Abundance of marbled murrelets (*Brachyramphus marmoratus*) off central California during the 2023 breeding season

Summary provisional data report to Luckenbach Trustee Council and California State Parks

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Recommended citation:

Felis JJ, White LM, Adams J, Kelsey EC, and Becker B. 2023. Abundance of marbled murrelets (Brachyramphus marmoratus) off central California during the 2023 breeding season: Summary provisional data report to Luckenbach Trustee Council and California State Parks, 21 pp.

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Disclaimer

Acknowledgements

We would like to thank Alex Rinkert (California State Parks), Gavin Haight (U.S. Geological Survey), Taylor Leischner (U.S. Geological Survey), and the U.S. Geological Survey Pacific Coastal and Marine Science Center Marine Facility for field and logistical support. This work was funded by the Luckenbach Trustee Council comprised of the California Department of Fish and Wildlife, the National Oceanic and Atmospheric Administration, and the Department of the Interior through the U.S. Fish and Wildlife Service.

Introduction

In 2023, the U.S. Geological Survey Western Ecological Research Center (USGS-WERC), in cooperation with the U.S. Fish and Wildlife Service and California State Parks, performed at-sea surveys as part of a long-term monitoring program to estimate abundance of marbled murrelets (*Brachyramphus marmoratus*) in U.S. Fish and Wildlife Service Conservation Zone 6 (central California—San Francisco Bay to Point Sur; Figure 1). 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 (U.S. Fish and Wildlife Service, 2021). Surveys to estimate the abundance of marbled murrelets at sea off central California have been done since 1999 (excluding 2004–06; Henkel and Peery, 2008; Peery and others, 2008; Peery and Henry, 2010; Henry and others, 2012; Henry, 2017; Felis and others, 2018, 2019, 2020, 2022a) and are 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 2023 to assess abundance 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 marbled murrelet response to the CZU Lightning Complex wildfire, which burned large areas of marbled murrelet nesting habitat in the Santa Cruz Mountains during late August and September 2020 (California Department of Forestry and Fire Protection, 2021). Changes in local murrelet abundance in the wake of this habitat loss are of conservation and management concern.

Recently updated analytical methods used herein are fully evaluated and described by Felis et al. (2023), and we made changes to the sampling design in 2023 based on the results of that comprehensive analysis of the long-term time series (described below in Methods). For future annual reporting, we intend to provide provisional summary reports annually and fully published evaluations of methods, results, and monitoring effectiveness every five years, similar to the 5-year reporting cycle of the USFS Northwest Forest Plan (McIver et al. 2022). Publication of new data to our data release for this program (Felis et al. 2022b) will follow the same 5-year cycle. We expect to produce fully published results and data next in 2025-26. We also present a summary of non-murrelet observations and results from this survey program in Appendix 2.

Methods

Spatial Sampling Design Updates

In the past (1999–2022), surveys were conducted along randomized, ~100-km-long zig-zag routes designed 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 marbled murrelet densities nearshore (Becker et al. 1997, Rachowicz et al. 2006). Felis et al. (2023) determined that only the nearshore stratum needed to be surveyed to generate robust estimates of abundance and trend, as so few murrelets were observed in the offshore stratum with little interannual variation. Variation in the alongshore distribution and clustering of murrelets was more significant interannually, suggesting that reappropriating offshore effort as increased linear effort (e.g. a tighter zig zag) in the nearshore stratum could reduce inter-survey encounter rate variance.

We generated a pool of new randomized zig-zag survey routes for just the nearshore stratum using comparable methods to those used for past years. Starting at a random distance from shore (between 200–1350 m), we drew an initial transect segment towards either the nearshore or offshore boundary (also chosen at random) at ~30° relative to the local orientation of that boundary. Thereafter, we alternated drawing segments to the nearshore and offshore boundaries using random segment lengths between 1700–2300-m in length, which served to randomize the route and achieved an overall desired transect length of ~115 km. We limited the maximum opening angle between segments to 120° and occasionally reduced segment length to less than 1700 m to accommodate tight bends in the coastline (e.g. Point Año Nuevo).

Temporal Sampling Design Updates

During 1999–2022, surveys were conducted during an established temporal window (June 1 – August 24; Felis et al. 2023; Peery et al. 2007), with a target sample size of nine surveys most years. Felis et al. (2023) found that variation in murrelet encounter rates among surveys each year was the primary driver of uncertainty in annual abundance estimates, but sub-sampling from the typical sample size (~9 surveys; what is currently logistically/financially possible) to as few as four per year did not increase encounter rate variance, suggesting fewer surveys could be conducted at lesser logistical/financial cost. Additionally, a seasonal pattern in murrelet densities was observed, with lower densities in June and August and higher densities in July (Felis et al. 2023). We thus established a new, shorter temporal window to reduce seasonally driven encounter rate variance, and we also reduced sample size (number of surveys) to four.

We extended the work of Felis et al. (2023) that examined seasonal murrelet density patterns in order to identify a "peak" density date around which to center a new, shorter study window. Using the survey-specific results of all surveys from 1999–2021 (Felis et al. 2023), we built a generalized additive model (GAM) to predict murrelet count (distance-corrected, N_c) by day of year (yday), with year as a random effect and allowing predicted count to vary by year:

$$N_c \sim s(yday, k = 5) + s(yday, by = year, m = 1, k = 5) + s(year, bs = \text{"re"}, k = 20)).$$

We used a negative binomial distribution for this model based on preliminary model evaluations, and year was treated as a factor. We used the default k values ("wiggliness") for each smooth (k = 5 for continuous yday and k=20 [the number of unique years] for the factor year). The model explained 56% of deviance and had an R^2 value of 0.45. The peak predicted day of year was July 21. We built a 50-day window (June 27 – August 15) around the peak, nearly half the original 84-day study window, and attempted to conduct one survey every ~12 days. See Appendix for additional model information.

Field and Analytical Methods

In 2023, we completed four at-sea boat-based surveys for marbled murrelets between Half Moon Bay and Santa Cruz, California (Figure 1, Table 1), following field methods described in Felis et al. (2023). We used line-transect methods (Buckland et al. 2001) by estimating murrelet observation distances from the transect line to correct counts for imperfect detection as a function of distance from the transect line. Two observers (one for each side of the boat) recorded all murrelet observations and classified them by behavior (“on the water” or “flying”) and age class (after-hatch-year [AHY] or hatch-year [HY], based on plumage).

To estimate the density and abundance of murrelets, we corrected murrelet observations for imperfect detection as a function of distance from the survey transect line (“distance-correction”) using detection function modeling with the “Distance” package in R (Buckland et al. 2001, Miller et al. 2019; Felis et al. 2023). We included all nearshore-stratum murrelet observations within 100-m perpendicular distance (“truncation distance”) of the transect line and modeled them using continuous distance values. All data (regardless of survey date) were used in detection function modeling. In Felis et al. (2023) we did not include flying murrelets because they were not recorded consistently in 1999–2003 and because they might have a different detection probability; however, flying murrelets account for a variable and sometimes significant number of annual sightings (1–21% annually, Felis et al. 2023). Herein, we included flying murrelets recorded from 2007–present (when they were consistently recorded) and evaluated two AHY murrelet global (all years pooled) hazard-rate detection function models: one with ~Year as a factor covariate and one with ~Year and ~Behavior as factor covariates. We included year in both models to account for differences in survey crews, vessels, and conditions among years, and because our goal was to produce the most accurate annual abundance estimates (Felis et al. 2023). Including Behavior as a covariate allowed us to evaluate any difference in detection probability of flying birds for the years they were consistently recorded (2007–present). We selected the detection function model with the lowest AIC.

Annual abundance estimates were generated by applying the selected global detection model to each year’s observation data only for surveys conducted in the new temporal study window with the Distance dht2 function in R. We conducted this twice to generated two sets of estimates: the first included both flying and resting birds for 2007–present, and the second included only resting birds for 1999–present. This process estimated survey-specific densities that were then averaged and applied to the nearshore study area (104.65 km^2) for annual abundance estimates. Variances for all estimates are reported as standard errors (SE), coefficients of variation (CV), and log-normal 95% confidence intervals (CI). We evaluated long-term trends in annual AHY abundance (1999–present for resting birds, 2007–present for all birds) using generalized linear models (GLMs) with a negative binomial distribution, following Felis et al. (2023).

Felis et al. (2023) found that sightings of HY murrelets were too rare and variable to credibly estimate annual HY abundance, HY:AHY ratios, or evaluate interannual trends in these metrics. We therefore do not calculate or report those here.

Results

We detected 85 groups (range 16–26 per survey) of 159 marbled murrelets (range 29–48 per survey) on our four surveys in 2023 (Figure 1, Table 1). We detected one HY murrelet while on effort on July 12 (near Half Moon Bay), and a second HY murrelet was detected while off effort (transiting, near Soquel Point) on August 9 (Table 1). Murrelets were sighted primarily in the northern and central parts of the study area in 2023 (Figure 1). We noted lesser than usual murrelet numbers in Año Nuevo Bay (a typical hot spot), and greater than usual aggregations near Half Moon Bay and Soquel Point (intra- and interannually variable hot spots) on several surveys (Figure 1, Figure 2).

We chose the detection function model that included both Year and Behavior as covariates because it had a lower AIC value than the model with only Year as a covariate (Table 2). The overall average probability of detection for AHY from the global detection function model was 0.58 (0.01 SE; Table 2, Figure 3) and flying birds had a greater probability of detection than resting birds, as expected. After detection function modeling, we estimated an AHY abundance for all behaviors (resting and flying) of 420 murrelets in 2023 (95% CI 295–597; CV 0.17; Table 3; Figure 4). This abundance estimate for 2023 was similar to the long term (2007–present) average of 373 murrelets (range 192–519 annually, all behaviors combined; Table 3). Using only birds resting on the water, we estimated 352 (95%CI 248–499; CV 0.17) in 2023, comparable to the long-term (1999–present) average of 370 (range 175–582 annually). The GLMs for annual AHY abundance were not statistically significant at the p=0.05 level, indicating no trend in abundance from 1999–2023 (resting birds only; slope=-0.010, SE=0.008, t=-1.184, p=0.25) or 2007–2023 (resting and flying birds; slope=0.015, SE=0.013, t=1.125, p=0.28).

Tables and Figures

*Table 1. Marbled murrelet (*Brachyramphus marmoratus*) survey dates, route direction (direction from which route was drawn), transect length, and number of murrelet observations (groups, individuals, and hatch year birds) for all surveys, U.S. Fish and Wildlife Service Conservation Zone 6, central California, 2023.*

Date	Route direction	Transect length (km)	Number of groups	Mean group size	Number of individuals	Number observed on water	Number of hatch year
2023_06_30	North	114.5	26	1.85	48	38	0
2023_07_12	South	115.1	22	1.77	39	22	1
2023_08_01	North	116.0	21	2.05	43	36	0
2023_08_09	South	115.2	16	1.81	29	27	0

Table 2. Detection function models for AHY marbled murrelets.

Model	Key function	Formula	C-vM p-value	Average detectability	SE(Average detectability)	AIC	ΔAIC
hr_YearBeh_final	Hazard rate	~Year+Behavior	0.005	0.584	0.010	-17704.23	0.00
hr_Year_final	Hazard rate	~Year	0.005	0.582	0.011	-17699.98	4.25

*Table 3. Annual after-hatch-year (AHY) marbled murrelet (*Brachyramphus marmoratus*) abundance estimates (N) for the nearshore stratum, including log-normal 95% confidence intervals (CI), standard errors (SE), coefficients of variation (CV), and sample sizes (k; number of surveys), for all surveys conducted June 27–August 15.*

Year	k	Abundance, resting only			Abundance, resting and flying		
		N (95%CI)	SE	CV	N (95%CI)	SE	CV
1999	4	361 (248–525)	57.13	0.16	NA	NA	NA
2000	7	342 (220–530)	66.08	0.19	NA	NA	NA
2001	13	527 (419–663)	58.34	0.11	NA	NA	NA
2002	11	568 (459–703)	58.25	0.10	NA	NA	NA
2003	9	582 (458–740)	66.85	0.11	NA	NA	NA
2007	3	288 (198–421)	47.38	0.16	337 (222–511)	57.76	0.17
2008	4	175 (91–337)	50.82	0.29	192 (92–401)	60.08	0.31
2009	6	472 (327–684)	74.95	0.16	493 (331–735)	83.61	0.17
2010	5	237 (167–335)	34.93	0.15	275 (195–386)	39.35	0.14
2011	3	300 (245–367)	30.92	0.10	315 (257–388)	33.18	0.11
2012	3	372 (196–707)	77.34	0.21	406 (300–550)	52.91	0.13
2013	3	368 (168–805)	85.34	0.23	461 (316–673)	63.61	0.14
2014	7	343 (229–512)	61.11	0.18	376 (258–548)	63.26	0.17
2015	7	203 (126–328)	43.39	0.21	211 (134–331)	42.65	0.20
2016	5	456 (301–692)	80.62	0.18	464 (300–719)	85.34	0.18
2017	5	464 (328–657)	71.28	0.15	519 (371–725)	76.51	0.15
2018	7	243 (147–402)	54.30	0.22	271 (164–450)	60.76	0.22
2019	4	365 (205–650)	80.76	0.22	392 (216–712)	88.70	0.23
2020	5	440 (262–739)	92.35	0.21	456 (268–776)	97.80	0.21
2021	6	388 (160–940)	143.20	0.37	439 (199–971)	145.41	0.33
2022	5	299 (191–469)	57.96	0.19	311 (210–459)	53.87	0.17
2023	4	352 (248–499)	60.29	0.17	420 (295–597)	71.31	0.17

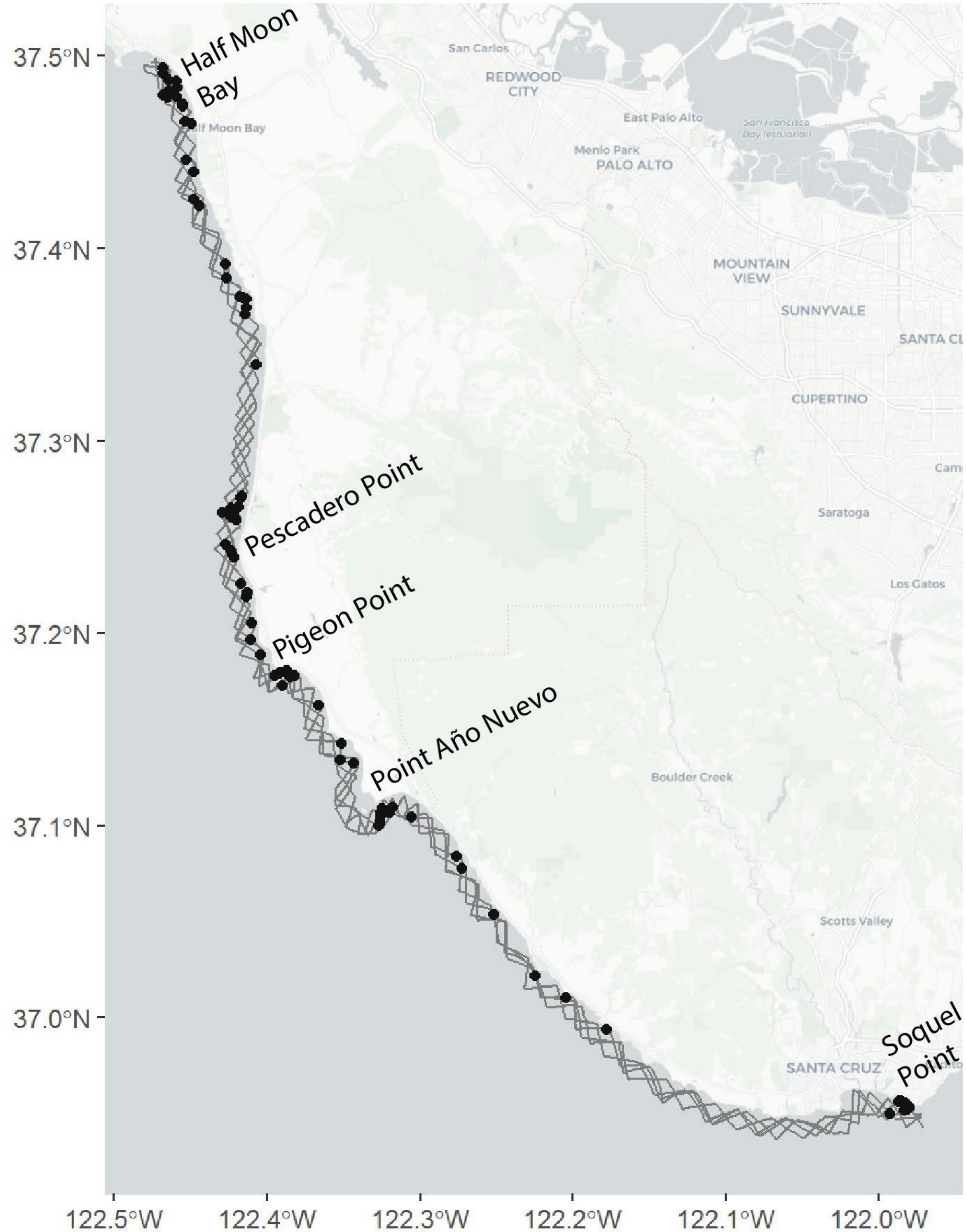

*Figure 1. Study area in U.S. Fish and Wildlife Service Conservation Zone 6 showing survey routes (grey lines) and marbled murrelet (*Brachyramphus marmoratus*) detections (black circles) from Half Moon Bay to Santa Cruz, central California, in 2023.*

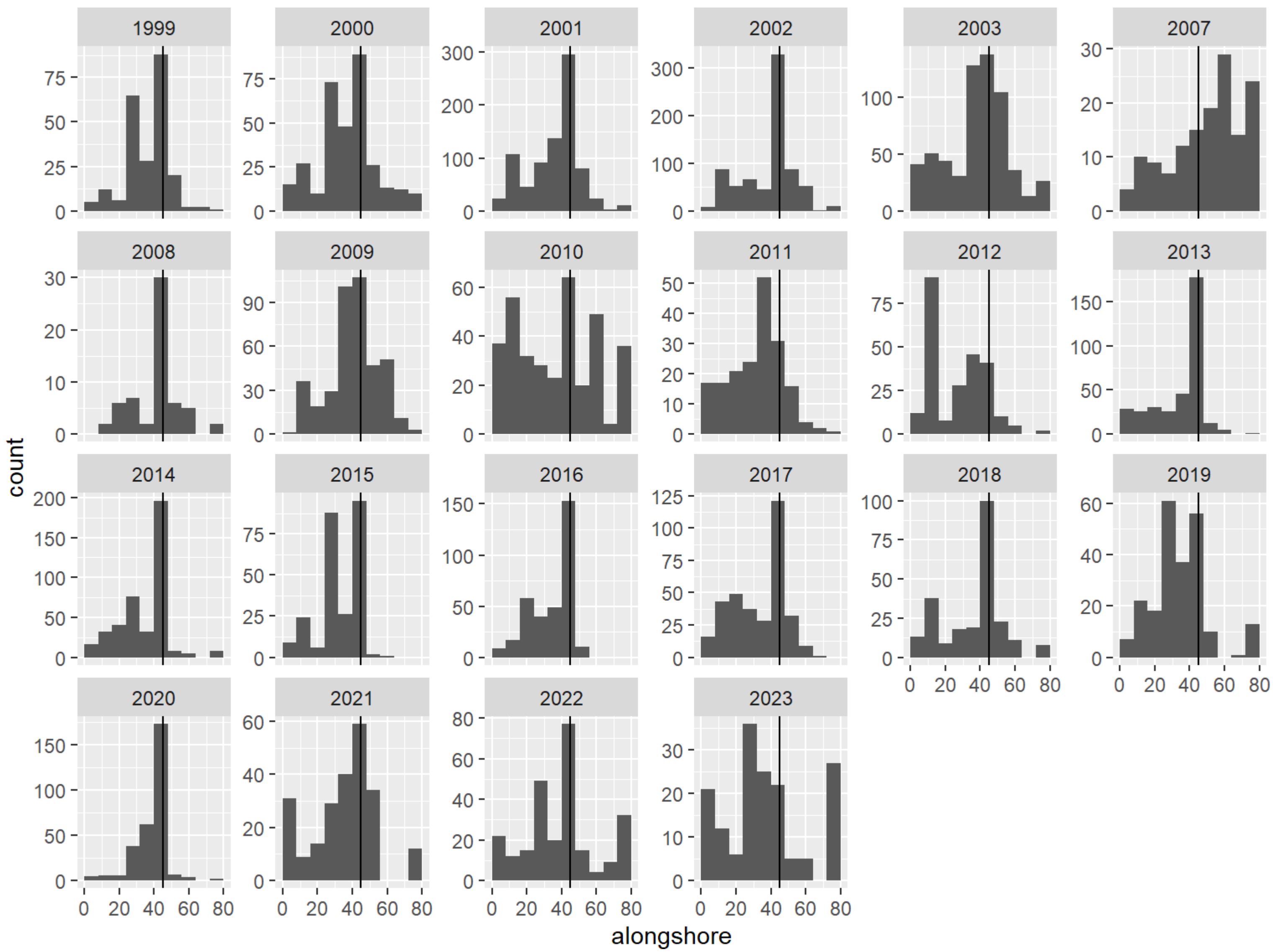

Figure 2. Annual histograms of marbled murrelets (Brachyramphus marmoratus) with respect to alongshore location in the study area, from Half Moon Bay (0) to Soquel Point (80). Counts are not corrected for detection probability or linear survey effort. Vertical black line indicates location of Año Nuevo Bay.

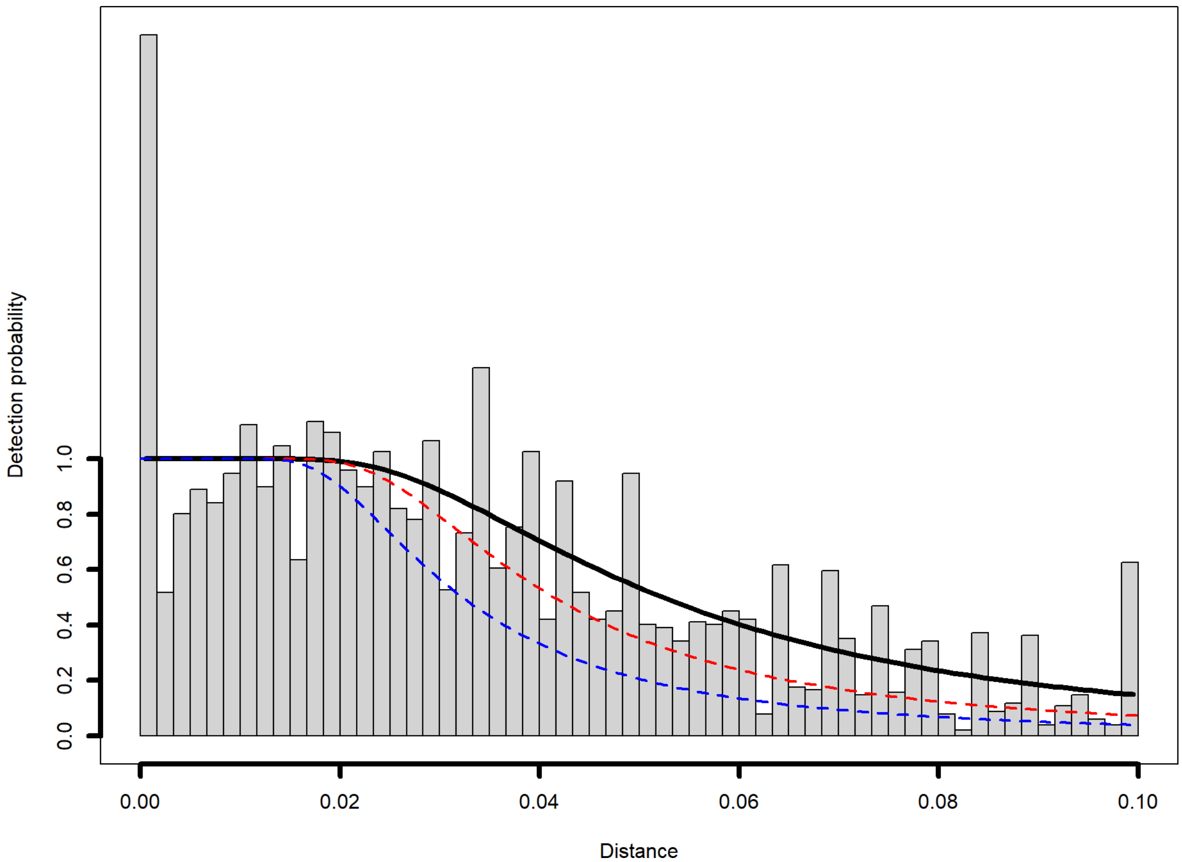

*Figure 3. Modeled probability of detection for after-hatch-year (AHY) marbled murrelets (*Brachyramphus marmoratus*) as a function of perpendicular distance (km) from vessel in U.S. Fish and Wildlife Service Conservation Zone 6, central California, 1999–present). Hazard rate key function models were developed with ~Year (as a factor) and ~Behavior (flying or resting) as covariates. Histograms shows the distribution of observation distances, black line shows the overall modeled detection function for all years and behaviors. Dashed red and blue lines show the scaled detection functions for flying and resting birds, respectively, in 2023. Observations were truncated at 100-m (0.1-km) perpendicular distance from the vessel. Note that observation distances were binned for background histogram plotting but detection-function-modeling was conducted with continuous observation distances.*

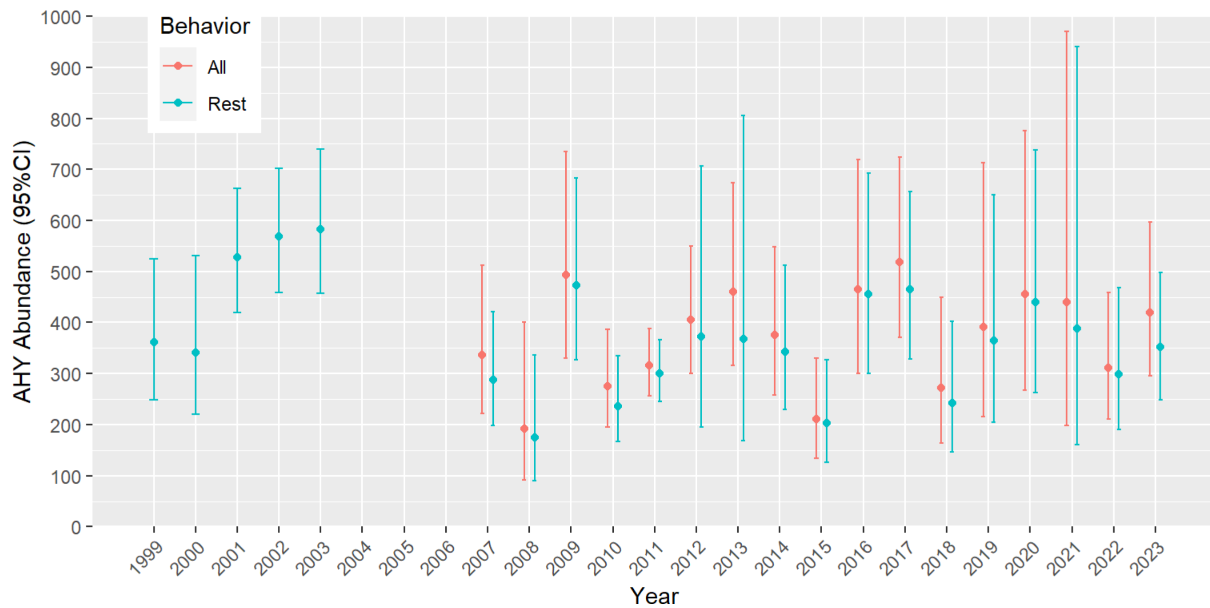

*Figure 4. Annual after-hatch-year (AHY) marbled murrelet (*Brachyramphus marmoratus*) distance-corrected abundance estimates and log-normal 95% confidence intervals (error bars) for all surveys June 27–August 15, 1999–present. Estimates in blue are limited to birds observed resting on the ocean surface, whereas estimates in red are for resting and flying birds combined.*

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Appendix 1

Detection function model summary output

Summary of chosen detection function model for after-hatch-year marbled murrelets for 1999–2023, with Year and Behavior as factor covariates.

```
Summary for distance analysis
Number of observations :  3575
Distance range         :  0 - 0.1

Model : Hazard-rate key function
AIC   : -17704.23

Detection function parameters
Scale coefficient(s):
                           estimate         se
(Intercept)            -2.607389597 0.15276996
as.factor(Year)2000     0.029215314 0.15654558
as.factor(Year)2001    -0.196681286 0.13717124
as.factor(Year)2002    -0.342720291 0.13696379
as.factor(Year)2003    -0.280660564 0.14256222
as.factor(Year)2007    -0.002469573 0.19676690
as.factor(Year)2008    -0.445122154 0.22222648
as.factor(Year)2009    -0.104931606 0.14689491
as.factor(Year)2010     0.437547443 0.19143873
as.factor(Year)2011    -0.236084634 0.16773872
as.factor(Year)2012    -0.188555853 0.16211259
as.factor(Year)2013     0.121656305 0.16094208
as.factor(Year)2014     0.081333306 0.15555204
as.factor(Year)2015     0.185976852 0.18119781
as.factor(Year)2016    -0.360014230 0.15219173
as.factor(Year)2017    -0.421952657 0.14919396
as.factor(Year)2018    -0.454496385 0.15613089
as.factor(Year)2019    -0.408647383 0.15908642
as.factor(Year)2020    -0.495656697 0.14966869
as.factor(Year)2021    -0.598556058 0.15850190
as.factor(Year)2022    -0.555650458 0.15364907
as.factor(Year)2023    -0.720603554 0.18036511
as.factor(Behavior)Rest -0.250537123 0.09262132

Shape coefficient(s):
             estimate         se
(Intercept) 0.9252263 0.05232756

                                    Estimate     SE          CV
Average p (detection probability)   0.5837733    0.01048536  0.01796135
```

GAM model summary output and response plots

GAM model detailed results and response plots for temporal study window redesign

```
## Family: Negative Binomial(7.045)
## Link function: log
##
## Formula:
## Nchat ~ s(yday, k = 5) + s(yday, by = year, m = 1, k = 5) + s(year,
```

```
##     bs = "re", k = NROW(unique(dNear$year)))
##
## Parametric coefficients:
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept)  3.93018    0.06828   57.56   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                         edf Ref.df Chi.sq p-value
## s(yday)           2.254e+00  2.686  7.740 0.06050 .
## s(yday):year1999  8.041e-05  4.000  0.000 0.66400
## s(yday):year2000  3.787e-01  4.000  0.437 0.29654
## s(yday):year2001  5.264e-05  4.000  0.000 0.86837
## s(yday):year2002  4.526e-01  4.000  0.665 0.21294
## s(yday):year2003  1.265e-04  4.000  0.000 0.40310
## s(yday):year2007  1.364e-04  4.000  0.000 0.53407
## s(yday):year2008  1.718e+00  4.000 19.838 0.00493 **
## s(yday):year2009  1.387e-04  4.000  0.000 0.64486
## s(yday):year2010  7.124e-02  4.000  0.077 0.30975
## s(yday):year2011  1.029e-04  4.000  0.000 0.95906
## s(yday):year2012  7.189e-01  4.000  1.528 0.13835
## s(yday):year2013  1.993e+00  4.000  6.432 0.03074 *
## s(yday):year2014  1.719e+00  4.000  5.373 0.04445 *
## s(yday):year2015  2.124e+00  4.000  9.227 0.00877 **
## s(yday):year2016  1.928e+00  4.000  9.199 0.00344 **
## s(yday):year2017  1.334e+00  4.000  4.226 0.02758 *
## s(yday):year2018  4.428e-01  4.000  0.756 0.20053
## s(yday):year2019  1.125e-04  4.000  0.000 0.78908
## s(yday):year2020  7.471e-01  4.000  1.549 0.12602
## s(yday):year2021  2.438e+00  4.000  6.124 0.04559 *
## s(year)           1.380e+01 19.000 67.141 < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.446   Deviance explained = 56.2%
## -REML = 763.69  Scale est. = 1         n = 165
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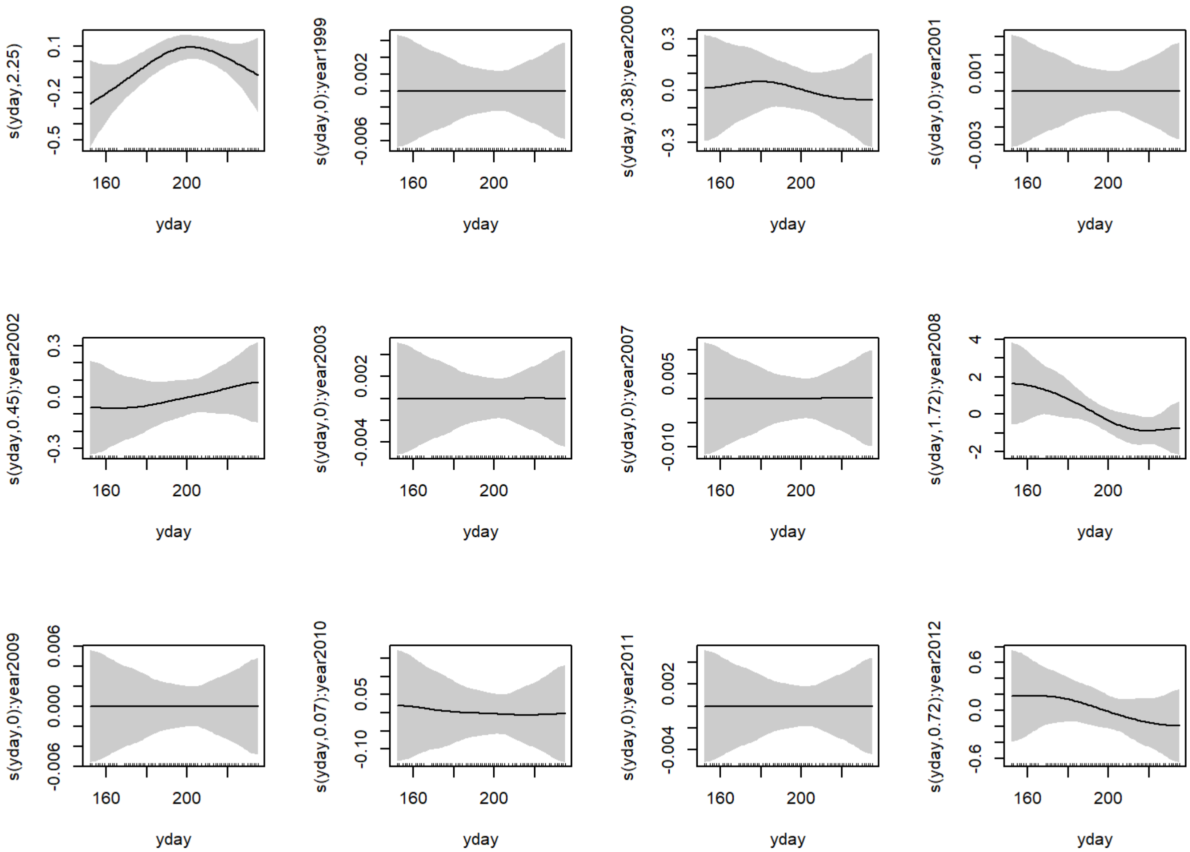
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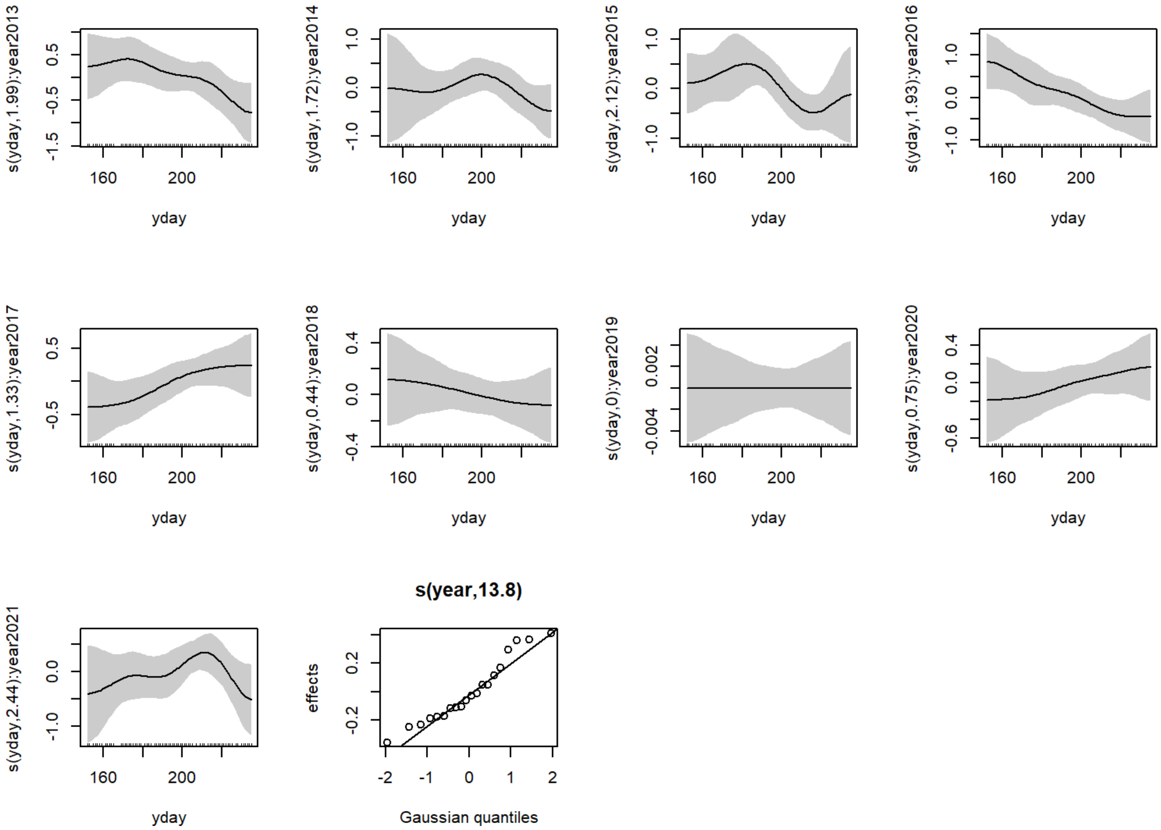
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yday
s(year,13.8)
effects
Gaussian quantiles

Appendix 2

Summary of non-murrelet animal observations and results, 2007-2023

Introduction

The annual Marbled Murrelet at-sea survey program has collected data on all marine mammal and bird species consistently since 2007. Herein, we summarize and report results for this component of the survey program.

Field methods

General study area, transect and sampling design, and field methods are described above for Marbled Murrelet surveys. Additional details specific to non-murrelet methods follow. Two observers, one standing on each side of the boat, recorded the observation time, species, count, behavior, and age class (when possible) of all birds, excluding Marbled Murrelets, within 50-m (100-m total strip width, 2007) or 75-m (150-m total strip width, 2008–2023) of the transect. Marine mammals (excluding humpback whales [*Megaptera novaeangliae*]) were surveyed with both strip- and line-transect methods (variably within survey/observer and among years). Marbled Murrelets and humpback whales were counted exclusively using line-transect (distance-sampling) methods by estimating angle off the bow (0–90°) and distance from the vessel in order to calculate perpendicular distance from the transect line, with no distance limit.

Data analysis and summary

For each survey, we summed the total counts of each bird species and calculated density by dividing by area surveyed (the product of route length and total strip width). Marbled murrelet observations were retained when distance estimates fell within the strip width for a given survey and are included in total count summaries, but we did not calculate annual murrelet densities herein because they are calculated appropriately using detection function modeling in the previous section of this report. Because some, but not all, marine mammal observations (excluding humpback whales) were recorded using line-transect methods, we only retained observations with distance estimates when they fell within the strip width for a given survey and then calculated density as above. All humpback whale observations, regardless of distance from the vessel, are included as annual encounter rates (animals km^{-1}) in lieu of densities because this species was present at lower numbers, visible at great distances, and unlikely to be encountered in the 100–150m total strip width.

We calculated species-specific mean annual densities and standard errors from each year's survey results. Because smaller species (e.g., auklets, guillemots, phalaropes) may not be perfectly detectable at the given strip width, calculated annual densities can be reasonably compared on a per-species basis (assuming consistent detection probabilities on a per-species basis), but inter-species comparisons of absolute estimates should be made with caution. In addition, no adjustments were made for animals that might not be counted due to time spent swimming or diving underwater ("availability bias", Buckland et al. 2001), and densities are biased towards the nearshore (200–1350m distance to coast) because most effort occurred in that stratum.

We evaluated annual density estimates for long-term trends using generalized linear models (GLMs) with gaussian distributions. We note that linear models may be adequate to explore at-sea density/population trends for species with local breeding populations (e.g., Brandt's Cormorants or Western Gull); however, annual densities for transient/migratory species (e.g., Sooty Shearwater or

Brown Pelican) could be more variable based on regional ocean and forage conditions. Because data were collected on surveys designed for marbled murrelet population monitoring (nearshore), these results could be conservatively interpreted as an estimate of nearshore use by these species but *not* an estimate of local population densities.

Table 4. Total counts of most common birds and mammals observed, 2007–2023. Species for each taxa category (birds or mammals) were ranked by count and included if they were part of the cumulative top 98% of animals observed.

	Common_Name	**Scientific_Name**	**Species**	**Count**
Birds	Common Murre	Uria aalge	COMU	53157
	Brandt's Cormorant	Phalacrocorax penicillatus	BRAC	32409
	Sooty Shearwater	Ardenna grisea	SOSH	18496
	Pigeon Guillemot	Cepphus columba	PIGU	8577
	Western Gull	Larus occidentalis	WEGU	7348
	Brown Pelican	Pelecanus occidentalis	BRPE	6888
	Heermann's Gull	Larus heermanni	HEEG	5329
	Pelagic Cormorant	Phalacrocorax pelagicus	PECO	3728
	Marbled Murrelet	Brachyramphus marmoratus	MAMU	3633
	Western/Clark's Grebe	Aechmophorus occidentalis/clarkii	WCGR	2090
	California Gull	Larus californicus	CAGU	1648
	Red/Red-necked Phalarope	Phalaropus fulicarius/lobatus	PHAL	1330
	Elegant Tern	Thalasseus elegans	ELTE	1292
	Caspian Tern	Hydroprogne caspia	CATE	512
	Surf Scoter	Melanitta perspicillata	SUSC	453
	Rhinoceros Auklet	Cerorhinca monocerata	RHAU	303
	Pacific Loon	Gavia pacifica	PALO	137
	Double-crested Cormorant	Phalacrocorax auritus	DCCO	136
	Northern Fulmar	Fulmarus glacialis	NOFU	77
Mammals	California Sea Lion	Zalophus californianus	CASL	2162
	Sea Otter	Enhydra lutris	SEOT	1230
	Harbor Porpoise	Phocoena phocoena	HAPO	860
	Risso's Dolphin	Grampus griseus	RIDO	297
	Harbor Seal	Phoca vitulina	HASE	130
	Bottlenose Dolphin	Tursiops truncatus	BODO	108
	Humpback Whale	Megaptera novaeangliae	HUWH	71

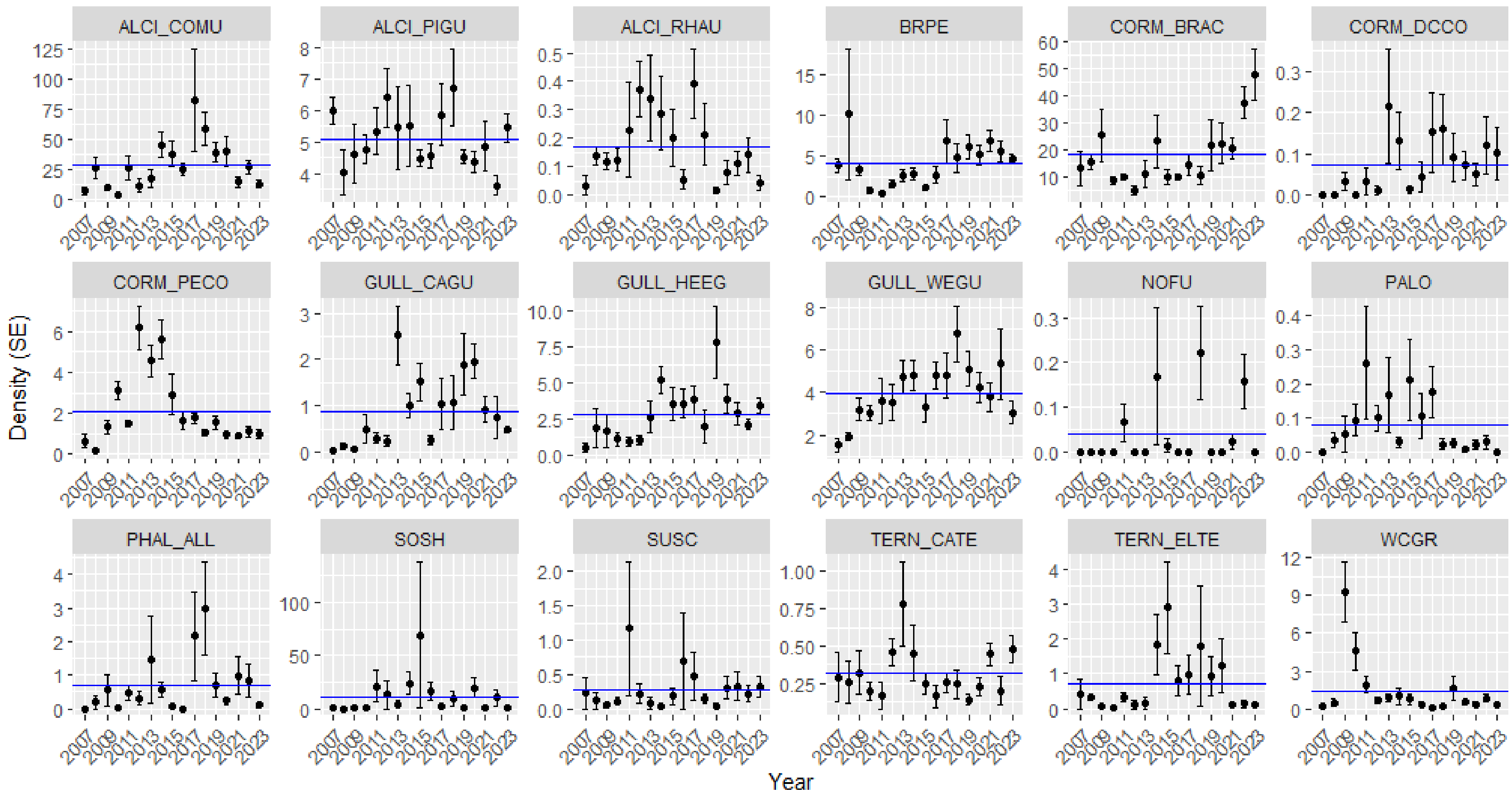

Figure 5. Mean annual densities (animals km-2) and standard errors (error bars) of most common bird species observed on surveys, 2007–2023. Horizontal blue lines represent long-term annual average. Note that density (y-axis) varies by species.

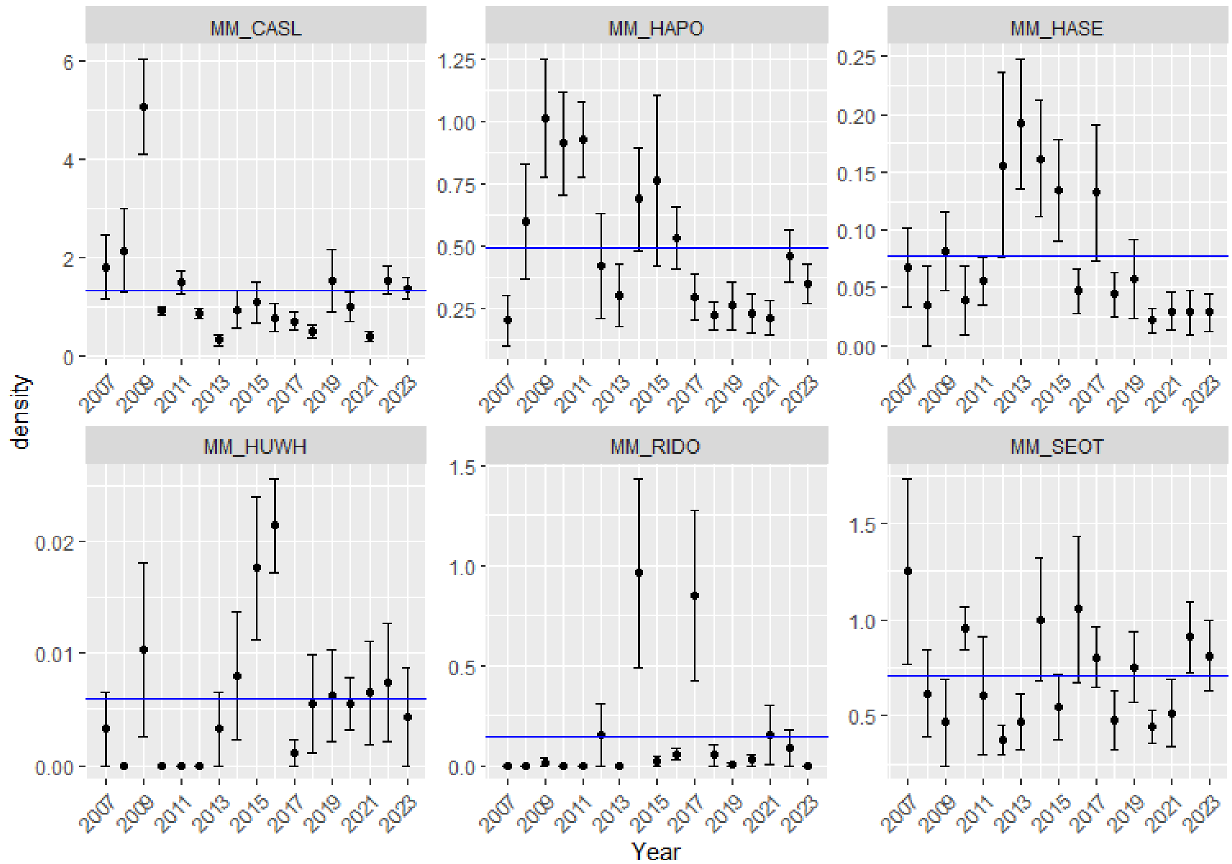

Figure 6. Mean annual densities (animals km-2) and standard errors (error bars) of most common mammal species observed on surveys, 2007–2023. Note that Humpback Whales (MM_HUWH) represent encounter rates per linear km, not density. Note that density (y-axis) varies by species.

Table 5. Generalized linear model results for long-term inter-annual trends of nearshore densities by species. Slope values significant at the $p<0.05$ level are indicated in bold italic.

	Species	Slope	SE	t	p
Birds	ALCI_COMU	1.402	0.989	1.418	0.177
	ALCI_PIGU	-0.024	0.043	-0.568	0.578
	ALCI_RHAU	-0.004	0.006	-0.673	0.511
	BRPE	0.141	0.125	1.123	0.279
	CORM_BRAC	***1.297***	***0.460***	***2.819***	***0.013***
	CORM_DCCO	***0.006***	***0.003***	***2.181***	***0.045***
	CORM_PECO	-0.072	0.089	-0.807	0.433
	GULL_CAGU	0.063	0.034	1.818	0.089
	GULL_HEEG	***0.189***	***0.079***	***2.383***	***0.031***
	GULL_WEGU	***0.153***	***0.054***	***2.821***	***0.013***
	NOFU	0.004	0.004	1.010	0.328
	PALO	-0.004	0.004	-1.075	0.299
	PHAL_ALL	0.046	0.040	1.131	0.276
	SOSH	0.154	0.875	0.176	0.863
	SUSC	0.002	0.015	0.132	0.896
	TERN_CATE	0.000	0.008	-0.023	0.982
	TERN_ELTE	0.026	0.041	0.627	0.540
	WCGR	-0.184	0.106	-1.733	0.104
Mammals	MM_CASL	-0.087	0.051	-1.713	0.107
	MM_HAPO	***-0.028***	***0.012***	***-2.319***	***0.035***
	MM_HASE	-0.003	0.003	-1.185	0.254
	MM_HUWH	0.000	0.000	0.949	0.358
	MM_RIDO	0.005	0.015	0.348	0.733
	MM_SEOT	-0.005	0.013	-0.392	0.700