ABUNDANCE AND PRODUCTIVITY OF MARBLED MURRELETS OFF CENTRAL CALIFORNIA DURING THE 2009 BREEDING SEASON

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Summary

We conducted at-sea surveys for Marbled Murrelets (*Brachyramphus marmoratus*) in Conservation Zone 6 (central California) offshore of breeding habitat between Half Moon Bay and Santa Cruz in 2009. Using distance sampling estimation techniques, we estimated the central California population to be 495 (95% CL: 232-1054) with surveys delineated from the north (n = 4), 789 (95% CL = 522-1193) with surveys delineated from the south (n = 4), and 631 (95% CL: 449-885) with all surveys (n = 8). These estimates were significantly greater than estimates in 2007-2008, when the population was estimated to have experienced large declines, and were similar to estimates from 1999-2003, when abundance was estimated to have been relatively high. The date-corrected juvenile ratio, an estimate of productivity commonly used to index reproductive success in Marbled Murrelets, was 0.028 (SE = 0.018) and similar to estimates in previous years. It is unclear whether our results indicate that Marbled Murrelets in central California moved out of the survey area in 2007 and 2008, and then returned in 2009, or if the recent increase was due to the immigration of murrelets from larger populations to the north. We plan to sample individuals in central California during the breeding season of 2010 and identify immigrant individuals using genetic analysis to discriminate between these two hypotheses.

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, and oil spills (Carter and Erickson 1988, Peery et al. 2004). 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 such efforts for the central California Marbled Murrelet population by controling food sources for corvids, initiating lethal control of some corvids, and 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 (using 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 this 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) from 661-699 individuals in the initial survey period (1999-2003). Here we report on similar surveys conducted in central California in 2009.

Methods

Estimating Abundance

We conducted eight approximately 100 km long at-sea surveys between Half Moon Bay and Santa Cruz in 2009 from 2 June to 11 August that followed zig-zag transect routes consistent with previous surveys conducted from 1999 through 2003, and in 2007 and 2008 (Peery et al. 2006a, Peery et al. 2009). Surveys were initiated immediately outside of the Half Moon Bay Harbor a random distance (200-2500 m) from shore. Transects included both a “nearshore” (200-1350 m from shore) and “offshore”

stratum (1350-2500 m from shore), and approximately three times more effort was spent surveying the neashore stratum due to historically much greater 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 indicate that transects drawn from the south tend to yield a higher densities that transect delineated from the north. Thus, to ensure that abundance estimates in 2009 would be consistent with estimates from 2001-2008 when both transects were used, four of the eight transects surveyed in 2009 were drawn from the south and four transects were drawn from the north. Moreover, continuing to use surveys delineated from the north allowed us to compare results from 2009 to estimates from 1999-2000, when surveys were only delineated from the north.

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 transect 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 (2% 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 2009 for consistency. Sightings data were analyzed using DISTANCE v.5.0 and density was estimated using

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

where $\hat{ESW}$ 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. All detections >120 m from the transect lines were discarded and the remaining detections were grouped into 7 20-m bins, similar to analyses conducted for previous years. A half-normal detection model with cosine adjustments was used to model detectability as a function of distances, as was used to model previous years' data. 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 192 to 234). Prior to 10 July, few (34%) young were expected to have fledged, 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 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-year s 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 $\hat{\text{var}}(\hat{\bar{R}})$ was estimated 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 b after-hatch-years 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 missing 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 on 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

Murrelets were detected throughout waters between Half Moon Bay and Santa Cruz during surveys conducted for the 2009 breeding season (Fig 1). However, murrelets were most concentrated between the mouths of the Pescadero Creek and Scott Creek (Fig. 1).

The mean number of groups detected per survey was 29.9 (range: 19-42) and mean group size was 1.7 (range: 1.47-1.89; Table 1). The sighting data deviated slightly from expectations according to the half-normal detection model with cosine adjustments ($\chi 2 = 4.1$, df = 4, $P = 0.04$). However, a visual examination of the detection function indicated that model fit the sighting data reasonably well (Fig. 2), and we therefore used this model for density and abundance estimation.

Using this detection function, we estimated ESW to be 48.2 m (SE = 6.4). Density was estimated to be 5.85 murrelets/km^2 (95% CL: 4.04-7.72 murrelets/km^2) in the nearshore stratum and 0.44 murrelets/km^2 (95% CL: 0.20-0.93 murrelets/km^2) in the offshore stratum. As was the case in previous years, surveys conducted in 2009 that followed transects delineated from the south yielded greater estimates of population size (mean = 789; 95% CL: 522-1193, $n = 4$) than transects delineated from the north (mean = 495; 95% CL: 232-1054, $n = 4$; Tables 1 and 2). The mean estimate of abundance from

all eight surveys was 631 (95% CL: 449-885; Tables 1 and 2). Thus, local abundance appeared to increase dramatically over estimates from 2007 and 2008, and were similar to estimates from 1999-2003 (Fig. 3).

Juvenile Ratios

Four juveniles were detected during the four surveys conducted within the window used to estimate juvenile ratios (10 July to 23 Aug). Three were located in Ano Nuevo Bay and one was located at the southern end of Half Moon Bay. A fifth juvenile was detected off of Pescadero Creek prior to the period used to estimate juvenile ratios. Using the calculations described above, we estimated the uncorrected juvenile ratio to be 0.015 (SE = 0.011) and the date-corrected juvenile ratio to be 0.028 (SE = 0.018). These estimates were consistent with low estimates for previous years (Table 3).

Discussion

Results from previous years' 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 122 individuals (for surveys drawn from the north). However, surveys conducted in 2009 (reported here) suggest that local abundance was similar 1999-2003 levels, when abundance was relatively high (Table 2, Figure 3). The decline and subsequent increase are not likely due to changes in methodology as survey and data analysis techniques have remained consistent across years. Rather, we believe that the increase in abundance in 2009 reflects an actual increase in the number of murrelets occurring in nearshore waters compared to 2007 and 2008. Indeed, murrelets were virtually absent from Ano Nuevo Bay in 2008, which is immediately adjacent to the largest concentration of murrelets nesting habitat in the Santa Cruz Mountains (Big Basin Redwood State Park), but were regularly observed in these waters in 2009 (MZP *personal observation*).

We believe that there are two primary hypotheses that can explain the decline and subsequent increase in the local abundance of Marbled Murrelets in central California. First, a large proportion of the population may have moved out of the survey area in 2007 and 2008, and then returned in 2009 (the "distribution hypothesis"). Second the population may have declined to low levels in 2007 and 2008 because mortality exceeded birth rates, and then the immigration of individuals from larger populations to the north resulted in an increase in the number of birds detected in 2009 (the "immigration hypothesis). Discriminating between these two explanations is challenging without information about individual movements (i.e., radio-telemetry), surveys conducted in other regions, or genetic information on whether or not individuals counted in 2009 represented migrants from other populations. The distribution hypothesis would seem plausible because Marbled Murrelets sometimes disperse out of the central California study area during breeding season and regularly so after the breeding season (Peery et al. 2008). However, the "distribution" hypothesis would require that population growth (λ) was reasonably stable from 1999 to 2009, when N = 487 and 495, respectively, using transects delineated from the north, despite the fact that population models predict

approximately a 9.5% annual decline from 1999 to 2003, largely due to very low reproductive success (Peery et al. 2006). Moreover, reproduction, as estimated with juvenile ratios, appeared to remain very low after 2003 (recognizing that surveys were not conducted in 2004-2006) and was zero in 2008, the year before the increase in abundance in 2008 (Table 3), further suggesting that the population was not sustaining itself. It is conceivable that juvenile ratios provide misleading (i.e., pessimistic) estimates of reproductive success due to violations of a number of assumption, but two recent studies suggest that juveniles ratios yield reasonably accurate productivity estimates (Peery et al. 2007, Wong et al. 2008). Nevertheless, the possibility of higher than estimated reproductive success resulting in higher than predicted population growth cannot be completely discounted.

The immigration hypothesis seems plausible as well because the proportion of murrelets classified as migrants (using genetic assignment tests), increased from 1999 to 2003, and potentially masked an underlying decline in the resident population (Hall et al. 2009, Peery et al. 2010). However, no sampling for genetic analyses was conducted after 2003, so it is unclear if immigration stopped or declined after 2003, making the local population decline evident in 2007 and 2008. Moreover, without genetic information there is no direct evidence that immigration was responsible for the sharp increase in local abundance from 174 individuals in 2008 to 631 individuals in 2009 (using transects delineated from both directions). Indeed, such a large increase in abundance would certainly require greater levels of migration than observed in 1999 to 2003 (mean = 7% of population classified as migrants). Nevertheless, only a very small proportion of the much larger populations to the north would need to emigrate in order to result in the observed increase, and this explanation cannot be discounted either.

Clearly, resuming the genetic monitoring conducted in 1999 to 2003 is needed to discriminate between the distribution and immigration hypotheses. Specifically, if a high proportion of individuals sampled in the breeding season of 2010 are determined to be of migrant origin, the immigration hypothesis would be supported. We are well positioned to test these hypotheses because we have developed the genetic markers and data analysis techniques needed to reliably identify migrant marbled murrelets sampled in central California (Hall et al. 2009). We plan to conduct this work with support from Command Trustees and other sources in 2010.

Regardless of the explanation for the decline in abundance in 2007-2008, and the subsequent increase, the consistently low reproductive success estimated with juvenile ratios from 2007 and 2009 suggests that ongoing conservation projects in the Santa Cruz Mountains may not be producing the desired effect of increasing recruitment. Increasing these efforts, particularly corvid management, may be required to increase local recruitment to the level needed for a self-sustaining population.

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Table 1. Results of eight "zig-zag" surveys for Marbled Murrelets between Half Moon Bay and Santa Cruz, California during the breeding season of 2009.

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
2-Jun	North	95.723	37	1.57	0	5.65	0.774	672
8-Jun	North	102.278	19	1.47	0	2.87	0	300
26-Jun	South	95.725	32	1.66	0	5.90	1.161	739
3-Jul	South	96.531	29	1.66	1	5.19	0.792	626
15-Jul	South	97.324	42	1.71	0	8.49	0	889
16-Jul	North	97.743	41	1.78	1	9.47	0	991
6-Aug	North	102.947	19	1.89	0	3.73	0.824	477
11-Aug	South	96.057	20	1.80	2	4.54	0	475

Table 2. Population estimates for Marbled Murrelets in central California between 1999 and 2009; 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

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 2007-2009. Surveys used to estimate ratios were limited to 10 July to 23 August. 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
2008	0	(0)	0	(0)	47	4
2009	0.015	(0.011)	0.028	(0.018)	201	4

Fig 1. Locations and density of Marbled Murrelets detected in 2009 using at sea surveys in central California.

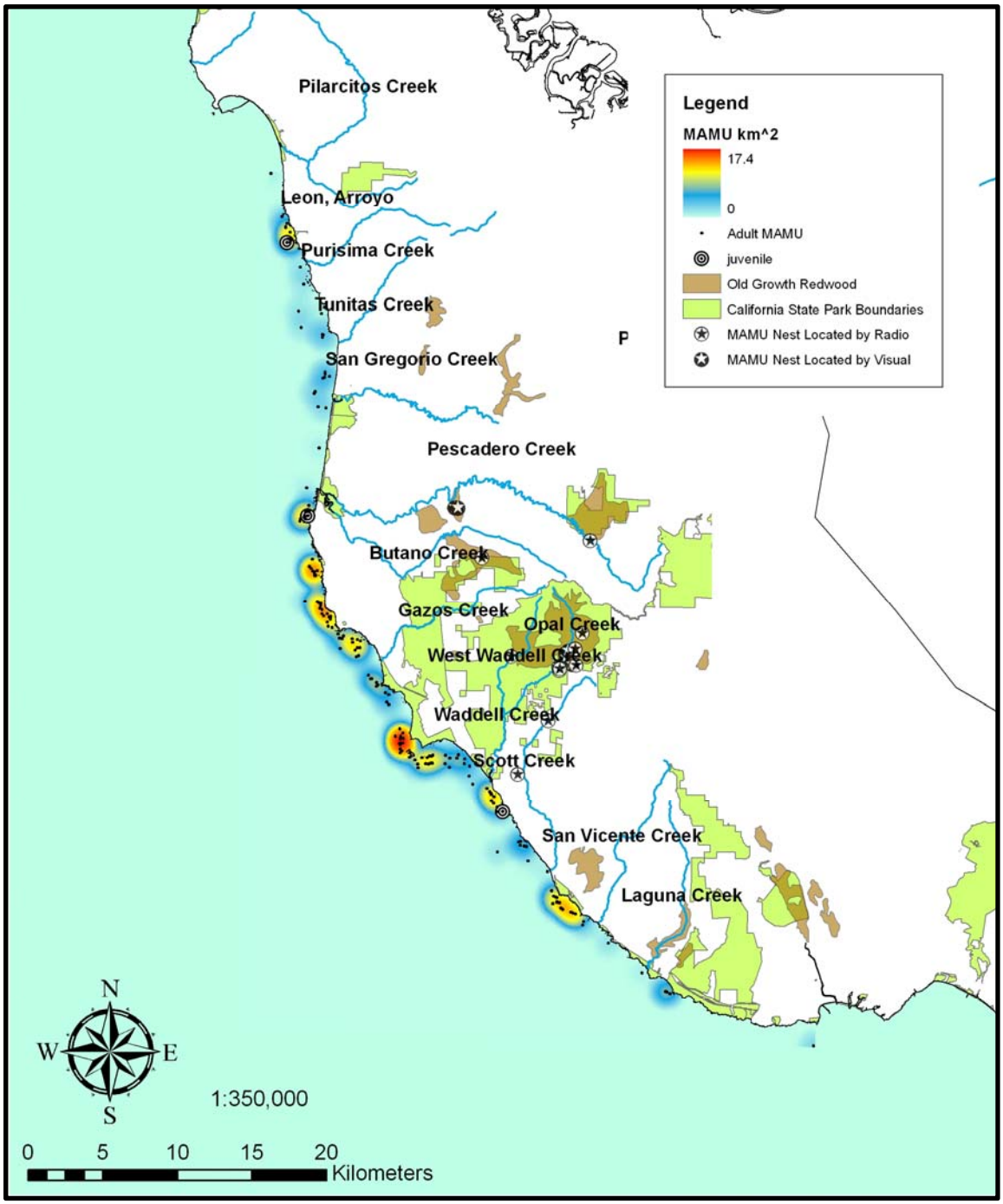

Fig. 2. Detection probabilities for Marbled Murrelet surveys conducted in central California during the 2009 breeding season.

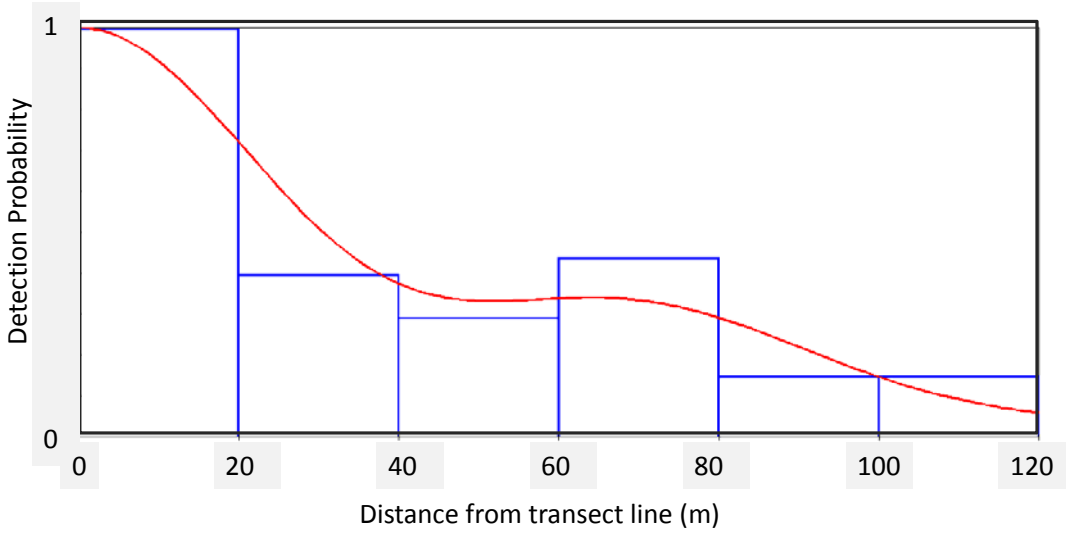

Fig 3. Abundance estimates for the central California population of Marbled Murrelets based on at-sea surveys, 1999-2009. Surveys were not conducted in 2004-2006.