MENDOCINO • HUMBOLDT
Redwood Companies

Marbled Murrelet Inland Monitoring

Annual Report 2023

February 1, 2024

Cover photo: Allen Creek MMCA (credit Barry Weinart).

PROJECT SUMMARY

Project Title: Marbled Murrelet Inland Monitoring

Subject Area: Habitat Conservation Plan (HCP) monitoring

Date initiated: March 1999

End Date: Ongoing

Project Manager: Sal Chinnici, Director, Forest Sciences

Executive Summary

An objective of the Habitat Conservation Plan (HCP) inland effectiveness monitoring program is to determine whether the Marbled Murrelet Conservation Areas (MMCAs) continue to be used by marbled murrelets. In pursuit of this objective, marbled murrelet activity is monitored in select MMCAs and the neighboring Headwaters Forest Reserve and Humboldt Redwoods State Park (Reserves). Areas within the Reserves serve as controls to gauge any changes in the MMCAs. Since the inception of HCP monitoring (1999), occupied behaviors have been observed using audio-visual (AV) surveys in the MMCAs and Reserve stands. In 2023, AV surveyors conducted 143 surveys at 33 stations and observed occupied behaviors (below canopy flight or circling) in all Reserves and in all MMCAs with the exception of the Shaw Gift MMCA.

Radar surveys track murrelets traveling to and from nesting areas within the MMCAs and Reserves. Radar counts are considered indices of the breeding population because non-breeding murrelets do not fly inland. In 2023, 56 radar surveys were conducted at 14 sites. Preliminary analysis of the data indicates that after 22 years of monitoring, trends in radar counts of murrelets in the MMCAs and Reserves have differed during the study period; there has been a significant decline in radar counts in both the Reserves and the MMCAs since the 2002 baseline, but the rate of decline in MMCAs has been slower.

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INTRODUCTION

Under the terms of the Habitat Conservation Plan (HCP), Marbled Murrelet surveys are carried out to determine the effectiveness of management measures (HCP 6.1.3; PALCO 1999):

> *The Company will implement the implementation and effectiveness monitoring program discussed in Section 6 on the covered lands. The goals will be as follows:*
>
> 1. *Determine whether the HCP conservation strategies are implemented as written.*
> 2. *Determine whether the conservation strategies are having the predicted impact and effect on Marbled Murrelets.*
>
> *These two monitoring goals can be regarded as implementation (or compliance) monitoring and effectiveness monitoring, respectively. These goals follow from the recommendations of the USFWS (Recovery Plan) and mirror similar efforts elsewhere in the region (e.g., Madsen et al. 1997, for federal lands).*

The overall goal of the monitoring surveys is to determine whether the MMCAs continue to be used by murrelets. In addition, the Reserves (Headwaters Forest Reserve [HFR] and Humboldt Redwoods State Park [HRSP]) are monitored for comparative purposes, essentially as controls. The HCP will be regarded as meeting conservation objectives if murrelets remain in occupancy of originally occupied sites, or any declines in occupancy occur at comparable rates in the MMCAs and Reserves (e.g., a change in occupancy rates due to a general population decline from oil spills or other stochastic events) (HCP section 6.1.3 pp. P-27 to P-31).

For effectiveness monitoring, audio-visual surveys were conducted to assess occupancy at the Reserves and MMCAs. In addition, radar surveys were conducted for comparing trends in murrelet counts between the Reserves and MMCAs.

2023 Objectives

- Complete all audio-visual and radar surveys.

- Determine current occupancy of MMCAs and Reserves.
- If declines have occurred, are such declines at comparable rates in the MMCAs and the Reserves?

Appended to this 2023 report are several documents requested by reviewers in 2010 to aid in understanding objectives, methods, and results:

- Marbled Murrelet Scientific Review Panel notes and recommendations of April 5, 2004.
- 1998 Pacific Seabird Group (PSG) Marbled Murrelet Survey Protocol and recommendations (including 1994 through 1998 protocols and revisions).
- HRC HCP Effectiveness Monitoring Radar Survey Protocol.
- 2023 audio-visual and radar survey summaries including dates, times, and results.

METHODS

BACKGROUND

The HCP, section 6.1.3 “Monitoring” of the Marbled Murrelet Conservation Plan (section 6.1), states:

> *The program will be overseen by PALCO’s existing Marbled Murrelet Scientific Review Panel (MMSRP). Members of the MMSRP will meet annually for the first five years of the plan to review monitoring program design and results and to make recommendations for future studies.*

The current monitoring program follows the MMSRP 2004 recommendations (MMSRP 2004).

1) Audio-visual surveys are conducted to assess occupancy at 33 stations (6 in the Reserves and 27 in the MMCAs) where each station is surveyed until an occupied behavior is observed or to a maximum of five times per season. Surveys are done according to the 1998 PSG protocol (HCP 6.1.3.3) and include circling behavior as a behavior indicative of occupancy. Inference is to the collection of stations, not to individual stations.

2) Radar surveys are used to track murrelet detections at 14 sites (6 in the Reserves and 8 in the MMCAs) where each site normally receives four visits per season and that radar counts be treated as indices of abundance of murrelets flying into or through an MMCA or Reserve.

In 2006, the MMSRP made the following observations and recommendations regarding the analysis of the data collected during radar surveys:

1) There is good evidence that murrelet inland counts may be related to ocean conditions (e.g., Peery et al. 2004, Bigger et al. 2006a). Explore the relationship between ocean conditions (e.g., sea surface temperature (SST) and Northern Oscillation Index (NOI)) and annual trends in radar counts by using ocean conditions as a covariate in the analysis of the trend data.

2) There appears to be a relationship between the annual estimates of population size based on at-sea counts and inland radar counts. Explore the relationship between the at-sea population estimates and annual trends in radar counts by using the at-sea estimates as a covariate in the analysis of the trend data.

2023 Survey Effort

As required by the HCP (6.1.3.3) and by agreement with the agencies, surveys were conducted at audio-visual monitoring stations in the Allen Creek MMCA (*n* = 11), Bell Lawrence MMCA (*n* = 7), Shaw Gift MMCA (*n* = 6), Cooper Mill MMCA (*n* = 3), with surveys conducted at stations in HFR (*n* = 3) and HRSP (*n* = 3) serving as controls. All audio-visual survey stations were located near, or in un-harvested and partially harvested (residual) old growth habitat (Figure 1). Stations that were within 200 meters (m) of un-harvested old growth were classified as ‘old growth’ stations; all other stations were classified as ‘residual’ stations. Each station was visited until occupied behavior was observed or to a maximum of 5 visits. A total of 33 audio-visual survey stations were surveyed in 2023. All subsequent AV analyses in this report use data from surveys at these stations.

Surveyors conducted audio-visual surveys from 45 minutes prior to sunrise to 75 minutes after sunrise. The unit of measurement was a “detection”, which was defined as sighting or hearing one or more murrelets. Murrelets typically fly in pairs, as singles, or in small groups (Naslund 1993) and groups of murrelets were counted as a single detection when the detection was not separated by at least 5 seconds, as required by survey protocol.

An occupied behavior is when a murrelet is seen flying below canopy or circling (above or below canopy). All surveys were conducted according to the methods set out in the 1998 Pacific Seabird Group (PSG) protocol (HCP 6.1.3.3). All surveys were conducted by staff of Sean McAllister of North Coast Field Biologists, and O'Brien Biological Consulting. All surveyors have received training and evaluation in marbled murrelet survey techniques. A total of 143 protocol surveys were conducted by the contractors. See Table 1 and Appendices for survey dates and outcomes.

Radar surveys were conducted from 75 min. prior to sunrise to 75 min. after sunrise at 6 Reserve sites and 8 MMCA sites (Figure 2). In 2023 radar surveys were again conducted by marbled murrelet biologist Adam Brown. Mr. Brown has been trained in HRC HCP radar techniques by HRC wildlife biologist Mark Freitas as per training techniques used throughout this study by Alaska Biological Research, Pacific Lumber Company, and HRC. See Appendices for the radar survey protocol. In 2023, each site (n = 14) was surveyed 4 times during the breeding season for a total of 56 radar surveys.

We used a Furuno® FR-1510 Mark-3 high-performance X-band radar that transmits 9410 ± 30 MHz with a peak power output of 12 kW. This radar used a 2 m antenna that was mounted on a pick-up truck 3.5 m above the ground. We set the antenna to rotate at 24 times per min and to scan a circular area with a 1.5 km radius (707 ha) with a pulse length set at 0.07 µsec. To be classified as a murrelet, radar targets had to be traveling at least 64 km per hr (Cooper et al. 2001) and leave an echo trail of ≥3 blips after 4 antenna sweeps. Single and multiple murrelets flying within a few meters of each other appear as a single echo on a radar screen (Burger 1997), and so each echo trail was counted as a single detection. (For further details, refer to "Conducting radar surveys for marbled murrelets: HCP Effectiveness monitoring protocol" [version 1.2] in Appendices).

Images on the radar screen were recorded using an Epiphan VGA2USB frame grabber device and reviewed for murrelet targets that might have been missed during the survey.

ANALYSES OF SURVEY DATA

The purpose of the effectiveness monitoring program is to determine the occupancy of the Reserves and MMCA stands so that the impacts of management and conservation measures on occupancy patterns can be assessed (HCP 6.1.3). At the 1999 MMSRP meeting, the MMSRP recommended that "trends in the MMCAs collectively should be considered to how they respond relative to the 'control' study areas in the reserves" (HRSP and HFR) (MMSRP 1999). Thus, this study was not designed to detect trends in individual MMCAs, Reserves, or stands within them.

A linear mixed model was used to model spatio-temporal variation in *ln* + 1 transformed radar counts from 2002 to 2020. Results from 2009 were not used due to a reduced survey effort that year. Mixed models can accommodate both fixed and random effects (Littell et al. 1996).

The Land-type (Reserves and MMCAs) term was treated as a fixed effect to test for differences between MMCAs and Reserves. A linear Year term was used to test for a trend in counts, and the interaction between Land-type and linear year. Year was used to test the hypothesis that slopes of the linear year effects differed between MMCAs and Reserves. Survey day was added as a linear continuous effect to account for an increase in counts later in the season (e.g., Rodway et al. 1993, Jodice and Collopy 2000).

We also included annual estimates of the Northern Oscillation Index (NOI) and Sea Surface Temperature (SST) as covariates to explore the relationship between inland counts and indices of ocean productivity. Sea surface temperature data (ºC) were averaged (SST_AVE) from NOAA buoys (Station 46022 - EEL RIVER - 17NM West-Southwest of Eureka, CA and Station 46027 - ST GEORGES - 8NM West Northwest of Crescent City, CA) and Northern Oscillation Index (NOI). Data were from https://coastwatch.pfeg.noaa.gov/erddap/index.html.

Finally, categorical Year and Site nested within Land-type were treated as random effects where categorical Year was a categorical factor with 18 levels (2002-2020, excluding 2009). It was assumed that the error term described the within-site variation. Restricted maximum likelihood estimation was first used to model the following covariance structures: variance component, compound symmetric, first-order autoregressive, and heterogeneous autoregressive (Littell et al. 1996). However, only the model with compound symmetric structure converged and this structure was therefore used to model fixed effects with full maximum likelihood estimation methods. Analyses of radar and audio-visual data from 2002-2020 were conducted by Kristin Brunk, PhD, Peery Wildlife Ecology and Conservation Lab, University of Wisconsin-Madison using SAS v9.4.

For exploratory purposes, a similar analysis was conducted using the audio-visual survey data collected from 2000 to 2020. Survey day was added as a linear continuous effect to account for an increase in counts later in the season (e.g., Rodway et al. 1993, Jodice and Collopy 2000). As with the radar analyses, only the model with compound symmetric structure converged and this structure was therefore used to model fixed effects with full maximum likelihood estimation methods.

Following approximately 20 years of monitoring and analyses of results for this project we were able to publish results of a more extensive analysis and assessment of HCP effectiveness (Brunk et al., 2021, full publication included in report appendices). The results of this analysis are included below. This annual report will not include the typical analysis as discussed above, including the 2023 monitoring data. Instead, we will continue to rely on the trends data as shown in Figures 3 through 9.

RESULTS

OCCUPANCY

During 2023, surveyors observed occupied behaviors at 12 of the 33 audio-visual survey stations (Table 1). Occupied behaviors were observed at 5 of the 6 Reserve stations and at 7 of the 27 MMCA stations. Occupied behaviors were observed at all the MMCA stands, with the exception of the Shaw Gift MMCA, and at both Reserves (Table 1).

In 2023, the annual proportion of Reserve stations with occupied behaviors was greater (0.83, 1SE = 0.15) as the proportion of MMCA stations with occupied behaviors (0.26 ± 0.084; Figure 3a). Overall, the annual proportion of MMCA stations with occupied behaviors appears to be tracking the proportion of Reserve stations with occupied behaviors over the study period, with the proportion declining in both the Reserves and the MMCAs in 2023 (Figure 3a).

Occupied behaviors, as defined by circling murrelet targets, were observed at the Reserve stands but at none of the MMCA stands on the radar surveys in 2023 (Table 2, Figure 3b). Radar surveyors observed circling murrelet targets at 1 of the 14 radar sites, R03 (HRSP) (Table 2). Among the radar sites, occupied behaviors were observed at 1 of the 6 Reserve radar sites and at 0 of the 8 MMCA radar sites. Overall, the proportion of occupied behaviors observed at the Reserve sites was the same and decreased at MMCA sites from 2022 (Figure 3b).

INLAND MURRELET COUNTS USING RADAR: 2002-2020

Overall, almost four times as many targets were detected in Reserves (mean = 12.0) compared to MMCAs (mean = 3.4) in 2023. From the analysis of the years 2002-2020, however, there was no significant difference in log-transformed radar counts in Reserves (2.81 $\pm$ 0.24) compared to MMCAs (2.31 $\pm$ 0.21; $t_{12} = -1.55$, $p = 0.15$). The linear year term was statistically significant ($F_{1,968} = 176.79$, $p < 0.001$) suggesting a trend in radar counts over the period 2002-2020. The land-type×year interaction, which tests whether the slopes of the trend lines in the MMCAs and Reserves are different, was statistically significant ($F_{1,968} = 20.39$, $p < 0.001$), suggesting that trends in radar counts of murrelets in Reserves and MMCAs differed since 2002 (Figure 4).

The estimated slope associated with the linear Year term for radar counts in the Reserves alone ($b = -0.073 \pm 0.01$) was statistically less than zero ($t_{968} = -11.84$, $p < 0.001$). Similar to 2019, the slope for MMCAs alone was also statistically less than zero ($b = -0.04 \pm 0.01$; $t_{968} = -6.69$, $p < 0.001$). These results suggest that counts have decreased in both the Reserves and in the MMCAs but have apparently decreased at a slower rate in the MMCAs. Julian date and NOI were not statistically significant ($F_{1,968} = 0$, $p = 0.96$ for Julian Date; $F_{1,968} = 1.17$, $p = 0.28$ for NOI), indicating that radar counts were stable within each season and were not associated with NOI. However, SST was statistically significant ($F_{1,968} = 22.92$, $p < 0.001$) and the estimated slope for SST was negative ($b = -0.26 \pm 0.05$), indicating that murrelet counts were lower in years with warmer SST (an index of marine productivity).

AUDIO-VISUAL COUNTS: 2000-2020 (EXPLORATORY)

Although audio-visual detections are not used for trends monitoring, there is a longer history of audio-visual surveys than radar surveys on the HCP covered lands and Reserves. Some patterns emerged after statistical analysis.

Results from the analysis of audio-visual count data from 2000-2020 revealed that, unlike previous years, the land-type by linear year interaction, which tests whether the slopes of the trend lines in the MMCAs and Reserves are different, was statistically significant ($F_{1,\ 3108} = 6.95$, $p = 0.01$), suggesting that trends in audio-visual murrelet detections in the Reserves and MMCAs were different during this period (Figure 5). Audio-visual murrelet detections in the Reserves were estimated to be significantly declining ($b = -0.03 \pm 0.01$, $p < 0.01$), and while counts in the MMCAs were also declining, they were declining more slowly ($b = -0.01 \pm 0.002$, $p < 0.01$). Despite the faster decline in Reserve areas, there were still significantly more murrelets detected in Reserves (least-squares means = 1.58 $\pm$ 0.21) than in MMCAs (least-squares means = 0.43 $\pm$ 0.12; $t_7 = -4.85$, $p < 0.01$). This is supported by the fact that means of raw audio-visual counts showed over five times more detections in Reserves (9.12 $\pm$ 0.94) than MMCAs (1.58 $\pm$ 0.23).

Audio-visual counts were strongly and positively related to the Julian date of the survey ($b = 0.0037 \pm 0.0004$, $F_{1,3108} = 58.05$, $p < 0.001$), but neither NOI nor SST were significant predictors of AV counts ($F_{1,3108} = 2.20$, $p = 0.14$ and $F_{1,3108} = 0.65$, $p = 0.42$, respectively).

At-sea Population Numbers

At sea surveys were conducted in Conservation Zone 4 (Coos Bay, Oregon to the Humboldt/Mendocino County line, California) in 2019 and 2021 (Figure 10). McIver, et al. (2022) reported that the Zone 4 population estimate for 2021 was 5,132 murrelets (CI = 3,739-8,243), and that the Conservation Zone 4 estimate showed significant evidence of a trend from 2000 through 2021 (2.8% increase per year; 95% CI: 0.9-4.6%). The at-sea estimate of marbled murrelets for the HCP region (Conservation Zone 4, Stratum 2) for 2021 was 657 birds (CI = 90-1,521).

In 2014 a reduced-sampling effort design was implemented for the at-sea population surveys. Conservation Zones 1 and 3 are sampled in even years, Conservation Zones 2 and 4 are sampled in odd years, and Conservation Zone 5 is sampled every fourth year in conjunction with Zone 4. Thus, there was no at-sea population estimate for Zone 4 in 2014, 2016, or 2018 (Lynch et al. 2016, McIver et al. 2019). As noted above, Zone 4 was surveyed in 2021.

DISCUSSION

An objective of HCP monitoring is to determine the occupancy of the MMCAs and Reserves. In 2023, the AV survey results show continued murrelet occupancy in both surveyed Reserves and in all MMCAs with the exception of Shaw Gift (Table 1, Figure 3a). This 2023 result is similar to previous years for both the Reserves and the MMCAs. Typically, both Reserves and at minimum the Allen Creek MMCA have at least one site with observations of occupancy. In contrast, observations of murrelets exhibiting occupied behaviors at some MMCAs, e.g., Shaw Gift, Cooper Mill, and Bell Lawrence, have been consistently more difficult to obtain over time.

Reduced visibility at several survey stations due to growth of vegetation is likely a factor. AV surveys began approximately 30 years ago in the study area and changes in size and location of tree canopy has been significant over time. Observation of occupied behavior at some of these sites appears to be a very opportunistic event. Even in years with low detection of occupied behaviors, there has continued to be relatively high radar counts at the sites covering these MMCAs, with the exception of Bell Lawrence (Table 2). The inconsistent nature of occupancy detections, and of AV detections in general, points out the limitations of AV surveys in which daily variation in weather, and changes in conditions at a survey site (e.g., surrounding vegetation), can influence the ability to detect murrelets and their behaviors.

Although inconsistent at some, the continued observation of occupancy of the MMCAs via AV surveys over the study period is a potential indication that the HCP has not so far resulted in adverse changes in murrelet occupancy of these stands. Trends in AV detections at MMCAs and Reserves appear to have tracked each other since 2000. Overall, after 24 years of AV monitoring there appears to be a declining trend in AV detections since the study began (Figure 5).

Differences in radar counts between MMCAs and Reserves from 2002-2020 were not significant at a threshold of $p \leq 0.05$ but were near significant at $p = 0.15$, indicating that the higher counts in Reserves compared to MMCAs may be biologically meaningful. The land-type x year interaction for radar surveys was significant at a threshold of $p \leq 0.05$, indicating a difference in trends between the MMCAs and Reserves. The estimates of the slopes of these trends indicate that there has been a decline in counts in both the MMCAs and the Reserves, but the counts in the MMCAs have been declining at a slower pace (Figures 4, 6, and 7).

The results of the exploratory AV analysis above indicated that mean AV counts remained statistically significantly higher in the Reserves than in the MMCAs at the $p \leq 0.05$ level; but in 2020 we detected a difference in trends between MMCAs and Reserves, indicated by the significant Land-type x Year interaction term. Similar to the radar analysis, it indicated that audio-visual counts are declining more slowly in MMCAs than in Reserves, although counts are significantly declining on both land-types (Figures 5, 8, and 9). Overall, radar has shown to be the better tool for tracking numbers of murrelets (e.g., Bigger et al. 2006*a*, 2006*b*).

For radar counts, Julian date and NOI were not significant factors, but SST was a significant factor. Given the strong El Niño affect in both 2017 and 2018, the significant relationship with SST is not surprising. SST was significant ($p < 0.05$) for the periods 2002-2006, 2002-2007, 2002-2015, and 2002-2016 as well. This has been followed by La Niña events that have provided cooler SST and better upwelling conditions for murrelet prey species. In contrast, Julian date continues to exhibit a strong, positive relationship with AV counts. It is possible that murrelet behavior is affected by Julian date – perhaps birds call more or make more frequent nest visits while provisioning chicks, which would make birds easier to detect during AV surveys later in the season, while not affecting radar detections. NOI and SST have not shown a relationship to AV counts.

Similar to the results above, Brunk et. al., (2021) found that based on occupancy models applied to audio-visual survey data, average occupancy was higher in Reserves (0.85; 85% confidence intervals [CI]: 0.79–0.90) than in MMCAs (0.46; 85% CI: 0.38–0.54). Numerically, trends in occupancy were slightly positive in Reserves (= 1.01; 85% CI: 0.94–1.08) and slightly negative in MMCAs (= 0.97; 85% CI: 0.87–1.06), but CI did not preclude stable occupancy on both ownerships. Based on generalized linear mixed models applied to inland radar survey data, murrelet counts in MMCAs (least-squares [LS] mean = 8.7; 85% CI: 6.2–12.2) were lower than those in Reserves (LS mean = 14.8; 85% CI: 10.1–21.7), but CI overlapped. Murrelet counts declined by 12–17% annually on both Reserves and MMCAs over the study period based on the top model, but a closely competing interactive model suggested more rapid declines in Reserves (14–20%) than in MMCAs (10–15%). Both models indicated that murrelet counts were negatively related to sea surface temperature, suggesting that warm ocean conditions negatively affect murrelet breeding effort. Collectively, these results suggest that while the MMCA habitat may be lower quality than that in the Reserves, the HCP has likely not exacerbated ongoing declines of murrelets in the region. In addition, habitat in the MMCAs is expected to improve over time as second growth trees grow further into the upper canopy and potentially develop suitable nest platforms.

At-sea counts of murrelets in the HCP bioregion (Conservation Zone 4, Stratum 2: Trinidad to Shelter Cove) appear to have increased during the study period (i.e., 2000 – 2021), though numbers were lower in 2021 compared to 2019. In 2021, McIver et al. (2022) found evidence of a population increase in Conservation Zone 4 (2.8% increase per year). Similarly, for the entire California sampling area, the current results suggest a significant increasing trend for the period of 2000 to 2021 (3.8% increase per year; 95% Cl: -0.8% - 0.9%) (McIver et al., 2023).

The murrelet population estimate for the entire sampling area (all conservation zones combined) for 2021 was 18,000 murrelets (95% Cl: 14,000 – 21,900 birds) and indicated a 0.1% increase per year (95% Cl: -6.4% - 0.9%), but because the Cl is small and includes zero, McIver et.al. concluded there is no evidence of a trend (McIver et.al., 2023). The 2021 Zone 4 estimate was 5,132 murrelets.

Although the at-sea population estimate of murrelets in the HCP bioregion appear to have increased, recent inland monitoring results suggest that overall numbers of inland detections, and detections of occupied behavior, appears to have decreased during the sampling period. This may be a result of the effects of El Niño, since fewer murrelets will fly inland to breed when ocean conditions are poor, and prey is less available. El Niño conditions are anticipated to continue through the Northern Hemisphere winter, with a greater than 95% chance through December 2023, to February 2024 (https://www.cpc.ncep.noaa.gov/products).

During the development of the HCP conservation strategy, it was predicted that murrelet counts and detections of occupancy would increase in the Reserves, and possibly in the MMCAs, as other non-reserve occupied stands were harvested. The current trends in radar counts might be an indication that: 1) murrelets that were nesting in previously harvested stands have since moved to the MMCAs, and/or 2) that more first-time breeders are choosing to nest in MMCAs. It will be interesting to note future results in trends given the significant change in forest management with the ownership change to HRC in 2008. HRC retains all old growth trees on the landscape and provides protection for Forest Stewardship Council (FSC) Type I and II old growth stands, in addition to continued protection of the MMCAs.

RECOMMENDATIONS

- No change in monitoring strategies or intensity is recommended at this time.

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Table 1. Mean annual counts* of total detections at audio-visual survey stations from 2000-2023.

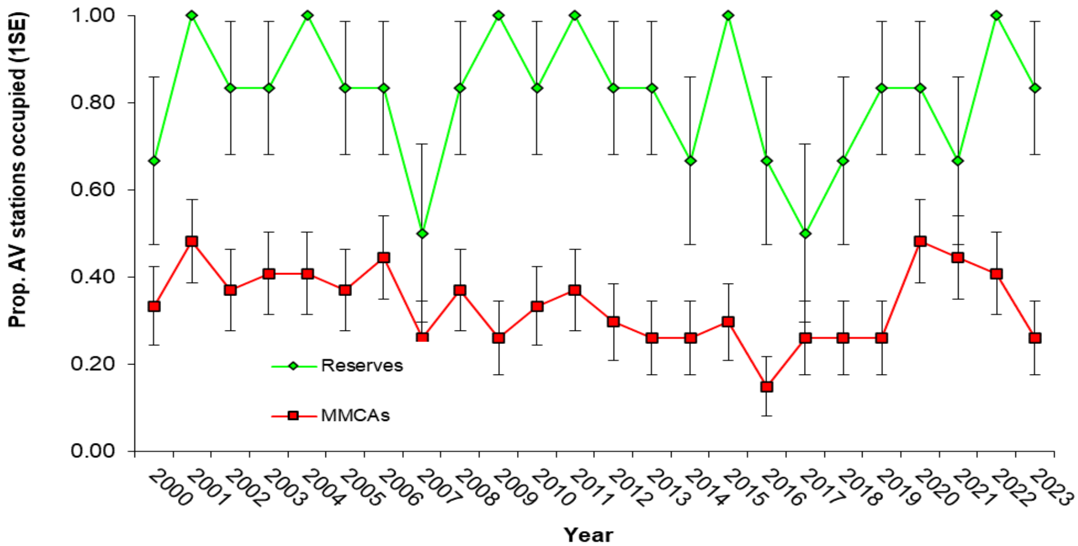
Location	Station	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Allen Creek MMCA	HM0104	0.0	1.1	0.4	0.0	0.0	0.4	0.8	2.0	0.0	0.0	0.6	0.4	0.6	1.2	2.0	1.0	0.0	2.8	0.0	0.6	0.0	4.4	5.6	0.4
	HM0105	**1.6**	0.0	0.0	0.3	0.8	0.0	0.4	0.0	0.0	1.0	0.8	0.0	**2.4**	0.0	**0.5**	**4.7**	0.0	**8.5**	0.0	0.0	**0.8**	0.4	**3.5**	0.4
	HM0107	**4.4**	**6.0**	**9.2**	**8.8**	**4.0**	**9.0**	**3.0**	7.3	**0.3**	**15.6**	**7.0**	**10.5**	5.8	**6.0**	1.0	2.2	1.6	**5.0**	1.0	**5.0**	**19.5**	**4.2**	**2.0**	**2.0**
	HM0109	0.0	0.0	0.0	0.0	**1.5**	0.0	0.8	0.0	**1.0**	3.2	0.4	**1.2**	0.0	0.4	0.0	0.2	0.0	0.0	0.0	4.2	0.2	0.0	2.6	0.0
	HM0111	4.2	14.6	1.0	0.7	0.8	**0.3**	1.2	2.4	1.0	0.8	4.4	1.8	1.4	0.8	0.6	0.0	6.4	**2.0**	1.0	**4.5**	**4.6**	**7.2**	**5.7**	2.0
	HM0124	**12.8**	2.2	2.8	1.5	**11.0**	**8.0**	**8.3**	0.0	**4.0**	**1.3**	**3.8**	0.8	**1.0**	**3.2**	1.0	1.8	**0.5**	6.0	**2.7**	2.0	**11.0**	**3.0**	9.6	**3.5**
	HM1013	0.0	0.6	2.4	0.0	0.8	0.0	0.0	1.2	0.8	3.2	0.4	1.0	0.2	0.0	**1.8**	**2.4**	0.0	0.0	**0.2**	0.2	0.0	**4.0**	0	0.0
	HM1106	**5.2**	**11.2**	**16.0**	3.3	**8.0**	**0.7**	**1.0**	**6.8**	**0.5**	**6.3**	**5.0**	**3.5**	**2.0**	**12.0**	**8.5**	**9.3**	1.0	**18.0**	**4.5**	**1.3**	**1.25**	**5.8**	**11.0**	**2.0**
	HM1107	0.8	**1.4**	**9.0**	1.0	**3.0**	**1.3**	0.6[c]	**5.6**	4.4	**6.6**	0.2	0.0	0.0	1.0	1.6	2.8	0.0	0.0	0.0	0.0	0.6	1.8	0.4	0.0
	HM2501	**3.0**	**4.8**	**18.2**	**7.2**	**13.0**	**1.0**	**12.0**	**13.3**	1.0	**8.6**	**6.0**	**9.75**	**3.3**	**8.5**	**7.5**	**2.8**	**11.0**	**5.3**	**6.5**	0.0	**4.0**	**10.5**	**4.5**	**5.8**
	HM2502	**5.4**	**8.0**	**8.6**	**2.0**	**6.5**	4.0	**2.0**	**3.0**	**3.8**	**18.4**	**3.7**	**2.0**	**2.7**	**2.0**	**1.8**	**0.8**	**8.0**	**9.0**	**6.4**	**5.5**	**25.75**	**7.5**	**3.0**	**3.2**
Bell-Lawrence MMCA	HM0201	0.4	0.0	**1.2**	**3.2**	0.4	0.7	**25.0**	**1.0**	**0.3**	**0.5**	0.0	**2.4**	0.0	0.0	0.6	1.6	**7.0**	0.2	**4.0**	0.6	1.0	0.4	0.4	0.0
	HM1203A	0.0	0.2	0.0	1.0	0.0	1.0	0.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**11.4**	**1.0**	**2.0**	**3.0**
	HM1204	**3.2**	**5.4**	**3.8**	0.3	**5.3**	**4.8**	**4.3**	1.4	**1.6**	0.0	0.0	**0.3**	0.8	**0.3**	0.0	0.0	0.6	0.2	0.0	0.2	0.0	**5.0**	**2.5**	0.8
	HM1206	**8.4**	**1.8**	**6.8**	**4.0**	**2.0**	**0.0**[b]	**4.0**	1.4	**16.5**	0.0	0.0	0.0	0.0	0.2	0.0	**2.0**	0.0	0.2	**6.5**	**0.2**	**0.75**	**2.3**	**11.3**	2.4
	HM1306	0.2	0.0	0.0	0.0	0.2	0.0	1.6	0.0	0.5	0.0	**3.0**	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0	0.0
	HM2301	0.0	**2.6**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.2	0.0	0.0	0.2	0.0	0.0	0.6	0.4	0.0	0.0	0.8	0.2	0	1.4
	HM2302	0.0	0.0	0.6	0.0	**5.3**	0.0	0.4	**1.3**	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.2	0.0	0.0	**0.2**	0.4	0.0	0	0.0
Cooper Mill MMCA	HM0804B	1.4	0.0	0.4	**2.8**	0.2	**1.8**	1.8	**18.0**	**4.8**	0.0	**0.3**	**1.0**	**2.3**	0.0	**2.0**	2.4	0.4	**1.0**	1.2	0.8	**5.67**	**3.6**	0.4	**1.0**
	HM0808	0.0	**0.4**	0.2	**1.0**	0.4	0.0	**2.7**	2.0	6.0	0.4	**0.3**	**1.3**	**1.3**	**1.0**	1.4	1.3	0.4	1.6	0.0	**2.0**	**13.25**	1.2	**2.0**	2.2
	HM0813	0.4	**0.6**	**0.3**	**3.2**	0.0	0.2	**3.0**	4.0	1.3	1.2	**1.6**	0.8	1.0	1.6	**1.3**	**3.0**	0.0	1.6	0.4	0.8	**7.67**	**5.0**	**17.0**	0.8
Shaw Gift MMCA	HM0405	0.0	0.0	0.4	0.0	**1.0**	**1.0**	**0.5**	0.4	0.2	0.0	0.0	**0.8**	**9.0**	0.0	0.0	**0.4**	0.0	0.0	0.0	0.0	0.0	0.2	0	0.0
	HM0413	2.2	**0.4**	0.0	**2.0**	0.8	0.8	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	**0.2**	0.0	0	0.0
	HM0503	0.0	0.0	**0.5**	0.0	0.2	0.0	0.6	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0	0.0
	HM0707	**1.0**	0.0	0.2	**0.5**	0.0	0.0	**1.0**	0.0	**0.3**	0.6	0.0	0.0	0.2	0.0	0.0	0.6	0.0	0.2	0.0	0.0	0.4	0.0	0	0.2
	HM0906	0.0	0.0	0.0	0.0	0.4	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0	0.2
	HM2401	0.0	**0.3**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0	0.0
HFR Reserve	CM0105A	0.0	**4.8**	**13.6**	**12.2**	**15.0**	**5.0**	**18.0**	3.4	**4.8**	**4.7**	**6.7**	**2.5**	**2.7**	**1.0**	4.4	**20.0**	**21.0**	**17.0**	**5.5**	**5.7**	**3.5**	**3.0**	**9.7**	**3.7**
	CM0207	**3.6**	**14.0**	**10.8**	**9.7**	**11.5**	**15.0**	**15.0**	**5.5**	**10.0**	**11.0**	**12.0**	**19.0**	**6.2**	**5.0**	**14.0**	**9.5**	**14.3**	**2.0**	**6.0**	**1.5**	**3.25**	2.2	**4.8**	**6.6**
	DM0103	**31.2**	**21.9**	**78.8**	**20.7**	**15.0**	**46.0**	**17.0**	**9.5**	**27.0**	**19.0**	**42.0**	**19.0**	**9.5**	**7.7**	**18.5**	**13.8**	**13.5**	**24.5**	**7.0**	**9.0**	**3.0**	**39.0**	**3.5**	**4.0**
HRSP Reserve	ZM0101	**4.4**	**8.2**	**14.8**	**3.0**	**3.6**	**10.0**	**7.0**	**3.0**	**41.5**	**2.0**	**6.2**	**4.0**	**1.5**	**1.5**	**5.6**	**1.0**	3.2	1.6	4.2	**2.5**	**0.5**	**1.5**	**0.7**	**1.0**
	ZM0108	1.2	**36.2**	**18.4**	**8.3**	**12.0**	**1.5**	**5.0**	7.4	**9.5**	**6.0**	**15.0**	**4.8**	**12.5**	**5.0**	**8.0**	**8.5**	**3.0**	4.4	**6.3**	**6.8**	**1.0**	**3.0**	**6.3**	**11.0**
	ZM0110	**0.6**	**1.4**	4.8	5.8	**5.7**	0.0	10.2	1.6	8.0	**16.6**	3.2	**4.6**	2.2	1.6	2.0	**0.6**	1.0	0.0	1.0	3.2	0.8	1.8	**6.0**	1.8

*Counts in bold indicate observation of occupied behaviors.

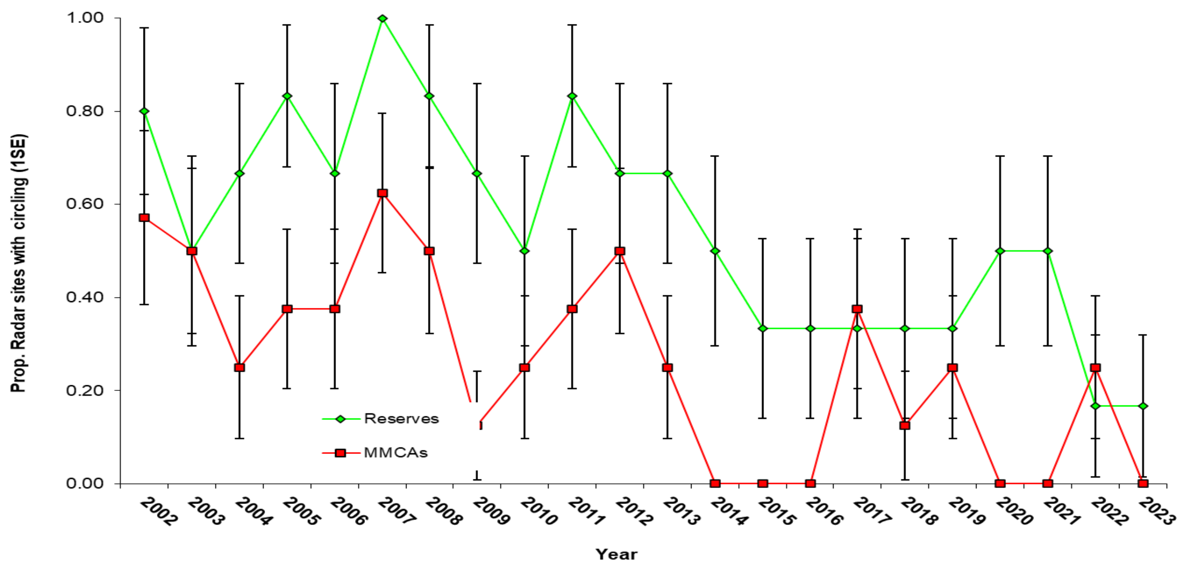
Table 2. Mean annual counts* of marbled murrelets at radar sites in the HCP Bioregion from 2002-2023.

Location	Site	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Allen Creek MMCA	R21	**44.7**	**28.3**	**40.3**	**25.3**	**32.5**	**62.0**	**19.3**	**46.7**	**22.5**	**47.0**	**22.8**	**19.0**	10.5	11.3	7.3	5.5	**11.5**	5.8	4.0	2.75	**2.8**	2.5
	R35	**10.8**	**8.5**	12.8	**10.8**	9.0	**17.8**	**12.3**	9[a]	**16.3**	13.3	**21.0**	11.0	10.3	5.8	10.3	**4.3**	4.5	**3.5**	7.5	6.25	2.8	2.0
	R48	8.7	20.0	7.8	26.6	22.0	16.7	48.3	48[a]	17.8	22.3	20.8	10.3	10.3	8.8	5.0	**3.5**	3.0	3.0	2.0	8.25	9.5	4.5
Bell-Lawrence MMCA	R60	-	**6.8**	19.3	13.3	**11.8**	**12.5**	**8.5**	18.5	11.0	16.8	9.0	**14.0**	9.8	4.3	5.0	4.5	3.3	2.0	4.25	6.25	2.0	2.0
Cooper Mill MMCA	R14	5.8	10.3	8.5	12.3	**10.8**	**16.5**	**18.3**	22[a]	13.8	20.8	**21.3**	9.8	11.0	13.8	11.5	**12.0**	8.3	**15.0**	5.75	5.25	**5.3**	4.3
Shaw Gift MMCA	R16	8.0	6.0	4.3	5.5	8.3	6.8	10.5	9[a]	9.3	**13.0**	**20.0**	11.3	9.3	7.8	9.0	7.8	7.5	4.5	10.25	6.25	9.3	3.0
	R36	**9.0**	**7.5**	**12.0**	**16.8**	9.0	**28.0**	5.8	25[a]	13.3	**24.3**	7.5	11.5	15.8	7.8	5.5	6.0	11.0	4.0	7.25	2.75	5.5	2.8
	R37	**20.3**	1.5	3.5	8.0	6.0	10.7	5.0	50[a]	14.8	21.0	32.0	20.5	26.8	16.5	11.8	4.0	13.3	10.0	4.75	4.75	6.0	5.8
HFR (Reserve)	R45	20.0	4.0	17.0	3.0	3.5	**20.3**	7.5	37[a]	12.0	**27.3**	14.8	16.5	20.8	3.8	3.3	3.3	1.3	2.3	3.0	5.5	2.3	2.0
	R63	-	8.0	8.8	**9.0**	3.8	**9.8**	**6.3**	**11**[a]	**2.3**	13.0	10.0	5.8	6.8	3.5	1.0	2.3	1.0	2.0	3.0	2.25	1.8	1.0
HRSP (Reserve)	R03	**81.3**	**60.5**	**92.5**	**74.8**	**53.3**	**92.0**	**73.8**	**108.5**	**62.0**	**102.8**	**95.5**	**87.0**	**71.8**	**54.8**	**49.5**	46.3	**48.3**	**62.3**	**76.5**	**56.0**	46.0	**40.5**
	R13	**41.8**	**29.0**	**39.3**	**30.3**	**53.0**	**48.3**	**70.7**	**143**	31.3	**41.5**	**47.3**	**35.8**	**15.3**	12.3	14.8	14.0	**10.8**	**10.3**	**33.5**	**8.75**	11.3	9.3
	R34	**45.0**	**26.8**	**43.8**	**37.0**	**43.3**	**31.5**	**27.8**	12[a]	**25.8**	**19.5**	**10.8**	**11.5**	7.0	**4.0**	2.3	**7.8**	3.0	2.8	**10.25**	**11.0**	**8.0**	5.0
	R61	**61.3**	34.5	**38.5**	**56.5**	**30.0**	**33.0**	**48.3**	**82**[a]	50.3	**50.5**	**57.3**	**53.0**	**32.0**	18.0	**12.5**	**17.5**	8.8	8.3	8.5	7.75	9.5	5.5

*Counts in bold indicate the observation of occupied (circling) behaviors.
[a] One survey.



a)



b)

Figure 3. a) Annual proportion of AV effectiveness monitoring stations with occupied behaviors from 2000 to 2023 in Reserves and MMCAs. b) Annual proportion of radar sites with observed circling behaviors from 2002 to 2023 in Reserves and MMCAs.
In 2001, 2004, 2009, 2011, 2015, and 2022 occupied behaviors were observed at all Reserve AV stations so SE was zero. In 2007, circling behaviors were observed at all Reserve radar stations so SE was zero. In 2014, 2015, 2016, 2020, 2021, and 2023 no circling behavior was observed at MMCA radar stations.

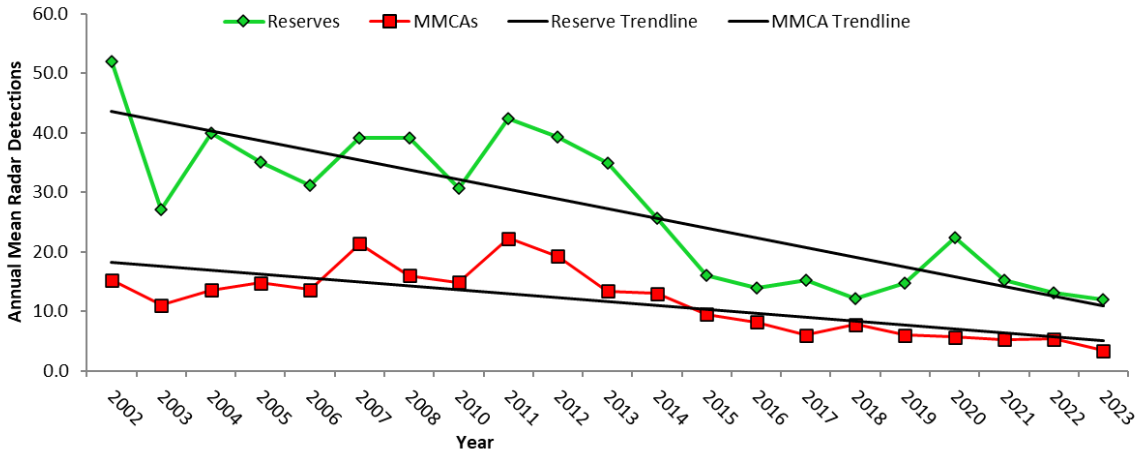


Figure 4. Estimated number of radar detected marbled murrelets per survey (annual means) and trend lines at survey sites in Reserves and MMCAs from 2002 to 2023 (excluding 2009).

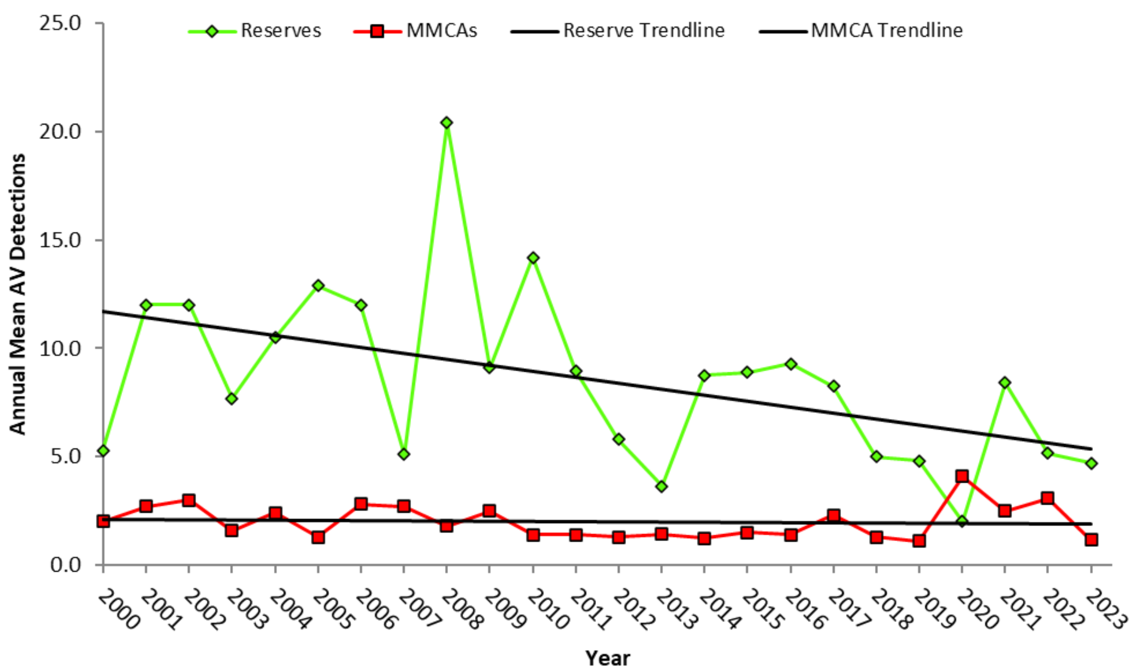


Figure 5. Estimated number of audio-visual detections per survey (annual means) and trend lines for marbled murrelets in Reserves and MMCAs from 2000 to 2023.

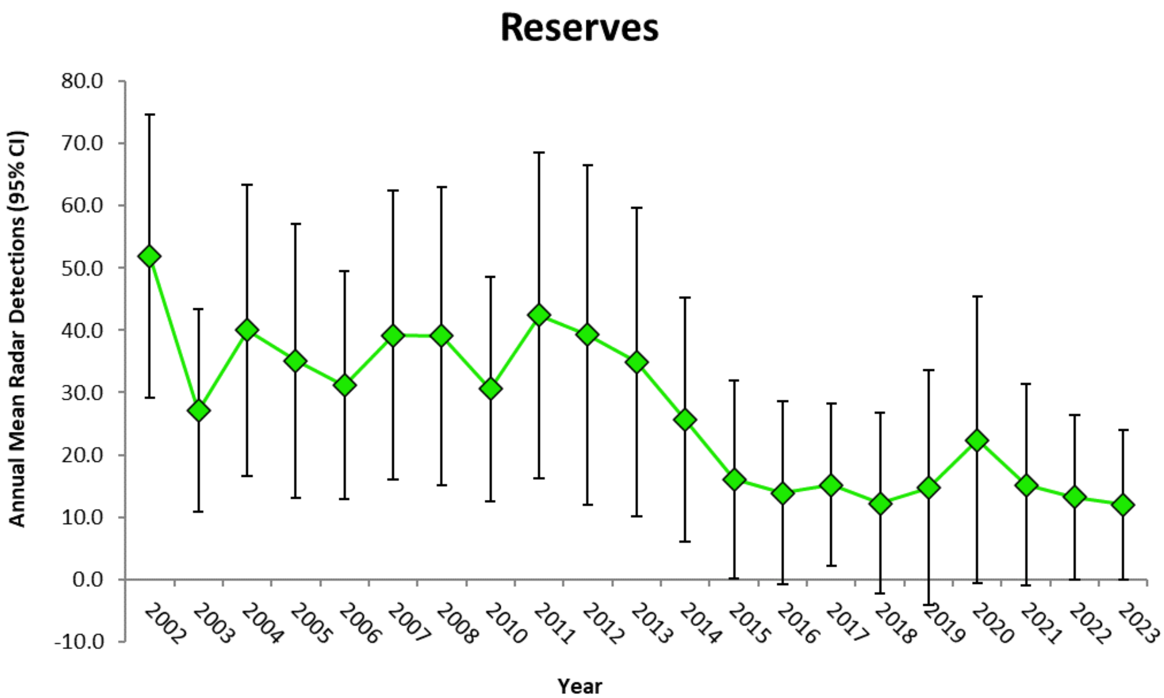


Figure 6. Annual mean radar detections (95% CI) in Reserves 2002-2023 (excluding 2009).

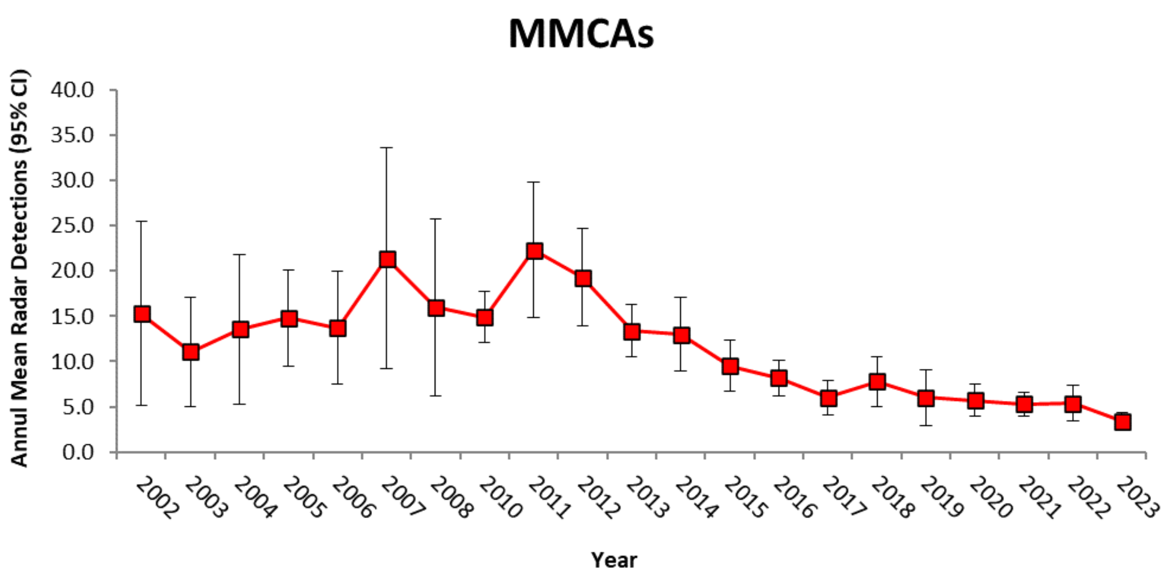


Figure 7. Annual mean radar detections (95% CI) in MMCAs 2002-2023 (excluding 2009).

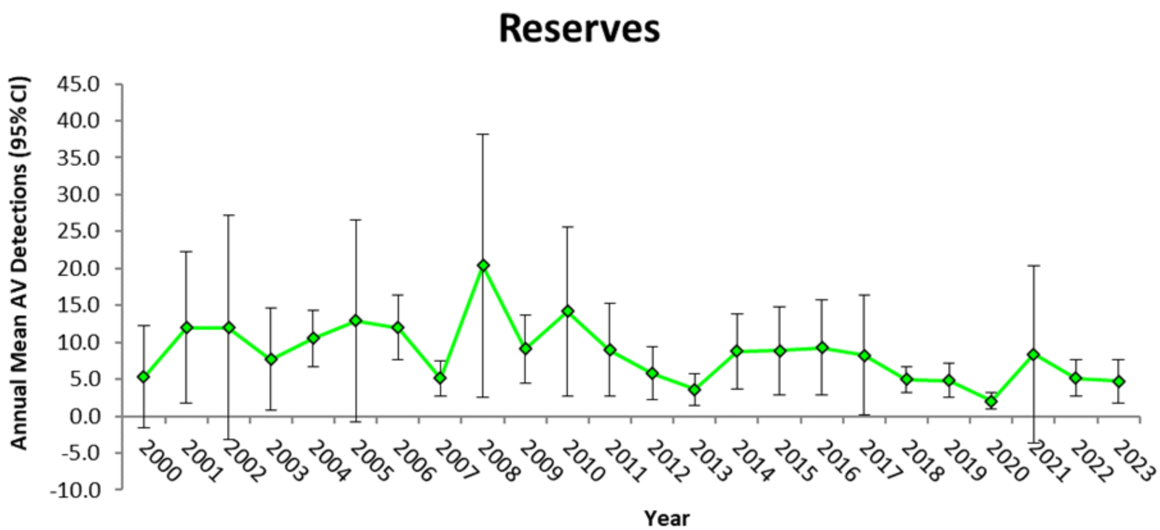


Figure 8. Annual mean audio-visual (AV) detections (95% CI) in Reserves 2000-2023.

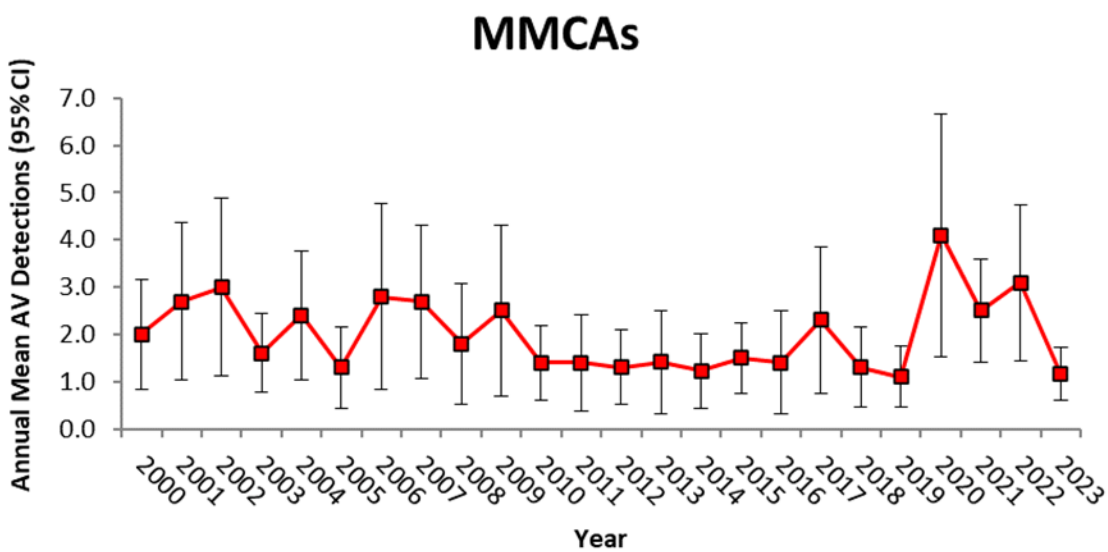


Figure 9. Annual mean audio-visual (AV) detections (95% CI) in MMCAs 2000-2023.

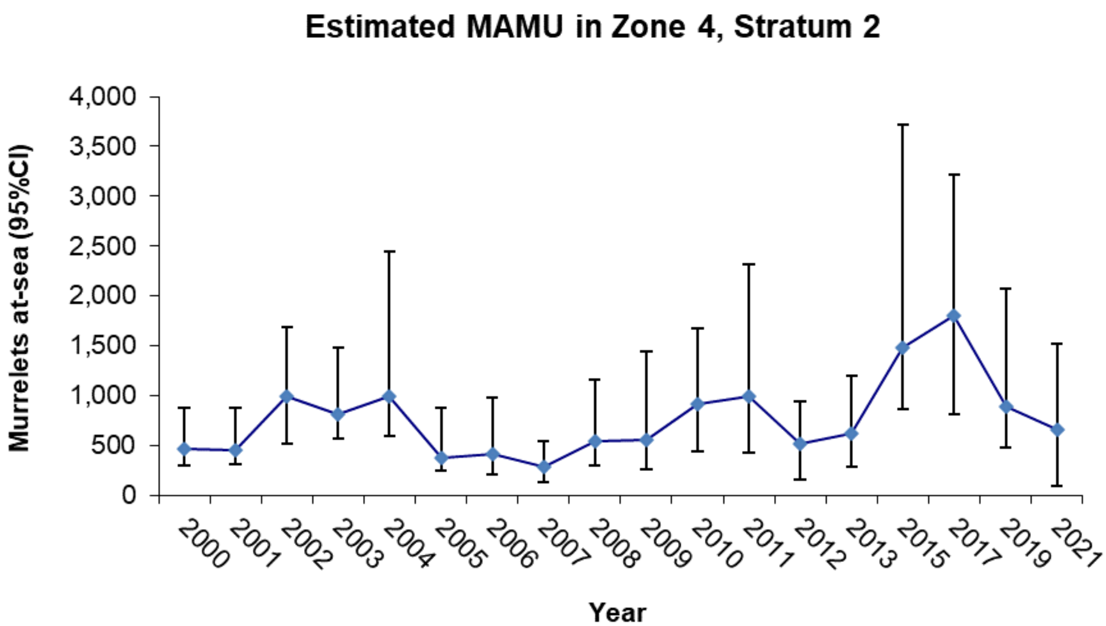


Figure 10. Mean annual number of marbled murrelets at-sea in the HCP region from Trinidad to Shelter Cove (Zone 4, Stratum 2) 2000-2021.

NOTE: In 2014 a reduced-sampling effort design was implemented for the at-sea population surveys. Conservation Zones 1 and 3 are sampled in even years, Conservation Zones 2 and 4 are sampled in odd years, and Conservation Zone 5 is sampled every fourth year in conjunction with Zone 4. Thus, there is no Zone 4 population estimate for 2014, 2016, 2018, or 2022 (Lynch et al., 2016, 2017, McIver et al., 2019). Zone 4 was surveyed in 2019 and in 2021, and was surveyed again in 2023, although results were not available at the time of this report (McIver et al., 2020, McIver et at., 2021, McIver et at., 2023).