 /
Width=&TruncateDistance /Left=0;”; */
  put “  Encounter by Sample;”;
  put “  Estimator /Key=HN /Adjust=CO /Criterion=AIC;”;
  /* put “  Estimator /Key=HA /Adjust=CO /Criterion=AIC;”; */
```

```
  put "  Estimator /Key=UN /Adjust=CO /Criterion=AIC;";
  put "  Monotone=Strict;";
  put "  Pick=AIC;";
  put "  GOF;";
  put "  Cluster /Mean;";
  put "  VarN=Empirical;";
  put "End;";
  run;
%mend MakeER;

%macro MakeBat;
* Create the MS-DOS batch file to run Distance;
data;
  file "&datadir.mamu.bat";
  put 'echo off';
  put 'rem Batch file for estimating density with Distance';
  put ' ';
  put 'rem Run the first analysis that creates densitystats.txt';
  put "cd &datadir";
  put "&distdir.d4 0 mamu1.txt";
  put ' ';
  put 'rem Run the second analysis that creates erstats.txt';
  put "&distdir.d4 0 mamu2.txt";
  put ' ';
  put 'rem Add to complete results file';
  put 'type results.txt >> bootstrap.txt';
  put ' ';
  put 'rem Keep track of log files and outputfiles for testing purposes';
  put 'rem type log1.txt >> logs.txt';
  put 'rem type out1.txt >> logs.txt';
  put ' ';
  *if &noDelete = 0 then do;
  *   put 'rem Clean-up';
  *   *put 'del log1.txt';
  *   put 'del log2.txt';
  *   put 'del boot1.txt';
  *   put 'del boot2.txt';
  *   put 'del plot1.txt';
  *   put 'del plot2.txt';
  *   put 'del out1.txt';
  *   put 'del out2.txt';
  *   put 'del results.txt';
  *   put 'del densitystats.txt';
  *   put 'del erstats.txt';
  *   put 'del PSUBoot.txt';
  *   put 'del Strtm.txt';
  *   put 'del mamu.dat';
  *   put 'del bootstrap.txt';
  *   put ' ';
  *end;
  put 'rem Return to SAS';
  put 'exit';
  run;
%mend MakeBat;

%macro GetPSU;
  proc sort data=PSUFile out=PSUFile;
    by zone stratum psu;
    run;

  * Now turn areas into an array by strata;
```

```
  data PSUInfo;
    set PSUFile;
    by zone stratum psu;
    array area(200) a1-a200;
    array psuID(200) psuID1-psuID200;
    retain a1-a200 psuID1-psuID200 nn;
    keep zone stratum a1-a200 psuID1-psuID200 nn;

    if first.stratum then do;
       nn=0;
       do i=1 to 200; area(i)=.; psuID(i)=.; end;
    end;
    if first.psu then do;
       nn = nn + 1;
       area(nn) = psuarea;
       psuID(nn) = psu;
    end;
    if last.stratum then output;
    run;

  proc sort data=PSUInfo out=PSUInfo;
    by zone stratum;
    run;

%mend GetPSU;

%macro GetDetect;

  * Get a listing of the clusters within a strata;
  proc sort data=Project out=Project;
    by zone stratum cluster psu days;

  data bootraw1;
    set Project;
    by zone stratum cluster;
    keep zone stratum cluster;
    if first.zone or first.stratum or first.cluster then output;

  proc sort data=bootraw1;
    by zone stratum cluster;
    run;

  * Get a listing of the PSU-date combinations for each cluster
    within each stratum;
  data bootraw2;
    set Project;
    by zone stratum cluster psu days;
    keep zone stratum cluster psu days;
    if first.zone or first.stratum or first.cluster or first.psu or first.days then output;

  proc sort data=bootraw2;
    by zone stratum cluster psu days;

  run;

%mend GetDetect;

%macro TruncateBoot;

  * Removes the observations with the largest 100p percent of the distances;
```

```
  * Get a dataset just with detections;
  data detections;
    set boot;
    if n > 0;
    run;

  * Sort by perpendicular distance;
  proc sort data=detections out=detections;
    by perp_dist;
    run;

  * Determine truncation distance;
  data;
    set detections nobs=nobs;
    retain k;
    * Determine nearest integer to nobs*(1-&TruncateP);
    if _n_ = 1 then k = int(nobs*(1-&TruncateP) + .5);
    if _n_ = k then call symput('TruncateDistance',perp_dist);
    run;

%mend TruncateBoot;

%macro GetBoot;

  * Get a random sample of clusters;
  data boot1;
    set bootraw1;
    by zone stratum cluster;
    array cl(&maxc) cl1-cl&maxc;     * Array of cluser IDs;
    array clf(&maxc) clf1-clf&maxc;  * Arrary of frequencies for clusters;
    retain seed nclusters cl1-cl&maxc;
    keep zone stratum cluster f;
    if _n_ = 1 then seed = -1;

    if first.stratum then nclusters=0;

    if first.cluster then do; nclusters=nclusters + 1; cl(nclusters) = cluster; end;

    if last.stratum then do;
       do i=1 to nclusters; clf(i) = 0; end; * initialize counts of clusters;
       * Generate a random cluster number;
       do i=1 to nclusters;
          k = 1 + int(nclusters*uniform(seed)); if k > nclusters then k = nclusters;
          clf(k) = clf(k) + 1;
       end;
       * Make output data set with cluster and frequency of selection;
       do i=1 to nclusters;
          if &noboot=1 then do; * Undo bootstrap selection if &noboot=1;
             f = 1;
             cluster = cl(i);
          end;
          else do;
             f = clf(i);
             cluster = cl(i);
          end;
          output;
       end;
    end;

    run;
```

```
proc sort data=boot1;
  by zone stratum cluster;

data boot;
  merge boot1 bootraw2;
  by zone stratum cluster;
  if f ne 0;

  run;

* Dataset boot has the random sample of clusters with the associated frequency;
* Now select PSUs with replacement;
data boot;
  set boot;
  by zone stratum cluster;
  keep zone stratum cluster psu days f;

  array fp(&maxPSU) fp1-fp&maxPSU;
  array p(&maxPSU) p1-p&maxPSU;
  array d(&maxPSU) d1-d&maxPSU;
  retain seed n p1-p&maxPSU d1-d&maxPSU;
  if _n_ = 1 then seed = -1;

  if first.cluster then n=0;

  n = n + 1;
  p(n) = psu;
  d(n) = days;

  if last.cluster then do;
     do j = 1 to n; fp(j) = 0; end; * initialize PSU frequencies;
     * Select random sample of clusters;
     do i = 1 to f;
        do j = 1 to n;
           k = 1 + int(n*uniform(seed)); if k>n then k=n;
           fp(k) = fp(k) + 1;
        end;
     end;
     * Output dataset of randomly selected PSUs with frequencies;
     if &noboot=1 then do;
        do j = 1 to n;
           psu = p(j);
           days = d(j);
           f = 1;
           output;
        end;
     end;
     else do;
        do j = 1 to n;
           if fp(j) > 0 then do;
              psu = p(j);
              days = d(j);
              f = fp(j);
              output;
           end;
        end;
     end;
  end;

* Now merge with raw data;
data boot;
```

```
    merge Project boot;
    by zone stratum cluster psu days;
    if f ne .;

    run;

  * Now determine truncation distance;
  %put "TruncateBoot";
  %TruncateBoot

%mend GetBoot;

%macro GetFixedWidthDensity;

  * Estimates density based on a fixed width transect of size &TransectHalfWidth;

  %put "GetFixedWidthDensity";

  %let Es = .;
  %let f0 = .;

  data bootxx;
    set boot;
    by zone stratum cluster psu days rep subpsu;
    retain count;

    if first.subpsu then count = 0;

    * Change counts to zero if perpendicular distance > &TransectHalfWidth;
    if perp_dist ne . then do;
       if perp_dist > &TransectHalfWidth then do;
          perp_dist = .;
          n = 0;
       end;
    end;

    count = count + n;

    if last.subpsu then output;

  * Now get density per PSU-day-rep combination;
    proc sort data=bootxx out=bootxx;
      by zone stratum cluster psu days rep;

    data bootxxx;
      set bootxx;
      by zone stratum cluster psu days rep;
      retain density totalarea;

      if first.rep then do;
         density = 0;
         totalarea = 0;
      end;
      density = density + subpsuarea * 1000 * count / (&TransectHalfWidth * 2 * survey_ef-
fort);
      totalarea = totalarea + subpsuarea;

      if last.rep then do;
         density = density / totalarea;
         output;
      end;
```

```
      %put ”Exiting GetFixedWidthDensity”;
      run;

%mend GetFixedWidthDensity;

%macro CleanUp;
* Clean up left-over files;
data;
  file ”&datadir.cleanup.bat”;
  put ”echo off”;
  if &noDelete = 0 then do;
     put ”del &datadir.mamu.bat”;
     put “del &datadir.mamu1.txt”;
     put “del &datadir.mamu2.txt”;
     put “del &datadir.log1.txt”;
     put “del &datadir.log2.txt”;
     put “del &datadir.boot1.txt”;
     put “del &datadir.boot2.txt”;
     put “del &datadir.plot1.txt”;
     put “del &datadir.plot2.txt”;
     put “del &datadir.out1.txt”;
     put “del &datadir.out2.txt”;
     put “del &datadir.results.txt”;
     put “del &datadir.densitystats.txt”;
     put “del &datadir.erstats.txt”;
     put “del &datadir.PSUBoot.txt”;
     put “del &datadir.Strtm.txt”;
     put “del &datadir.mamu.dat”;
     put “del &datadir.bootstrap.txt”;
  end;
  put ”exit”;
  run;
x ”&datadir.cleanup.bat”;
%mend CleanUp;

%macro MakeBoot;

* Expand based on the frequencies of selection;
  data boot;
    set boot;
    do rep = 1 to f; output; end;
    run;

  proc sort data=boot out=boot;
    by zone stratum cluster psu days rep subpsu;
    run;

  data bootxx;
    set boot;
    by zone stratum cluster psu days rep subpsu;
    keep zone stratum psu subpsu rep survey_effort days
         psuarea subPSUarea stratumarea PSUNum;
    retain PSUNum;
    if _n_ = 1 then PSUNum = 0;
    if last.subpsu then do;
       PSUNum = PSUNum + 1;
       output;
    end;

  proc sort data=bootxx out=bootxx;
    by PSUNum;
```

```
* Makes file readable by Distance and obtains info for creating PSUBoot.txt;
  data psuareas;
    set boot;
    by zone stratum cluster psu days rep subpsu;
    file ”&datadir.mamu.dat”;
    keep psuarea1 psuarea2 psu zone stratum;
    retain nstrata PSUNum psuarea1 prevPSUNum;

    * Initialize counters for unique strata and unique psu-subunits;
    * (This is because I think Distance requires this.  The problem
       occurs when two consecutive entries have the same psu id and
       have zero counts.  Either having unique ids or separating the
       observations seems to work.);
    if _n_ = 1 then do;
       nstrata = 0;
       PSUNum = 0;
       prevPSUNum = -1;
    end;
    if first.stratum then do; nstrata = nstrata + 1; end;
    if first.subpsu then do; PSUNum = PSUNum + 1; end;

    %put stratum cluster psu days rep subpsu n;
    if n = 0 then do;
       *put nstrata stratum ’09’x stratumarea ’09’x PSUNum psu 3.0 subpsu
           ’09’x survey_effort ’09’x ’09’x;
       * Do not put out a zero if the previous observation has a non-zero count as
         Distance 3.5 complains;
         if prevPSUNum ne PSUNum then
            put stratum ’09’x stratumarea ’09’x PSUNum psu 3.0 subpsu
           ’09’x survey_effort ’09’x;
    end;
    else do;
       *put nstrata stratum ’09’x stratumarea ’09’x PSUNum psu 3.0 subpsu
           ’09’x survey_effort ’09’x perp_dist ’09’x n;
       put stratum ’09’x stratumarea ’09’x PSUNum psu 3.0 subpsu
           ’09’x survey_effort ’09’x perp_dist ’09’x n;
    end;
    if subpsu = ”N” then psuarea1 = subpsuarea;
    if subpsu = ”x” then do;
       psuarea1 = subpsuarea; psuarea2 = 0;
    end;
    if last.subpsu and subpsu = “O” then do;
       psuarea2 = subpsuarea; output;
    end;
    if last.subpsu and subpsu = “x” then do;
       psuarea1 = subpsuarea; psuarea2 = 0; output;
    end;

    prevPSUnum = PSUnum;

    run;

%mend MakeBoot;

%macro TooFew;

  * Checks for warning from Distance that there are too few observations;

  * Macro variable “status” is set to “1” if sufficent observations,
    “0” if too few observations;
```

```
  %put “TooFew”;
  %let status=1;
  run;
  data log1;
    length logrecord $ 50;
    infile “&datadir.log1.txt” missover;
    input logrecord $ 1-50;

    * Initialize status;

    * Check for a line in log1.txt that contains “number of observations is small”;
    if index(logrecord,”number of observations is small”) > 0 then do;
      call symput(“status”,”0”);
    end;
    run;
    %put “Status = &status”;
    run;

%mend TooFew;

%macro GetERStats;

  * Now get encounter rates for each PSUNum from erstats.txt;
  data erstats;
    infile “&datadir.erstats.txt”;
    keep PSUNum numobs;
    if _n_ = 1 then input;
    input istrat isample iest imod istat value;
    if imod = 1 and istat = 1 then do;
       PSUNum = isample;
       numobs = value;
       output;
    end;

  proc sort data=erstats out=erstats;
    by PSUNum;
    run;

  data bootxx;
    merge bootxx erstats;
    by PSUNum;
    erate = numobs / survey_effort;
    run;

%mend GetERStats;

%macro GetDensity;
  * Reads DensityStats.txt and retrieves the estimates of f(0) and E(s).
    The values are put into macro variables called &f0 and &es.
  ;

  %put ”GetDensity”;
  data density;
    infile ”&datadir.densitystats.txt”;

    if _n_ = 1 then input;
    input istrat isample iest imod istat value;

    if istrat = 0 and isample = 0 and imod = 2 and istat = 4 then do;
       call symput(’f0’,value);
    end;
```

```
  if istrat = 0 and isample = 0 and imod = 3 and istat = 4 then do;
     call symput('es',value);
  end;
run;

%GetERStats

data bootxx;
  set bootxx;
  density = 1000 * erate * &f0 * &es / 2;

* Now get individual PSU-day-rep estimates of density;
proc sort data=bootxx out=bootxx;
  by zone stratum psu days rep subpsu;

data bootxxx;
  set bootxx;
  by zone stratum psu days rep subpsu;
  keep zone stratum psu PSUNum density psuarea days psudays stratumarea;
  retain PSUDensity TotalArea;
  if first.rep then do;
     PSUDensity = 0;
     TotalArea = 0;
  end;
  PSUDensity = PSUDensity + density*subpsuarea;
  TotalArea = TotalArea + subpsuarea;
  if last.rep then do;
     density = PSUDensity / TotalArea;
     psudays = psu*days;
     output;
  end;

  run;

* Make data file with subPSU densities;
data bootsubpsu;
  set bootxx;
  by zone stratum psu days rep subpsu;
  keep zone stratum psu days neardensity neararea nearbirds fardensity fararea farbirds;
  retain neardensity neararea nearbirds;
  if subpsu = "N" then do;
     neardensity = density;
     neararea = subpsuarea;
     nearbirds = density*subpsuarea;
  end;
  if subpsu = "O" then do;
     fardensity = density;
     fararea = subpsuarea;
     farbirds = density*subpsuarea;
     output;
  end;
  if subpsu = "x" then do;
     neardensity = density;
     neararea = subpsuarea;
     nearbirds = density*subpsuarea;
     fardensity = .;
     fararea = 0;
     farbirds = .;
     output;
  end;
  run;
```

```
    proc means data=bootsubpsu mean noprint;
      by zone stratum psu;
      var fardensity neardensity farbirds nearbirds fararea neararea;
      output out=bootsubpsusum mean=fardensity neardensity farbirds nearbirds
                                  fararea neararea;
      run;

    %put "Exiting GetDensity";

%mend GetDensity;

%macro ModelAssist;

  * Calculate the model assisted estimate for each strata;

  * Perform model-assisted regression (just one regression for zone);
  proc reg data=bootxxx outest=bootr noprint;
    model density = psu days psudays;
    run;

  data;
    set bootr;
    call symput('Intercept',Intercept);
    call symput('b_psu',psu);
    call symput('b_days',days);
    call symput('b_psudays',psudays);

  data boots;
    merge PSUInfo StratumFile;
    by zone stratum;
    keep a1-a100 psuID1-psuID100 stratum Intercept
         b_psu b_days b_psudays nn stratumarea f0 Es;
    f0 = &f0;
    Es = &Es;
    Intercept = &Intercept;
    b_psu = &b_psu;
    b_days = &b_days;
    b_psudays = &b_psudays;
    run;

  data bootg;
    set boots;
    array area(100) a1-a100;
    array psuID(100) psuID1-psuID100;
    keep zone stratum density stratumarea f0 Es;

    * Determine number of days in time period of interest;
    ndays = juldate(mdy(&emonth,&eday,&eyear)) - juldate(mdy(&smonth,&sday,&syear)) + 1;

    stratum_mean = 0;
    totalarea = 0;
    *put 'nn = ' nn;
    *put stratum 3.0 @;
    *do j = 1 to nn;
       *put psuID(j) 5.0 @;
    *end;
    *put ;
    do i = 1 to ndays;
       *put i 3.0 @;
       do j = 1 to nn;
          den = Intercept + b_psu*psuID(j) + b_days*i + b_psudays*i*psuID(j);
```

```
          *put den 5.1 @;
          if den < 0 then den = 0;
          stratum_mean = stratum_mean + area(j)*den;
          totalarea = totalarea + area(j);
       end;
       *put ;
    end;
    density = stratum_mean / totalarea;
    *put ;
    *put density;
    *put ;

  * Calculate weighted mean (weighted by stratum area);
    proc sort data=bootg out=bootgg;
      by zone stratum;

  * Now combine stratum estimates to a single zone estimate;

    * Attach stratum areas to stratum means;
    data bootv;
      merge bootgg StratumFile;
      by zone stratum;

    data bootv;
      set bootv end=LastOne;
      by zone stratum;
      keep Zone ZoneArea ZoneDensity nstrata Density1-Density&maxStrata
           StratumArea1-StratumArea&maxStrata f0 Es;
      array den(&maxStrata) density1-density&maxStrata;
      array sarea(&maxStrata) StratumArea1-StratumArea&maxStrata;
      retain ZoneDensity nstrata ZoneArea Density1-Density&maxStrata
             StratumArea1-StratumArea&maxStrata;

      if _n_ = 1 then do; ZoneDensity = 0; ZoneArea = 0; nstrata = 0; end;

      nstrata = nstrata + 1;
      ZoneDensity = ZoneDensity + density * stratumarea;
      if ZoneDensity = . then do;
         put stratum density stratumarea;
      end;
      ZoneArea = ZoneArea + stratumarea;
      *den(nstrata) = density;
      den(stratum) = density;
      *sarea(nstrata) = Stratumarea;
      sarea(nstratum) = Stratumarea;

      if LastOne = 1 then do;
         ZoneDensity = ZoneDensity / ZoneArea;
         output;
      end;
    run;

%mend ModelAssist;

%macro NoAssist;

  * Estimates mean density without the model-assisted approach;

  proc sort data=bootxxx out=bootxxx;
    by zone stratum;
```

```
  proc means data=bootxxx mean noprint;
    by zone stratum;
    var density stratumarea;
    weight psuarea;
    output out=bootzzz mean=den sarea;

  proc sort data=bootzzz out=bootzzz;
    by zone stratum;

  * Now put results for each stratum into a single record;
  data bootv;
    set bootzzz nobs = NumObs;
    by zone stratum;
    array density(&maxstrata) density1-density&maxStrata;
    array stratumarea(&maxstrata) stratumarea1-stratumarea&maxStrata;
    retain density1-density&maxStrata stratumarea1-stratumarea&maxStrata
           nstrata ZoneArea ZoneDensity;
    keep zone stratum density1-density&maxStrata stratumarea1-stratumarea&maxStrata
         Es f0 nstrata ZoneArea ZoneDensity;

    if _n_ = 1 then do;
       nstrata = 0;
       ZoneArea = 0;
       ZoneDensity = 0;
    end;

    nstrata = nstrata + 1;
    ZoneArea = ZoneArea + sarea;
    density(nstrata) = den;
    ZoneDensity = ZoneDensity + den*sarea;
    stratumarea(nstrata) = sarea;

    if _n_ = NumObs then do;
       ZoneDensity = ZoneDensity / ZoneArea;
       f0 = &f0;
       Es = &Es;
       output;
    end;

%mend NoAssist;

%macro WeightedPSU;
  * Estimates weighted mean density of PSU means;

  %put "WeightedPSU";

  * Get PSU means;
    proc sort data=bootxxx out=bootxxx;
      by zone stratum psu;

   proc means data=bootxxx mean noprint;
      by zone stratum psu;
      var density psuarea stratumarea;
      output out=bootzzz mean=density psuarea stratumarea;

  * Get weighted means of PSU means;
    proc sort data=bootzzz out=bootzzz;
      by zone stratum;

    proc means data=bootzzz mean noprint;
      by zone stratum;
```

```
      var density stratumarea;
      weight psuarea;
      output out=bootvv mean=den sarea;

    proc sort data=bootvv out=bootvv;
      by zone stratum;

  * Now put results for each stratum into a single record;
    data bootv;
      set bootvv nobs = NumObs;
      by zone stratum;
      array density(&maxStrata) density1-density&maxStrata;
      array stratumarea(&maxStrata) stratumarea1-stratumarea&maxStrata;
      retain density1-density&maxStrata stratumarea1-stratumarea&maxStrata
             nstrata ZoneArea ZoneDensity;
      keep zone stratum density1-density&maxStrata stratumarea1-stratumarea&maxStrata
           Es f0 f00 nstrata ZoneArea ZoneDensity TruncateDistance;

      if _n_ = 1 then do;
         nstrata = 0;
         ZoneArea = 0;
         ZoneDensity = 0;
      end;

      nstrata = nstrata + 1;
      ZoneArea = ZoneArea + sarea;
      *density(nstrata) = den;
      density(stratum) = den;
      ZoneDensity = ZoneDensity + den*sarea;
      *stratumarea(nstrata) = sarea;
      stratumarea(stratum) = sarea;

      if _n_ = NumObs then do;
         ZoneDensity = ZoneDensity / ZoneArea;
         f00 = &f0;
         f0 = &f0;
         if f0 > &maxf0 then do;
            abort return;
            f0 = &maxf0;
            ZoneDensity = &maxf0 * ZoneDensity / f00;
            do i=1 to &maxStrata;
               if density(i) ne . then density(i) = &maxf0 * density(i) / f00;
            end;
         end;
         Es = &Es;
         TruncateDistance = &TruncateDistance;
         output;
      end;

    %put "Exiting WeightedPSU";

%mend WeightedPSU;

%macro TimeAssist;

  * Estimates mean density with the model-assisted approach only on time;

    data bootg;
      density = 1.2;
      run;
```

```
%mend TimeAssist;
%macro GetData;

* Import MAMU data from Excel into SAS;

  %put "&datadir.&datafile";
  %put "----------------------";

* Get Stratum File;
  PROC IMPORT OUT=StratumFile
    DATAFILE="&datadir.&datafile"
    DBMS=EXCEL2000 REPLACE;
    GETNAMES=YES;
    RANGE = "Strata$";

  proc sort data=StratumFile out=StratumFile;
    by zone stratum;

  run;

* Get PSU Info;
  PROC IMPORT OUT=PSUFile
    DATAFILE="&datadir.&datafile"
    DBMS=EXCEL2000 REPLACE;
    GETNAMES=YES;
    RANGE = "PSUs$";

  data PSUFile;
    set PSUFile;
    drop near_area off_area;
    psuarea = near_area + off_area;
    if zone = 1 and stratum = 3 then do;
      subpsu = "x"; subPSUarea = near_area; output;
    end;
    else do;
      subpsu = "N"; subPSUarea = near_area; output;
      subpsu = "O"; subPSUarea = off_area; output;
    end;
    run;
  proc sort data=PSUFile out=PSUFile;
    by zone stratum PSU subpsu;

  * Make a dataset with just the PSU totals;
  data PSUInfo;
    set PSUFile;
    by zone stratum PSU;
    drop subpsu subPSUarea;
    if first.PSU;

* Get Cluster info;
  proc import out=clusters0
    datafile="&datadir.&datafile"
    dbms=excel2000 replace;
    getnames=yes;
    range="Clusters$";

  data clusters;
    set clusters0;
    mo = month(date);
    dy = day(date);
    yr = year(date);
```

```
  proc sort data=clusters out=clusters;
    by zone stratum psu yr mo dy;

* Get detection data;
  PROC IMPORT OUT=project
    DATAFILE="&datadir.&datafile"
    DBMS=EXCEL2000 REPLACE;
    GETNAMES=YES;
    RANGE = "Project$";
  run;

  %put 'Project 1';
  data project0;
    set project;
  data project1;
    set project;
    drop PSUID;
    if zone = . then delete;  * Remove any data lines with a missing zone;
    subpsu = substr(PSUID,length(PSUID));
    psu = input(substr(PSUID,1,length(PSUID)-1),1.);
    *mo = month(datepart(date));
    *dy = day(datepart(date));
    *yr = year(datepart(date));
    mo = month(date);
    dy = day(date);
    yr = year(date);
    %if &FixedWidthOnly = 0 %then %do;
       if perp_dist = -1 then do;
          delete;  * Get rid of records with missing values;
          put "Deleted because perp_dist = -1";
       end;
    %end;
    if n = 0 then perp_dist = .;

    * Number of days since starting date;
    days = juldate(mdy(mo,dy,yr)) - juldate(mdy(&smonth,&sday,&syear)) + 1;
  proc sort data=project1 out=project1;
    by zone stratum psu yr mo dy;
   %put 'Project after some manipulation';
    run;

 * Merge project and cluster information;
  data project2;
    merge project1 clusters;
    by zone stratum psu yr mo dy;

  proc sort data=project2 out=project2;
    by zone stratum psu subpsu;

  %put 'Merged with project and cluster information';
    run;

  * Merge with stratum and PSUFile;
  %put "Merge with stratum and PSUFile";
  data project3;
    merge project2 PSUFile;
    by zone stratum psu subpsu;
    if cluster ne .;  * Get rid of unsampled PSUs;

  proc sort data=project3 out=project3;
    by zone stratum psu subpsu;
```

```
  %put "Merged with PSUFile";
    run;

  %put "Merge project and StratumFile";
  data project4;
    merge project3 StratumFile;
    by zone stratum;
    if survey_effort ne .;

  proc sort data=project4 out=project;
    by zone stratum cluster days psu subpsu;

  run;

%mend GetData;

%macro boot(data);

  * Make bootstrap runs;

  %global status f0 Es datafile;

  * Initialize bootstrap results file;
    data;
      file "&datadir.bootstrap.txt";
      run;

  * Initialize some macrovariables;
    %let status = .;
    %let f0 = .;
    %let Es = .;
    %let maxStrata = 4;
    %let datafile = &data;
    %put "&datafile";
    %put "****************";
    %put "&data";
    %put "****************";
    run;

  * Initialize some datasets;
    data boot;
    data bootxx;
    data bootxxx;
    data bootz;
    data bootzzz;
    run;

  * Make MS-DOS batch file to run Distance batch files;
    %MakeBat

  * Get input data (stratum, PSU, and observations);
    %GetData
    %GetDetect
    %GetPSU

  %if "&noboot" = "1" %then %let nboot = 1;

  * Perform bootstrap iterations;
  %do ii = 1 %to &nboot;
```

```
* Get a random sample of clusters within each stratum
  and then a random sample of PSUs within clusters;
  %put ”GetBoot”;
  %GetBoot

* Write to mamu.dat in a format that Distance can read;
  %put ”MakeBoot”;
  %MakeBoot

* Make distance batch file for estimates of density and encounter rates;
  %put ”MakeDen”;
  %MakeDen
  %put ”MakeER”;
  %MakeER

* Create PSUBoot.txt;
  data;
    set psuareas;
    file ”&datadir.PSUBoot.txt”;
    put psuArea1 psuArea2;
    run;

* Create Strtm.txt;
  data sfile;
    merge psuareas StratumFile end=LastStrata;
    by zone stratum;
    retain npsu nstrata;

          if _n_ = 1 then nstrata = 0;
    if first.stratum then do; nstrata = nstrata + 1; npsu = 0; end;
    npsu = npsu + 1;
    if last.stratum then output;
    if LastStrata=1 then call symput(’nstrata’,nstrata);
    run;
  data;
    set sfile;
    file ”&datadir.Strtm.txt”;
    if _n_ = 1 then put ”&nstrata”;
    put stratumarea npsu npsu;
    run;

%put ”Fixed width only: &FixedWidthOnly”;
%if &FixedWidthOnly = 0 %then %do;

    * Run analyses with Distance;
    * (Output will be in bootstrap.txt);
      x ”&datadir.mamu.bat”;
      run;

    * Check for too few observations;
      %TooFew

    * If there are too few observations, then estimate density based on a
      fixed width transect of size &TransectHalfWidth;
      %if &status = 0 %then %do;
          %put ”Fixed width density being estimated”;
          %GetFixedWidthDensity;
      %end;

    * Otherwise get estimates of f(0) and E(s) and PSU densities;
      %if &status = 1 %then %GetDensity;
```

```
    %end;
    %else %do;
       %let status = 0;
       %GetFixedWidthDensity;
    %end;

    * Model-assisted adjusted mean or not?;
      %if &noassist = 0 %then %ModelAssist;
      %if &noassist = 1 %then %NoAssist;
      %if &noassist = 2 %then %TimeAssist;
      %if &noassist = 3 %then %WeightedPSU;

    * Accumulate results;
      data summary;
        set summary bootv;
        run;

    * Clean up SAS ODS results files;
      dm 'odsresults' clear;
      run;

  %end;

  * Delete some temporary files;
  *%CleanUp;

%mend boot;
```

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