ABUNDANCE AND REPRODUCTIVE INDICES OF MARBLED MURRELETS AND OTHER ALCIDS IN OREGON DURING 2000: RESULTS OF AT-SEA MONITORING.

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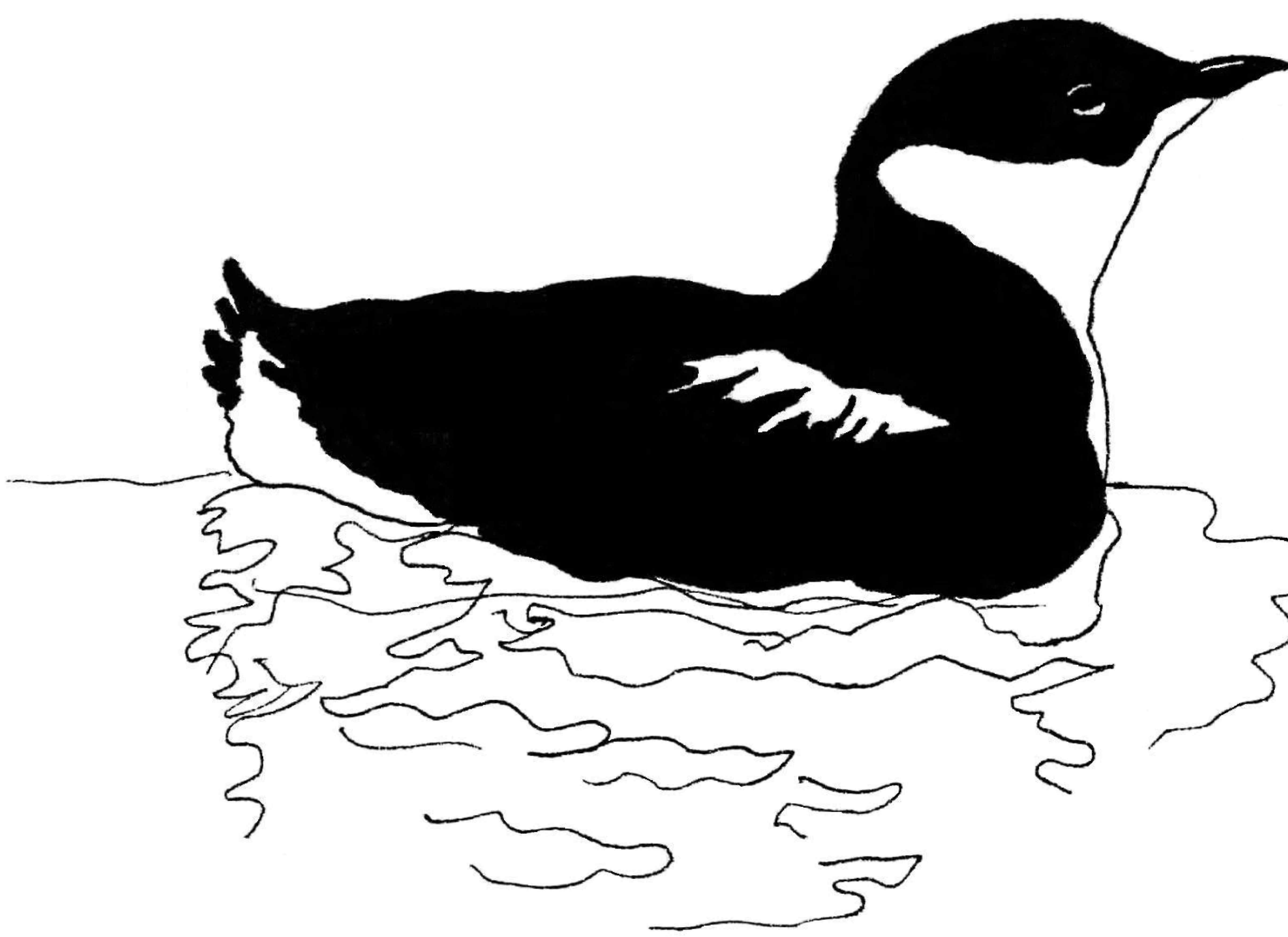

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SUMMARY

Marbled Murrelets have been surveyed by vessel along the Oregon coastline using a standard protocol since 1992. In 2000 the survey protocol remained the same, but a new design of transect layout was initiated in an attempt to minimize variability and obtain statistically sound measures of density, following the pilot program of at-sea Marbled Murrelet monitoring under the Effectiveness Monitoring Portion of the Presidents Forest Plan. This report describes how the pilot year of the Monitoring Plan program at sea was implemented in Marbled Murrelet Conservation Zone 3 by Crescent Coastal Research, and the northern (Oregon) portion of Zone 4 by CCR in cooperation with the U.S. Forest Service' Redwood Sciences Laboratory. Also included are results of the 2000 season, population estimates, productivity indices, and a comparison of the new program to prior years results.

Murrelet distribution was similar to other cold, upwelling years during 2000 in that they were concentrated close to shore. Mean density, calculated by strip or line transect analysis, was markedly lower than in all prior years in Conservation Zone 3 (northern and central Oregon), even when using the subset of 2000 data most comparable to earlier years. The Marbled Murrelet population for this area was estimated at 6,465 birds. Indices of productivity were higher than in any other year, with a state average of 8.04% of birds aged as hatch-year fledglings. These findings could not directly be attributed to the different sampling design, and may indicate a continued decline in the adult population coupled with a successful nesting season.

It was not possible to follow the program of stratified random sampling of Primary Sample Units in the prescribed order developed for the Monitoring Plan through the field season due to weather and mechanical problems. However, sampling was dispersed through space and time, and a bootstrap randomization scheme developed by the at-sea working group allowed statistical sampling a posteriori to meet the assumptions of the Plan.

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DISCLAIMER

The analyses and interpretation of data presented in this report are the product of Crescent Coastal Research and do not necessarily represent the views of the Oregon Department of Fish & Wildlife or the U.S. Fish and Wildlife Service.

INTRODUCTION

The Marbled Murrelet (*Brachyramphus marmoratus*) is a small diving seabird of the Alcid family which is on the Federally Threatened Species list, and is state listed as endangered or threatened in California, Oregon, and Washington (Nelson, 1997). Because their nests are dispersed and difficult to locate within old forests on the west coast, most research on overall abundance and reproductive output is conducted at sea, where the birds are concentrated within a few km of shore on the open coast (Miller and Ralph 1995, Strong 1995, Nelson 1997, Becker et al. 1997). Since 1992 Crescent Coastal Research has conducted standardized boat transects of the nearshore waters to monitor the abundance and distribution of Marbled Murrelets along the Oregon coast (Strong and Carten 2000). By 1994 we developed indices of productivity and tracked the relative reproductive success of the murrelets, as well as that of Common Murres, Pigeon Guillemots, and Rhinoceros Auklets (Strong 1996). During 2000 a new sampling design to monitor the murrelet population was initiated for our transects and for other researchers in the 3 state area by the At-Sea Working Group under the Effectiveness Monitoring component of the Northwest Forest Plan (Madsen et al. 1997, Bentivoglio 2001). In this report we provide a description of the new design and how some parameters of sampling were chosen, and present population estimates for Oregon using the new and prior survey program. A summary of densities of murrelets and their reproductive success in 3 regions of the Oregon coast during 2000 is compared with those from 1992-1999.

METHODS

Equipment

Vessel surveys were made from 20 ft. boats equipped with marine radio, compass, Global Positioning System receiver (GPS), and digital sonar depth finder, which also relayed sea surface temperature. Other equipment included binoculars, digital watches, and micro tape recorders for each person, maps covering planned transect lines, and buoys on measured lines. The deck of the boat is about level with the waterline, and observer viewing height is about 2 m above water. The GPS was loaded with the randomly selected transect route prior to each survey.

Observation Protocol and Personnel Duties

Two observers and a vessel driver were on board for all transects. Each observer scanned a 90° arc between the bow and the beam continuously, only using binoculars to confirm identification or to observe plumage or behavior of murrelets. Search effort was directed primarily towards the bow quarters and within 50 m of the vessel, so that densities based on line and narrow strip transects will be at their most accurate (Buckland et al. 1993). All seabirds within 50 m of the boat and on the water were recorded, and all Marbled Murrelets sighted at any distance were recorded with the following information:

A) Time of sighting to the minute.
B) Group size; a group being defined as birds within a few m of each other or vocalizing to one another.
C) Side of vessel, categorized as port, bow, and starboard.
D) Estimated perpendicular distance from the transect line to each murrelet detection.
D) Behavior in one of 5 categories: fly in apparent response to the vessel, flying by in transit, dive in possible response to the vessel, diving not in response to the vessel, and stay on the surface during vessel passage.
E) Molt class and age (see 'productivity assessment'), and noteworthy behavior such as fish carrying, vocalizing, or unusual flight or diving behavior.

Distance estimates were calibrated by towing a measured buoy at varying distances from the boat, 5 to 120 m away. First distances were told to observers to gain familiarity with estimation, then a series of distances were estimated where the buoy operator did not reveal the true distance until others had made their estimates. When all observers were consistently estimating within 5 m of the measured value when the buoy was within 60 m of the boat, and within 10 m when farther away, they were considered qualified. A formal test of estimation accuracy completed by Becker and Beissinger (1999) showed the CCR crew to average within 8% of the true distance with no bias toward higher or lower estimation.

Any association with other species or water characteristics (ie; current zones, scattering layers) were also recorded. All data were recorded on cassette tapes and later transcribed to forms and entered on computer. At the beginning and end of each transect segment, or when conditions changed (observing conditions, shore type, course heading, etc.), the time, location water temperature and depth, weather and observing conditions were recorded. Observing conditions as they relate to murrelet detectibility were rated excellent, very good, good, fair, and poor corresponding with beaufort sea states of 0 to 4, respectively, but observing conditions were also modified by effects of glare, fog, and other impairments to visibility.

The vessel driver maintained a speed of 10 knots, monitored course on the transect route and watched for navigational hazards. The driver participated in searching for murrelets when not otherwise occupied. Transects were paused sometimes to rest, make observations, or for equipment reasons. The time and distance elapsed are recorded at the beginning and end of all off-transect activities. Transects are resumed at the same approximate location where they left off. A break from duties was taken at least every 3 hours. This protocol is as has been used since 1996, with minor variations in earlier years.

Sampling design

The sampling format for estimating the abundance of murrelets has changed considerably from prior years to follow the new Marbled Murrelet Effectiveness Monitoring Plan, at-sea sampling design The design was developed over several years by the Working Group, and was in a pilot phase during the 2000 season.

Population Monitoring

The time period designated for monitoring the population of murrelets was selected between 20 May and 31 July, on the basis that breeding murrelets will be associated with nesting habitats during the incubation and nestling stages in this time (Hamer and Nelson 1995). Surveys during the final 10 days of July were used for both population and productivity assessment.

Transects were conducted within 20 km long Primary Sampling Units (PSU) arranged in a contiguous format along the coast (Fig. 1). The 20 km length was selected as a distance where both the inshore and offshore legs can be completed in less than one day, allowing completion before seasonal afternoon winds become strong. If wind remained light, then two PSU were sampled in a day. For the pilot study of this year, it was estimated that at least 30 PSU's be sampled within a Conservation Zone to make an inference about population size with relatively low variance. A complicated scheme was developed to sample the desired amount of PSU's in the 3 regions in a randomized spatial and temporal format while limiting logistic inefficiency (Appendix A). but this proved unworkable in the face of weather and other logistic complications. PSU sampling was dispersed in space and time, but was based on efficiency and logistic constraints (similar to prior year's sampling) rather than on the strategy outlined in Appendix A. Using either scheme, however, Primary Sampling Units were surveyed in spatial and temporal clusters where our boat was stationed in one area for several surveys (see *Data Analysis)*.

A higher level of effort was devoted to central Oregon, which has had higher densities, to minimize variance around this more important area. To do this, two strata are distinguished within Conservation Zone 3: a northern strata from the Columbia River to Cascade Head (140 km 7 Primary Sampling Units), and a southern strata, from Cascade Head to Coos Bay (200 km, 10 Primary Sampling Units, Fig. 1). The strata boundaries correspond almost exactly with the northern and central regions of Oregon in used from 1993 to 1999, and include an additional 38 km from the Columbia River to Tilamook Head at the north and 66 km from the Siuslaw River to Coos Bay at the south from the areas sampled from 1997 to 1999. In Conservation Zone 4 the Oregon coast extends for approximately 180 km, but we have included and additional 20 km into northern California to maintain consistency with earlier research, thus this region included 10 Primary Sampling Units. Surveys in Conservation Zone 4 were conducted cooperatively with the USFS Redwood Sciences Laboratories (RSL) to achieve the desired level of sampling.

On all parts of the contiguous United States range of murrelet, they concentrate in nearshore waters and occur with decreasing frequency out over the shelf waters (Nelson 1997). The actual shape of this distribution varies by region and by year, (Rachowicz and Beissinger 1999, Strong et al. 1995). To address this, the working group designated two subunits corresponding to areas with relatively high nearshore and low offshore density, and used the following density dependent formula to sample more heavily in the nearshore area and generate a minimum variance for the two areas:

$$ratio = a_i[d_i \,/\, a_o[d_o$$

where *ratio* is the proportion of survey effort devoted to inshore and offshore subunits, based on the area (*a*) and density (*d*) of each (densities for Zone 3 were from offshore distribution samples from 1993-1999). Researchers in each conservation zone selected their own boundaries between inshore and offshore subunits, and the outer limit of the offshore unit, beyond which was excluded from the target population. In 21 of 83 offshore sample transects conducted from 1992 to 1999 did surveys carry beyond 3000 m offshore, and in just 3 (3.6%) did they carry beyond 5000 m (these surveys ended where no murrelets were seen for one or more transects). Years in which surveys were carried beyond 5000 m were seasons of low primary productivity (1993, 1996) thus birds may have been increasing their foraging range. I considered a 5000 m outer limit of the sampled population as conservative with respect to including over 95% of the population within our boundaries, even considering annual variability. To determine the boundary between the high density inshore subunit and the low density offshore subunit, I examined where peak densities occurred in the 83 samples of offshore distribution from 1992-1999. Peak density occurred at 500 m in 49 cases, at 1000 m in 20 cases, and at 1500 m in 12 cases, and at 2000 m in only 2 instances (2.2%). I selected 1500 m as capturing the zone of high density. The intent of this selection was to avoid 'diluting' density estimates in their zone of peak occurrence with the generally lower values found offshore, while still maintaining some room for annual variability. In Zone 4 Redwood Sciences selected 2000 m as the inshore/offshore subunit boundary, and 3000 m as the outer limit for unknown reasons. Using the area of water surface from GIS mapping and densities of murrelets from prior surveys in the above formula, and with an inshore subunit transect length set at 20 km, we computed an offshore transect length of 24.6 km in the northern region (Zone 3 stratum 1), and of 17.1 km in the central region (stratum 2). In Zone 4, the offshore sampling effort was just 6 km based on Redwood Sciences Lab. data.

Transect Layout

Within the inshore subunit, four 5 km sections of coast were set at stratified-random distances from shore for a total transect length of 20 km, covering the length of the PSU. These segments were themselves divided into 4 categories of distance-to-shore and a specific distance, as well as the order of the categories, was chosen at random. Thus all categories of distance-to-shore within the inshore subunit were represented in each PSU survey. For example, distances may be at 450, 1250, 950, and 850 m in one PSU, and 1350, 550, 850, and 650 m in another, whatever a calculator random number generated for a PSU (the 50 m break points were selected to avoid overlap between subunits). Within the offshore subunit, a zig-zag pattern of transect was conducted with a randomized starting point. One or more complete cycles of zig-zags (ending up at the same distance offshore as at starting so that all shore distances have equal contribution to the detection rate), were conducted. The total length of the offshore sampling was based on the formula given above. One subunit, inshore or offshore, was selected at random to be the first conducted, and the alternate subunit was surveyed on the return trip to port.

Index of Productivity

The primary index of productivity for Marbled Murrelets was a simple ratio of hatch-year fledglings (HY) to after-hatch-year (AHY) birds, given as a percent HY. Because AHY may disperse following fledging, and most HY are seen in late July and August, I also used a ratio of AHY density during June or July to HY density in August, and this was the productivity index used for other alcids as well. How these indices represent actual production of young per breeding pair is not known, thus they can only be considered indices, which are comparable over years (but see Strong 1996, Kuletz and Kendall 1998). During 2000, age ratios were also computed as an average of the ratio in each PSU, grouped by stratum, Zone, or the state.

Determining the age of the birds is critical to obtaining valid productivity indices. The plumage of HY Marbled Murrelets at sea is very similar to the black-and-white basic plumage of older birds. Difficulty in age determination does not arise until AHY birds are in an advanced stage of prebasic molt, which is usually seen by late July or early August in some birds. Prior to August, HY Marbled Murrelets were easily told from older birds by bright white feathers on the belly, epaulets, and neck, compared with the overall darker appearance of alternate plumate or partially molted AHY birds. We tracked the progression of AHY molt through the season by categorizing the molt state of all murrelets detected as follows:

CLASS 1) Very little or no molt, entirely in alternate plumage.

CLASS 2) Obvious body molt with lighter neck and body color, but estimated at less than 50% of alternate plumage lost or replaced.

CLASS 3) Over 50% of alternate plumage lost or replaced, but still clearly distinguishable from HY birds by brown feathers on back, breast, and belly. Molting birds were placed in class 3 if their throat and neck appeared whitish in overall color.

CLASS 4) Appears to be in basic plumage when seen from a distance. By definition class 4 birds were those that required close examination to verify age. This class included all HY as well as advanced-molt AHY birds.

When birds in plumage class 4 (C4, advanced prebasic molt) were detected, the transect was halted and we approached more closely to record age determining characteristics. Characteristics that qualified a C4 bird as AHY were a) presence of dark brown alternate plumage feathers on back, neck, or breast, visible when viewed closely; b) presence of dark alternate plumage on the belly seen as it dove; or c) missing or molting flight feathers. Characteristics that qualified a bird as HY were a) crisp black and white plumage, sometimes with fine speckling on the breast; b) crisp plumage combined with an entirely white belly; and c) full, non-molting wings combined with other characteristics. The usefulness of these criteria was date-dependent and changed through August; presence of full, non-molting wings was the only conclusive criteria by late August, when all but the flight feathers of some AHY birds had been replaced with basic plumage (see Strong 1998). We also quantified behavioral components when examining C4 birds on an opportunistic basis: whether birds flapped their wings following the first avoidance dive due to our approach, and how strongly the birds remained paired or in a group

In August, transects were interrupted more frequently as the month progressed in order to examine birds in C4 molt. Transects resumed after every examination of a C4 bird and proceeded until the next C4 bird was encountered or the line was completed. Because productivity data collected in August were not to be used for population assessment, we did not attempt to randomize the ordering of PSU's and surveyed north to south for the most part.

Data Management and Analysis

Density of murrelets, in birds/km^2, was calculated in several ways. For all density calculations, only June and July data were used, only birds first detected on the water were included, and only surveys conducted at beaufort states of 3 or less were used. Area of each PSU was computed using GIS (by K. Ostrom in Zone 3 and B. Hogoboom in Zone 4). For the Marbled Murrelet Monitoring Plan, initiated this year, densities were first computed using line transect analyses with program DISTANCE (Laake et al. 1999, v. 3.5). Because PSU's were sampled in clusters of adjacent dates and PSU units, the data were run through a bootstrap program (J. Baldwin, T. Max, 2000 for the Monitoring Plan) which introduced a random selection of PSU's within the clusters and effectively creates a random selection a posteriori. Then to account for potential covariance between inshore and offshore subunits of each PSU and variations in their relative area, a program was developed to use DISTANCE output and generate a common density for each entire Zone and a valid variance estimate (J. Laake and M. Raphael 2000, program 'PSUvariance' for the Monitoring Plan). Options that varied from defaults in program DISTANCE were:

object= cluster
distance truncated at 5% of greatest distances, = 90 m in Zone 3
detection by all;
density by stratum;
estimator key= half-normal, adjustments= cosine;
estimator /key=uniform, adjustments= cosine;
estimator /key=hazard, adjustments= cosine;

Refer to the Monitoring Plan 2000 report (Bentivoglio et al. 2001) for further detail on the process of density and variance estimation by this method.

To compare density and abundance with prior years, data for the inshore and offshore subunits of each region (north, central and southern Oregon) were considered strata, and the mean density and variance of each were computed for each using both 100 m fixed strip transect and line transect analyses, with PSU's being sample units. A days effort, weighted by transect length, was the sampling unit of prior years. To more closely compare density values on the inshore 'coastline' transects run extensively in prior years at roughly 500 and 1000 m from shore, 2000 data were subdivided to only include transects within 200 m of those distances and the 5 km segments were considered sample units in comparison with 4 km divisions in long transects of prior years.

To assess productivity, we summed all data after 20 July (when most HY are present at sea) to produce an overall ratio of HY:AHY for comparison with earlier years. The mean ratio of encounter rate (number of birds/km of transect) for all PSU was also used, and a measure of variance and confidence intervals for the ratio were obtained by this method using the formula:

$$\text{Variance } Q = Q^2 \,(\text{var(HY)}/\text{HY}^2\,)+(\text{var(AHY)}/\text{AHY}^2) - (2*\text{covariance(HY-AHY)}/2*\text{AHY}))$$

where HY and AHY are encounter rates of each age grouop (number/km of transect), Q = the mean ratio of HY/AHY, and var(HY or AHY) is the variance of their encounter rate. Standard error, used in confidence intervals, is the square root of the variance. The mean monthly density of HY and AHY were calculated for all alcid species, and ratios of the density of HY:AHY at their peak month of occurrence were used as an additional means of comparing productivity indices among Common Murres, Pigeon Guillemots, Marbled Murrelets, and Rhinoceros Auklets.

RESULTS

Survey Effort

from 8 June to 25 August, a total of 37 days were spent conducting surveys at sea, during which 49 PSU were surveyed, covering a total of 1864 Km of transects. In addition, we surveyed 81 km of inshore habitat over 3 days late in the season to better assess HY distribution (Table 1). Due to an extended period of foul weather in mid June and a mechanical problems in July, we only surveyed 26 of the targeted 30 PSU in Zone 3 and 6 of the planned 10 PSU in Zone 4 during the population monitoring period (June and July). Two of these in Zone 3 were incomplete and discarded from density analysis. During the Productivity assessment period from 20 July to 25 August, however, we exceeded our goals by surveying 22 PSU in Zone 3 and 6 in Zone 4, where 20 and 5 had been planned. The randomized clustering of surveys was not completed in the same order as originally laid out due to weather and other logistic constraints (see Appendix A). However, an arbitrary selection of PSU clusters distributed in a disperse fashion through the season and along the coast was accomplished. During August, we did not attempt even an arbitrary geographic distribution of survey order, but conducted surveys north to south through the middle of the month to achieve maximum coverage.

Assisted by GIS routes, sampling the near shore waters using the 20 km long PSU format proved very workable, however we encountered two difficulties in following prescribed GIS-generated routes. First, on days where swell size caused breakers, we could not always safely follow the most near shore transect line. In the 7 cases where this occurred, we moved to the nearest distance offshore where safe navigation was possible, as detailed in Table 2. In some instances, GPS-generated routes led us into islands or reefs, or were consistently offset from the intended distance-from-shore. The offset problem occurred primarily in Zone 4 (at least 7 instances) where the route was set to a NAD83 geo-reference datum and our GPS was set to NAD27, and twice in northern Oregon, where the coastline has changed significantly since the 1927 datum was developed (in PSU 1 and the northern portion of PSU 2, along Clatsop Spit). These problems can be corrected with communication between GIS personnel and adjustments to the base map to include the small islets and reefs. Since we did not compare our GPS-generated track lines with the GIS routes, navigation error may have caused some minor differences from planned routes as well.

Distribution

The statewide pattern of distribution remained similar to all prior years: densities were relatively low to the north of Cascade Head (Zone 3 stratum 1, northern Oregon), high in central Oregon (Zone 3 stratum 2), and intermediate with some areas of high density in southern Oregon (Zone 4, Coos Bay to Pt. St. George, California, Fig. 1). As in other years, peak densities were found adjacent to the Siuslaw National Forest in central Oregon. Murrelets were concentrated close to shore throughout the season, with the density of birds in the inshore unit (300 to 1500 m) at 12 to 15 times that in the offshore subunit (1500 to 5000 m). Even in the offshore subunit, virtually all murrelet detections were in the inner half, less than 3000 m offshore. The only exception to this occurred in Zone 4 in PSU 9 and 10, where dispersal farther offshore was noted in other years. A seasonal increase in abundance in southern Oregon was noted during August, as in other years, but without a corresponding decrease in central Oregon (see Strong and Fisher 1998). It was difficult to have a sense of abundance or distribution in the field since the sampling effort was broken up by changing shore distance every 5 km and covered just 20 km of coast per PSU.

Abundance

Densities of Marbled Murrelets were lower than in prior years for all 3 regions of the Oregon coast (Table 3). This was true even when the survey coverage was limited to the sample areas used since 1997 and distance-to-shore was selected from the data to be comparable with the focus of survey effort in prior years (Table 3 bottom row, and Strong 1999).

Population estimates for Zone 3 (northern and central Oregon) were somewhat lower for strip transect estimates and similar between the different line transect analytical techniques, ranging from 5,476 to 6,465 birds in 2000 (Table 4). The 3 line transect analyses shown are progressive refinements to obtain statistical validity and minimize variance estimates. The strip transect estimate was 84% of the Bootstrap line method estimate and 96% of the simple line transect estimate from DISTANCE. This is typical of the conservative results from strip transects, resulting from the assumption that all birds within the strip are detected (Strong 1996, Becker et al 1997). The difference between line transect densities cannot be easily explained.

Population estimates were lower for all methods than those calculated in 1999 for a smaller area of Zone 3 using strip transects. The 1999 estimate of 7,100 murrelets from Tillamook Head to Florence was 23% higher than the 2000 estimate even though the 2000 estimate included an additional 104 km of coastline from Columbia River to Coos Bay. GIS refinements in calculating sea surface area in 2000 slightly increased the area of calculation, making the difference even more extreme.

Productivity

A total of 94 Hatch-year and 48 After-Hatch year advanced molt (C4) murrelets were aged out of 168 black-and white (C4) birds detected, for an ageing success rate of 84%. This is similar or slightly lower than other years (range 81-91%, Strong and Carten 2000). Ten of the HY and 7 of the AHY were of unconfirmed age, where cues during observation were not adequate to confirm the age with certainty, but enough to be reasonably confident. These were included in the productivity index data used below.

Where densities were at their lowest in comparison with prior years, productivity was at its highest in 2000. The overall ratio of HY to AHY murrelets for the state was 86:983 (8.04% HY) for all aged birds after 20 July, more than twice the highest ratio encountered through the 1990's (4.75% in 1992, Table 5). The mean HYAHY ratio from PSU samples was 1:0.1037 in northern Oregon (se = 0.181, n = 9) and 1:0.0657 central Oregon (se = 0.112, n = 15), or 1:0.080 for the whole Zone (se. = 0.0959, n = 24). In southern Oregon, data from Redwood Sciences Laboratories surveys produced a ratio of 23:207 (10.% HY), comparable with our counts of 29:232 (11.5% HY) for that area. The average ratio by PSU in Zone 4 was 1:0.936 (10.56% HY, se = 0.116, n = 14) from combined CCR and RSL surveys. Coefficients of variation around ratios based on PSU sampling were generally over 100%, resulting in unreasonable confidence intervals (from negative values to over twice the mean), thus the only useful information obtained by this method is in comparing ratios as qualitative indices among years and regions.

Higher productivity indices were not simply a result of lower AHY abundance, since the density of HY in central Oregon was a record high, and numbers of HY were above average despite the modest survey effort (Tables 5, 6). The consistency of results between CCR and RSL observers, who use differing methods in ageing birds, further confirms the relatively high productivity this year.

Oceanographically, 2000 was characterized by strong upwelling indices and high primary productivity. High primary productivity correlates well with high prey availability and corresponding reproductive success in the Common Murre (Boekelheide et al 1990, Jaques and Strong 2001), but until this year Marbled Murrelets have not shown a strong signal of increased productivity during cold water upwelling years, unlike the murres. Returns of several salmon species to the Columbia and other river systems have been at their highest in decades during 2000, corresponding with the good murrelet productivity this year, though the mechanics of the relationship are unknown.

DISCUSSION

The first issue of concern regarding the 2000 results is the large drop in murrelet densities from the previous 4 years, which were themselves lower than during the early 1990's. It is difficult to see how the new sampling program could have effected such a change itself, since it covers the same waters in similar proportion. Even when 2000 data are limited to the two distance-offshore strata where most effort was conducted in prior years, and to the same geographic regions, 2000 densities were just 72% of those in 1999 in central Oregon, the lowest recorded. Admittedly, the subset of data from 2000 for comparison with prior years results in a small sample size, but the complete data set shows a greater decline. Two of the 3 observers in 2000 had also been observers in prior years, and both were sharp and consistent in their effort, thus the difference cannot be explained by observer variability. Distribution of the murrelets showed a concentration close to shore, with a negligible number occurring over 3 km out to sea, so there is little possibility that a disproportionate number were farther offshore than in other years. It is possible that the sampling effort missed a number of high density patches of the birds close inshore, but not likely, since a drop in numbers was apparent in two regions. We are left with the likelihood that the decline observed through the 1990's is continuing (Strong in prep.). The slight differences in the bootstrap estimate values of this report from that of Bentivoglio (2001) are due to slightly different areas of sea surface used in extrapolation to abundance.

Our analysis did not include birds first detected in flight. Flying birds comprised 11.2% of the 908 detections in Zone 3 (all data), but their contribution to the density estimates would be less than this since flying birds were farther away from the transect line. For the 50 m fixed strip width (as used in Table 4), just 40% of flying birds were included within the strip, where 78.5% of birds detected on the water were included. Thus if flying birds were included in the fixed strip, it would have increased the estimate by about 4.5% (0.112*0.4). For line transect analysis, the change would be less, as the density is based on f(0), the detection rate at and very near the transect line. For example, at 25 m 89.2% of flying birds would not be included in the estimate. Flying birds have not been included in analyses during the 1990's in Oregon, but have been included elsewhere in their range (eg; inland waters of Washington, M. Raphael pers. comm.). Including or omitting flying birds should be standardized between all zones in coming years.

There is the possibility that the observed productivity changes this year are the consequence of a longer term climatic shift. Some researchers have described a regime change from a warmer, low productivity period since the mid 1970's to a cooler more productive coastal ocean starting in 1999 (the 'Pacific Decadal Oscillation', Francis et al. 1998). If this were the case, and murrelet reproduction had been limited by prey resources, the decline in Oregon murrelet numbers witnessed through the 1990's may be halted or reversed due to oceanographic change. Alternatively the numbers may decline to a point supported by remaining nesting habitat, but it is not possible to say what that point is. Considering the lack of response in the murrelet productivity indices during severe El Nino events in the 1990's, it is unlikely that a change in oceanographic conditions will cause the population to rebound.

It would be of great value to have other means of population and productivity monitoring to evaluate the conclusions from these at-sea surveys. Radar monitoring of a few selected drainages in Oregon could provide a cost effective means of assessing change in the nesting population of murrelets. Radar surveys from 1996 to 1999 can be used as a baseline by which to assess more recent changes (Cooper et al. 2000).

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Table 1. Summary of daily survey coverage, Marbled Murrelets detected, and age ratios for 3 regions of the Oregon coast during 2000. Refer to Fig. 1 for PSU locations.

Date	Zone	Stratum	PSU	Transect length (km) inshore	Transect length (km) offshore	Total murrelets Detected Inshore	Total murrelets Detected offshore	Known-age Murrelets AHY	Known-age Murrelets HY
June 8	3	1	1	20	23.6	2	1	3	0
13	3	2	8	20	28.2	57	1	57	0
13	3	2	9	20	29.5	57	2	59	0
19	3	2	10	20	21.3	25	0	24	0
20	3	1	4	20	27.4	6	0	5	0
21	3	1	2	20	27.5	5	0	5	0
24	3	2	11	20	17.2	125	2	125	0
24	3	2	12	20	25.0	68	6	69	0
25	3	2	13	20	17.2	41	3	43	0
27	4	_	9	20	6.0	9	2	10	0
30	3	1	3	20	18.5	15	1	16	0
30	3	1	5	20	24.6	12	0	11	0
July 1	3	1	6	20	24.6	20	1	20	1
1	3	1	7	20	24.6	21	0	21	0
2	3	2	8	20	17.2	24	0	15	0
2	3	2	9	20	17.2	47	4	39	0
3	3	2	15	20	25.0	20	2	22	0
4	3	2	17	20	17.2	42	5	44	0
14	3	2	10	20	17.2	18	6	24	0
15	4	_	7	20	6.0	15	0	15	0
16	4	_	10	20	6.0	19	11	31*	2*
18	4	_	8	20	6.0	0	0	-	-
19	4	_	1	20	6.0	37	4	39	2
19	4	_	2	20	6.0	32	0	19	3
21	3	2	16	20	17.2	16	16	30	1
22	3	2	14	20	17.2	133	0	104	5
22	3	2	15	20	17.2	29	1	25	0
24	3	2	11	2.2*	17.2	7	0	6	0
25	3	1	3	20	nd	9	-	9	0
25	3	1	4	20	24.6	0	2	2	0
26	3	1	5	20	24.6	12	3	13	1
26	3	1	7	20	18.2	6	2	7	0
August 10	3	1	1	20	24.6	4	0	4	0
10	3	1	2	20	24.6	3	0	2	1
11	3	1	6	20	24.6	10	0	10	0
12	3	2	10	20	17.2	51	0	44	6
13	3	2	11	20	17.2	222	0	190	17
13	3	2	12	20	17.2	86	1	77	2
14	3	2	14	20	17.2	50	1	47	3
14	3	2	15	20	17.2	72	0	56	2

Table 1, continued.

Date	Zone	Stratum	PSU	Transect length (km) inshore	Transect length (km) offshore	Total murrelets Detected Inshore	Total murrelets Detected offshore	Known-age Murrelets AHY	Known-age Murrelets HY
15	3	2	16	20	17.2	5	0	5	0
15	3	2	17	20	17.2	7	0	6	0
16	4	_	2	20	6.0	102	3	81	15
17	4	_	5	20	6.0	60	0	31	5
17	4	_	6	20	6.0	22	0	21	1
18	4	_	8	29.5*	6.0	47	0	35	6
18	4	_	9	30.5*	6.0	33	0	27	0
19	4	_	10	20	6.0	24	19	37	2
22	3	2	9	20	17.2	12	0	11	1
23	3	2	13	20	17.2	45	0	30	5
24	3	2	8	20	17.2	32	0	23	2
24	3	2	9	18.5*	-	70	-	48	10
25	3	1	3	20	24.6	4	0	3	1
25	3	1	4	20	24.6	2	0	2	0
TOTAL	37								

*Incudes transects other than PSU sampling.

Table 2. Instances where distance-to-shore was adjusted from the prescribed transect route,

				Shore distance		
Date	Zone	PSU	Segment	Planned	Actual	Notes, cause
6/08	3	1	D	950	500	Route off, beach change since datum?
6/13	3	9	A	350	650	Swells.
6/13	3	8	C	350	500	Swells.
6/19	3	10	B	850	1050	Go around reefs.
6/19	3	10	C	550	550-850	Swells, vary on/off route dep. water depth.
6/20	3	4	A	450	500	Swells.
6/21	3	2	B, N. end	950	350	Route off, beach change since datum?
7/14	3	10	A	350	400-550	Swells.
7/16	4	10	D	450	450	Route is 300 m inshore of our course.
7/16	4	10	C	1350	950	Route 350 m inshore of planned, datum?
7/16	4	10	B	1150	850	Route is 350 m inshore of where stated.
7/18	4	8	A	650	850	Kelp for 3.5 of 5 km segment.
7/19	4	1	D	1150	850	Route 300 m inshore of where stated.
7/19	4	1	B	650	850	Kelp, reefs, and route not where planned.
7/19	4	2	D	550	350	Route still further inshore of us, datum?
7/19	4	2	A	1150	850	Route is 350 m inshore of where stated.
8/10	3	2	D	450	450-700	Swells for ½ of segment
8/12	3	10	A	1050	850	Planned route is over reef, stay inshore.
8/13	3	11	D	550	550-850	Go around Alsea rivermouth bar.
8/13	3	12	A	750	850	Waypoint/GPS error
8/17	4	5	B	850	850-1050	Kelp for ½ of segment
8/25	3	4	D	350	450	Swells.

Table 3. Marbled Murrelet densities (birds/km^2) in the inshore waters (250 to 1250 m out to sea) for 3 regions of the Oregon coast from 1992 to the present. Data are based on 100 m wide fixed strip transects during June and July, only including birds seen on the water in good to excellent observing conditions. In 'portion' during 2000 only transects <750 m and transects between 850 and 1150 m offshore were used to compare with extensive transects at roughly 500 and 1000 m offshore in other years.

		Region								
		Northern Oregon			Central Oregon			Southern Oregon to Pt. St. George, northern Calif.		
Year	Area*	mean	std. dev.	n days	mean	std. dev.	n days	mean	std. dev.	n days
1992	All	7.45	2.23	3	83.65	28.37	12	23.05	3.86	2
1993	All	15.40	13.54	3	41.00	27.59	15	11.85	9.68	4
1995	All	8.55	0.95	2	62.55	25.89	7	22.20	13.05	5
1996	All	6.65	3.20	3	35.10	20.21	7	13.45	11.95	6
1997	Portion	7.25	12.73	4	27.85	13.60	13	6.35	2.91	7
1998	Portion	6.90	3.29	4	28.75	4.70	13	7.15	7.25	5
1999	Portion	6.11	5.94	3	23.96	23.47	12	5.42	7.41	5
2000	All	3.27	2.02	11	15.79	11.27	14	5.67	5.25	6
2000	Portion	3.69	6.05	8	17.37	19.65	9	4.73	9.18	6

* All refers to survey coverage of the entire region, portion includes survey coverage from Tillamook Head to Cascade Head in northern Oregon, Cascade head to Florence in central Oregon, and Rogue River to Pt. St. George in southern Oregon.

Table 4. A comparison of methods in computing density and abundance of Marbled Murrelets in Conservation Zone 3 during June and July, 2000 using the same data set from 24 Primary Sampling Units surveyed in June and July. Densities include area-weighted data from the offshore subunit, thus are lower than those of Table 3.

Statistic	Analysis method			
	100 m fixed strip transect	Line transect		
		DISTANCE	PSUvariance	Bootstrap
Density per km^2	3.514	3.640	3.748	4.149
Std. deviation	3.100	1.209	2.878	1.207
Coeff.. Variation	0.882	0.138	0.119	0.291
Population est.	5,476	5,672	5,841	6,465
95% C.I.	3,436 - 7,516	4,284 - 7,509	4,587 - 7,437	3,671 - 10,766

Table 5. Number of after hatch year (AHY) and hatch year fledgling (HY) Marbled Murrelets and percent HY for 3 regions of the Oregon coast. Data include all aged birds after 20 July, 1992 to 2000.

Year	Northern		Central		Southern		State total	
	HY/AHY	(%HY)	HY/AHY	(%HY)	HY/AHY	(%HY)	HY/AHY	(%HY)
1992	7/99	(6.60)	70/2229	(3.04)	20/967	(2.03)	97/3295	(2.86)
1993	7/441	(1.56)	16/1606	(0.99)	No data		23/2047	(1.11)
1994	6/119	(5.04)	23/883	(2.54)	19/555	(3.31)	48/1557	(2.99)
1995	14/100	(12.28)	33/1199	(2.68)	33/728	(4.34)	80/2027	(3.80)
1996	7/91	(7.14)	62/2343	(2.58)	22/716	(2.98)	91/3150	(2.81)
1997	4/51	(7.27)	26/1265	(2.01)	17/340	(4.76)	47/1656	(2.76)
1998	9/93	(8.82)	30/1500	(1.96)	11/440	(2.44)	50/2033	(2.40)
1999	7/79	(8.14)	38/1522	(2.44)	20/639	(3.03)	65/2240	(2.82)
2000	3/49	(5.77)	54/702	(7.14)	29/232	(11.55)	86/983	(8.04)
2000 including Redwood Sciences data					52/439	(10.59)	109/1190	(8.39)

Table 6. Densities per km^2 of 4 alcid species in 3 regions of the Oregon coast from 1996 to 2000 divided by age. Density (D) is total birds/total km of survey during their month of peak abundance. HY/AHY is the ratio of Hatch-Year to After-Hatch-Year densities at their month of peak abundance, and in parentheses is the total number of birds on which the ratio was based.

		Species							
		Common Murre		Pigeon Guillemot		Marbled Murrelet		Rhinoceros Auklet	
		AHY	HY	AHY	HY	AHY	HY	AHY	HY
Northern Region, Zone 3 stratum 1									
1996	D	63.76	0.59	18.75	0.22	6.65	0.510	0.56	0.37
	HY/AHY	0.009	(1092)	0.012	(258)	0.077	(120)	0.661	(13)
1997	D	82.39	0.667	17.35	1.467	7.21	0.533	0.598	0.133
	HY/AHY	0.0081	(969)	0.0845	(214)	0.0739	(189)	0.223	(8)
1998	D	76.78	14.00	18.97	0.64	7.65	0.770	1.28	0.90
	HY/AHY	0.182	(1634)	0.034	(306)	0.101	(139)	0.703	(38)
1999	D	104.40	22.22	16.78	0.70	14.26	0.35	1.39	0.50
	HY/AHY	0.213	(1641)	0.042	(207)	0.024	(171)	0.36	(17)
2000	D	119.83	18.25	7.58	0.677	3.75	0.167	0.333	0.155
	HY/AHY	0.152	(1658)	0.089	(99)	0.045	(47)	0.500	(6)
Central Region, Zone 3 stratum 2									
1996	D	86.51	0.79	6.44	0.22	32.74	0.38	1.60	0.13
	HY/AHY	0.009	(2570)	0.034	(200)	0.012	(977)	0.081	(96)
1997	D	34.31	2.23	8.95	1.75	36.65	0.559	3.92	0.28
	HY/AHY	0.065	(1721)	0.195	(153)	0.0152	(1312)	0.071	(60)
1998	D	47.36	1.07	8.63	0.68	32.25	0.640	3.83	0.61
	HY/AHY	0.023	(2356)	0.079	(440)	0.020	(561)	0.159	(131)
1999	D	49.80	20.77	8.14	1.21	33.58	0.688	3.21	0.74
	HY/AHY	0.417	(2351)	0.149	(355)	0.019	(1345)	0.23	(118)
2000	D	50.68	36.97	5.50	1.01	24.92	2.34	1.60	0.28
	HY/AHY	0.729	(1627)	0.183	(88)	0.094	(329)	0.175	(32)
Southern Region, Zone 4, Coos Bay to Pt. St. George, California									
1996	D	25.61	0.81	10.65	1.38	25.29	1.38	6.49	0.19
	HY/AHY	0.032	(914)	0.130	(165)	0.055	(368)	0.029	(206)
1997	D	69.83	4.34	11.38	1.03	20.65	1.25	13.46	0.22
	HY/AHY	0.062	(1274)	0.09	(162)	0.061	(347)	0.016	(178)
1998	D	54.52	0.00	9.04	0.19	18.45	0.58	2.21	0.29
	HY/AHY	0.000	(567)	0.021	(96)	0.031	(54)	0.131	(26)
1999	D	55.89	29.35	8.58	1.70	23.19	0.50	11.94	0.28
	HY/AHY	0.53	(2114)	0.20	(145)	0.022	(129)	0.02	(300)
2000	D	70.20	14.20	16.00	1.50	8.20	1.36	4.36	0.71
	HY/AHY	0.202	(844)	0.094	(127)	0.166	(101)	0.163	(67)

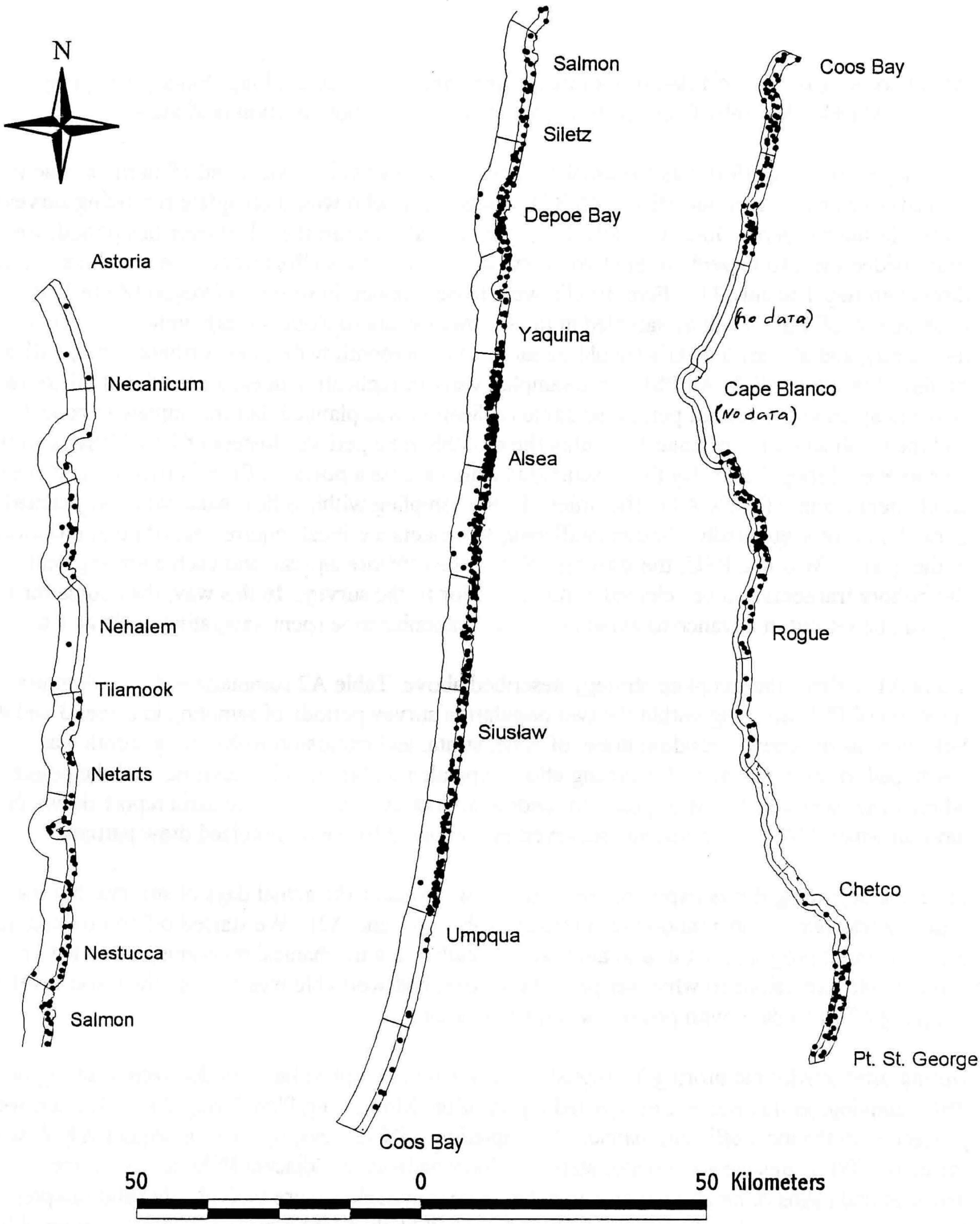

Figure 1. A representation of Marbled Murrelet Primary Sampling Unit boundaries in Conservation Zone 3 strata 1 and 2, and the Oregon portion of Zone 4 (from left to right). Dots represent murrelet detections, placed randomly within the near or off shore subunit of each strata.

Appendix A. Concept and design for randomized sampling of 20 km long Primary Sampling Units in Marbled Murrelet Conservation Zone 3 and the northern portion of Zone 4.

The target sampling effort was to complete surveys of 30 PSU in Zone 3 and 10 in the northern 10 PSU of Zone 4 (in cooperation with RSL researchers, who would complete remaining surveys there) during the period June 1 to July 31. To temporally spread the effort over this period, we first divided the effort evenly in the two month interval (20 days effort from June 1 to June 30, 20 days from July 1 to July 31). Five PSU's were to be sampled in southern Oregon (Zone 4) in each period, all PSU's will be sampled in the southern strata of Zone 3 (with highest density of murrelets), and at least 5 PSU's should be sampled each month within the northern strata, with a preferred target of all 7. All PSU's are sampled without replication in each period, but all are re-sampled again in the second period, so some replication was planned, but incomplete in zone 4 and the north strata (1) of zone 3. Within the monthly time period, clusters of 2 to 5 PSU's were be surveyed during 2 to 3 day field excursions which access a portion of the Conservation Zone in an efficient manner (Table A1). The order of PSU sampling within a field excursion was planned at random (not sequentially, though inefficient, this meets a critical requirement of randomization in the plan). Within a PSU, the starting point of the offshore zig-zag and each 5 km segment of the inshore transects will be selected at random prior to the survey. In this way, the course for the day can be set out in advance to avoid errors and minimize time spent navigating while at sea.

Table A1 outlines the sampling strategy described above, Table A2 summarizes the random pre-selection of PSU ordering within the two population survey periods of sampling in Zones 3 and 4. Selection, as opposed to random draw, of zone, strata, and excursion within each month was developed to meet the ratio of sampling effort expended within each Zone/strata, and the points where order was selected as opposed to random are noted. Table 1 of the main report shows the days on which PSU's were actually surveyed as compared to the randomized draw pattern.

From the beginning it was expected that weather would alter the actual days of surveys, but the ordering was planned in a randomized format (Tables A1 and A2). We started off approximating the conceptual program, but due to alternating weather and mechanical problems, we ended up making field excursions to whatever part of the coast had workable weather and the lower level of sampling effort to date, with priority was given to Zone 3.

During productivity monitoring in August, we made no attempt to have randomized ordering of PSU sampling, as this was not designated a part of the Monitoring Plan during 2000. Rather, we proceeded in the most efficient manner of completing PSU surveys, by moving sequentially down the coast. While this clearly violates statistical independence of adjacent PSU coverage, the densities and ratios of hatch-year and after-hatch-year murrelets were biologically valid samples. In coming years, sampling for productivity indices will likely adopt a more statistically acceptable format.

Table A1. Summary of proposed geographic and temporal scheme to sample 17 Primary Sampling Units in two strata of Conservation Zone 3. All surveys are completed without replacement within the month/sampling format, and with random replacement if effort exceeds the minimum coverage.

Stratum	No of PSU	Field Excursion Area (access ports)	No. PSU/ excursion area	No. of Excursions/mo	Order of excursion selection	Order of PSU selection	Total PSU's sampled per month	season
Monitoring Plan program for sampling 30 PSU's (34) Zone 3, 10 PSU in Oregon portion of Zone 4								
North	7	Columbia R.	2	1	Random within stratum	Random within excursion	2	4
		Nehalem, Tillamook Bay	4 - 5	2			5	10
South	10	Depoe Bay, Newport	5 - 6	3	Random within stratum	Random within excursion	5	10
		Florence, Reedsport, Coos Bay	5	2 - 3			5	10
Zone 4	10	Coos Bay, Bandon, Port Orford	5	1	Coordinated With RSL	Random in excursion	2-3	4-6
		Gold Beach, Brookings	5	1	Coordinated with RSL	Random in excursion	2-3	4-6
Additional sampling of PSU's to obtain larger sample size, as time allows through entire season, Zone 3								
North	7	All	vary	as time allows	Random	Random	As time allows	
South	10	Depoe Bay, Newport	5	as time allows	Random in stratum	Random		
		Florence, Reedsport, Coos Bay	5	as time allows	Random in stratum	Random		
Sampling for productivity assessment, 21 July - 25 August								
North	7	All	7	2	Random	Random in excursion	5	5
South	5	Depoe Bay, Newport	5	2	Random	Random in excursion	5	5
	5	Florence, Reedsport, Coos Bay	5	2	Random	Random in excursion	5	5
Zone 4	5	Coos Bay to Brookings, (all)	5	2	Random	Random in excursion	5	5

Table A2. Summary of random draw ordering of PSU selection through two population sampling time periods between 20 May and 31 July for Marbled Murrelet surveys in Conservation Zones 3 and 4. S = selected criteria (as opposed to random), R= random number generator draw. In parentheses is the value chosen. Dashes indicate information is as above (ie: repeating sampling within excursion). 'Last' indicates last remaining choice within that hierarchy, thus it was the default choice.

Period 1: May 20 - June 25				Period 2: June 26 - July 31			
Zone	Strata	Excurs.	PSU	Zone	Strata	Excurs.	PSU
S (3)	S (2)	R (3)	R (9)	S (3)	R (1)	R (2)	R (6)
-	-	-	R (8)	-	-	-	R (3)
-	-	-	R (7)	S (3)	S (2)	R (3)	R (11)
S (3)	R (1)	R(1)	R (2)	-	-	-	R (8)
S (3)	R (2)	R (4)	R (15)	S (3)	R (2)	S (4)	R (12)
-	-	-	R (12)	-	-	-	R (17)
R (4)	na	R (1)	R (5)	-	-	-	R (13)
-	na	-	R (6)	R (4)	na	R (2)	R (10)
-	na	-	R (9)	-	-	-	(9) last
S (3)	S (2)	R (2)	R (17)	S (3)	S (2)	R (3)	R (9)
-	-	-	R (13)	-	-	-	R (10)
S (3)	R (2)	S (3)	R (11)	S (3)	R (2)	S (4)	R (16)
-	-	-	(10) last	-	-	-	R (15)
R (3)	S (1)	S (2)	R (6)	-	-	-	(14) last
-	-	-	R (5)	R (4)	na	(1) last	R (4)
S (3)	S (1)	(2) last	R (4)	-	-	-	(2) last
-	-	-	(3) last	S (3)	(1) last	R (1)	R (1)
R (4)	na	(1) last	R (2)	-	-	(2) last	R (5)
-	-	-	(3) last	-	-	-	(4) last
(3) last	(2) last	(4) last	R (14)	(3) last	(2) last	(3) last	(7) last
-	-	-	(16) last				