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ABUNDANCE AND PRODUCTIVITY OF MARBLED MURRELETS OFF CENTRAL CALIFORNIA DURING THE 2013-2016 BREEDING SEASONS

Report
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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 from 2013-2016. Using distance sampling estimation techniques, we estimated the central California population in 2013 at 628 (95% CL: 386-1022), 2014 at 438 (95% CL: 307-624), 2015 at 243 (95% CL: 152-386), and 2016 at 657 (95% CL: 406-1063). Estimates from 2012, 2014, and 2016 are similar to those of 2009 – 2012. The 2013 estimate is close to those for 2007-2008, when the population was estimated to have experienced large declines. 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 recent temporary dips in abundance estimates. The date-corrected juvenile ratio, an estimate of productivity commonly used to index reproductive success in Marbled Murrelets was 0.093 (SE = 0.025) in 2013, 0.081 (SE = 0.035) in 2014, 0.059 (SE = 0.020) in 2015, and 0.108 (SE = 0.051) in 2016. 2016 saw the highest juvenile ratios observed for this population. While these data are positive signals for the recovery of the Region 6 marbled murrelet population, long-term persistence will continue to rest on the efficacy of key management actions that increase reproductive output such as reducing the depredation of young.

Introduction

We present abundance and juvenile ratio estimates for marbled murrelets breeding in Region 6, the Santa Cruz Mountains, as determined by at sea surveys in adjacent near shore waters during the 2013-2016 breeding seasons. At sea surveys for Marbled Murrelets in Region 6 began in 1995 and covered the core area of Region 6 nearshore waters from Pigeon Point South to Greyhound Rock (Becker et al. 1997). These original surveys were run at constant distances from shore (400-4400m) and provided data for calculation of juvenile ratio estimates (Peery et al. 2007). Resulting data were also used to refine line transect survey methodology for abundance estimation that is in use today (Becker et al. 1997). In 1999 Becker and Beissigner (2003) initiated zig-zag transects 200-2500m offshore from Half Moon Bay to Soquel Point. These transects covered the length of nearshore habitat adjacent to breeding populations and allowed for estimation of both juvenile ratio and murrelet density across the entire Region 6 breeding area. Ongoing monitoring of murrelet juvenile ratio and abundance has continued via zig-zag surveys from 1999 – 2016 with a short hiatus from 2004 – 2006 (Peery and Henry 2010a, Henry et al. 2012, Henry and Tyler. 2016).

Methods

Estimating Abundance

We performed annual at sea surveys (n ranging from 6-9) for Marbled Murrelets between Half Moon Bay and Santa Cruz (1 June to 24 August) from 2013-2016. Young of year and adults were identified during surveys (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 2012 (Peery et al. 2006a, Henkel and Peery 2008, Peery et al. 2009, Peery and Henry 2010a, Henry et al. 2012, Henry and Tyler 2016). 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.

We selected from a pool of survey routes created by Becker and Beissinger (2003). We selected equal numbers of routes that were originally drawn using starting points at the north and at the south ends of the survey area. Survey route drawn from the south result in an increase the percentage of habitat surveyed in leeward bays, which are south facing, and often hold increased concentrations of marbled murrelets. Previous analyses show that transects drawn from the south yield higher densities than transects delineated from the north (Henkel and Peery 2008). Surveys were compiled separately (depending on delineation), in order to examine any bias, and to allow for comparability with previous surveys from 1999-2000. We randomly selected survey routes from a set of routes that were previously used during surveys from 1999-2012.

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. Birds were counted in flight if they crossed a line perpendicular to the track line and even with the observers. Including flying birds in counts 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 $\hat{ESW}$ 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 in km (Buckland et al. 2001).

Estimating *ESW* requires modeling the decline in detection probability as a function of distance from the sighting data. All detections <=120 m from the transect lines (see Results) were grouped into bins. A half-normal detection model with cosine adjustments was used to model detectability as a function of distances, as in previous years. To derive abundance from density estimates, survey- and stratum-specific density estimates generated by DISTANCE were multiplied by the total area of the stratum (104.65 km^2 for both strata).

Estimating Juvenile Ratios

Juvenile ratios (the ratio of hatch-year to after-hatch-year individuals) were estimated for Marbled Murrelets based on surveys conducted from 10 July to 24 August (Julian Date 192 to 237 for all years). Prior to 10 July, few (34%) young are expected to fledge, and in late August, hatch-year and after-hatch-year murrelets become indistinguishable as the latter progress in their pre-basic molt (Peery et al. 2007). For this analysis we included surveys performed on or before Aug 24, having confidence that we correctly identified hatch-year birds following techniques outlined by Long (2001). Only birds of known age class were included in juvenile ratio calculations. The following equation was used to estimate the (observed or date-corrected, see below) juvenile ratio R in year t:

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

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). The $\mathrm{var}(\hat{R}_t)$ was estimated using:

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

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). The mean juvenile ratio for the entire study period ($\hat{\bar{R}}$) was estimated by averaging unweighted annual estimates and estimated $\hat{\mathrm{var}}(\hat{\bar{R}})$ 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 (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, the equation below was used 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, it was assumed that no birds were incubating and the observed number of after-hatch-years was not corrected.

Juvenile ratios may suffer a negative bias because surveys are conducted prior to the completion of fledging (Peery et al. 2007). 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 Estimates

The working dataset from 1999-2016 included a total of 5459 murrelets observed during 3095 encounters with 2955 murrelets observed <=120m from the vessel. Murrelets were detected throughout waters between Half Moon Bay and Santa Cruz during the 2013-2016 breeding seasons years (Figure 1). The majority of murrelet detections were made in the Central and Northern portions of the survey area during all years. We detected few murrelets within the southern portion of the survey area including that portion within Monterey Bay. This said, observations of adults and hatch year murrelets were shifted slightly further south in 2013. The highest concentrations of murrelets occurred near Año Nuevo Point, Franklin Point, Pigeon Point, and just south of Pescadero Creek. We encountered lower and relatively even densities between Tunitas Creek and Half Moon Bay.

Results and abundance estimates for individual surveys are shown in Table 1. The mean number of groups detected in adult abundance surveys from 2013-2016 was 24.35 (range: 6-55) and mean group size was 1.75 (range: 1.31-2.29) (Table 1). In 2016 the mean number of groups detected was 25.14 (range: 13-46) and mean group size was 1.88 (range: 1.77-2.04). In 2015 the mean number of groups detected was 16.11 (range: 6-34) and mean group size was 1.68 (range: 1.507-2.03). In 2014 the mean number of groups detected was 25.56 (range: 6-40) and mean group size was 1.78 (range: 1.66-2.29). In 2013 the mean number of groups detected was 34.00 (range: 13-55) and mean group size was 1.65 (range: 1.31-2.07). The annual detection probability functions for 2013-2016 are shown in Figure 2. For each year the sighting data were not significantly different from those expected using the half-normal detection model with cosine adjustments (2016: $\chi 2 = 2.97$, df = 3, $P = 0.40$, 2015: $\chi 2 = 2.02$, df = 3, $P = 0.57$, 2014: $\chi 2 = 5.10$, df = 4, $P = 0.28$, 2013: $\chi 2 = 2.42$, df = 2, $P = 0.49$). The detection probability approaches zero at 120m and we therefore excluded observations >120m from the transect line for all abundance estimates for all years.

Using this detection function, in 2016 we estimated ESW to be 45.7 m (95% CL 39.2-55.7 m) with a density of 6.20 murrelets/km^2 (95% CL: 4.08-9.44 murrelets/km^2) in the nearshore stratum and 0.07 murrelets/km^2 (95% CL: 0.01-0.38 murrelets/km^2) in the offshore stratum. In 2015 we estimated ESW to be 76.2 m (95% CL 56.9-101.9 m) with a density of 2.11 murrelets/km^2 (95% CL: 1.35-3.30 murrelets/km^2) in the nearshore stratum and 0.20 murrelets/km^2 (95% CL: 0.05-0.86 murrelets/km^2) in the offshore stratum. In 2014 we estimated ESW to be 66.0 m (95% CL 58.9-74.0 m) with a density of 3.87 murrelets/km^2 (95% CL: 2.78-5.39 murrelets/km^2) in the nearshore stratum and 0.31 murrelets/km^2 (95% CL: 0.13-0.76 murrelets/km^2) in the offshore stratum. In 2013 we estimated ESW to be 56.9 m (95% CL 45.1-71.7 m) with a density of 5.60 murrelets/km^2 (95% CL: 3.92-9.19 murrelets/km^2) in the nearshore stratum and zero murrelets in the offshore stratum.

As in previous years, transects delineated from the south yielded greater estimates of population size. With the exception of 2015, which was among the lowest observed, region abundance estimates from 2013-2016 are consistent with those from 2010-2012, greater than the 2007/08 estimates, but less than estimates from 1999-2003 (Figure 3A).

Juvenile Ratio Estimates

We detected 11, 4, 15, and 23 hatch year murrelets in 2016, 2015, 2014, and 2013 respectively (Table 1.). Annual estimates of hatch-year to after-hatch-year ratios (*R*) and standard errors (SE) for Marbled Murrelets are presented in Table 3 and Figure 3B. Corrected juvenile ratios (R) were lowest over the 4-year period in 2015 ($R^{corr} = 0.059$). The 2016 juvenile ratio estimate ($R^{corr}=0.108$) value is the greatest value observed for the Region 6 population.

Discussion

Abundance Estimates

The Marbled Murrelet population in central California seems to have had a significant and rapid decline from 2003 to 2007. This decline continued in 2008 when abundance estimates were as low as 174 individuals. Our recent population estimates including those from 2013-2016, indicated the population continues to rebound from the 2007-2008 nadir. This rebound follows corvid population/predation control measures that CA Department of Parks and Recreation (CADPR) first began implementing in 2006. While still remaining below historic population estimates from the 1999-2003, results presented in this report may signify a positive population response to CADPR actions.

Researchers have evaluated several hypotheses to explain recent dip and subsequent increases in abundance estimates. Vásquez-Carrillo et al. (2013) found evidence for a '*distribution hypothesis*' where genetic data show birds in the post-recovery Region 6 population were more similar to the pre-decline population than birds from northern populations. They concluded that while some individuals sampled were more genetically similar to northern populations, the estimated percentage increase in abundance due to northern migrants in the post-recovery period was small (<9%) which does not support the an alternative '*rescue hypothesis'* (i.e., immigration from northern populations).

The decline and subsequent increase in abundance does not appear to be related to changes in methodology, as survey and data analysis techniques have remained consistent across years. However, sample size and at sea weather conditions can influence survey estimates (Becker & Beissinger 1997). Observer error may also contribute to observed variation, unfortunately accounting for this error source requires a large number surveys. Future use of models that incorporate continuous habitat data such as depth and distance to shore (Gerrodette & Eguchi 2011) could improve abundance estimates.

Two things support the 'distribution hypothesis'. First, there is evidence of long distance movements during the breeding season from radio telemetry data (Burkett unpublished data, Peery et al. 2008b, Henkel personal communication). Systematic documentation of this phenomenon via at-sea survey effort is prohibitive due to difficulties with assessing murrelet distribution in vast areas during years of high dispersal (Henry and Tyler 2016). Second, the 2015 abundance estimate was among the lowest observed, in line with record lows in 2007 and 2008. Yet 2015 was followed by a high estimate in 2016. Self-recruitment cannot account for this magnitude of short-term variation, suggesting that the birds are not present in the Region 6 survey area during some years. 2015 at sea conditions were dominated by El Niño, which began in March of that year. This co-occurrence of low murrelet abundance and El Niño conditions suggests that extrinsic factors, such as ocean conditions, may drive the inter-annual variation seen in abundance estimates.

Variation in at sea distribution and local abundance may be related to changes in prey availability over longer time scales. Prey availability can be driven by short and long-term changes in ocean conditions as well as ocean management practices. For example the Central California coast witnessed the warm ‘blob’ in the 2014, which was associated with changes in distribution and abundance of marine fishes (Leising et al 2015). Regional fisheries management, such as heavy market squid fishing pressure or spillover effects of enhanced rockfish recruitment from the relatively young Año Nuevo Marine Reserve may also influence prey availability.

The West Coast market squid (*Doryteuthis opalescens*) fleet operates within the Region 6 survey zone and likely removes the largest biomass tonnage from the nearshore ecosystem. This has potential to directly and indirectly influence murrelet prey. The market squid fishery is California’s highest value fishery and the total catch in the Monterey Bay Area has seen recent increases in ex-vessel tonnage (2010 42,914,950 mt; 2011 30,529,740; 2012 19,425,126 mt; 2013 30,298,982 mt; 2014 90,355,473 mt; 2015 74,040,216 mt; 2016 NA, State of California Natural Resources Agency 2017). The proportion of the total California market squid catch that was caught in Monterey has also risen (2010 15%; 2011 11%; 2012 9%; 2013 13%; 2014 40%; 2015 91%; 2016 NA, State of California Natural Resources Agency 2017). This trend was evident in 2015 and 2016 when we observed high concentrations of squid boats in the Region 6 waters (Figure 4).

While market squid are not high caloric prey species for murrelets, heavy extraction and lowering of squid biomass could impact murrelets. Interactions with the market squid fleet are not well studied. Bright lights may impact murrelets, however Peery observed that MAMU do not appear to be highly active at night (Peery pers. obs). There may be potential for displacement of murrelets during the day at market squid breeding sites where light boats and recreational fishermen aggregate to follow squid schools and fish for squid predators. Within Region 6 nearshore waters, over the past 7-8 years the market squid population has appeared to have high fidelity to specific breeding sites, which are consistently fished each year (Henry pers. obs). The removal of large amounts of squid biomass from the Region 6 system likely affects other predatory fish species, including adult rockfish whose productivity contributes to local recruitment of juvenile rockfish.

Juvenile rockfish are known murrelet prey items (Burkett 1995). Recruitment of Young of Year (YOY) rockfish (*Sebastes spp*) has high inter-annual variability. YOY Rockfish have relatively high caloric value and regional seabird productivity appears to respond favorably to high YOY recruitment. During 2015 YOY Rockfish abundance was high at sea (Sukuma 2016), however this may not translate to high local nearshore recruitment where murrelets feed. The Ramondi/Carr Lab at UCSC historically examined rockfish recruitment in the nearshore waters of Southern Region 6, where murrelets are encountered. They observed record highs in 2013, which coincided with high murrelet abundance estimates. There may be some predictive association here, unfortunately rockfish recruitment efforts were discontinued in the southern Region 6 due to lack of funding (unpublished data PISCO UC Santa Cruz rockfish recruitment monitoring 1999-2011, pers comms Dan Malone, UC Santa Cruz).

Data on patterns of recruitment and distribution of nearshore rockfish, market squid, and other prey species including Northern Anchovy (*Engraulis mordax*), Pacific Sardine (*Sardinops sagax caerulea*), and Pacific sandlance (*Ammodytes hexapterus*) may help shed light on the connection between local prey availability murrelet population dynamics. These data may also contribute to active investigations in murrelet diet using next generation DNA sequencing techniques (Peery pers comms).

Juvenile Ratio Estimates

Estimates of juvenile ratios remained low since 1996 (Table 2). The 2016 corrected juvenile ratio (0.108, SE=0.051) is the highest observed to date. However, even the highest ratios observed for this population do not reflect productivity levels necessary to support stable murrelet populations, which is estimated to be between 0.18 and 0.28 (Beissinger & Nur 1997 in Peery et al. 2004).

Seabird reproductive success in this region is highly correlated with the availability of prey species such as krill, juvenile rockfish, mysids, sardines, anchovies, and squid (Ainley et al. 1995, Sydeman et al. 2001, and Beisseinger 1997). The high 2016 population and juvenile ratios estimates followed low estimates from the previous year when the 2015 El Niño event dominated ocean conditions in Region 6. El Niño is associated with poor reproduction fo seabirds that reside in upwelling systems (Barber & Chavez 1983). Interestingly, work by Hester et al. (2016) did not detect catastrophic nest failure of seabirds nesting on Año Nuevo in 2015, despite being located in the center of the Region 6 survey area. However, some seabird species nesting on Año Nuevo exhibited decreased productivity in 2007 and 2008, matching the historic low estimates of murrelet abundance and juvenile ratios. The observed record murrelet adult numbers and juvenile ratios in 2016 may reflect an increase in nesters in response to a return to more favorable ocean conditions and prey availability following the El Niño.

The total number of breeding birds could also influence increases in juvenile ratios. Birds that nest in high predation sites may have disappeared from the population over time. As these birds with low reproductive output senesce, the population could be domination by fewer breeders with high productivity. If true, this scenario may suggest that availability of nest sites with low predation and low fragmentation continue to regulate the population. Regardless the juvenile ratio trend has increased since lows in 2008 with recent numbers exceeding pre-crash estimates. Hopefully these estimates will continue to rise and support recruitment levels sufficient to recover the Region 6 murrelet population.

Changes in Distribution

Figure 1 shows what appears to be a northward shift in murrelet detections between 2013 and 2016. Terrestrial attributes, including nesting habitat, make the strongest contribution to at sea distribution of murrelet populations in Northern California, Oregon, and Washington (Raphael et al. 2014). Changes in at sea distribution may be in part explained by the quality of nesting habitat. Anthropogenic impacts (i.e. fragmentation, recreational use, and rural housing footprint) can impact the quality of nesting habitat. These impacts appear to be highest in the southern portion of the Region and lower in the north. If the population continues to recover and ongoing enhancements to nesting habitat, especially to core old growth nesting habitat in the central portion of Region 6, are successful we may expect to see shift in relative abundance back towards the central southern portions of Region 6.

Research and Management Recommendations

Research Recommendations

1. Continue at sea monitoring as the method for monitoring the entire Region 6 population.
2. Investigate the connection between at sea prey base and murrelet population dynamics.
    a. Collect background prey base metrics from static stations or vessel born instruments.
    b. Compare prey base with diet via next generation sequencing from birds captured at sea.
    c. Complete mass balance analyses of regional impact of fisheries, especially that of the market squid. Include trophic transfer to other species that consume squid are or produce murrelet prey.
    d. Evaluate the impact of Año Nuevo Marine Reserve on murrelet prey base.
3. Investigate how at sea and terrestrial distribution change over time.
    a. Model of at sea distribution over time with random effects of SST, upwelling, and other at sea variables.
    b. Examine at sea distribution in relation to watershed-based polygons and compare with historic records of inland distribution and/or multiple inland survey locations (via observer or automated sensors).

Management Recommendations

1. Continue corvid control with tactics geared toward reducing jay abundance and predation.
2. Require implementation of corvid population control measures/best management practices (BMPs) on all lands in Region 6, including coastal access points and landfills. Expand “Crumb Clean” standards outreach to private landowners and inhabitants. Start this effort in close proximity to prime habitat. Mandate *all* coastal and inland development to accommodate BMPs and integrate monitoring protocol to assess adherence to BMPs.

Conclusion

Recent trends in abudance and juvenile ratio estimates show a small degree of cautious optimism for the future of the Region 6 marbled murrelet population. Abundance estimates have rebounded from lows of 2007 and 2008. Initiation of corvid management by the California Department of Parks and Recreation is followed by positive trends in at sea abundance and juvenile ratios. More research and mitigation of corvid predation and other drivers of murrlet productivity, including at sea factors, will help inform and accelerate the possibility of recovery of the Region 6 marbled murrelet population. We recommend continuation of consistent at sea surveys as the best method for estimating the Region 6 marbled murrelet population until positive population growth and rising population numbers are consistently documented.

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Table 1. Results of 6 "zig-zag" surveys for Marbled Murrelets between Half Moon Bay and Santa Cruz, California during the breeding season of 2013-2016.

Survey Date	Direction of Transect	Survey Type	Transect Length (km)	Number of Groups	Mean Group Size	Number of Juveniles	Nearshore Density (birds/km^2)	Offshore Density (birds/km^2)	Abundance Estimate
6/6/16	South	zig	97.3	46	2.04	0	12.553	0.000	1313.67
7/6/16	North	zig	103.9	25	1.84	0	5.745	0.000	601.21
7/17/16	South	zig	96.5	33	1.91	1	8.416	0.000	880.73
7/26/16	North	zig	103.7	17	1.94	0	4.284	0.000	448.32
8/2/16	South	zig	95.7	21	1.81	4	4.758	0.525	552.87
8/3/16	North	zig	101.7	21	1.86	5	4.737	0.000	495.73
8/22/16	South	zig	101.1	13	1.77	1	3.095	0.000	323.89
6/1/15	South	zig	96.5	18	1.61	0	2.099	1.529	379.67
6/8/15	North	zig	103.7	14	1.57	0	1.695	0.000	177.38
7/7/15	South	zig	97.3	34	2.03	0	4.602	0.000	481.60
7/16/15	North	zig	101.7	19	1.63	0	2.502	0.000	261.83
7/21/15	South	zig	95.7	19	1.58	1	2.489	0.341	296.16
7/29/15	North	zig	99.1	12	1.75	1	1.780	0.000	186.28
8/4/15	South	zig	101.1	6	1.50	0	0.660	0.000	69.07
8/5/15	North	zig	103.9	8	1.63	1	1.041	0.000	108.94
8/11/15	South	zig	101.6	15	1.80	1	2.209	0.000	231.17
6/27/14	South	zig	103.9	24	1.71	0	3.602	0.000	376.95
7/1/14	North	zig	102.1	13	1.69	0	1.794	0.692	260.15
7/8/14	South	zig	99.1	40	1.73	2	6.159	0.000	644.58
7/15/14	North	zig	95.7	38	1.66	0	5.840	0.788	693.62
7/22/14	North	zig	97.3	28	2.29	2	5.887	1.200	741.67
7/26/14	South	zig	101.7	33	1.85	2	4.467	0.000	467.51
8/12/14	South	zig	103.7	19	1.68	2	2.444	0.000	255.72
8/16/14	North	zig	101.1	29	1.76	7	3.617	0.350	415.12
8/21/14	North	zig	96.5	6	1.67	0	1.009	0.000	105.57
6/6/13	North	zig	97.3	27	1.41	0	4.146	0.000	433.88
6/25/13	South	zig	107.5	55	1.69	4	9.520	0.000	996.27
7/9/13	North	zig	95.7	29	2.07	3	6.318	0.000	661.18
7/18/13	South	zig	99.1	34	1.74	1	5.674	0.000	593.78
7/24/13	North	zig	102.1	46	1.70	3	8.107	0.000	848.40
7/25/13	South	near	91.8	49	1.63	2	-*	-	-
8/1/13	South	near	93.1	41	1.90	4	-	-	-
8/21/13	South	zig	103.7	13	1.31	5	1.929	0.000	201.87
8/24/13	South	near	93.1	20	2.10	1	-	-	-

* Density estimates were not made for focal nearshore juvenile surveys in 2013

Table 2 Population estimates for Marbled Murrelets in central California between 1999 and 2016; 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
2013	628	386-1022	6	439	233-827	3	556	126-2456	3
2014	438	307-624	9	444	258-765	4	434	231-817	4
2015	243	152-386	9	225	136-370	4	296	159-549	5
2016	657	406-1063	7	510	358-726	3	720	297-1747	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 2007-2016. 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_{hy}	n_{inds}	$n_{surveys}$
1996	0.00626	(0.00255)	0.01033	(0.00337)	4	643	4
1997	0.010086	(0.00275)	0.02235	(0.00669)	7	701	5
1998	0.006881	(0.00321)	0.01304	(0.00579)	3	439	6
1999	0.016105	(0.00492)	0.03274	(0.01024)	11	694	10
2000	0.023916	(0.00813)	0.04917	(0.01585)	16	685	9
2001	0.033505	(0.00835)	0.06997	(0.0215)	13	401	8
2002	0.02551	(0.00377)	0.05083	(0.00936)	15	603	11
2003	0.024155	(0.00515)	0.04915	(0.0107)	10	424	8
2007	0.016667	(0.01792)	0.04877	(0.05182)	2	122	3
2008	0	*NA*	0	*NA*	0	60	4
2009	0.015152	(0.01075)	0.02837	(0.01758)	3	201	4
2010	0.036765	(0.01756)	0.08135	(0.03863)	5	141	3
2011	0.053191	(0.01545)	0.08001	(0.0172)	5	99	4
2012	0.020492	(0.01418)	0.03179	(0.01918)	5	249	5
2013	0.051282	(0.01808)	0.09291	(0.02491)	16	328	6
2014	0.048689	(0.02455)	0.08119	(0.03493)	13	280	6
2015	0.031496	(0.0109)	0.05885	(0.02046)	4	131	6
2016	0.060773	(0.03007)	0.1079	(0.05084)	11	192	5

Figure 1. Adult and juvenile at sea survey locations detected during at sea surveys in A) 2016, B.) 2015, C.) 2014, and D.) 2013. At-sea regions offshore of specific watersheds are delineated with different (arbitrary) shades of blue.

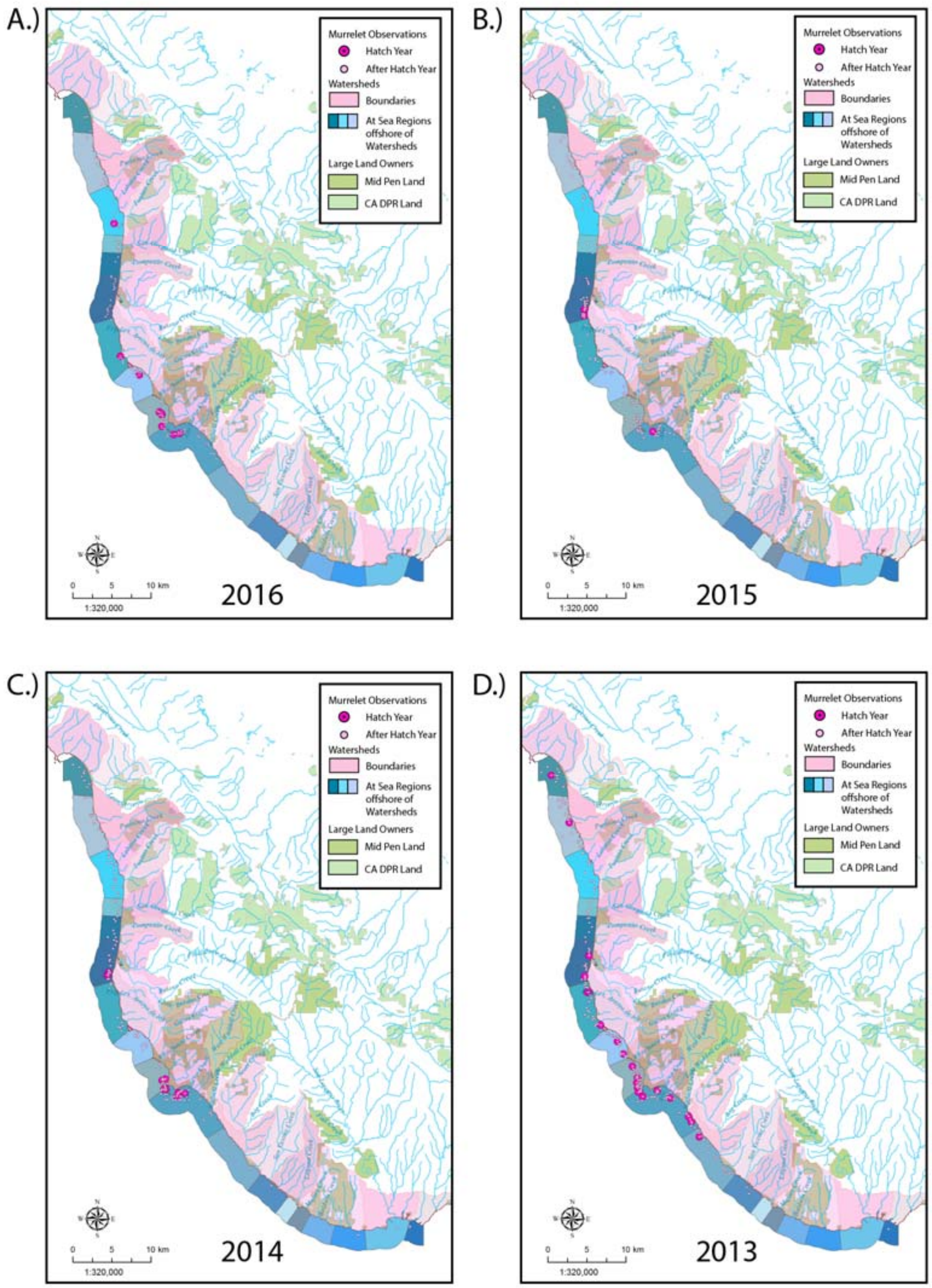

Figure 2. Detection probabilities for Marbled Murrelet surveys conducted in central California during A.) 2016, B.) 2015, C.) 2014, and D.) 2013 breeding seasons.

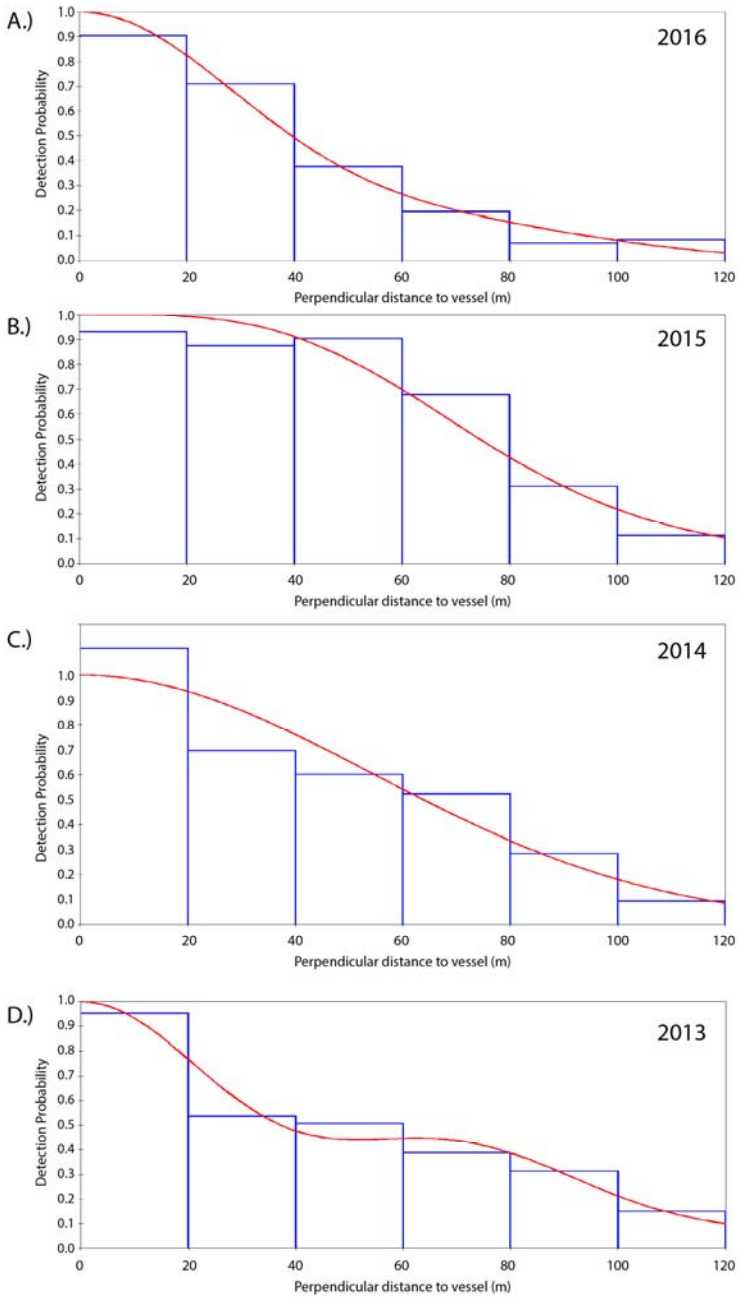

Figure 3. A) Abundance estimates for the central California population of Marbled Murrelets based on at sea surveys, 1999-2016 (dashed lines 95% confidence intervals for surveys drawn in Both directions). Data are absent from years 2004-2006. Zig-zag surveys were not conducted prior to 1999 and from 2004-2006. B) Juvenile ratios solid lines (dashed lines ±1 standard error) for 1996-2016. Data are absent from years 2004-2006. The approximate date for initiation of corvid predation control is indicated.

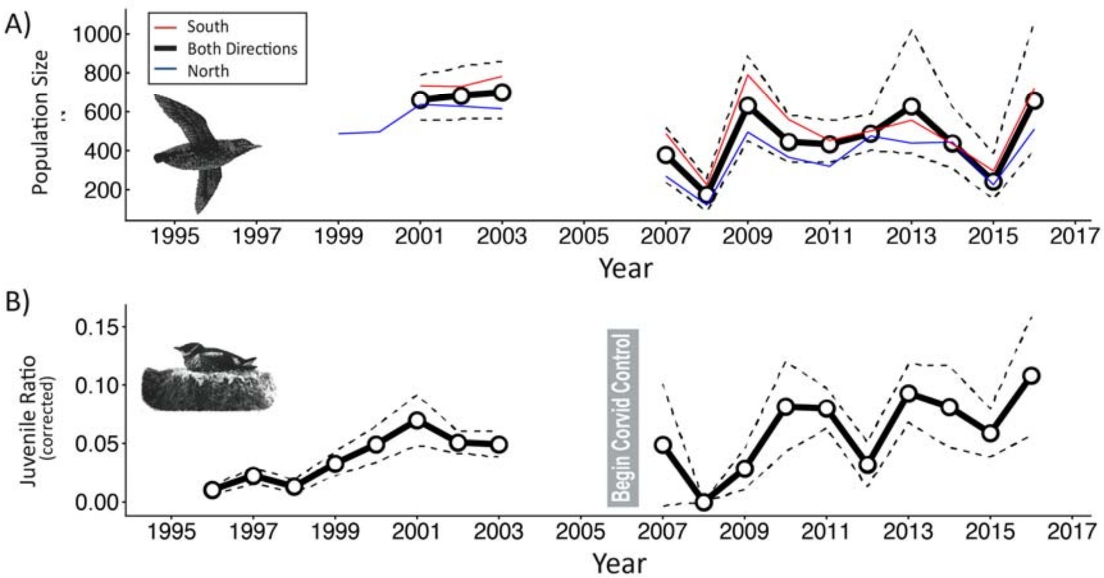

Figure 4. High densities of market squid fishing vessels off Davenport in late July, 2016 in the Region 6 survey area (photo Bill Henry).