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Abundance and Productivity of Marbled Murrelets (*Brachyramphus marmoratus*) Off Central California During the 2018 Breeding Season

Data Series 1107

U.S. Department of the Interior
U.S. Geological Survey

Cover: Juvenile marbled murrelet (*Brachyramphus marmoratus*) off Santa Cruz, California. Photograph by David Presksta, Bureau of Ocean Energy Management, August 1, 2017.

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)

U.S. customary units to International System of Units

Multiply	By	To obtain
	Speed	
nautical mile per hour (knot)	1.852	kilometer per hour (km/h)

Datum

Horizontal coordinate information is referenced to the World Geodetic System of 1984 (WGS 84).

Abbreviations

χ^2	chi-squared
AHY	after hatch year
df	degrees of freedom
CI	confidence interval
GPS	Global Positioning System
HY	hatch year
P	probability value
R/V	research vessel
SE	standard error
USGS	U.S. Geological Survey
WERC	Western Ecological Research Center

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Abstract

Marbled murrelets (*Brachyramphus marmoratus*) have been listed as "endangered" by the State of California and "threatened" by the U.S. Fish and Wildlife Service since 1992 in California, Oregon, and Washington. Information regarding marbled murrelet abundance, distribution, population trends, and habitat associations is critical for risk assessment, effective management, evaluation of conservation efficacy, and ultimately, to meet Federal- and State-mandated recovery efforts for this species. During June–August 2018, the U.S. Geological Survey Western Ecological Research Center continued previously established, long-term (1999–2018), at-sea surveys to estimate abundance and productivity of marbled murrelets in U.S. Fish and Wildlife Service Conservation Zone 6 (San Francisco Bay to Point Sur in central California). Using conventional distance sampling methods, we estimated marbled murrelet abundance using 137 detections of 227 individuals observed on 9 surveys. The abundance estimated for the entire study area using all surveys in 2018 was 370 birds (95-percent confidence interval, 250–546 birds). Estimated abundance from 2018 is comparable to most prior years of study, except for 2001–03, when greater abundances were estimated. In 2018, we estimated reproductive productivity (calculated as the hatch-year [HY] to after-hatch-year [AHY] ratio) using four detections of four HY individuals observed on six surveys. After date-correcting HY and AHY counts to account for birds expected to be absent from the water while inland at nests, the date-corrected juvenile ratio was 0.047 ± 0.024 standard error. We updated a synthesized database of all Zone 6 marbled murrelet survey data since 1999 with 2018 data to allow scientists and managers to evaluate established survey methods and assess trends in abundance and productivity estimates.

Introduction

The marbled murrelet (*Brachyramphus marmoratus*) is a small, diving seabird of the family Alcidae. Marbled murrelets inhabit North American nearshore marine waters from Alaska to central California. In California, marbled murrelets nest from March to October in forests within 80 kilometers (km) of the coast (Nelson, 1997). The southernmost known breeding area for marbled murrelets is south of San Francisco Bay in forested areas of the Santa Cruz Mountains near Point Año Nuevo and is separated from the nearest northern California population by 240–320 km. An estimated 174–699 individuals compose the annual breeding population of marbled murrelets in this disjunct area (Henry, 2017). During their breeding season (April to August), the at-sea distribution of marbled murrelets extends from Half Moon Bay to Santa Cruz, with greatest abundance in the waters near Point Año Nuevo (Henry, 2017). Sightings of marbled murrelets south of Santa Cruz in Monterey Bay during the breeding season are infrequent (Ralph and Miller, 1995; Henkel, 2004), but there has been less consistent survey effort in this region.

In 2018, the U.S. Geological Survey Western Ecological Research Center (USGS–WERC) partnered with California State Parks to continue long-term, at-sea surveys to estimate abundance and reproductive productivity of marbled murrelets in U.S. Fish and Wildlife Service Conservation Zone 6 (central California—San Francisco Bay to Point Sur). Marbled murrelets have been listed as "endangered" by the State of California and "threatened" by the U.S. Fish and Wildlife Service since 1992 in California, Oregon, and Washington. Abundance of marbled murrelets has been estimated at sea off central California since 1999 (excluding 2004–06; Henkel and Peery, 2008; Peery and others, 2009; Peery and Henry, 2010; Henry and others, 2012; Henry, 2017) and is funded by the U.S. Fish and Wildlife Service Natural Resource Damage Assessment and Restoration Program under the guidance of the Luckenbach Oil Spill Trustee Council. Information regarding marbled murrelet abundance, distribution, population trends, and habitat associations is critical for risk assessment, effective management and evaluation of conservation efficacy, and ultimately to meet Federal- and State-mandated recovery efforts for this species.

The USGS–WERC continued at-sea surveys in 2018 to assess abundance and productivity for two primary purposes: (1) to maintain efforts to quantify the status of marbled murrelets in central California (U.S. Fish and Wildlife Service Conservation Zone 6) and (2) to help evaluate potential benefits and marbled murrelet response to ongoing corvid control in coastal California State parks. Additionally, marbled murrelet distribution data at sea may help resource managers designate critical at-sea habitat for the species (for example, Bellefleur and others, 2009). In this report, we describe our methods and provide summaries of survey efforts and routes and results estimating marbled murrelet abundance and productivity (juvenile ratio) for 2018.

Methods

At-Sea Survey Methods

In 2018, USGS–WERC completed nine at-sea surveys for marbled murrelets between Half Moon Bay and Santa Cruz, California (fig. 1). We conducted surveys during the previously established survey window (June 1–August 24; Henry, 2017) and allocated surveys to two periods within this window—three surveys during June 1–July 9 and six surveys during July 10–August 24. Surveys were almost exclusively conducted when viewing conditions were excellent to good (table 1). We used data from all surveys to estimate marbled murrelet abundance; however, we only used the six surveys during the second survey period to estimate juvenile ratio (following Henry, 2017).

Table 1. Observer view condition classifications and descriptions for marbled murrelet (*Brachyramphus marmoratus*) surveys conducted from Half Moon Bay to Santa Cruz, central California, 2018.

[m, meter; ~, approximately]

View condition	Description
5—Excellent	Glassy.
4—Very good	Wavelets and (or) minor glare.
3—Good	Small waves/wavelets and (or) minor glare; still able to reliably detect murrelets within ~150 m of line.
2—Fair	Waves and (or) moderate glare; chance of missing murrelets within ~150 m of line.
1—Poor	High wind waves and (or) high glare; murrelets very difficult to detect.

Historically, survey routes were designed as continuous, about 100-km zigzag transect lines to sample nearshore (200–1,350 meters [m] from coast) and offshore (1,350–2,500 m from coast) strata, with approximately four times greater effort within the nearshore stratum owing to greater known marbled murrelet densities nearshore (see Henry, 2017, and references therein). Routes originally were drawn starting at a random distance (200–2,500 m) from shore, and an equal number of routes were drawn using starting points at the north and south ends of the survey area. When navigated from north to south (standard procedure), survey routes that were drawn from the south resulted in a greater amount of habitat surveyed in south-facing, leeward bays that often had greater relative abundances of marbled murrelets than more exposed stretches of the coast (Henry, 2017).

In 2018, we identified 10 unique survey routes (5 each drawn from north and south) used by Henry (2017) during 2013–16 surveys and randomly selected our survey routes from this pool (without replacement) for each survey; ultimately, we used 9 survey routes (4 drawn from the north and 5 from the south) to complete the 9 surveys. We conducted all surveys by following the selected route from north (Pillar Point Harbor, Half Moon Bay) to south (Soquel Point, Monterey Bay) using a Global Positioning System (GPS). When the survey route intersected land or crossed hazardous areas (for example, high surf areas nearshore), we maintained survey effort while safely navigating to the next transect segment. We conducted surveys from a small boat using line-transect methods (Becker and others, 1997; Peery and others, 2006; Henry, 2017). Two observers, standing on either side of a 6-m open skiff (R/V *Lucy M*, also used during 2013–16) traveling 12–15 knots (22–28 km per hour), recorded the observation time, angle off the transect line, and the distance to all groups of marbled murrelets detected. Observers counted marbled murrelets as a group when individuals were within 2 m of each other or if they showed behavior indicative of group status (for example, co-diving or vocalizing with one another; Strong and others, 1995). Observers recorded the age-class of each marbled murrelet based on three plumage classifications: (1) “after-hatch-year” (AHY), (2) “hatch-year” (HY), or (3) “unknown.” Behavior was recorded as “resting” on the water or “flying,” with flight direction noted. Distance and angle were estimated at the time of first detection, regardless of behavior. Prior to each survey, observers calibrated distance estimation using a laser rangefinder on buoys and other targets in the harbor. To facilitate estimations of sighting angles, we placed marks along the bow of the boat in 10-degree increments. The vessel occasionally paused or deviated from the transect line to properly identify marbled murrelet age-class; no additional observations were counted during these deviations.

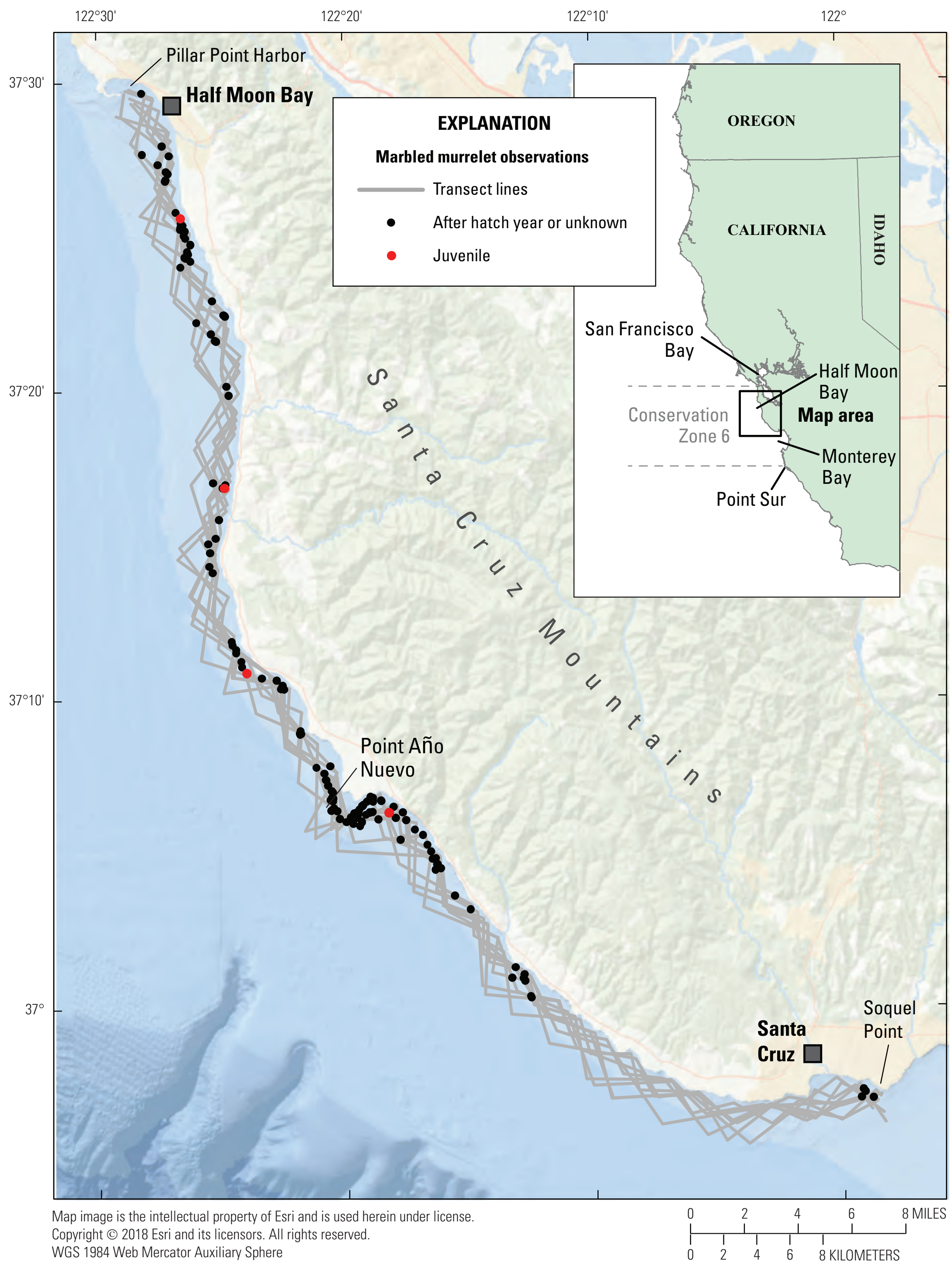

Figure 1. Map of U.S. Fish and Wildlife Service Conservation Zone 6 showing survey routes and marbled murrelet (*Brachyramphus marmoratus*) detections from Half Moon Bay to Santa Cruz, central California, 2018.

Observers recorded all observations and observation times using digital voice recorders, including survey start and end times, ocean conditions (Beaufort Sea state), viewing conditions (table 1), and time periods when effort was paused for any reason (for example, vessel paused or deviated from the transect line to identify marbled murrelet age-class). Observers reviewed their own recordings and transcribed and tabulated their sighting data into a single spreadsheet that was examined for quality assurance and quality control and then merged into a combined spreadsheet. We acquired a continuous 1-second GPS track during each survey using a handheld GPS unit; this track was used to georeference observations based on matching date/time using custom scripting in R (R Core Team, 2016). We created a spatial representation of strata in ArcGIS™ based on the same coastline shapefile used in previous years (California Department of Fish and Wildlife, 2004) and calculated linear effort for each survey within each stratum consistent with previous years by using the hypothetical survey route delineated by the zigzag segment nodes (table 2).

We updated a synthesized database of all marbled murrelet survey data since 1999 with 2018 data to allow scientists and managers to evaluate established survey methods and assess trends in abundance estimation and juvenile ratios (Felis and others, 2018).

Abundance Estimation Methods

We calculated perpendicular distance for each detection (sine of the sighting angle × observation distance) and inspected the distribution of perpendicular detection distances to select a truncation distance where detections approached zero, beyond which we excluded observations from analysis. Consistent with previous years, we included sightings of flying birds in our analysis, despite the potential that flying birds likely have a different probability of detection and including these could affect abundance estimates.

Table 2. Marbled murrelet (*Brachyramphus marmoratus*) survey dates, route direction, effort, observations, and density/abundance estimates for all surveys, U.S. Fish and Wildlife Service Conservation Zone 6, central California, 2018.

[CI, confidence interval; km, kilometer; km², square kilometer; mm/dd/yyyy, month/day/year; %, percent]

Survey date (mm/dd/yyyy)	Route direction*	Route name	Transect length (km)	Number of groups	Mean group size	Number of individuals	Number of hatch-year individuals	Nearshore density, birds per km² (95% CI)	Offshore density, birds per km² (95% CI)	Abundance birds (95% CI)
06/19/2018	South	USGS01S	97.3	25	1.60	40	0	5.09 (4.05–6.40)	0.54 (0.45–0.66)	589 (471–739)
06/26/2018	North	USGS09N	99.1	23	1.70	39	0	4.63 (3.63–5.91)	1.89 (1.56–2.30)	682 (543–859)
07/02/2018	South	USGS10S	102.1	10	1.50	15	0	1.92 (1.42–2.59)	0.00	201 (149–271)
08/03/2018	North	USGS02N	103.9	25	1.76	44	0	5.50 (4.40–6.89)	0.00	576 (460–721)
08/06/2018	South	USGS08S	101.6	7	1.57	11	0	1.30 (0.90–1.80)	0.48 (0.40–0.58)	186 (136–249)
08/08/2018	South	USGS03S	96.5	11	1.64	18	2	2.46 (1.87–3.22)	0.00	257 (196–337)
08/10/2018	South	USGS07S	101.1	7	1.57	11	0	1.42 (1.01–1.99)	0.00	149 (106–208)
08/13/2018	North	USGS04N	103.7	15	1.73	26	2	3.31 (2.62–4.16)	0.39 (0.32–0.47)	387 (308–485)
08/20/2018	North	USGS06N	101.7	14	1.64	23	0	2.90 (2.18–3.85)	0.00	303 (228–403)

*Route direction is the direction from which the route was drawn; all routes were surveyed from north to south.

Following Henry (2017), we used the program DISTANCE v7.1 (Thomas and others, 2010) to model our detection function and estimate marbled murrelet abundance using conventional distance sampling (see Buckland and others, 2015, for detection function modeling, model selection, and line transect abundance estimation methods). Specifically, using DISTANCE v7.1, we pooled observations from all 2018 surveys to create a global detection function for 2018 surveys and applied this function to each survey to calculate stratum- and survey-specific density estimates based on the linear effort sampled during each survey. Consistent with Henry (2017), we grouped perpendicular detection distances into 20-m bins, used a 120-m truncation distance, and evaluated the half-normal function, with or without cosine expansion; we selected the detection function with the smallest Akaike information criterion (AIC; Burnham and Anderson, 2004) value (that is, most parsimonious fit). We used the mean of observed cluster size method to estimate cluster (group) sizes. We assigned marbled murrelet observations to either the nearshore or offshore stratum in ArcGIS™ based on spatial overlap. We calculated survey-specific abundances by multiplying the stratum-specific density estimate by the total area of each stratum in the study area (104.65 square kilometers [km^2] for each) and then summed the two stratum-specific abundance values for a total area abundance estimate. Consistent with Henry (2017), we repeated the analysis described above with the data partitioned by survey route draw-direction to evaluate the effect of survey route direction on abundance estimation. New, direction-specific detection functions were modeled for these subsets of the data and used to estimate abundance (following Henry, 2017). We report annual abundances and 95-percent confidence intervals (95-percent CI) estimated by DISTANCE v7.1.

Juvenile Ratio Estimation Methods

We estimated the juvenile ratio (the ratio of HY to AHY individuals) for marbled murrelet surveys conducted during the fledging period. The previously established fledging period ranged from July 10, when an estimated 34 percent of HY birds are thought to have fledged, to August 24, about the time when HY and AHY murrelets become indistinguishable at sea because AHY birds begin pre-basic molt (Long and others, 2001; Peery and others, 2007). Thus, we included only surveys between July 10 and August 24 to estimate the 2018 juvenile ratio (following Henry, 2017). Identification of HY birds followed techniques outlined by Long and others (2001) and were aided by reviewing photographs and resources provided by the Alaska murrelet group (K. Nesvacil, Alaska Department of Fish and Game, written commun., 2017) before surveys. We included only those birds confidently identified to age class to estimate the juvenile ratio.

We adjusted HY and AHY counts to account for birds estimated to have been inland during the time of the survey. A certain percentage of AHY birds are still incubating young during the fledging period and, therefore, are not on the water during at-sea surveys, potentially creating a positively biased juvenile ratio. The proportion of AHY birds incubating is reported to be less than 6 percent between July 10 and July 17 and less than 1 percent after July 17 (Peery and others, 2004, 2007). Therefore, to correct for the number of AHY birds counted at sea between July 10 and July 17, we calculated, as the date-corrected number of AHY individuals,

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

where

$A_{observed}$ is the number of after-hatch-year (AHY) birds counted on survey i, and

the denominator is 1 minus the linear regression model for the proportion of incubating AHY individuals estimated for the Julian Day of survey i (*DATEi*; Peery and others, 2007).

For surveys after Julian Day 199, we assumed no birds were incubating, and the observed number of AHY birds was not corrected.

In addition to adjusting for incubating adults (to avoid positive bias in the estimated ratio), the juvenile ratio calculation can be negatively biased by not accounting for HY birds that have not yet fledged by the time of the survey. Based on 47 observed fledging events in California, Peery and others (2007) estimated that 75 percent of juveniles had fledged by August 24, considered herein to be the last day of the fledging period. Therefore, to adjust for the number of HY birds observed during a given at-sea survey, we calculated $H_{corrected}$ after Peery and others (2007):

$$H_{corrected} = \frac{H_{observed}}{-1.5433 + 0.0098 \times DATE_i} \quad (2)$$

where

$H_{corrected}$ is the date-corrected number of hatch-year (HY) individuals,

$H_{observed}$ is the number of HY individuals counted on survey i, and

the denominator is the regression model for the cumulative proportion of HY birds fledged, predicted according to Julian Day (*DATEi*).

We used $A_{corrected}$ and $H_{corrected}$ to estimate the juvenile ratio ($\hat{R}_t$) for year t,

$$\hat{R}_t = \frac{\sum_1^n H_i}{\sum_1^n A_i} \quad (3)$$

where

H_i and A_i are the number of hatch-year and after-hatch-year individuals for survey i, respectively, and

n is the number of surveys done in year t (Levy and Lemeshow, 1991).

We estimated the variance of the juvenile ratio ($\hat{\mathrm{var}}\left(\hat{H}_t\right)$) as

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

where

$\hat{\mathrm{var}}\left(\hat{H}_t\right)$ is the variance in the number of hatch-year (HY) individuals observed in year t,

$\hat{\mathrm{var}}\left(\hat{A}_t\right)$ is the variance in the number of after-hatch-year (AHY) individuals observed in year t,

$\hat{\mathrm{cov}}\left(\hat{A}_t, \hat{H}_t\right)$ is the covariance between the numbers of HY and AHY individuals observed in year t, and

$\hat{H}_t$ and $\hat{A}_t$ are the mean number of HY and AHY individuals observed in year t, respectively (van Kempen and van Vliet, 2000; Peery and others, 2007; Henry, 2017).

We did all calculations to estimate juvenile ratios (uncorrected and corrected) and associated variance using R (R Core Team, 2016).

Marbled Murrelet Abundance and Productivity Results

Abundance Estimation Results

We detected 144 marbled murrelet groups consisting of 239 individuals on all surveys combined in 2018. Murrelet sightings were concentrated around Point Año Nuevo. Sightings were sporadic between Half Moon Bay and Point Año Nuevo and infrequent between Point Año Nuevo and Santa Cruz (fig. 1). Detections approached zero at 120 m horizontal sighting distance; therefore, consistent with Henry (2017), we excluded from analysis observations that were greater than 120 m from the transect line. We included flying birds (8 percent of all detections less than or equal to 120 m from the transect line; following Henry, 2017). After removing 6 detections greater than 120 m and 1 detection with no specified distance, we estimated marbled murrelet abundance using 137 detections of 227 individuals (table 2; fig. 1).

For all surveys combined (regardless of draw direction), the half-normal detection model with a cosine adjustment (order 2) was the best-fitting model, and the observed number of sightings was not significantly different from the number predicted using this detection model (chi-squared [χ^2] = 0.45, degrees of freedom [df] = 3, probability value [P] = 0.93; fig. 2). Survey-specific marbled murrelet density estimates ranged from 1.30 to 5.50 birds per km^2 in the nearshore stratum and from 0.00 to 1.89 birds per km^2 in the offshore stratum; survey-specific abundance estimates ranged from 149 to 682 individuals (table 2). The abundance estimated for the entire study area in 2018 using all surveys was 370 birds (95-percent CI, 250–546 birds; percent coefficient of variation [CV], 18.83; table 3). The half-normal detection model with a cosine adjustment (order 2) was the best-fitting model for north-drawn surveys (χ^2 = 1.09, df = 3, P = 0.78). The half-normal detection model with no cosine adjustment was the best-fitting model for south-drawn surveys (χ^2 = 0.72, df = 4, P = 0.95). Estimated abundance for surveys drawn from the north (513 birds; 95-percent CI, 334–788 birds) was more than for surveys drawn from the south (227 birds; 95-percent CI, 112–460 birds; table 3). Estimated abundances for all study years (1999–2018) are shown in table 3 and figure 3.

Productivity—Juvenile Ratio Results

We detected four HY marbled murrelets in 2018: two on August 8 and two on August 13 (table 2; fig. 1). In 2018, the uncorrected juvenile ratio (R) was = 0.030 ± 0.020 standard error (SE), and the corrected juvenile ratio ($\hat{R}$) was 0.047 ± 0.032 SE (table 4). Estimated uncorrected and corrected juvenile ratios for all study years (1996–2018) are shown in table 4 and figure 4. Historical juvenile ratio values presented in table 4 and figure 4 were obtained using various survey transect designs. Surveys used for juvenile estimates followed (1) shore-parallel transects near Point Año Nuevo for 1996–98, (2) standardized zigzag transects for 2001–11 and 2014–18 (a subset of the abundance estimation transects), (3) a combination of shore-parallel Point Año Nuevo transects and standardized zigzag transects for 1999–2000, or (4) a combination of nearshore transects and standardized zigzag transects for 2012–13. We present historical values (pre-2017)

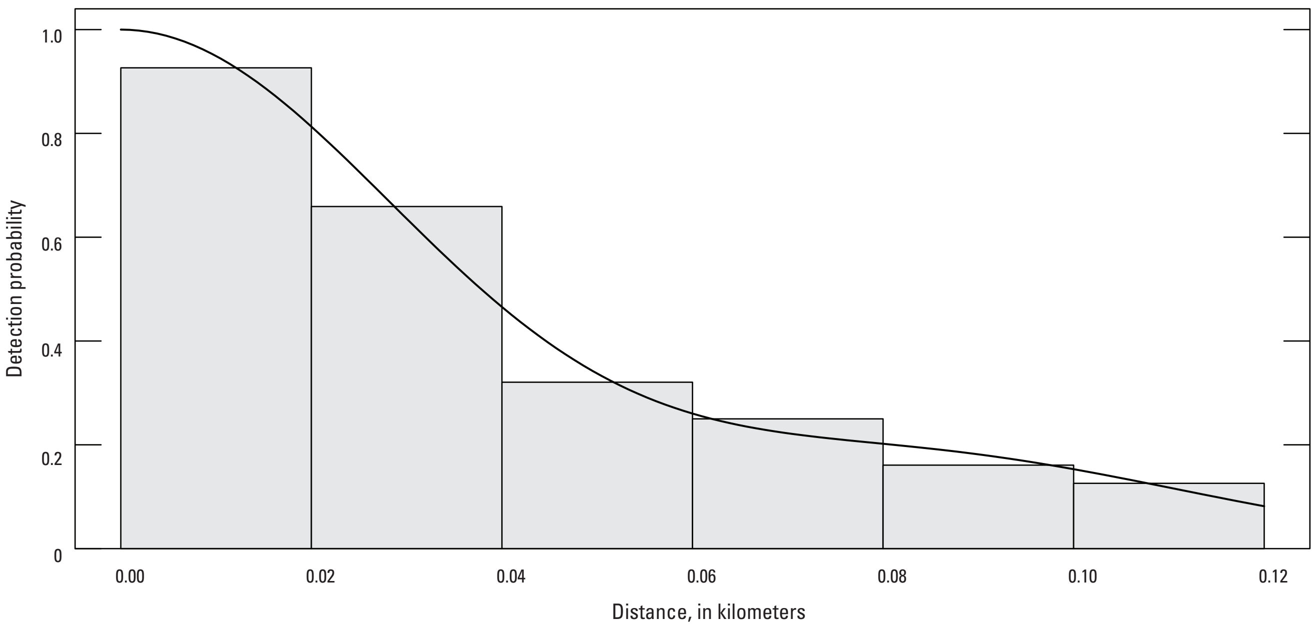

Figure 2. Graph showing mModeled detection probability of marbled murrelets (*Brachyramphus marmoratus*) sighted within perpendicular distance less than or equal to 0.12 kilometers of vessel for all surveys, U.S. Fish and Wildlife Service Conservation Zone 6, central California, 2018. Bin width is 0.02 kilometers.

Table 3. Annual at-sea marbled murrelet (*Brachyramphus marmoratus*) estimates for surveys drawn in both directions, surveys only drawn from the north, and surveys only drawn from the south, U.S. Fish and Wildlife Service Conservation Zone 6, central California, 1999–2018.

[All values from years prior to 2017 were referenced from Henry (2017). **Abbreviations**: CI, confidence interval; *N*, population estimate (number of birds); *n*, number of surveys; N/A, not applicable; %, percent]

Year	Both directions			North			South		
	N	**95% CI**	***n***	***N***	**95% CI**	***n***	***N***	**95% CI**	***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	494–1,075	6
2003	699	567–860	12	615	463–815	6	782	570–1,074	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	232–1,054	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	386–1,022	6	439	233–827	3	556	126–2,456	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	406–1,063	7	510	358–726	3	720	297–1,747	4
2017	530	384–732	9	413	247–689	4	790	487–1,280	5
2018	370	250–546	9	513	334–788	4	227	112–460	5

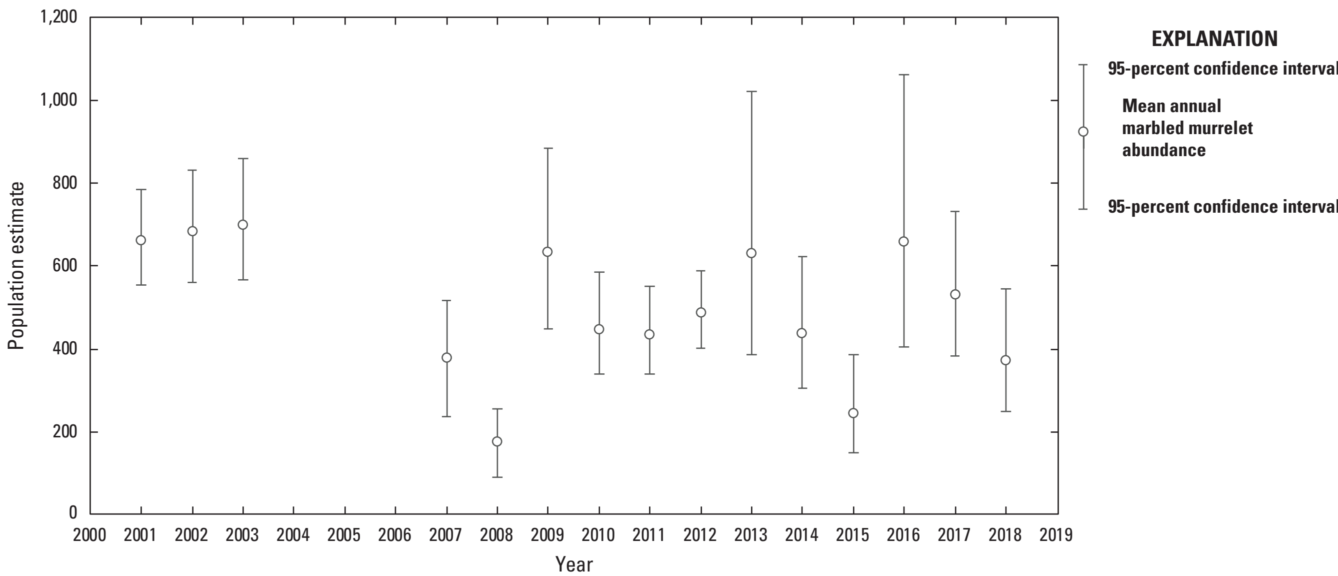

Figure 3. Graph showing mMean annual marbled murrelet (*Brachyramphus marmoratus*) at-sea abundance estimates, U.S. Fish and Wildlife Service Conservation Zone 6, central California, for all years for which survey data was available during 2001–18. Years 1999 and 2000 are excluded because survey routes were only drawn from the north in those years, and no surveys were conducted in 2004–06. All values from years prior to 2017 were referenced from Henry (2017).

Table 4. Annual estimates of hatch-year to after-hatch-year ratios (*R*), date-corrected ratios ($\hat{R}$), and standard errors (SE) for marbled murrelets (*Brachyramphus marmoratus*) from at-sea surveys done during the breeding season, U.S. Fish and Wildlife Service Conservation Zone 6, central California, 1996–2003 and 2007–18.

[All values from years prior to 2017 were referenced from Henry (2017). Surveys used to estimate ratios were limited to July 10–August 24. Date-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 done (see Peery and others, 2007). Survey transect designs varied across years. **Abbreviations**: *n*, number of surveys; N/A, not applicable]

Year	*n*	Observed		Corrected	
		R	(SE)	($\hat{R}$)	(SE)
1996	4	0.006	0.003	0.010	0.003
1997	5	0.010	0.003	0.022	0.007
1998	6	0.007	0.003	0.013	0.006
1999	10	0.016	0.005	0.033	0.010
2000	9	0.024	0.008	0.049	0.016
2001	8	0.034	0.008	0.070	0.022
2002	11	0.026	0.004	0.051	0.009
2003	8	0.024	0.005	0.049	0.011
2007	3	0.017	0.018	0.049	0.052
2008	4	0.000	N/A	0.000	N/A
2009	4	0.015	0.011	0.028	0.018
2010	3	0.037	0.018	0.081	0.039
2011	4	0.053	0.015	0.080	0.017
2012	5	0.020	0.014	0.032	0.019
2013	6	0.051	0.018	0.093	0.025
2014	6	0.049	0.025	0.081	0.035
2015	6	0.031	0.011	0.059	0.020
2016	5	0.061	0.030	0.108	0.051
2017	6	0.012	0.009	0.022	0.015
2018	6	0.030	0.020	0.047	0.032

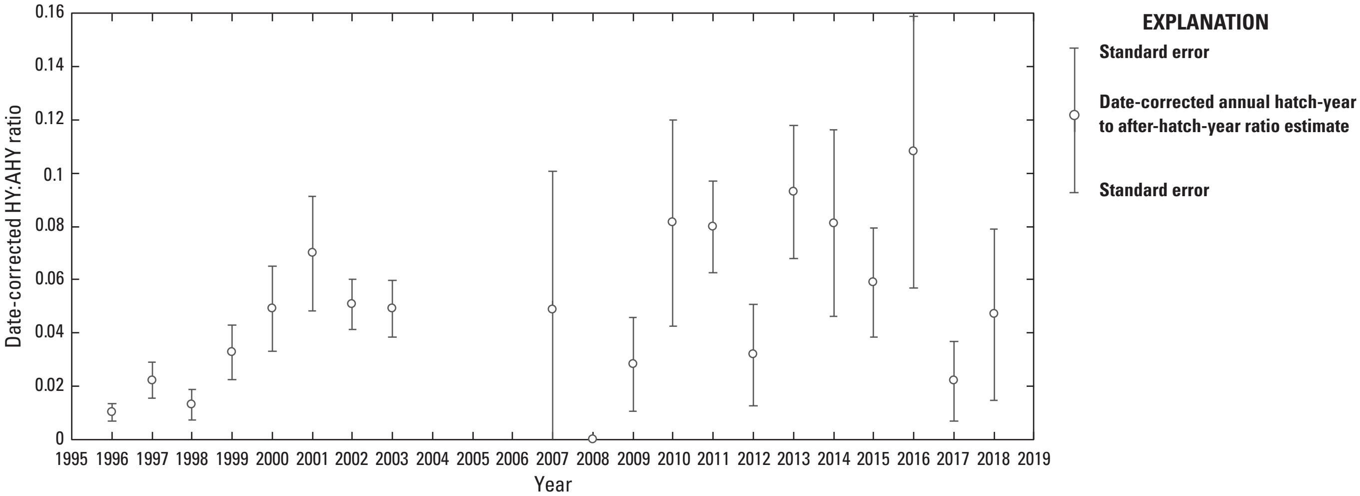

Figure 4. Graph showing dDate-corrected marbled murrelet (*Brachyramphus marmoratus*) hatch-year to after-hatch-year ratios, plus or minus standard errors, U.S. Fish and Wildlife Service Conservation Zone 6, central California, for all years for which survey data was available during 1996–2018. All values from years prior to 2017 were referenced from Henry (2017). Surveys used to estimate ratios were limited to July 10–August 24. Date-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 done (see Peery and others, 2007). Survey transect designs varied across years.

here as calculated and reported by Henry (2017), but we do not compare values across years.

Discussion

We followed survey methods and analytical procedures to estimate densities and abundances for marbled murrelets using conventional distance sampling off central California according to methods described in Henry (2017). Estimated abundance from 2018 was below the long-term mean (2001–18: 497 murrelets) but is comparable at the 95-percent CI level to most prior years of study, except for 2001–03, which had greater estimated abundances. The corrected juvenile ratio in 2018 (0.047) was similar to the long-term mean (1996–2018: 0.049); however, interannual comparison could be complicated by methodological changes through time (see "Marbled Murrelet Abundance and Productivity Results" section). The annual marbled murrelet survey program has involved several different research groups through time; therefore, we updated a synthesized database of all marbled murrelet survey data since 1999 with 2018 data to allow scientists and managers to evaluate established survey methods and assess trends in abundance estimation and juvenile ratios (Felis and others, 2018). This database also facilitates annual survey logistics (for example, pre-survey planning) and promotes repeatability of analytical methods across years and project teams.

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