ABUNDANCE AND PRODUCTIVITY OF MARBLED MURRELETS OFF CENTRAL CALIFORNIA DURING THE 2012 BREEDING SEASON

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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 2012. Using distance sampling estimation techniques, we estimated the central California population in 2012 to be 475 (95% CL: 373-605) with surveys delineated from the north (n = 3), 501 (95% CL = 359-699) with surveys delineated from the south (n = 3), and 487 (95% CL: 403-588) with all surveys (n = 6). These estimates are similar to those of 2010 and 2011 and greater than 2007-2008, when the population was estimated to have experienced large declines. The 2012 population estimates 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 is the most probable explanation for 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 0.032 (SE = 0.019) in 2012, markedly lower than 2010 and 2011 when juvenile ratios were among the highest observed for this population. To better juvenile ratio estimates, we tested whether focal near shore surveys (less than 1200 m from shore) yeilded different juvenile ratio estimates than standard zig zag surveys and found no significant differences. Our results follow a trend that dates back to 1996 of consistently low estimates for the adult population and for juvenile ratios. These demographic estimates continue to be insufficient to support positive population growth (λ). The chances for long-term persistence of the Region 6 Marbled Murrelet population continues to rest on the efficacy of key management actions that increase reproductive output such as reducing the depredation of young.

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 consistently too low to compensate for adult mortality (Peery et al. 2006a). To aid in determining the efficacy of restoration efforts in the Santa Cruz Mountains, the Command Trustee Council funded at sea surveys in Zone 6 during the 2007-2010 breeding seasons (Henkel and Peery 2008). The Luckenbach Oil Spill Trustee Council continued funding in 2011 and 2012. 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). The 2010 and 2011 estimates of the adult population showed a decrease to 446 and 433 individuals respectively. The juvenile ratio estimates for 2010 and 2011 were the highest observed for this population, however they remained below the threshold for a sustainable population. Here we report on adult population and juvenile ratio estimates from surveys conducted in central California in 2012.

Methods

Estimating Abundance

We conducted 8 at sea surveys for Marbled Murrelets between Half Moon Bay and Santa Cruz in 2012 (19 June to 23 August). Two surveys (25 July and 23 August focused on juvenile detection in the nearshore stratum (see below). We identified young of year and adults following Strong (1998). Surveys were approximately 100 km long and followed zig-zag transect routes consistent with surveys conducted from 1999 through 2003, and 2007 through 2011 (Peery et al. 2006a, Henkel and Peery 2008, Peery et al. 2009, Peery and Henry 2010a, Henry et al. 2012). Surveys began at a random distance (200-2500 m) from shore, immediately outside of the Half Moon Bay Harbor and continued SSE to Pleasure Point, Santa Cruz. Transects included both a "nearshore" (200-1350 m from shore) and "offshore" stratum (1350-2500 m from shore), with approximately four 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. South drawn surveys increase the percentage of habitat surveyed in leeward bays, which can hold increased concentrations of marbled murrelets and previous analyses show that transects drawn from the south yield 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 (10.4% of sightings <120 m in 2012) 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:

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

where $ES\hat{W}$ 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 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 6 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 $\mathrm{var}(\hat{R}_t)$ 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 hatch-years 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 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 $\hat{\mathrm{var}}(\hat{\bar{R}})$ 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 positive 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 2012 breeding seasons (Figure 1). The highest concentrations of murrelets occurred between the North of Purisma Creek to Tunitas Creek, between the mouths of Pescadero Creek and Gazos Creeks, near Pigeon Point, and Ano Nuevo Point (Figure 1). Murrelet density was greater in the northern portion of the survey area than in recent previous years. We detected relatively few murrelets within the southern portion of the survey area including that portion within Monterey Bay.

The mean number of groups detected in adult abundance surveys was 22.83 (range: 10-30) and mean group size was 1.82 (range: 1.60-2.20) in 2012 (Table 1). The sighting data were not significantly different from those expected using the half-normal detection model with cosine adjustments ($\chi 2 = 3.83$, df = 4, $P = 0.43$). The detection function shows the model fit the sighting data well (Figure 2).

Using this detection function, we estimated ESW to be 59.6 m (95% CL 52.1-68.2 m). We estimated density to be 4.40 murrelets/km^2 (95% CL: 3.67-5.25 murrelets/km^2) in the nearshore stratum and 0.26 murrelets/km^2 (95% CL: 0.10-0.65 murrelets/km^2) in the offshore stratum. As in previous years, transects delineated from the south yielded greater estimates of population size. The 2012 estimates for the central California population were 475 (95% CL: 373-605) with surveys delineated from the north ($n = 3$), 501 (95% CL = 359-699) with surveys delineated from the south ($n = 3$), and 487 (95% CL: 403-588) with all surveys ($n = 6$). These results indicate regional abundance has remain relatively similar since 2010, greater than the 2007/08 estimates, but less than estimates from 1999-2003 and 2009 (Figure 3A).

Juvenile Ratios

We detected six juveniles in 2012, one detection occurred on June 25, before 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 Pigeon Point Bay (Figure 1). Wong et al. (2008) found that juveniles remain closer to shore than adults, which could negatively bias our juvenile ratio estimates. To test this we performed additional surveys that targeted the nearshore strata. Using the calculations described above, we estimated uncorrected juvenile ratios (R) were 0.011 (SE=0.009) and corrected R = 0.024 (SE=0.019) for the zig-zag surveys (n=3) and uncorrected R = 0.026 (SE=0.027) and corrected R = 0.033 (SE=0.035) for the focal nearshore surveys (n=2). These ratios were not significantly different (t=-0.75, p=0.57 uncorrected and t=-0.33, p=.78 corrected), thus we pooled all surveys for juvenile ratios and estimated an uncorrected juvenile ratio of 0.020 (SE = 0.014) and date-corrected juvenile ratio of 0.032 (SE = 0.019, 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, the 2009 estimates of local abundance was similar to pre-decline estimates from 1999-2003 (Table 2, Figure 3A). The ensuing 2010 - 2012 population estimates are similar to each other and suggest the population is intermediate the previous high and low estimates. Regardless, the average estimate from the past years 2010-2012 is 33% less than the 2001-2003 estimates, suggesting the population is on a downward trajectory. The 2009 rebound in population numbers along with higher observed juvenile ratios are of interest and might be explained by several hypotheses (Perry and Henry 2010a, Henry et al. 2012, Vásquez-Carrillo et al. 2013).

Recent Increases in Abundance

Recent population estimates are lower than 1999-2003 estimates, but perhaps not as abysmally low as suggested by the 2007 and 2008 numbers. Vásquez-Carrillo et al. (2013) used genetic techniques to explore two primary hypotheses for the inter-annual variation in Marbled Murrelet population estimates.

The '*rescue*' hypothesis holds the 2007-2008 dip and subsequent 2009 population increase resulted from birds from northern population recruiting to central California. 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. 2008a, Hall et al. 2009). Vásquez-Carrillo et al. (2013) 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.

Since population persistence is not supported by source sink dynamics then we return to the *'distribution hypothesis'*. Terrestrial attributes (nesting habitat) made the strongest contribution to at sea distribution of murrelet populations in Northern California, Oregon, and Washington (Raphael et al. 2014). However, Region 6 murrelets tracked with VHF tags can make long distance movements during the breeding season (Burkett unpublished data, Peery et al. 2008b, Henkel personal communication). Long distance movements could lead to temporary displacements that explain the 2007-08 decreases and subsequent 2009 increase in population estimates.

Additional surveys outside the current at sea study area during years of low population estimates (e.g. 2008) and/or electronic tracking of individuals during irruptive years (e.g. 2009) could shed further light on this phenomenon. Vessel based surveys across large areas require prohibitively high effort and may be insufficient to detect 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 used to detect marbled murrelets south of Region 6 during years of low abundance in the primary survey area. However, the large size of the potential search area combined with difficulties in consistently detecting small murrelets from the air would make aerial surveys extremely difficult. Displacements would be better detected using deployment of lightweight electronic tracking tags, the lightest of which are vhf tags. This technique could utilize aerial vhf scanning. If birds remained close to shore, automated vhf signal detectors could be deploy at strategic points along the coast to scan for vhf tags. This may be the best option to test if the distribution hypothesis drives interannual variation in local abundance.

We do not believe the decline and subsequent increase in population numbers was due to changes in methodology, as survey and data analysis techniques have remained consistent across years. However, the 2007 and 2008 surveys (n=4 for each) had between 33-73% fewer surveys than other estimates. These low sample sizes could have produced misleading results. Also, while we attempt to survey under optimal conditions, at sea conditions are highly variable and can influence survey estimates (Becker & Beissinger 1997). In the future, completing a sufficient number of surveys (n=6-9) will help capture more optimal survey days and help minimize the confidence intervals of population estimates. Observer error may also contribute to observed variation, however accounting for this error source requires a large number surveys (n=20-30). Finally, use of models that incorporate continuous habitat data such as depth and distance to shore (Gerrodette & Eguchi 2011) might improve our estimates.

The “distribution” hypothesis, predicts population growth (λ) was reasonably stable from 1999 to 2012, given abundance estimates of when N = 487 and 475, 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). During this time estimates from juvenile ratios, were very low, in fact zero in 2008, before increasing in 2009 (Table 3). Research suggests that juvenile ratios yield reasonably accurate productivity estimates (Peery et al. 2007, Wong et al. 2008). Despite relatively high juvenile ratios observed in 2010 and 2011, productivity remains well below the historical estimates (~0.3 HY/AHY) associated with stable population growth (λ) (Beissinger and Peery 2007). Recent juvenile ratios do not appear to explain the current population size.

Juvenile Ratios

The 2012 juvenile ratio estimate is similar to those made in the late 1990's but some 57-65% lower than estimates made in 2010 and 2011, respectively. Productivity is highly variable in many seabird species and variability in murrelet juvenile ratio estimates may result from changes in both terrestrial and at sea conditions. The positive uptick in 2010 and 2011 juvenile ratios may have been be related to improved breeding conditions resulting from predator control at core breeding areas. California Department of Parks and Recreation had stepped up public outreach and education efforts to reduce anthropogenic food subsidies to corvid populations (Halbert pers. Comms, Henry et al. 2012). In 2012 Gabriel et al. (2014) began a conditioned taste aversion project aimed towards reducing corvid predation and enhancing murrelet productivity. The 2012 juvenile ratios do not demonstrate evidence for the efficacy of these programs. Nest predation rates may also be influenced by other abiotic (i.e. climatic) and biotic (i.e. competitive) factors that affect predator distribution, prey choice, and abundance.

Changes in ocean conditions can also 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 not abundant in the diet of Rhinoceros Auklets that breed in the central California murrelet study area during 2012 (Carle et al. 2014). Auklet diet was dominated by Pacific saury (*Cololabis saira*) and market squid (*Loligo opalescens*). Pacific saury is not common in nearshore habitats where murrelets are found and market squid have low energy density which decreases calories delivered per chick provisioning trip. Additional research on murrelet prey choice, prey availability, chick provisioning rates and the distance between foraging and nesting sites might provide insight on the relationship between conditions at sea and productivity.

Finally, we observed similar northern biased pattern in adult and juvenile distribution to that of 2010 and 2011 (Figure 1). It is still unclear whether this is due to nesting location, foraging conditions, or prey abundance. Modern electronic tracking techniques could help better understand the terrestrial and at sea habitat preferences of murrelets. 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.

Regardless, juvenile ratios remain far below the R=0.30 value observed when the population was more robust (Beissinger et al. 2007). Thus, if this number is correct, conservation efforts will need to make substantial gains 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 2013). 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, managers have avoided Jay removal, 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.

In summary, the 2012 at sea survey data suggest continued improvement for the central California marbled murrelet population, however juvenile ratios were lower than recent years. 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 2010-2011 increases in juvenile ratios was likely due to a combination of factors including reduced corvid predation, favorable prey abundance at sea, and possibly 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 murrelet conservation measures 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. The focal juvenile ratio surveys in 2012 did not appear to provide more accurate data on murrelet productivity however statistical power was lower due to small sample size. Adult population and juvenile estimates remain low and focusing additional predator control efforts on the primary murrelet nest predator (i.e. Steller's jays) appears to represent an important management tool that could enhance local recruitment to the level needed for a self-sustaining Zone 6 population. Concurrent conservation investment in contiguous swaths of inland nesting habitat via preservation and enhancement of old growth characteristics will continue to assist with recovery of this species.

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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 2012.

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
19-Jun-12	North	101.61	30	1.60	0	4.809	0.393	544.38
25-Jun-12	South	101.75	30	1.63	1	4.125	0.000	431.66
30-Jun-12	North	102.12	26	1.81	0	4.372	0.767	537.83
15-Jul-12	South	95.79	24	1.83	1	4.847	0.397	548.81
23-Jul-12	North	101.15	17	1.82	0	3.269	0.000	342.06
25-Jul-12*	South	90.25	47	1.85	0	-	-	-
16-Aug-12	South	97.32	10	2.20	0	5.042	0.000	527.60
23-Aug-12*	South	92.37	42	1.69	4	-	-	-

* Density estimates were not made for focal nearshore juvenile surveys

Table 2. Population estimates for Marbled Murrelets in central California between 1999 and 2012; 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
2012	487	403-588	6	475	373-605	3	501	359-699	3

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 2007-2012. 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
2010	0.032	(0.014)	0.074	(0.033)	141	3
2011	0.060	(0.024)	0.091	(0.027)	99	4
2012	0.020	(0.014)	0.032	(0.019)	249	5

Figure 1. Locations of Marbled Murrelets and juveniles detected during at sea surveys in central California in 2012. Inland detections source: California Fish and Game, Marbled Murrelet Database (2008).

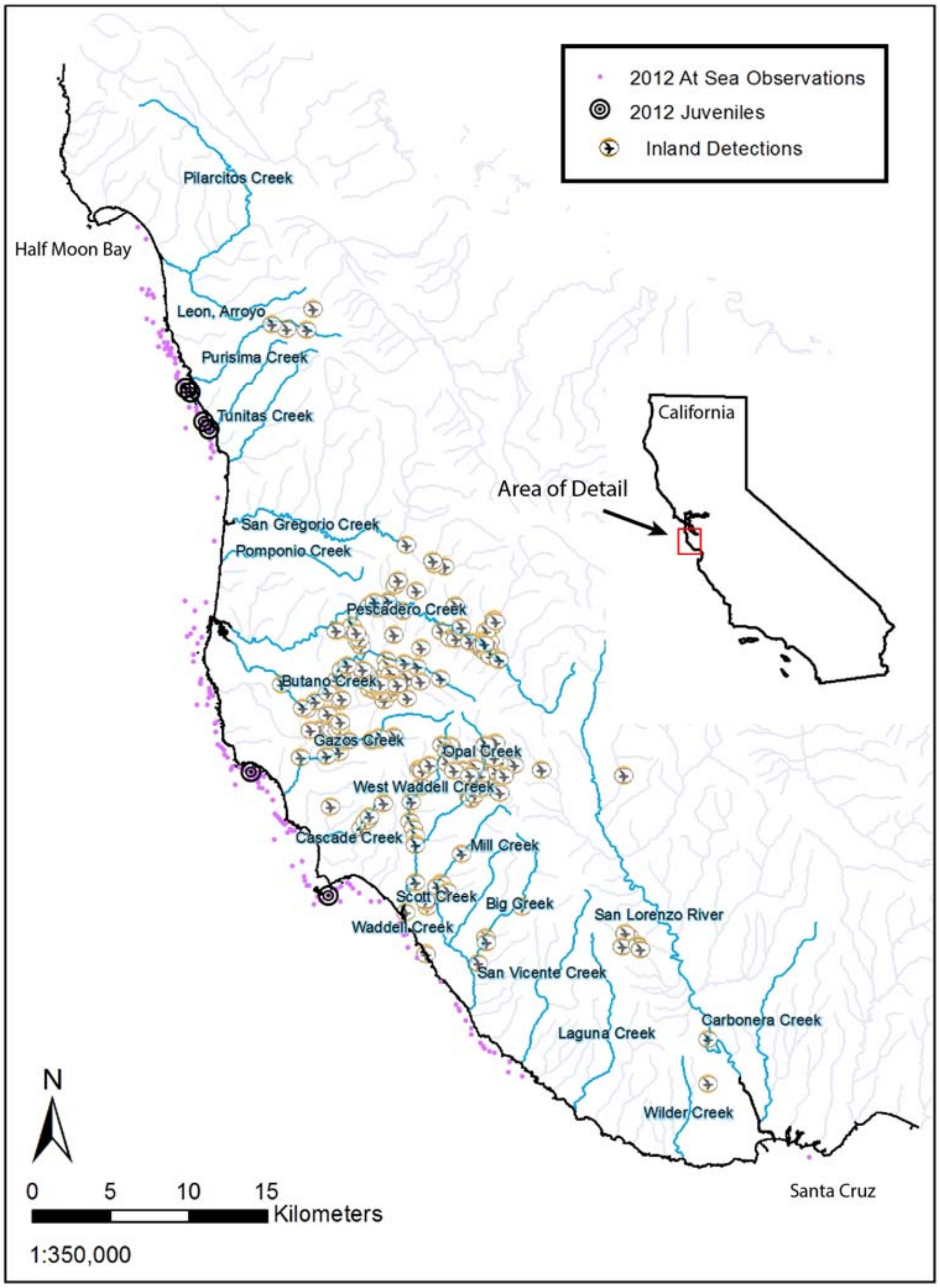

Figure 2. Detection probabilities for Marbled Murrelet surveys conducted in central California during the 2012 breeding season ($\chi2$ = 3.83, df = 4, *P* = 0.43).

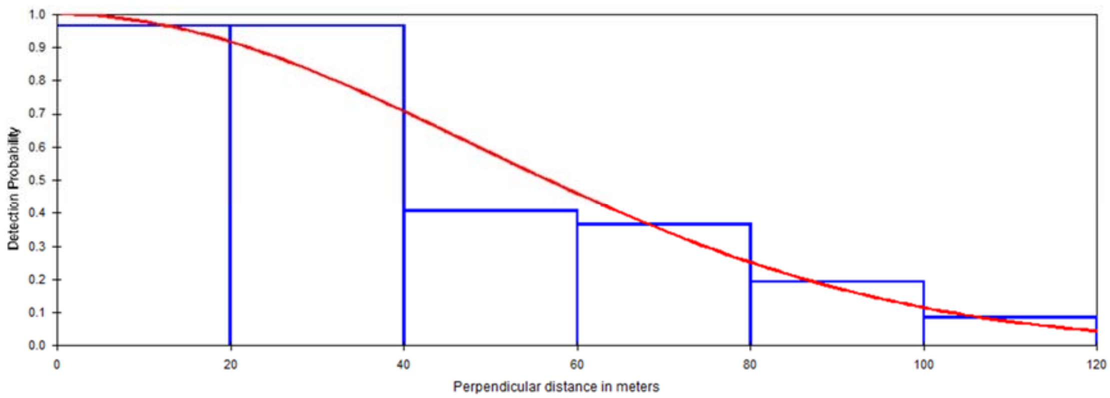

Figure 3. A) Abundance estimates for the central California population of Marbled Murrelets based on at sea surveys, 1999-2012 (dashed lines 95% confidence intervals for surveys drawn in Both directions). Zig-zag surveys were not conducted prior to 1999 and from 2004-2006. B) Juvenile ratios solid lines (dashed lines ±1 standard error). Data absent from years 2004-2006. The approximate date of the beginning of corvid subsidy control is indicated.