ABUNDANCE AND PRODUCTIVITY OF MARBLED MURRELETS OFF CENTRAL CALIFORNIA DURING THE 2007 BREEDING SEASON

Final Report
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Summary

We conducted five at-sea surveys for Marbled Murrelets (*Brachyramphus marmoratus*) off central California during the 2007 breeding season; four surveys offshore of breeding habitat between Half Moon Bay and Santa Cruz, and one survey in northern Monterey Bay. Using distance sampling, we estimated the central California population at 367 (95% CL = 240-562) individuals in 2007. This represents a 47% decline since the last surveys were conducted in 2003. The date-corrected ratio of juveniles to after-hatch-year birds in 2007 was 0.049 (SE = 0.0051), which was similar to estimates from 1996-2003. Based on this value, reproductive success is not sufficient to support a viable population. Looking at historic population estimates dating back to 1989, it appears that the central California population of Marbled Murrelets is continuing to experience a substantial long-term decline.

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) availability, increasing predator populations, gill-netting bycatch, and oil spills (Carter and Erickson 1988, Peery et al. 2004, Peery et al. 2006b). To work towards recovery of the species, various oil spill trustee councils have provided funding for restoration, including protection of nesting habitat and management of predatory corvids. In the last several years, the Command Trustee Council (for the 1998 T/V Command oil spill) has initiated efforts to control food sources for corvids in the Santa Cruz Mountains, initiated lethal control of some corvids, and acquired 80 acres of potential nesting habitat in the Santa Cruz Mountains, to be incorporated into Butano State Park.

Population monitoring of Marbled Murrelets typically is conducted using at-sea surveys. Other monitoring methods are used to monitor inland activity, including radar surveys and audio-visual surveys, but these methods do not provide information on actual population size. Population size has been monitored using mark-recapture studies and at-sea line transect surveys (Peery et al. 2006a). Regular (e.g., annual) population estimates are critical in determining the success of restoration efforts and the current status of the species range-wide. Under the Northwest Forest Plan, annual at-sea monitoring occurs in California within Conservation Zones 1-5, from the Oregon border south to San Francisco Bay. Conservation Zone 6, from San Francisco Bay south to Monterey Bay, is not included in the Northwest Forest Plan; thus population monitoring within Zone 6 has occurred in some years with a combination of state, federal, and private funding, but monitoring has not occurred since 2003. To aid in determining the success of restoration efforts in the Santa Cruz Mountains, the Command Trustee Council funded limited at-sea surveys in Zone 6 during the 2007 breeding season.

Methods

We conducted four at-sea surveys between Half Moon Bay and Santa Cruz (approximately 100 km), and one at-sea survey between Santa Cruz and Moss Landing (approximately 27 km). The surveys between Half Moon Bay and Santa Cruz followed zig-zag transect routes consistent with similar surveys conducted between 1999 and 2003 (Peery et al. 2006a). These surveys included between 70 and 87 km of transect in a "nearshore" stratum (200-1350 m from shore) and between 15 and 27 km of transect in an "offshore" stratum (1350-2500 m from shore); they were conducted between 20 June and 19 July 2007 (Table 1). The survey routes were created using random starting points (Peery et al. 2006a). In previous years an equal number of routes were drawn from starting points at the north and south ends of the survey area. In 2007, two transects were drawn from the south and two transects were drawn from the north.

The survey between Santa Cruz and Moss Landing was conducted on 20 August 2007 to assess whether a substantial number of murrelets had dispersed south out of the primary study area into northern Monterey Bay. This survey was conducted along transect parallel to shore, approximately 400 m offshore, consistent with the methods of Henkel (2004).

For all surveys, line transect methods were used (Becker et al. 1997, Peery et al. 2006a). Two observers, standing on either side of a 6-m open skiff, recorded angle off the track line and distance to all groups of Marbled Murrelets seen (prior to each survey, observers calibrated distance estimation using a laser rangefinder on buoys in the harbor). Birds in flight were counted if they crossed a line perpendicular to the track line, even with the observers. Counting flying birds (16% of sightings were of flying birds) may result in overestimation of abundance (Spear et al. 1992, Piatt et al. 2007), but this method was used for previous surveys in Central California, and was used in 2007 for consistency. Sightings data were analyzed using DISTANCE v.5.0 (see Peery 2006a for details on how density estimates are derived using DISTANCE). After discarding all sightings beyond 120 m ($n = 3$), we had 81 sightings. These data were not adequate to include any covariates in the DISTANCE models (e.g., observer or observation conditions); all data were included in global estimates of effective strip width. The model of declining detectability with distance (a half-normal curve with cosine adjustments) fit the observed data well (chi = 2.2, df = 4, $P = 0.70$). Effective strip width (ESW) was 64.1 m. To calculate abundance, we multiplied density estimates generated by DISTANCE by the total area of each stratum (104.65 km^2).

Estimating Juvenile Ratios

We used the ratio of juvenile (0 year old; hatch-year or HY) murrelets to after-hatch-year ($\geq$1 year old; AHY) murrelets observed during at-sea surveys as an estimate of productivity (i.e., reproductive success). Juveniles were distinguished from after-hatch-year murrelets using the characteristics reviewed by Strong (1998). Methodology used to estimate juvenile ratios followed Peery et al. (2007) and is described below.

We estimated juvenile ratios for Marbled Murrelets based on at-sea surveys conducted from Julian Date 192 (July 10) to 234 (Aug 23), when 34% to 75% of young were expected to have fledged. After 23 August, after-hatch-year murrelets have progressed far enough in their pre-basic molt that they are indistinguishable from juveniles. However, only a proportion of juveniles is expected to have fledged and is available to be counted by at-sea surveys during this period. Therefore, we date-corrected juvenile ratios for the number of juveniles that had not fledged at the time each survey was conducted. To this end, we estimated the proportion of young expected to have fledged as a function of date based on 47 known fledging events in California using linear regression analysis, with the cumulative proportion of young fledged as the dependent variable and Julian Date as the independent variable (Peery et al. 2007). The number of HY observed or captured ($H_{observed}$) during on a given at-sea survey was then corrected using following equation:

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

where the denominator represented the regression model for the cumulative proportion of juveniles fledged regressed against date, $H_{corrected}$ was the date-corrected number of juvenile individuals, and $DATE_i$ was the Julian Date for survey or capture session i.

Juvenile ratios can be upwardly biased because incubating after-hatch-year murrelets are not available to be counted during at-sea surveys. We used the equation below to correct the number of after-hatch-murrelets observed during a particular at-sea survey for the number of after-hatch-years that were expected to be incubating at the time of the survey.

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

where the right side of the denominator represented the regression model for the proportion incubation AHY regressed against date, $A_{corrected}$ was the date-corrected number of AHY individuals, and $DATE_i$ was the Julian Date for survey or capture session i. This regression model was estimated based on the proportion of radio-marked after-hatch-year murrelets that were incubating on a given date (Peery et al. 2007).

We estimated the (observed and date-corrected) 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 juvenile and after-hatch-year individuals for survey i, respectively, and n was the number of surveys conducted in year t. We estimated $\mathrm{var}(\hat{R}_t)$ as:

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

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

$$\hat{\mathrm{var}}(\hat{\bar{R}}) = \frac{\sum_{1}^{n} \hat{\mathrm{var}}(\hat{R}_t)}{n}$$

where n was the number of years in which surveys were conducted.

Results

The mean estimate of abundance from the four surveys conducted from Half Moon Bay to Santa Cruz was 367 (95% CL = 240-562). Individual survey estimates ranged from 187 to 492 (Table 1). No murrelets were detected in the offshore stratum in Half Moon Bay to Santa Cruz surveys, nor were any murrelets detected on the survey between Santa Cruz and Moss Landing.

Survey direction (zig-zag transects drawn from the north vs. drawn from the south) can affect abundance estimates because surveys drawn from the south are more likely to sample protected coves. We provide the 2007 data along with historic data collected between 1999 and 2003 in this context (Table 2). Using data from both directions, the estimated abundance in 2007 represents a 47% decline from 2003 (Fig. 1). Using data only from surveys drawn from the north, there was a 56% decline from 2003 to 2007; and from the south, there was a 38% decline.

Consistent methods were used for at-sea surveys in central California beginning in 1999. Population estimates between 1989 and 1995 based on at-sea surveys using slightly different survey methods ranged from 763 to 853 (Carter et al. 1992, Ralph and Miller 1995, Strong and Becker 1996). Although the variable methods used before 1999 mean that these historic data are not directly comparable with data from 1999 to the present, combining these data with current data show a fairly consistent (and statistically significant) decline in the local population (Fig. 2).

Only two juveniles were detected, both on the 10 July survey. Based on three surveys conducted between 10 July and 23 August we estimate that the uncorrected juvenile ratio was 0.017 (SE = 0.017) and the date-corrected juvenile ratio was 0.049 (SE = 0.051; Table 3). This value is similar to juvenile ratios estimated from 1996-2003.

Discussion

Our results suggest that the Marbled Murrelet population in central California is undergoing a significant decline. Peery et al. (2006a) determined that, based on low reproductive success, the central California population should show a consistent annual decline in the absence of immigration. However, abundance estimates based on at-sea surveys conducted between 1999 and 2003 showed no population decline; thus, Peery et al. (2006) suggested that immigration from northern California was supporting the central California population. The population decline observed between 2003 and 2007 suggests that during this time either: 1) immigration has declined or 2) Peery et al (2006) did not detect a decline that was in fact occurring. Although Peery et al. (2006a) used data collected in a consistent manner from 1999 on, data from other historic surveys indicate a larger population decline. Considering the larger, albeit inconsistently collected, dataset, the lack of decline between 1999 and 2003 could potentially represent sampling “noise” on a fine scale (e.g., from dispersal into and out of the survey area), in the context of a long-term population decline. We have no means of assessing whether immigration into central California has declined since 2003.

The low abundance estimate in 2007 could also be due in whole or in part to increased dispersal out of the study area compared with previous years. Marbled Murrelets sometimes disperse out of the central California study area during summer, although little is known regarding annual variation in how many birds disperse (Peery et al. in press). Marine climate in central California during spring and summer 2007 may have somewhat anomalous. Considerable numbers of Horned Puffins (*Fratercula corniculata*) were present in central California during this time (up to 8 were recorded on our surveys), which is very unusual. This influx of a typically high-latitude species may have been related to lower than normal air temperatures during spring. Similarly, high adult mortality of Snowy Plovers (*Charadrius alexandrinus*) during winter/spring 2007 is thought to be related to this cold snap of sub-freezing temperatures (K. Neuman, pers. comm.). Anomalous ocean conditions could have led to non-breeding Marbled Murrelets leaving the study area. Marbled Murrelets are normally very rare off the Monterey Peninsula (Roberson 2002), yet local birders recorded groups here several times throughout the summer (e.g., 7 on 21 June; B. Sullivan pers. comm.). Similarly, 22 were reported on 9 June off Sunset State Beach, in northern Monterey Bay (Santa Cruz Bird Club files), whereas Henkel (2004) never recorded more than a single Marbled Murrelet in this area during two years of summer surveys. However, we did not find any Marbled Murrelets in Northern Monterey Bay during the August survey, and aerial surveys conducted in nearshore waters of Monterey Bay and south to Big Sur in June and July failed to detect any Marbled Murrelets south of Santa Cruz (L. Henkel, unpubl. data). Additionally, we are not aware of any anomalously high numbers of Marbled Murrelets off San Luis Obispo County or areas further south in 2007.

The estimate of the juvenile ratio for 2007 (0.049), like estimates for all years between 1996 and 2003, was very low and too low support a viable population (Peery et al. 2006a). The estimate was reasonably similar to the mean observed across all years from 1996 to 2007 (0.034). However, we suspect that it was numerically greater than the mean largely because both juveniles observed in 2007 happened to be observed on the July 10 survey. This date represents the earliest date in which we conduct juvenile-ratio surveys and received a large "date correction factor". Had these two juveniles been observed later in the survey period, we believe that our estimate of the 2007 juvenile ratio would have been considerably lower. The juvenile ratio could also be artificially high if substantial numbers of AHY individuals had dispersed out of the study area, as discussed above.

Surveys conducted during 2007 provide important information on the status of the central California population of Marbled Murrelets. These data indicate that recent restoration projects implemented in the Santa Cruz Mountains may not be sufficient to increase reproductive success to a level that would sustain a viable population. However, to determine whether the observed population decline is real and sustained, regular (ideally annual) series of surveys are required. Recent research has shown that the central California population appears to be genetically distinct from populations to the north (Friesen et al. 2005, Piatt et al. 2007). Given the predicted and observed decline of this population, the genetic uniqueness of the population, and the susceptibility of this population for local extirpation (Peery et al. 2004), there is a clear need for immediate conservation action, and for annual monitoring of the success of these conservation efforts. For robust population estimates in future years, we recommend planning for eight surveys, four drawn from each direction.

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Table 1. Results of four surveys for Marbled Murrelets between Half Moon Bay and Santa Cruz in 2007.

Survey Date	Number of Groups	Mean Group Size	Number of Juveniles	Transect Length (km)[1]	Population Estimate[2]	Survey Direction[3]
20 June	13	1.5	0	87.1	187 (138-254)	North
10 July	18	1.8	2	76.8	351 (280-439)	North
12 July	25	1.7	0	69.6	492 (393-616)	South
19 July	25	1.7	0	70.8	483 (383-612)	South

[1]Nearshore stratum only; no murrelets were seen in the offshore stratum.
[2]95% CL in parentheses.
[3]Direction transect drawn from.

Table 2. Population estimates (95% CI in parentheses) of Marbled Murrelet in central California between 1999 and 2007. Historic data from Peery et al. (2006); n is number of surveys. No surveys were conducted from 2004 to 2006.

Year	From North Pop. Estimate	n	From South Pop. Estimate	n	Both Directions Pop. Estimate	n
1999	487 (333-713)	5		0		0
2000	496 (338-728)	8		0		0
2001	637 (441-920)	8	733 (583-922)	7	661 (556-786)	15
2002	628 (487-809)	9	729 (494-1075)	6	683 (561-832)	15
2003	615 (463-815)	6	782 (570-1074)	6	699 (567-860)	12
2007	264 (142-489)	2	488 (408-585)	2	367 (240-562)	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. Surveys and captures used to estimate ratios were conducted from 10 July to 23 August, 1996-2003, 2007. Corrected 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	0.010	(0.003)	0.022	(0.007)	701	5
1998	0.002	(0.003)	0.004	(0.004)	437	6
1999	0.015	(0.005)	0.030	(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
Total	**0.016**	**(0.003)**	**0.034**	**0.007**	**4398**	**62**

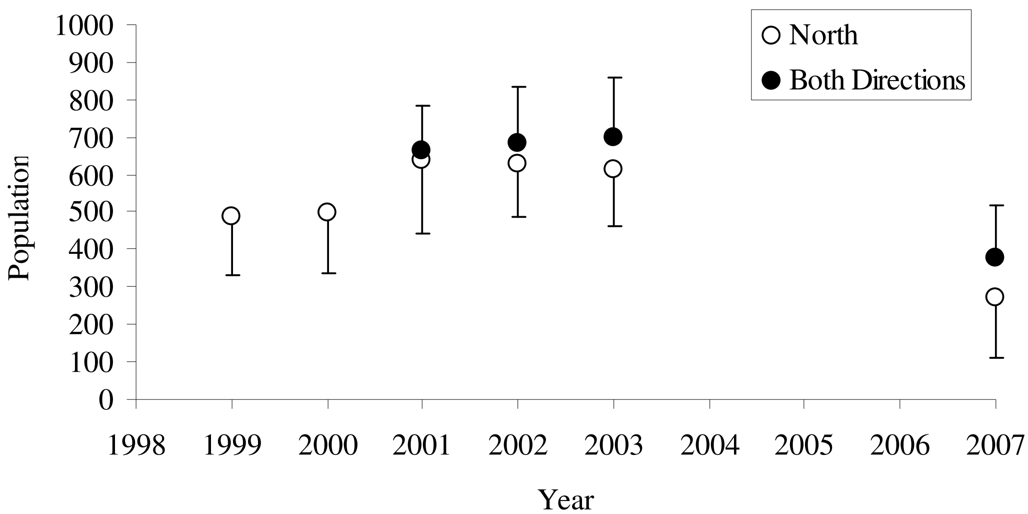

Figure 1. Abundance estimates for the central California population of Marbled Murrelets based on at-sea surveys, 1999-2007. Error bars are 95% confidence intervals. Because surveys before 2001 were conducted only on transects drawn from the north, these survey data are presented separately.

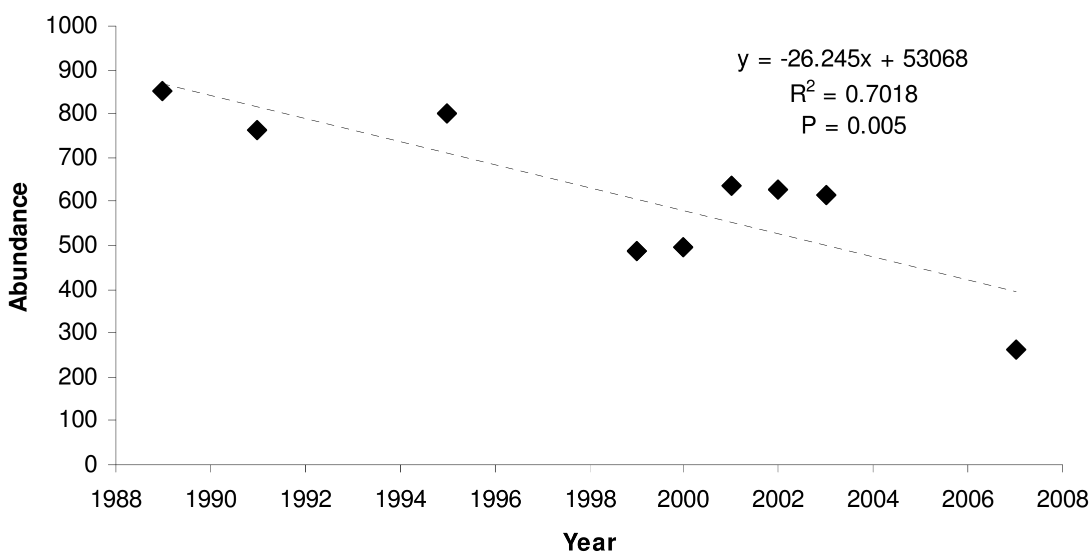

Figure 2. Abundance estimates for the central California population of Marbled Murrelets based on at-sea surveys, 1989-2007. Surveys before 1999 used slightly different methods; surveys drawn from the north were used from 1999-2003 and in 2007.