ABUNDANCE AND PRODUCTIVITY OF MARBLED MURRELETS OFF CENTRAL CALIFORNIA DURING THE 2010 and 2011 BREEDING SEASONS

Final Report Submitted to:

The Luckenbach and Command Oil Spill Trustees
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Funded by:
2010 Command Oil Spill Trustee Council
2011 Luckenbach Oil Spill Trustee Council

October 2012

Summary

We conducted at sea surveys for Marbled Murrelets (*Brachyramphus marmoratus*) in Conservation Zone 6 offshore of central California breeding habitat between Half Moon Bay and Santa Cruz in 2010 and 2011. Using distance sampling estimation techniques, we estimated the central California population in 2010 to be 366 (95% CL: 240-559) with surveys delineated from the north (n = 4), 560 (95% CL = 343-925) with surveys delineated from the south (n = 3), and 446 (95% CL: 340-585) with all surveys (n = 7). During 2011, we estimated the central California population to be 320 (95% CL: 225-454) with surveys delineated from the north (n = 2), 452 (95% CL = 331-618) with surveys delineated from the south (n = 4), and 433 (95% CL: 339-553) with all surveys (n = 6). These estimates are greater than 2007-2008, when the population was estimated to have experienced large declines, and are lower than estimates from 1999-2003 and in 2009, when abundance was estimated to have been relatively high. While source-sink metapopulation dynamics do not appear to be the major factor for observed increases, a temporary exodus of after-hatch-year birds may explain the recent 2007-2008 population dip. The date-corrected juvenile ratio, an estimate of productivity commonly used to index reproductive success in Marbled Murrelets, was 0.074 (SE = 0.033) and 0.091 (SE = 0.027) for 2010 and 2011, respectively. These are the highest recorded juvenile ratios for the central California Zone 6 population and may result from corvid management, favorable ocean conditions, and/or a relative increase in the proportion of the population nesting in low predation areas. Recent changes in adult population numbers and juvenile ratios are not sufficient to support positive population growth (λ). The long-term persistence of the Region 6 population may rest on targeting corvid management efforts towards the primary murrelet predators (i.e. Steller's Jays).

Introduction

The Marbled Murrelet (*Brachyramphus marmoratus*) is a small seabird that is federally-listed as Threatened and state-listed in California as Endangered. Potential threats to Marbled Murrelets in California include loss of old-growth forest nesting habitat, changes in prey (small fish and squid) availability, increasing predator populations, and oil spills (Carter and Anderson 1988, Peery et al. 2004, Peery and Henry 2010b)). To compensate for murrelet injuries due to oil spills, numerous oil spill trustee councils have provided funding for restoration, including protection of nesting habitat and management of predatory corvids. Over the last several years, the Command Trustee Council (for the 1998 *T/V Command* oil spill) and Luckenbach Trustee Council (for the 1992-2003 *S.S. Luckenbach* oil spill) have funded projects that provide restoration for the central California Marbled Murrelet population by reducing anthropogenic food sources for corvids in campgrounds and parks, by controlling ravens and crows (but not Steller's jays) through lethal removal, and by acquiring potential nesting habitat in the Santa Cruz Mountains, the only known nesting area for this population.

Monitoring changes in population and reproductive success is critical for assessing the effectiveness of conservation efforts. Population monitoring and the estimation of productivity based on the ratio of juveniles to adults are typically conducted for Marbled Murrelets using at sea surveys. Other methods, such as radar and audio-visual surveys, can be used to assess inland activity but do not provide estimates of population size or productivity. Under the Northwest Forest Plan, annual at sea monitoring occurs in California within Conservation Zones 4 and 5, from the Oregon border south to San Francisco Bay. Conservation Zone 6, from San Francisco Bay south to Monterey Bay (i.e. central California), is not included in the Northwest Forest Plan, but population monitoring within central California was conducted from 1999 through 2003 with a combination of state, federal, and private funding. No decline was detected during that period, despite the fact that reproductive success was too low to compensate for adult mortality (Peery et al. 2006a). To aid in determining the success of restoration efforts in the Santa Cruz Mountains, the Command Trustee Council funded at sea surveys in Zone 6 during the 2007 breeding season (Henkel and Peery 2008). These surveys suggested that the population had declined to 378 individuals in 2007 and 174 individuals in 2008 (based on survey transects delineated from both the north and the south, see below). The 2009 population estimate was 631 individuals, similar to the 661-699 individuals in the initial survey period (1999-2003). Here we report on similar surveys conducted in central California in 2010 and 2011.

Methods

Estimating Abundance

We conducted 7 at sea surveys between Half Moon Bay and Santa Cruz in 2010 (3 June to 28 July) and 6 surveys in 2011 (2 June to 8 August). Surveys were approximately 100 km long and followed zig-zag transect routes consistent with surveys conducted from 1999 through 2003, and 2007 through 2009 (Peery et al. 2006a, Henkel and Peery 2008, Peery et al. 2009, Peery and Henry 2010a). Surveys began at a random distance (200-2500 m) from shore, immediately outside of the Half Moon Bay Harbor. Transects included both a "nearshore" (200-1350 m from shore) and "offshore" stratum (1350-2500 m from shore), with approximately three times greater effort surveying the nearshore stratum due to historically greater bird densities near shore.

Starting in 2001, an equal number of routes were drawn using starting points at the north and south ends of the survey area. Previous analyses indicated that transects drawn from the south yielded higher densities than transects delineated from the north. Surveys were compiled separately (depending on delineation), in order to examine any bias, and to allow for comparability with 1999-2000 surveys.

For all surveys, we used line transect methods (Becker et al. 1997, Peery et al. 2006a). Two observers, standing on either side of a 6-m open skiff, recorded the angle off of the transect line and the distance to all groups of Marbled Murrelets. Prior to each survey, observers calibrated distance estimation using a laser rangefinder on buoys in the harbor. We counted birds in flight if they crossed a line perpendicular to the track line and even with the observers. Including flying birds in counts (2% of sightings in 2010 and 2011) may result in overestimation of abundance (Spear et al. 1992, Piatt et al. 2007); however, because this method was used for previous surveys in central California, we retained it for consistency. We analyzed sighting data using DISTANCE v.6.0 release 2 and estimated density using the following equation:

$$D = \frac{\hat{E}(n) \cdot \hat{E}(s)}{2L \cdot \widehat{ESW}}$$

where $E\hat{S}W$ was the estimated effective strip width, $\hat{E}(n)$ was the expected number of groups, $\hat{E}(s)$ was the expected number of birds per group, and L was the length of the line transect (km; Buckland et al. 2001).

Estimating *ESW* requires modeling the inevitable decline in detection probability as a function of distance from the sighting data. We discarded all detections >120 m from the transect lines and grouped the remaining detections into 7 20-m bins, similar to analyses conducted for previous years. We used a half-normal detection model with cosine adjustments to model detectability as a function of distances, as in previous years. To derive abundance from density estimates, we multiplied survey- and stratum-specific density estimates generated by DISTANCE by the total area of the stratum (104.65 km^2 for both strata).

Estimating Juvenile Ratios

We estimated juvenile ratios (the ratio of hatch-year to after-hatch-year individuals) for Marbled Murrelets based on surveys conducted from 10 July to 23 August (Julian Date 191 to 235 in perpetual years, 192 to 236 in leap years). Prior to 10 July, few (34%) young are expected to fledge, and after August 23, hatch-year and after-hatch-year murrelets become indistinguishable as the latter progress in their pre-basic molt (Peery et al. 2007). We included only birds of known age class to calculate juvenile ratios. We estimated the (observed or date-corrected, see below) juvenile ratio *R* in year *t* with the following equation:

$$\hat{R}_t = \frac{\sum_1^n H_i}{\sum_1^n A_i}$$

where H_i and A_i were the number of hatch-year and after-hatch-year individuals for survey *i*, respectively, and *n* was the number of surveys conducted in year *t* (Levy and Lemeshow 1991). We estimated $\text{var}(\hat{R}_t)$ as:

$$\hat{\text{var}}(\hat{R}_t) = \frac{1}{n}\left(\frac{\hat{\text{var}}(\hat{H}_t)}{\hat{\bar{A}}_t^2} + \frac{\hat{\bar{H}}^2\,\hat{\text{var}}(\hat{A}_t)}{\hat{\bar{A}}_t^4} - \frac{2\hat{\bar{H}}_t\,\hat{\text{cov}}(\hat{H}_t,\hat{A}_t)}{\hat{\bar{A}}_t^3}\right)$$

where $\hat{\text{var}}(\hat{H}_t)$ was the variance in the number of hatch-years observed in year *t*, $\hat{\text{var}}(\hat{A}_t)$ was the variance in the number of after-hatch-years observed in year *t*, $\hat{\text{cov}}(\hat{A}_t, \hat{H}_t)$ was the covariance between the number of hatch-years and after-hatch-years observed in year *t*, and $\hat{\bar{H}}_t$ and $\hat{\bar{A}}_t$ were the mean number of hatch-years and after-hatch-years observed in year *t*, respectively (van Kempen and van Vliet 2000). We estimated the mean juvenile ratio for the entire study period ($\hat{\bar{R}}$) by averaging unweighted annual estimates and estimated $\hat{\text{var}}(\hat{\bar{R}})$ as:

$$\hat{\text{var}}(\hat{\bar{R}}) = \frac{\sum_1^n \hat{\text{var}}(\hat{R}_t)}{n}$$

where *n* was the number of years in which surveys were conducted (Thompson et al. 1998).

Date Correcting Juvenile Ratios. Juvenile ratios potentially suffer from a negative bias due to incubating after-hatch-year birds not being on the water during at sea surveys. However, based on radio-telemetry, the proportion of after-hatch-years incubating between 10 and 17 July was <6%, and no incubation was observed after 17 July (Peery et al. 2004a, Peery et al. 2007). Nevertheless, to minimize potential biases due to the absence of incubating murrelets during at sea surveys, we used the equation below to correct the number of AHYs observed during surveys conducted from 10 to 17 July:

$$A_{corrected} = \frac{A_{observed}}{1-\left(18.7145545 - 0.18445455 \bullet DATE_i + 0.00045455 \bullet DATE_i^2\right)}$$

The right side of the denominator was the regression model for the proportion incubating after-hatch-year individuals regressed against date, $A_{corrected}$ was the date-corrected number of after-hatch-year individuals, and $DATE_i$ was the Julian Date for survey *i* (Peery et al. 2007). For surveys after Julian Date 199, we assumed that no birds were incubating and did not correct the observed number of after-hatch-years.

Juvenile ratios may suffer a negative bias because surveys are conducted prior to the completion of fledging (Peery et al. 2007). Indeed, regression models based on 47 observed fledging events in California predicted that only 75% of juveniles are expected to have fledged by the end of surveys on 23 August (Peery et al. 2007). Thus, we used the following equation to correct the number of juveniles observed ($H_{observed}$) during a given at sea survey for the proportion of juveniles that had not yet fledged:

$$H_{corrected} = \frac{H_{observed}}{-1.5433 + 0.0098 \bullet DATE_i}$$

where the denominator represented the regression model for the cumulative proportion of hatch-year fledged regressed against date, $H_{corrected}$ was the date-corrected number of hatch-year individuals, and $DATE_i$ was the Julian Date for survey or capture session *i* (Peery et al. 2007).

Results

Abundance

We detected murrelets throughout waters between Half Moon Bay and Santa Cruz during surveys conducted in the 2010 and 2011 breeding seasons (Figure 1). In both years murrelets were concentrated between the mouths of Pescadero Creek and Scott Creek (Figure 1). Murrelet density was greatest off the northern aspect of Año Nuevo in 2010 and in the lee of Pigeon Point in 2011. We detected murrelets frequently near west of Soquel Point, close to the Santa Cruz Harbor, in 2010 but not in 2011. We detected more murrelets in the southern portion of the survey area in 2010 than in 2011.

The mean number of groups detected per survey was 29.7 (range: 17-41) and mean group size was 1.67 (range: 1.53-1.94) in 2010 (Table 1). These means were greater than in 2011, when the mean number of groups detected per survey was 18.7 (range: 13-27) and mean group size was 1.65 (range: 1.46-1.73). The sighting data were not significantly different from those expected using the half-normal detection model with cosine adjustments ($\chi2 = 5.94$, df = 4 $P = 0.20$ in 2010 and $\chi2 = 1.16$, df = 3, $P = 0.76$ in 2011). The detection functions for both years show that the model fit the sighting data well (Figure 2).

Using this detection function, we estimated ESW to be 78.6 m (95% CL: 69.1-89.5 m) in 2010 and 44.6 m (95% CL: 36.4-54.7 m) in 2011. In 2010, density was estimated to be 3.50 murrelets/km^2 (95% CL: 2.66-4.61 murrelets/km^2) in the nearshore stratum and 0.76 murrelets/km^2 (95% CL: 0.49-1.17 murrelets/km^2) in the offshore stratum. In 2011, density was estimated to be 3.96 murrelets/km^2 (95% CL: 3.13-5.02 murrelets/km^2) in the nearshore stratum and 0.17 murrelets/km^2 (95% CL: 0.05-0.53 murrelets/km^2) in the offshore stratum.

As in previous years, transects delineated from the south yielded greater estimates of population size. The 2010 estimates for the central California population were 366 (95% CL: 240-559) with surveys delineated from the north (n = 4), 560 (95% CL = 343-925) with surveys delineated from the south (n = 3), and 446 (95% CL: 340-585) with all surveys (n = 7). The 2011 estimates were 320 (95% CL: 225-454) with surveys delineated from the north (n = 2), 452 (95% CL = 331-618) with surveys delineated from the south (n = 4), and 433 (95% CL: 339-553) with all surveys (n = 6). Regional abundance appears to be greater than estimates from 2007 and 2008, but less than estimates from 1999-2003 and 2009 (Figure 3A).

Juvenile Ratios

We detected four juveniles in 2010 and five juveniles in 2011 during each of the three surveys conducted within the window used to estimate juvenile ratios (10 July to 23 Aug). Juveniles were detected north of Waddell Creek with all but one seen north of Ano Nuevo Point (Figure 1). Using the calculations described above, we estimated the uncorrected juvenile ratio to be 0.032 (SE = 0.014) and the date-corrected juvenile ratio to be 0.074 (SE = 0.033) for 2010. We estimated the uncorrected juvenile ratio to be 0.060 (SE = 0.024) and the date-corrected juvenile ratio to be 0.091 (SE = 0.027) for 2011. These estimates are the highest recorded from the central California population (Table 3 and Figure 3B).

Discussion

Results from previous surveys suggested that the Marbled Murrelet population in central California underwent a significant and rapid decline between 2003 and 2007 and that this decline continued in 2008 when abundance estimates were as low as 174 individuals. However, estimates of local abundance in 2009 was similar to the higher 1999-2003 estimates (Table 2, Figure 3A). The 2010 and 2011 population estimates (reported here) are similar to each other and suggest the population is intermediate between previous high and low estimates. The rebound in population numbers and higher observed juvenile ratios might be explained by several hypotheses.

Recent Increases in Abundance

The decline and subsequent increase in population numbers was not likely due to changes in methodology, as survey and data analysis techniques have remained consistent across years. It appears that the population is currently lower than 1999-2003 estimates, but perhaps not as abysmally low as suggested by the 2007 and 2008 numbers. Two hypotheses have been proposed to explain the inter-annual variation in Marbled Murrelet populations (Peery and Henry 2010a).

First, the 2007-2008 dip and subsequent 2009 increase in population numbers resulted from a '*rescue*' of the central California sink population by recruits from northern populations. Rescue of the central California population to the magnitude required by the high 2009 estimates is unlikely as previous estimates put the immigration rate of murrelets from populations to the north at ~2-6% per year (Peery et al. 2008, Hall et al. 2009). Recent work by Peery (unpublished data) found birds sampled in 2010 and 2011 were genetically very similar to birds sampled in central California in 1997-2003, discounting the presence of a strong metapopulation structure with north to south source-sink dynamics.

Second, given the tendency for murrelets to make long distance movements during the breeding season (Burkett unpublished data, Peery et al. 2008, Henkel personal communication), the 2007-08 decreases and subsequent increases may be an artifact of temporary movements. The 2007-08 decreases could result from exodus without true emigration from the Region 6 population and the 2009 increase may reflect a temporary influx without true immigration from populations to the North of Region 6. This *distribution hypothesis*, a temporary exodus or influx of adults may explain changes in population estimates. Additional surveys outside the current at sea study area during years of low population estimates (e.g. 2008), intensive genetic sampling, and/or electronic tracking of individuals during irruptive years (e.g. 2009) could shed further light on the *distribution hypothesis*. However, additional vessel based at sea surveys may be insufficient to detect a change in sparse bird distributions given the effort required to cover a large area and the relatively small (100s) number of birds potentially involved in a temporary exodus. Previous work by Henkel and others (personal communication) has suggested birds may move south of Region 6 to waters off of Central California. If true, large-scale aerial at sea surveys, such as those conducted by California Fish and Games - Office of Spill Prevention and Response (CDFG-OSPR), could be valuable for detecting marbled murrelets to the south of Region 6 during years of low abundance in waters adjacent to the Santa Cruz Mountains.

The "distribution" hypothesis, predicts population growth (λ) was reasonably stable from 1999 to 2011, given abundance estimates of when $N = 487$ and 320, respectively (using transects delineated from the north). This contradicts population models predicting a 9.5% annual decline from 1999 to 2003, ostensibly due to very low reproductive success (Peery et al. 2006). Moreover, reproductive success, estimated from juvenile ratios, was very low, in fact zero in 2008, before increasing in 2009 (Table 3) and further suggests that the population was not sustaining itself. While recent juvenile ratios (2010 and 2011) are the highest observed, they remain well below historical estimates (~0.3 HY/AHY) associated with stable population growth (λ) (Beissinger and Peery 2007). Recent studies suggest that juvenile ratios yield reasonably accurate productivity estimates (Peery et al. 2007, Wong et al. 2008). However, Wong et al.

(2008) found that juveniles remain closer to shore than adults, which may negatively bias our juvenile ratio estimates. At sea surveys targeting the nearshore strata are planned for 2012 and results may help to determine whether current at sea surveys are adequate to estimate juvenile ratios.

Recent Increases in Juvenile Ratios

The 2010 and 2011 increases in juvenile ratios are a small positive sign for the Region 6 population. We discuss three hypotheses that may explain these observations. First, recent improvements in juvenile ratios may signal that a *regional corvid management* program at State Parks, initiated in 2005 with funding from the Command Trustee Council and continued with funding from the Luckenbach Trustee Council, is beginning to decrease murrelet nest predation. Historical estimates of juvenile ratios when the population was more robust indicate juvenile ratios were over three times greater than our observed values (Beissinger et al. 2007). Thus, if this hypothesis is correct, then existing corvid control programs will still require substantial improvements in efficacy to rescue the Region 6 population. A major opportunity in the corvid control program lies in management of Steller's jays, the most common documented murrelet nest predator. Despite efforts to reduce human food subsidies, jays continue to have inflated populations in key murrelet nesting habitat (Doucet-Beer pers comms). A pilot project to reduce jay predation on murrelet eggs through conditioned taste aversion began in 2012. It is too soon to evaluate its efficacy. Direct removal of jays is another management option that could provide instant decreases in jay populations and could be implemented to reduce nest predation on murrelets. Despite ongoing removal of Ravens, Jay removal has not been implemented, even at the experimental level. Continued at sea monitoring of the murrelet population and juvenile ratios along with monitoring of the corvid population at inland breeding hotspots may elucidate the linkage between productivity and corvid control efforts.

Changes in ocean conditions can affect murrelet prey populations and murrelet productivity (Becker et al. 2007). Becker et al. (2007) found high juvenile rockfish abundance was positively associated with high murrelet productivity. Juvenile rockfish were abundant in the central California study area from 2008 – 2010 (PISCO unpublished data). A disconnect in 2008 between the zero juvenile detections and high rockfish abundance suggest that at sea conditions are not solely responsible for murrelet productivity but that other factors such as predation influence reproductive output. A second factor that may influence marbled murrelet prey is the recent creation of the Año Nuevo State Marine Reserve. While marine protected areas can produce increased fish recruits, they also harbor more high trophic fish predators, which may ultimately compete with murrelets for prey resources.

Finally, population-level c*hanges in nesting distribution* could be inflating our juvenile ratios. Since murrelets are thought to have high nest stand fidelity (Divoky and Horton 1995, Burger et al. 2009), recent population declines may be due to a senescing portion of the population that nests in stands with high predation rates and low recruitment. New recruits may recruit to stands with low predation rate resulting in higher relative reproductive success. Under this scenario the resulting population would have a higher per capita reproductive output. This hypothesis is supported by survey data (Figure 1) where relatively few hatch year birds were observed near Año Nuevo Bay, despite the abundance of adjacent nesting old growth habitat in Big Basin State Park. It is worth noting that Big Basin both hosts high numbers of Steller's jays (Suddjian 2005, Doucet-Beer personal communications) and has heavy human use. This *nesting distribution* hypothesis could be further explored by comparing historic inland breeding locations with updated information using modern tracking equipment (e.g. miniaturized radios with non-invasive attachment techniques). Updated tracking data could also provide nesting range data to a host of private entities in need of metrics for prioritization of land acquisition for conservation benefit.

In summary, the 2010 and 2011 at sea survey data suggest an improving scenario for the central California marbled murrelet population. The primary hypothesis for the dramatic 2007-2008 dip in population numbers appears to be a temporary exodus from the survey study area. As with all of the survey data, it is important to recognize the complexities and errors associated with surveying a small elusive bird in the marine environment. The 2010 and 2011 increases in juvenile ratios are likely due to a combination of factors including reduced corvid predation, favorable prey abundance at sea, and a shifting inland distribution to stands with lower predation. Interpretation of these positive signals should be met with caution, as despite heavy investment in ongoing conservation projects in the Santa Cruz Mountains, both murrelet population numbers and juvenile ratios remain well below estimates necessary to maintain stable population growth. Results support that nest predation remains a limiting factor for this population, and given the small size of the population, justify the continuation of existing corvid control efforts. Planned focal juvenile ratio surveys in 2012 may provide more accurate data on murrelet productivity. Regardless of these results, adult population numbers remain low and focusing additional predator control efforts on the primary murrelet nest predator (i.e. Steller's jays) could be the key management action to increase local recruitment to the level needed for a self-sustaining Zone 6 population.

Acknowledgments

We thank CDFG-OSPR staff, particularly Jack Ames, R.C. Mitchell, Laird Henkel, and Frank Wilhelm for their help with surveys and logistical support. We also thank Abe Borker, Jared Figurski, Walter Heady, Jonathan Felis for assisting with observations and Rodrigo Beas, Liam Doust, Brenna Mahoney, Portia Halbert, Alex Mcleod, and Ben Weitzman for logistical support. We also thank members of the Command and Luckenbach Trustee Councils for review and comments on this manuscript. This project was funded through a contract with the University of California, Santa Cruz from the Command and Luckenbach Trustee Councils as part of the integrated monitoring of a corvid control programs administered by the California Department of Parks and Recreation.

Literature Cited

Becker, B.H., and S.R. Beissinger. 1997. At sea density monitoring of Marbled Murrelets in central California: methodological considerations. Condor 99: 743-755.

Becker, B. H., M. Z. Peery, and S. R. Beissinger. 2007. Ocean climate and prey availability affect the trophic level and reproductive success of the marbled murrelet, an endangered seabird. Marine Ecology-Progress Series **329**:267-279.

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

Beissinger, S. R. and M. Z. Peery. 2007. Reconstructing the historic demography of an endangered seabird. Ecology **88**:296-305.

Burger, A. E., I. A. Manely, M. P. Silvergieter, D. B. Lank, K. M. Jordan, T. D. Bloxton, and M. G. Raphael. 2009. Re-use of nest sites by Marble Murrelets (*Brachpramphus marmoratus*) in British Columbia. Northwestern Naturalist **90**:217-226.

Carter, H.R. and R.A. Anderson. 1988. Population status and conservation problems of the Marbled Murrelet in California, 1892-1987. Unpubl. Rept. for California Dept. of Fish and Game, Sacramento, CA.

Divoky GJ, Horton M (1995) Breeding and natal dispersal, nest habitat loss and implications for marbled murrelet populations. in: Ecology and Conservation of the Marbled Murrelet (eds Ralph CJ, Hunt GL, Jr , Raphael MG, Piatt JF), pp. 83–87. USDA Forest Service General Technical Report PSW-GTR-152. Pacific Southwest Research Station, Albany, California.

Hall, L. A., S. R. Beissinger, P. J. Palsbøll, J. T. Harvey, M. Bérubé, M. G. Raphael, S. K. Nelson, R. T. Golightly, S. Newman, L. McFarlane-Tranquilla, and M. Z. Peery. 2009. Characterizing dispersal patterns of a threatened seabird with limited genetic structure. Molecular Ecology. 18:5074–5085.

Friesen, V.L., T.P. Birt, J.F. Piatt, R.T. Golightly, S.H. Newman, P.N. Hebert, B.C. Congdon, and G. Gissing. 2005. Population genetic structure and conservation of Marbled Murrelets (*Brachyramphus marmoratus*). Conservation Genetics 6(4): 607-614.

Henkel, L.A., and M.Z. Peery. 2008. Abundance and productivity of Marbled Murrelets off central California during the 2007 breeding season. Unpubl. Report, Moss Landing Marine Laboratories, Moss Landing, CA.

Levy, P. S. and S. Lemeshow. 1991. Sampling of Populations: Methods and Applications. 2nd edition. John Wiley and Sons, New York, New York.

Peery, M.Z., S.R. Beissinger, S.H. Newman, E.B. Burkett, and T.D. Williams. 2004. Applying the declining population paradigm: diagnosing causes of poor reproduction in the Marbled Murrelet. Conservation Biology 18: 1088-1098.

Peery, M. Z., B. H. Becker, and S. R. Beissinger. 2007. Age ratios as estimators of productivity: testing assumptions on a threatened seabird, the Marbled Murrelet. Auk.124:224-240.

Peery, M.Z., B.H. Becker, and S.R. Beissinger. 2006a. Combining demographic and count-based approaches to identify source-sink dynamics of a threatened seabird. Ecological Applications 16: 1516-1528.

Peery, M.Z., S.R. Beissinger, E. Burkett, and S.H. Newman. 2006b. Local survival of Marbled Murrelets in central California: roles of oceanographic processes, sex, and radiotagging. Journal of Wildlife Management 70: 78-88.

Peery, M. Z., S. R. Beissinger, R. F. House, M. Berube, L. A. Hall, A. Sellas, and P. J. Palsboll. 2008. Characterizing source-sink dynamics with genetic parentage assignments. Ecology **89**:2746-2759.

Peery, M.Z., L.A. Henkel, B.H. Becker, S.H. Newman, J.T. Harvey, C. Thompson, and S.R. Beissinger. 2008. Effects of rapid flight-feather molt on post-breeding dispersal in a pursuit-diving seabird. Auk 125:113-123

Peery, M. Z., L. A. Hall, A. Sellas, S. R. Beissinger, C. Moritz, M. Bérubé, M. G. Raphael, S. K. Nelson, R. T. Golightly, L. McFarlane-Tranquilla, S. Newman, P. J. Palsbøll. 2009. Genetic analyses of historic and modern marbled murrelets suggest decoupling of migration and gene flow after habitat fragmentation. Proceedings of the Royal Society, Biological Series. [Available Online]

Peery, M. Z. and R. W. Henry. 2010a. Abundance and productivity of Marbled Murrelets off Central California during the 2009 breeding season., California State Parks, Half Moon Bay.

Peery, M. Z. and R. W. Henry. 2010b. Recovering marbled murrelets via corvid management: A population viability analysis approach. Biological Conservation **143**:2414-2424.

Piatt, J.F., K.J. Kuletz, A.E. Burger, S.A. Hatch, V.L. Friesen, T.P. Brit, M.L. Arimitsu, G.S. Drew, A.M.A. Harding, and K.S. Bixler. 2007. Status review of the Marbled Murrelet (*Brachyramphus marmoratus*) in Alaska and British Columbia. USGS Open File Report 2006-1387, USGS, Reston, VA.

Spear, L.B., N. Nur, and D.G. Ainley. 1992. Estimating absolute densities of flying seabirds using analyses of relative movement. Auk 109(2): 385-389.

Strong, C.S. 1998. Techniques for Marbled Murrelet age determination in the field. Pacific Seabirds 25(1): 6-8.

Suddjian, D. 2005. Summary of 2005 Corvid Monitoring Surveys In The Santa Cruz Mountains. Command Oil Spill Trustee Council, Office of Spill Prevention and Response, California Dept of Fish and Game.

Thompson, W. L., G. C. White, and C. Gowan. 1998. Monitoring Vertebrate Populations. Academic Press, Santa Diego, California.

Wong, S. N. P., R. A. Ronconi, A. E. Burger, and B. Hansen. 2008. Marine distribution and behavior of juvenile and adult Marbled Murrelets off southwest Vancouver Island, British Columbia: Applications for monitoring. Condor **110**:306-315.

van Kempen, G. M. P. and L. J. van Vliet. 2000. Mean and variance of ratio estimators used in flourescence imaging. Cytometry **39**:300-305.

Table 1. Results of eight "zig-zag" surveys for Marbled Murrelets between Half Moon Bay and Santa Cruz, California during the 2010 and 2011 breeding seasons.

Survey Date	Direction of Transect	Transect Length (m)	Number of Groups	Mean Group Size	Number of Juveniles	Nearshore Density (birds/km^2)	Offshore Density (birds/km^2)	Abundance Estimate
4-Jun-10	South	101.615	41	1.68	0	5.07	1.189	655
14-Jun-10	North	103.721	17	1.53	0	1.89	0.968	299
28-Jun-10	South	101.148	19	1.94	1	2.64	0.589	338
8-Jul-10	North	99.081	37	1.63	2	4.27	0.000	447
22-Jul-10	South	95.725	32	1.70	2	4.24	0.661	513
23-Jul-10	North	95.788	36	1.55	2	3.84	0.595	465
29-Jul-10	North	100.554	26	1.65	0	2.61	1.267	405
2-Jun-11	South	100.723	13	1.46	0	2.78	0.000	291
21-Jun-11	North	99.129	18	1.73	0	3.86	0.474	454
6-Jul-11	South	101.141	19	1.72	0	4.34	0.533	510
28-Jul-11	South	102.118	18	1.71	1	4.05	0.000	424
11-Aug-11	South	97.292	17	1.71	1	4.14	0.000	434
22-Aug-11	North	101.746	27	1.57	3	4.55	0.000	476

Table 2. Population estimates for Marbled Murrelets in central California between 1999 and 2011; no surveys were conducted from 2004 to 2006. Surveys conducted using transects delineated from the north and south are presented separately because surveys from the south typically yield greater population estimates.

	Both Directions			North			South		
Year	*N*	95% CL	*n*	*N*	95% CL	*n*	*N*	95% CL	*n*
1999	*N/A*			487	333-713	5	*no surveys*		
2000	*N/A*			496	338-728	8	*no surveys*		
2001	661	556-786	15	637	441-920	8	733	583-922	7
2002	683	561-832	15	628	487-809	9	729	494-1075	6
2003	699	567-860	12	615	463-815	6	782	570-1074	6
2004	*no surveys*			*no surveys*			*no surveys*		
2005	*no surveys*			*no surveys*			*no surveys*		
2006	*no surveys*			*no surveys*			*no surveys*		
2007	378	238-518	4	269	109-429	2	488	349-626	2
2008	174	91-256	4	122	61-184	1	225	131-319	3
2009	631	449-885	8	495	232-1054	4	789	522-1193	4
2010	446	340-585	7	366	240-559	4	560	343-925	3
2011	433	339-553	6	320	225-454	2	452	331-618	4

Table 3. Annual estimates of hatch-year to after-hatch-year ratios (*R*) and standard errors (SE) for Marbled Murrelets from at sea surveys conducted in the breeding season in central California, 1996-2003 and 2007-2011. Surveys used to estimate ratios were limited to 10 July to 23 August. Estimates were corrected for the proportion of hatch-year murrelets that had not fledged and the proportion of after-hatch-year murrelets still incubating at the time the survey was conducted (see Peery et al. 2007). n_{inds} = the number of individuals observed and $n_{surveys}$ = the number of surveys conducted.

	Uncorrected		Corrected			
Year	*R*	(SE)	*R*	(SE)	n_{inds}	$n_{surveys}$
1996	0.004	(0.003)	0.006	(0.004)	517	3
1997	0.01	(0.003)	0.022	(0.007)	701	5
1998	0.002	(0.003)	0.004	(0.004)	437	6
1999	0.015	(0.005)	0.03	(0.010)	693	10
2000	0.021	(0.010)	0.034	(0.016)	495	8
2001	0.031	(0.006)	0.063	(0.016)	400	8
2002	0.022	(0.005)	0.045	(0.011)	601	11
2003	0.024	(0.005)	0.049	(0.011)	424	8
2007	0.017	(0.017)	0.049	(0.051)	130	3
2008	0	(0)	0	(0)	47	4
2009	0.015	(0.011)	0.028	(0.018)	201	4
2010	0.032	(0.014)	0.074	(0.033)	129	3
2011	0.060	(0.024)	0.091	(0.027)	89	3

Figure 1. Locations and kernel density plots of Marbled Murrelets and juveniles detected during at sea surveys in central California in A) 2010 and B) 2011. Inland detections source: California Fish and Game, Marbled Murrelet Database (2008).

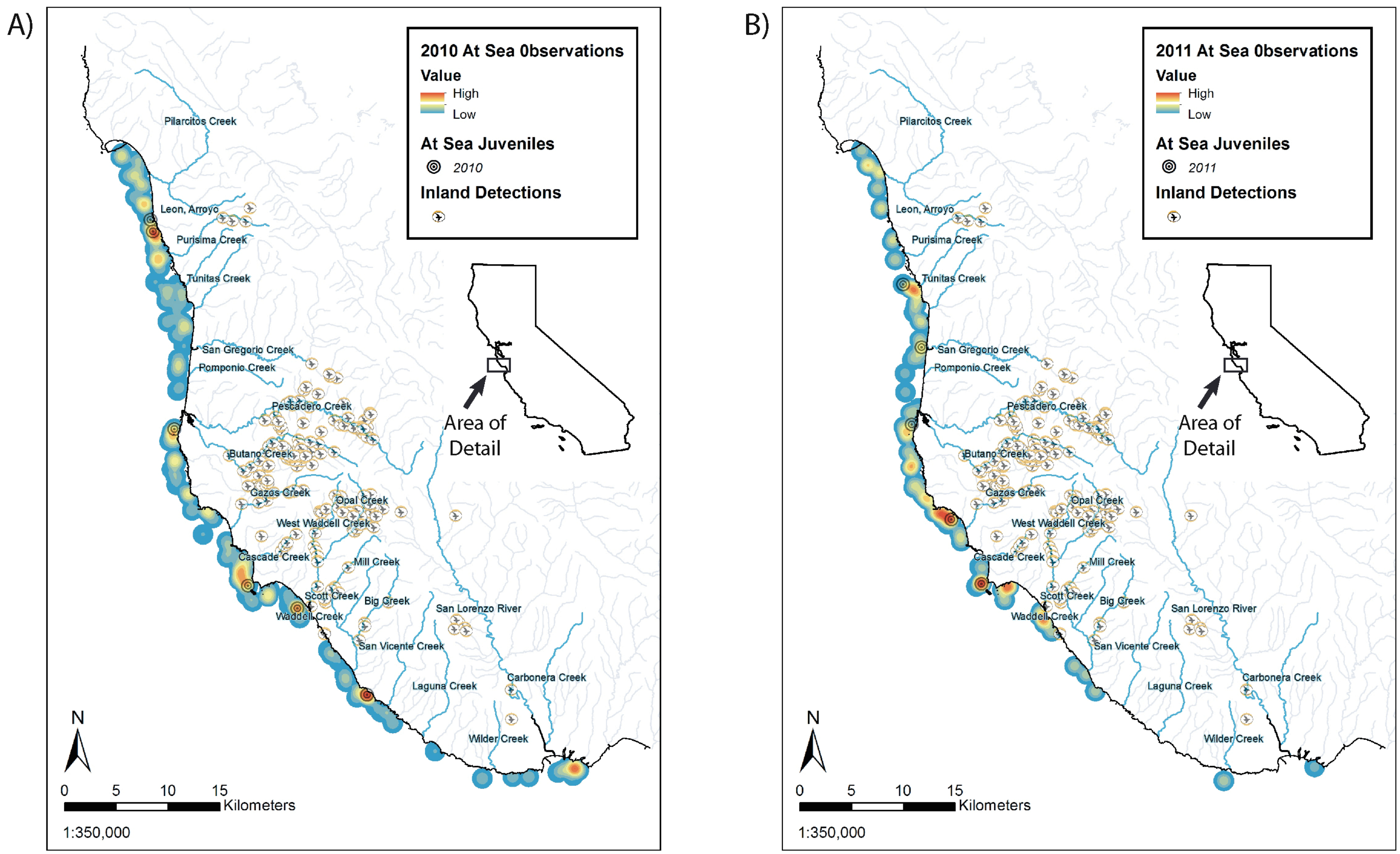
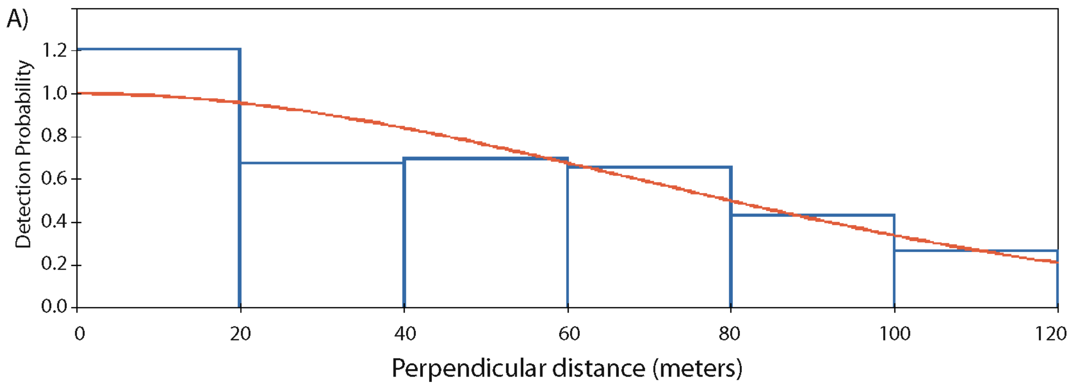


Figure 2. Detection probabilities for Marbled Murrelet surveys conducted in central California during the 2010 (A) and 2011 (B) breeding seasons.



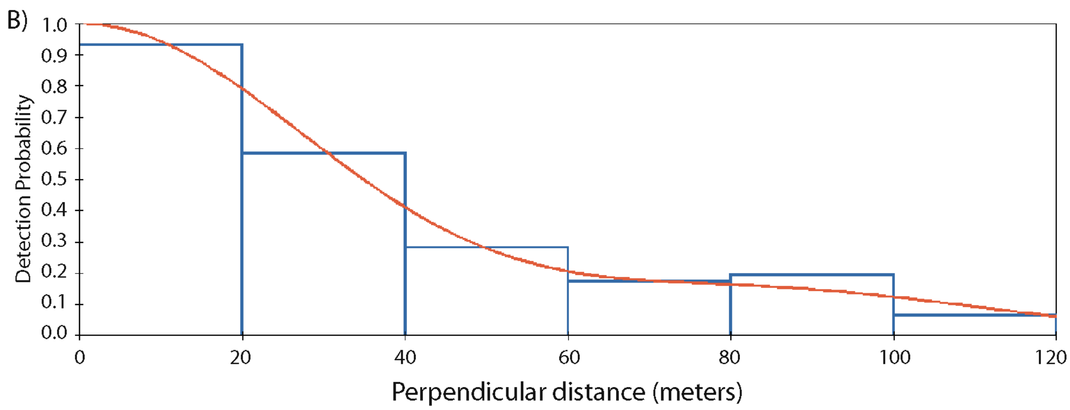


Figure 3. A) Abundance estimates for the central California population of Marbled Murrelets based on at sea surveys, 1999-2009 (dashed lines 95% confidence intervals for surveys drawn in Both directions). Zig-zag surveys were not conducted prior to 1999 and from 2004-2006. B) Juvenile ratios solid lines (dashed lines ±1 standard error). Data absent from years 2004-2006.