Humboldt Redwood™

Marbled Murrelet Inland Monitoring

Annual Report 2015

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PROJECT SUMMARY

Project Title: Marbled Murrelet Inland Monitoring

Subject Area: Habitat Conservation Plan (HCP) monitoring

Date initiated: March 1999

End Date: Ongoing

Project Managers: Sal Chinnici, Manager, Forest Sciences, HRC, Mark Freitas, Wildlife Biologist, HRC. Analyses of radar and audio-visual data were conducted by Gavin Jones, Doctoral Candidate and Graduate Research Assistant, Peery Wildlife Ecology and Conservation Lab, University of Wisconsin-Madison.

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 2015, AV surveyors conducted 143 surveys at 33 stations and observed occupied behaviors (below canopy flight or circling) in all monitored Reserves and all MMCAs.

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 2015, 56 radar surveys were conducted at 14 sites. Preliminary analysis of the data indicates that after 13 years of monitoring, trends in radar counts of murrelets in the MMCAs and Reserves have differed during the study period; there has been a decline in radar counts in the Reserves but not in the MMCAs since the 2002 baseline.

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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.

2015 Objectives

- Complete all audio-visual and radar surveys.

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

Appended to this 2015 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).
- 2015 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.

2015 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 2015. 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, 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 2015 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 2015, each site (n = 14) was surveyed 4 times during the breeding season for a total of 56 radar surveys (See Table 1 in the "Marbled Murrelet Effectiveness Monitoring 2015 Third Quarter Report" and Appendices for dates and outcomes of individual radar surveys).

We used a Furuno® FR-1510 Mark-3 high-performance X-band radar that transmits 9410 $\pm$ 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 continued 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 general linear mixed model was used to model spatio-temporal variation in $ln + 1$ transformed radar counts from 2002 to 2015. 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). Surveys that started >5 minutes late or ended >5 minutes early were not included in these analyses (all surveys met timing requirements in 2015).

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 www.pfeg.noaa.gov.

Finally, categorical Year and Site nested within Land-type were treated as random effects where categorical Year was a categorical factor with 13 levels (2002-2015, 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 were conducted by Gavin M. Jones, Ph.D. candidate and graduate research assistant, using SAS v9.3.

For exploratory purposes, a similar analysis was conducted using the audio-visual survey data collected from 2000 to 2015. 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. Similar to the radar analyses, surveys that started >5 minutes late or ended >5 minutes early were not included in these analyses (all surveys met timing requirements in 2015).

RESULTS

OCCUPANCY

During 2015, surveyors observed occupied behaviors at 14 of the 33 audio-visual survey stations (Table 1). Occupied behaviors were observed at all 6 of the Reserve stations and at 8 of the 27 MMCA stations. Occupied behaviors were observed at all MMCA stands (Table 1).

In 2015, the annual proportion of Reserve stations with occupied behaviors was three times as great (1.00, 1SE = 0.0) as the proportion of MMCA stations with occupied behaviors (0.30 ± 0.09; Figure 3a). Overall, the annual proportion of MMCA stations with occupied behaviors appears to be tracking the proportion of Reserve stations with occupied behaviors, with an increase in both in 2015 (Figure 3a).

Occupied behaviors, as defined by circling murrelet targets, were observed at two of the HRSP Reserve stands, but not at any of the MMCA stands on the radar surveys in 2015 (Table 2, Figure 3b). Radar surveyors observed circling murrelet targets at 2 of the 14 sites (Table 2). Among these sites, occupied behaviors were observed at 2 of the 6 Reserve radar sites and at 0 of the 8

MMCA radar sites. Unlike the AV survey results, the proportion of occupied behaviors observed at the Reserve sites in 2015 declined, while the proportion observed at MMCA sites remained at 0 (Figure 3b). There has been a continued decline in this metric since 2012 (Figure 3b).

INLAND MURRELET COUNTS USING RADAR: 2002-2015

Due to the lower number of surveys conducted in 2009 it has again been excluded from the analysis of radar counts.

Overall, over twice as many targets were detected in Reserves (mean = 34.8) compared to MMCAs (mean = 15.7). From the analysis of the years included, however, there was no significant difference in log-transformed radar counts in Reserves (3.09 $\pm$ 0.24) compared to MMCAs (2.50 $\pm$ 0.21; $t_{12} = -1.86$, $p = 0.087$). The linear Year term was statistically significant ($F_{1,690} = 6.76$, $p = 0.0095$) suggesting a trend in radar counts over the period 2002-2015. The Land-type×Year interaction, which tests whether the slopes of the trend lines in the MMCAs and Reserves are different, was statistically significant ($F_{1,690} = 13.93$, $p = 0.0002$), 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 ($b = -0.042 \pm 0.010$) was statistically less than zero (t_{690} −4.19, $p < 0.0001$). In contrast, the slope for MMCAs alone was not statistically different from zero ($b = 0.00657 \pm 0.00876$; $t_{690} = 0.75$, $p = 0.45$), suggesting that counts may have decreased in the Reserves but remained relatively stable in MMCAs. Julian date and NOI were not statistically significant ($F_{1,690} = 0.04$, $p = 0.85$ for Julian Date; $F_{1,690} = 0.86$, $p = 0.35$ for NOI), indicating that radar counts did not change during survey periods and were not associated with NOI. However, SST was statistically significant ($F_{1,690} = 8.59$, $p = 0.0035$) and the estimated slope for SST was negative ($b = -0.174 \pm 0.059$), indicating that murrelet counts were lower in years with warmer SST (an index of marine productivity).

AUDIO-VISUAL COUNTS: 2000-2015 (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. Several patterns do emerge after rigorous statistical analysis.

Results from the analysis of audio-visual count data revealed some differences from previous analyses. The Land-type by linear Year interaction, which tests whether the slopes of the trend lines in the MMCAs and Reserves are different, was not statistically significant ($F_{1,2190} = 0.29$, $p = 0.59$), suggesting that trends in audio-visual murrelet detections in the Reserves and MMCAs were tracking each other during this period (Figure 5). After removing the non-significant Land-type by linear Year interaction, audio-visual counts were significantly greater in the Reserves (least-squares means = 1.70 ± 0.20) than in the MMCAs (least-squares means = 0.45 ± 0.10; $t_{31} = -5.56$, $p < 0.0001$). Means of raw audio-visual counts supported this result with over five times more detections in Reserves (11.0) than MMCAs (1.9). The linear Year term, which was not significant ($p = 0.14$) in the previous year's analysis, was significant ($F_{1,2191} = 10.64$, $p = 0.0011$) in this year's analysis, indicating that there was evidence for an overall trend in audio-visual detections since 2000. The significantly negative slope associated with audio-visual detections was the same for Reserves and MMCAs ($b = -0.0114 \pm 0.003$).

Audio-visual counts were strongly and positively related to the Julian date of the survey ($b = 0.0053 \pm 0.0005$, $F_{1,2191} = 101.49$, $p < 0.001$), but neither NOI nor SST were significant predictors of AV counts ($F_{1,2191} = 2.65$, $p = 0.10$ and $F_{1,2191} = 2.21$, $p = 0.13$, respectively).

At-sea numbers

At-sea estimates of marbled murrelets for the HCP region for 2014 and 2015 were not available at the time of this report. A reduced at-sea sampling effort was implemented in 2014 and there were no data for 2014 (Falxa, et al. 2014). Zone 4 was surveyed in 2015 and the results should be available in early 2016. Therefore, no analysis comparing trends in radar counts and at-sea population numbers could be conducted.

In 2013, the reported number of murrelets off-shore of the HCP region near southern Humboldt County increased from 2012 (Figure 10). The estimated number of murrelets in the HCP region from Trinidad to Shelter Cove (Zone 4, Stratum 2) was 626 (compared to 521 in 2012), with lower and upper 95% confidence limits of 290 – 1,199 (Falxa, et al. 2014).

DISCUSSION

An objective of the HCP monitoring is to determine the continued occupancy of the MMCAs. In 2015, the AV survey results show continued murrelet occupancy in the surveyed Reserves and MMCAs (Table 1, Figure 3a). This is the first year since 2011 that occupied behaviors have been observed at all MMCAs. Observations of murrelets exhibiting occupied behaviors at some MMCAs, e.g. Shaw Gift and Bell Lawrence, have been difficult to obtain over time, leading to inconsistent results.

There is no current explanation for the inconsistent nature of these occupied observations, or the lack thereof. Reduced visibility at several survey stations due to growth of vegetation is a likely factor. Similar to 2014 results, there were low numbers of AV detections at both Bell Lawrence and Shaw-Gift in 2015. Observation of occupied behavior at these sites appears to be a very opportunistic event. However, there continue to be relatively high radar counts at the sites covering both the Bell Lawrence and Shaw-Gift MMCAs (Table 2). The inconsistent nature of occupancy detections and of AV detections in general points out the limitations of AV surveys in which 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 have tracked each other since 2000. After 15 years of AV monitoring there has been a declining trend in AV detections since the study began.

Differences in radar counts between MMCAs and Reserves was not significant at a threshold of $p \leq 0.05$ but were nearly significant at $p = 0.087$, indicating that the higher counts in Reserves compared to MMCA's may be biologically meaningful. The Land-type × Year interactions for radar surveys were both significant at a threshold of $p \leq 0.05$, in contrast to last year's analysis that reported a non-significant Land-type × Year interaction. However, upon close inspection, last year's analysis inadvertently excluded 24 radar surveys from 2002 and 2003 which, when included, would have resulted in a significant Land-type × Year interaction. However, this error would not have changed the conclusion that there were increased counts in MMCAs but not in

the Reserves, which had relatively stable counts. The most recent analysis supersedes the previous analysis and indicates a significant decline in counts in Reserves and stable counts in the MMCAs (Figures 4, 6, and 7).

The results of the exploratory AV analysis above indicated that AV counts were significantly greater in the Reserves than in the MMCAs, similar to the results from the Radar analysis in which this same difference existed (but was not statistically significant). The AV analysis also indicated that there has been a significant decline in AV counts from 2000-2015 for both Reserves and MMCAs, although AV counts in MMCAs appear to have remained relatively steady for the past six years (Figures 5, 8, and 9).

Interestingly, while radar detections on the MMCAs has remained relatively stable (Figure 4), the trend in audio-visual detections was negative (Figure 5), providing somewhat conflicting results. In contrast, both the radar and audio-visual trends for the Reserves were negative. Overall, radar has shown to be the better tool for tracking numbers of murrelets (e.g. Bigger et al. 2006*a,* 2006*b*).

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.

For radar counts Julian date and NOI were not significant factors, but SST was a significant factor. In contrast, Julian date continues to exhibit a strong, positive relationship with AV counts. NOI and SST have not shown a relationship to AV counts. Given the growing El Niño affect in 2015, the significant relationship with SST is not surprising. SST was significant ($p < 0.05$) for the periods 2002-2006 and 2002-2007 as well, but then was not significant again until this year (2002-2015).

At-sea counts of murrelets in the HCP bioregion (conservation zone 4, stratum 2: Trinidad to Shelter Cove) have not changed significantly during the study period. The 2013 population estimate for conservation zone 4, stratum 2 is 626 murrelets (95 percent confidence interval: 290 to 1,199 birds) (Falxa, et al 2014). For the combined 5-conservation zone area (Canadian border to San Francisco Bay) for the 2001-2013 period, Falxa et al (2014) observed a weak downward population trend of about 1.2% decline per year. At the scale of individual conservation zones, they estimated strong annual declines in Conservation Zones 1 and 2 (Washington State). There was no decline reported for Zone 4 off of the north coast of California, including the HCP bioregion.

The murrelet population estimate for the entire sampling area for 2013 was 19,617 birds (95 percent confidence interval: 15,396 to 23,838 birds. At the conservation zone scale, 2013 population estimates ranged from about 7,900 in Conservation Zone 3 (Oregon north of Coos Bay) to 75 in Zone 5 (from San Francisco Bay north to Shelter Cover, California). The 2013 Zone 4 estimate was 5,993 murrelets. There were no 2014 data, and the completed 2015 analysis was not available at the time of this report.

Improved approaches to power analysis of murrelet inland survey data suggest that it is possible to detect annual declines in the murrelet population using radar or audio-visual approaches (Bigger et al. 2006*a*). Given that statistical power to detect trends and differences in trends was lower for audio-visual than radar surveys and radar counts reflected annual changes in the breeding population, the use of radar has been recommended to monitor inland populations of marbled murrelets and to estimate the effect of land management on local populations (Bigger et al. 2006*a*). As indicated by power analyses using the current radar monitoring design, it will take 10 years to detect a 5% difference in trends between murrelet populations in the Reserves and MMCAs with 87% power (Bigger 2005). 2014 was the twelfth year of surveys. To detect a 2.5% difference between populations with at least 80% power, it will take 15 years of radar surveys at the same 8 MMCA and 6 Reserve sites where each site is visited 4 times per year (Bigger 2005).

RECOMMENDATIONS

- No change in monitoring strategies or intensity is recommended at this time, although HRC would like to discuss with the Wildlife Agencies a hiatus from this monitoring

program, given the current results and that there is currently no plan to change conservation strategies.

- Continue using AV and radar surveys for HCP effectiveness monitoring of the breeding murrelet population in the HCP Bioregion.
- Continue to use any ancillary data (e.g., offshore counts of murrelets, ocean conditions); if possible, to infer whether changes in annual trends in radar counted murrelets are associated with management activity.

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Table 1. Mean annual counts* of total detections at audio-visual survey stations from 2000-2015.

Location	Station	*Habitat* [a]	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Allen Creek MMCA	HM0104	OG	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
	HM0105	OG	**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**
	HM0107	OG	**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
	HM0109	OG	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
	HM0111	OG	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
	HM0124	OG	**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
	HM1013	R	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**
	HM1106	R	**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**
	HM1107	R	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
	HM2501	OG	**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**
	HM2502	R	**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**
Bell-Lawrence MMCA	HM0201	OG	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
	HM1203A	OG	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
	HM1204	OG	**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
	HM1206	OG	**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**
	HM1306	R	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
	HM2301	OG	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
	HM2302	OG	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
Cooper Mill MMCA	HM0804B	R	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
	HM0808	R	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
	HM0813	R	0.4	**0.6**	**0.3**	**3.2**	0.0	0.2	**3.0**[a]	4.0	1.3	1.2	**1.6**	0.8	1.0	1.6	**1.3**	**3.0**
Shaw Gift MMCA	HM0405	OG	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**
	HM0413	OG	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
	HM0503	R	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
	HM0707	OG	**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
	HM0906	R	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
	HM2401	R	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
HFR Reserve	CM0105A	OG	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**
	CM0207	OG	**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**
	DM0103	OG	**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**
HRSP Reserve	ZM0101	OG	**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**
	ZM0108	OG	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**
	ZM0110	OG	**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**

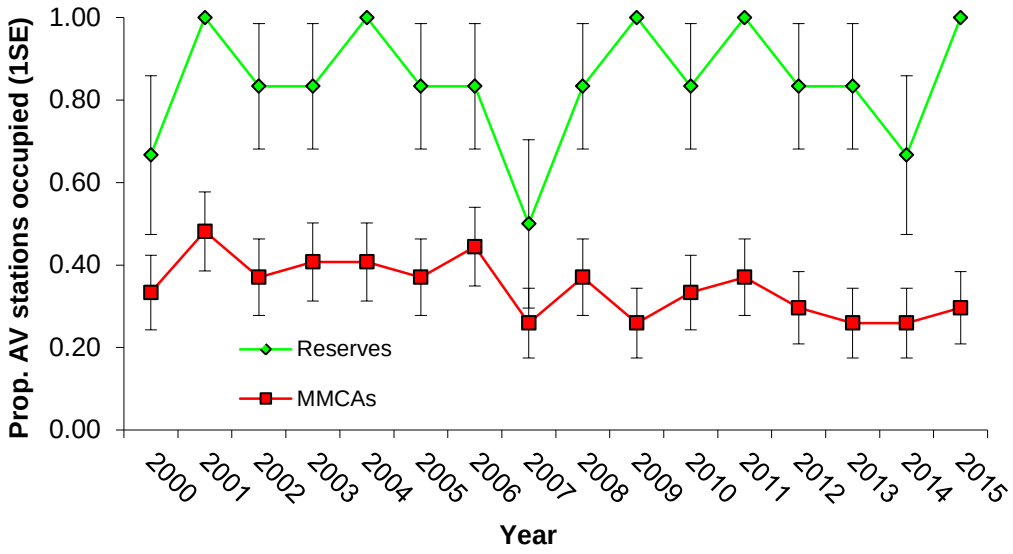
*Counts in bold indicate observation of occupied behaviors.

[a] OG = un-harvested old growth and R = residual old growth (Figure 1).

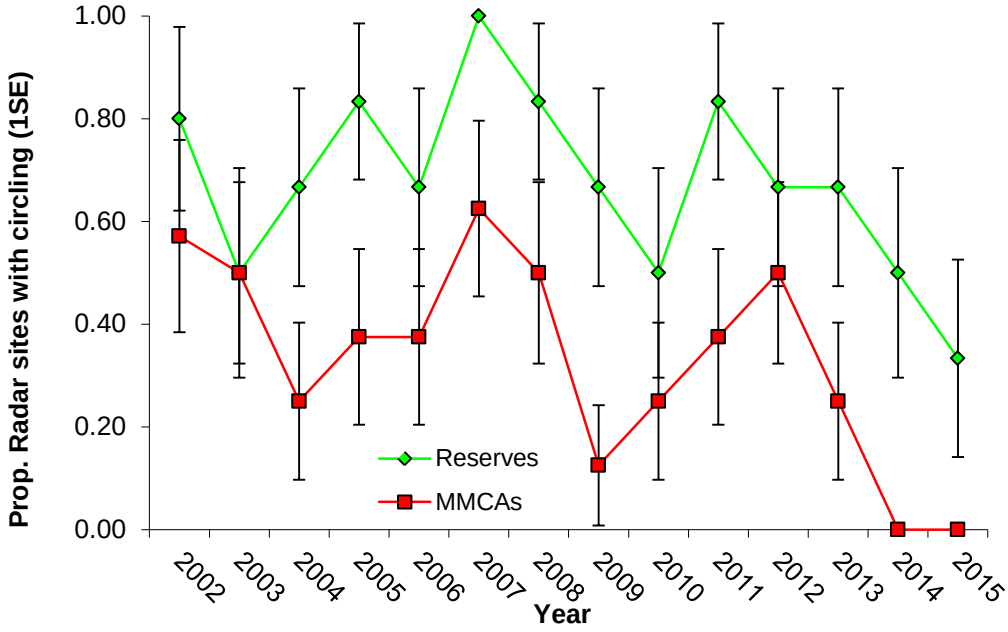
Table 2. Mean annual counts* of marbled murrelets at radar sites in the HCP Bioregion from 2002-2015.

Location	Site	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
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
	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
	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
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
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
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
	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
	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
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
	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
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**
	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
	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**
	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

*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 2015 in Reserves and MMCAs. b) Annual proportion of radar sites with observed circling behaviors from 2002 to 2015 in Reserves and MMCAs.

In 2001, 2004, 2009, 2011 and 2015 occupied behaviors were observed at all Reserve stations so SE was zero. In 2007, circling behaviors were observed at all Reserve stations so SE was zero. In 2014 and 2015 no circling behavior was observed at MMCA stations.

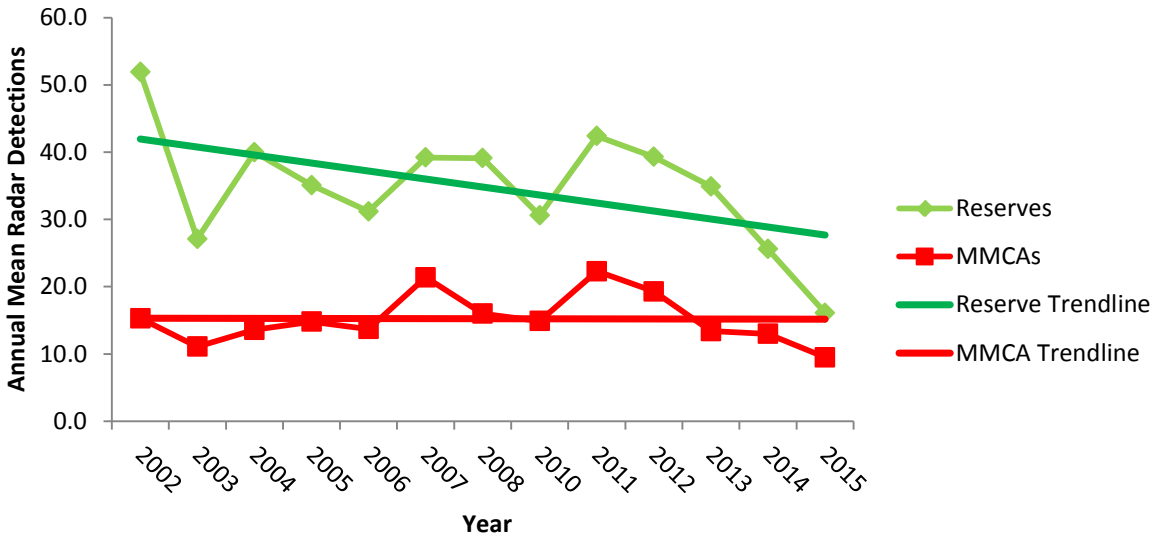


Figure 4. Estimated number of radar detected marbled murrelets per survey (annual means) and trend lines at survey sites in Reserves and MMCAs from 2002 to 2015 (excluding 2009).

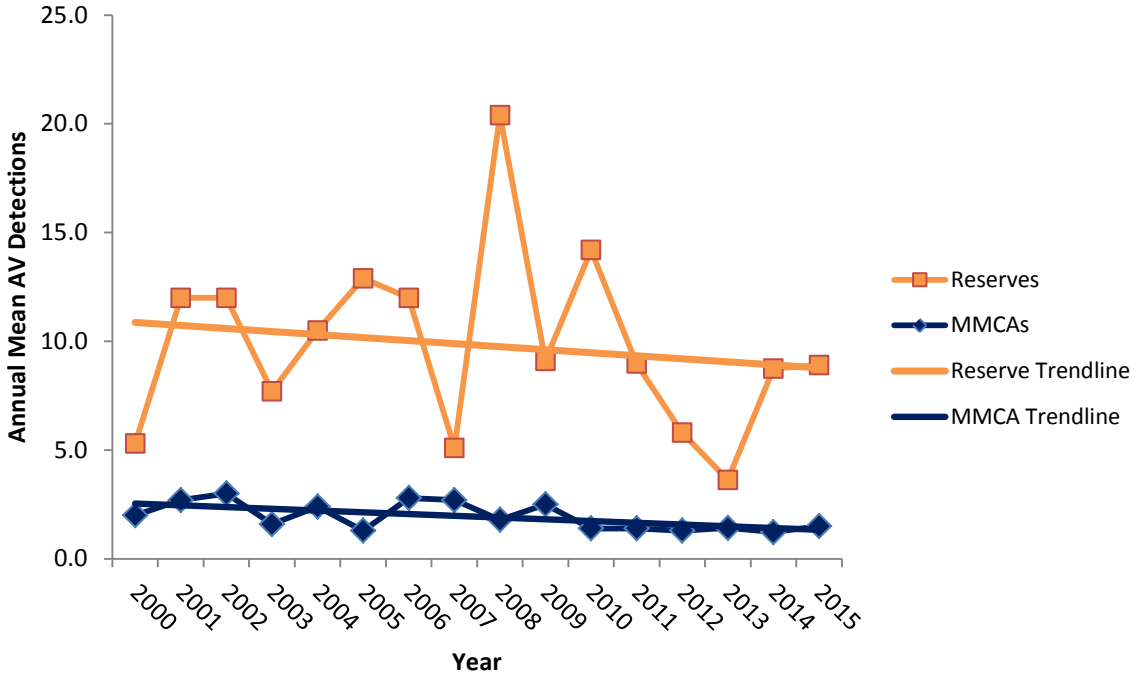


Figure 5. Estimated number of audio-visual detections per survey (annual means) and trend lines for marbled murrelets in Reserves and MMCAs from 2000 to 2015.

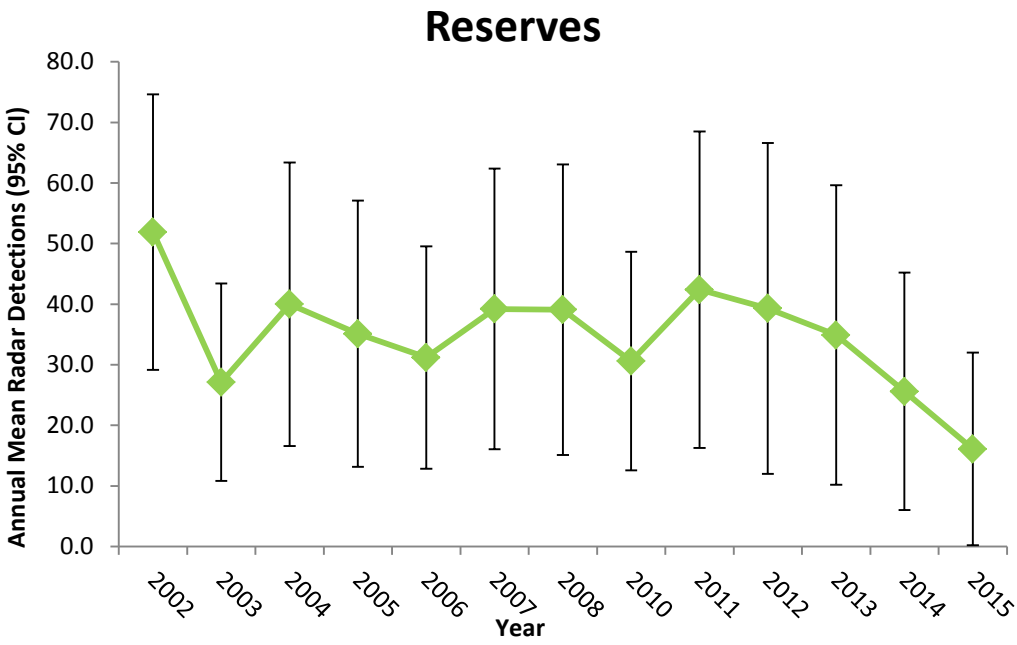


Figure 6. Annual mean radar detections (95% CI) in Reserves 2002-2015 (excluding 2009).

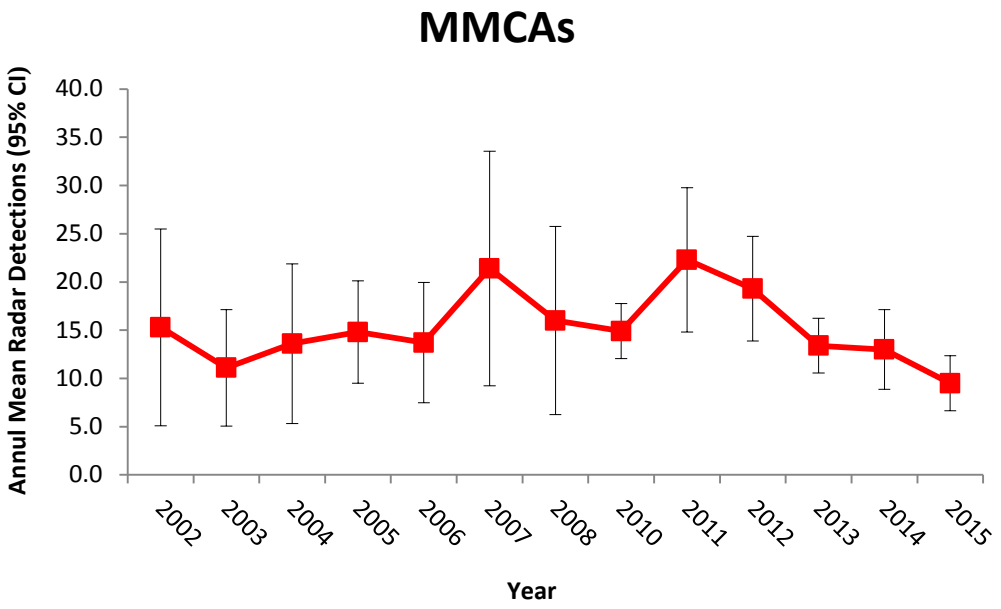


Figure 7. Annual mean radar detections (95% CI) in MMCAs 2002-2015 (excluding 2009).

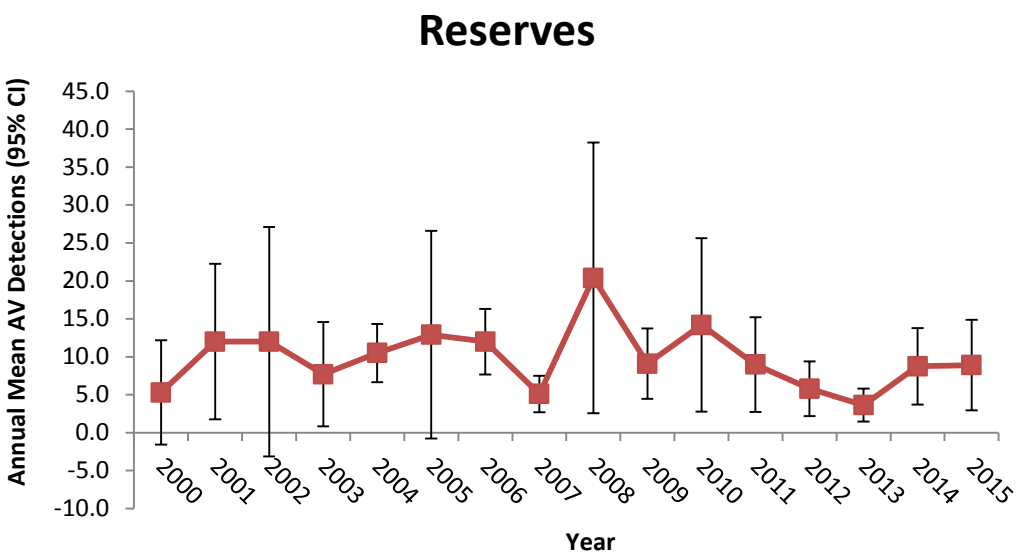


Figure 8. Annual mean audio-visual (AV) detections (95% CI) in Reserves 2000-2015.

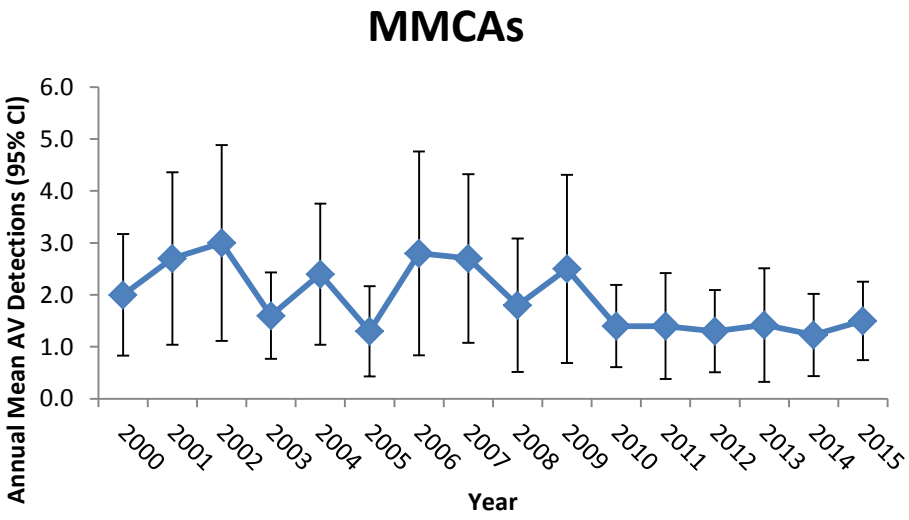


Figure 9. Annual mean audio-visual (AV) detections (95% CI) in MMCAs 2000-2015.

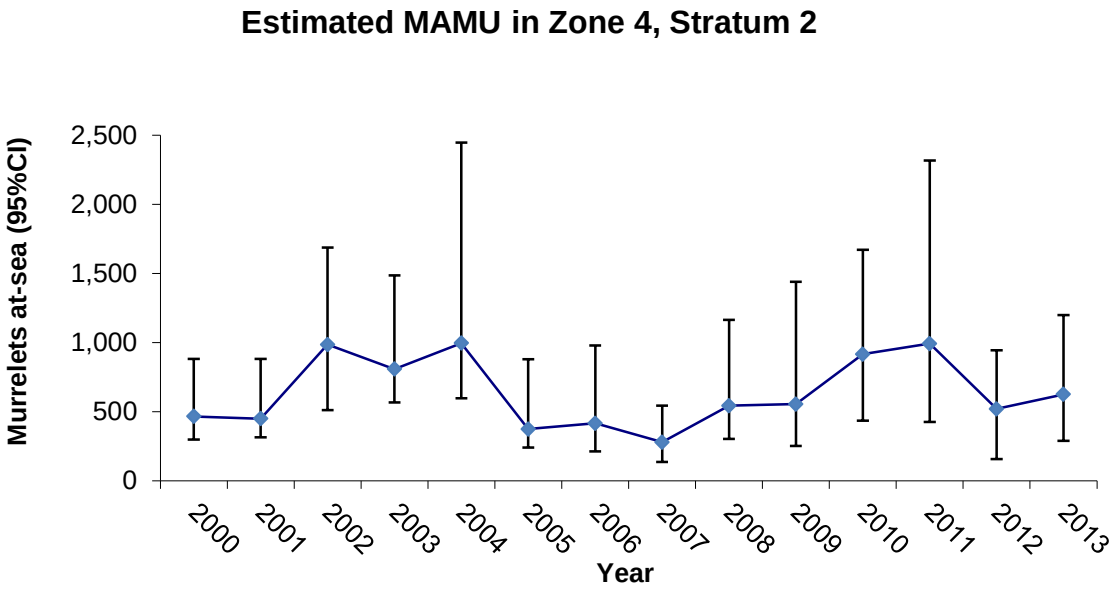


Figure 10. Mean annual number of marbled murrelets at-sea in the HCP region from Trinidad to Shelter Cove (Zone 4, Stratum 2) 2000-2013.

NOTE: There are no population estimates or trend results for Zone 4 in 2014 (Falxa, pers. comm., Falxa, et al. 2014).

Humboldt Redwood Company

Marbeled Murrelet Conservation Areas

Map Legend

- MMCA
- MMCA Boundary

Observed Behavior

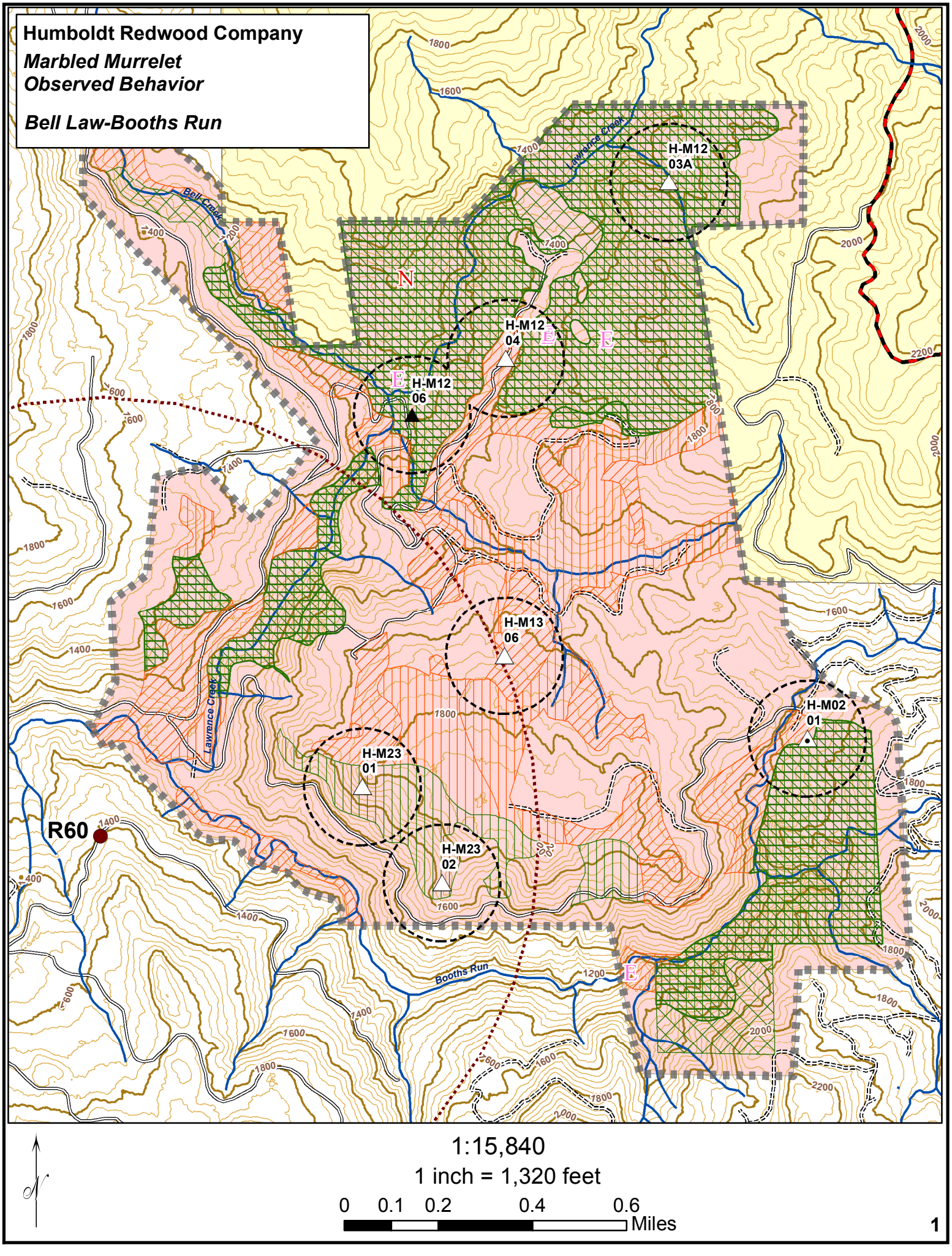
- ▲ Occupied
- ◬ Presence
- △ No Detections
- 200 Meter Coverage Boundary for AV Sites
- ● MAMU Radar Sites
- 1.5 Km Coverage Boundary for Radar Sites
- N Nest Trees
- E Eggshell Fragments

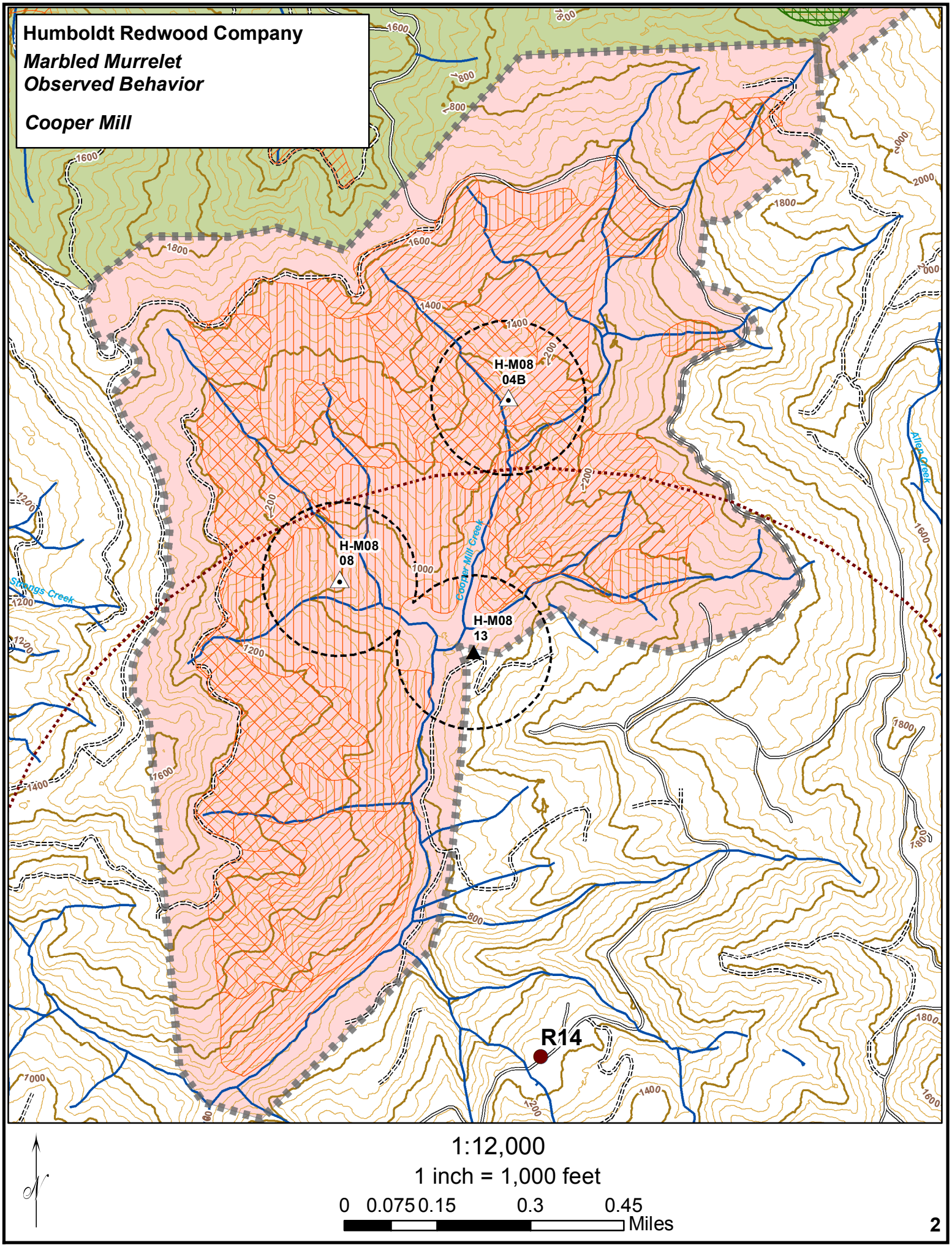
- HRC Ownership
- Other Ownership
- River
- Class I and II Watercourses
- Paved Road or Highway
- Rocked Roads
- Dirt Roads

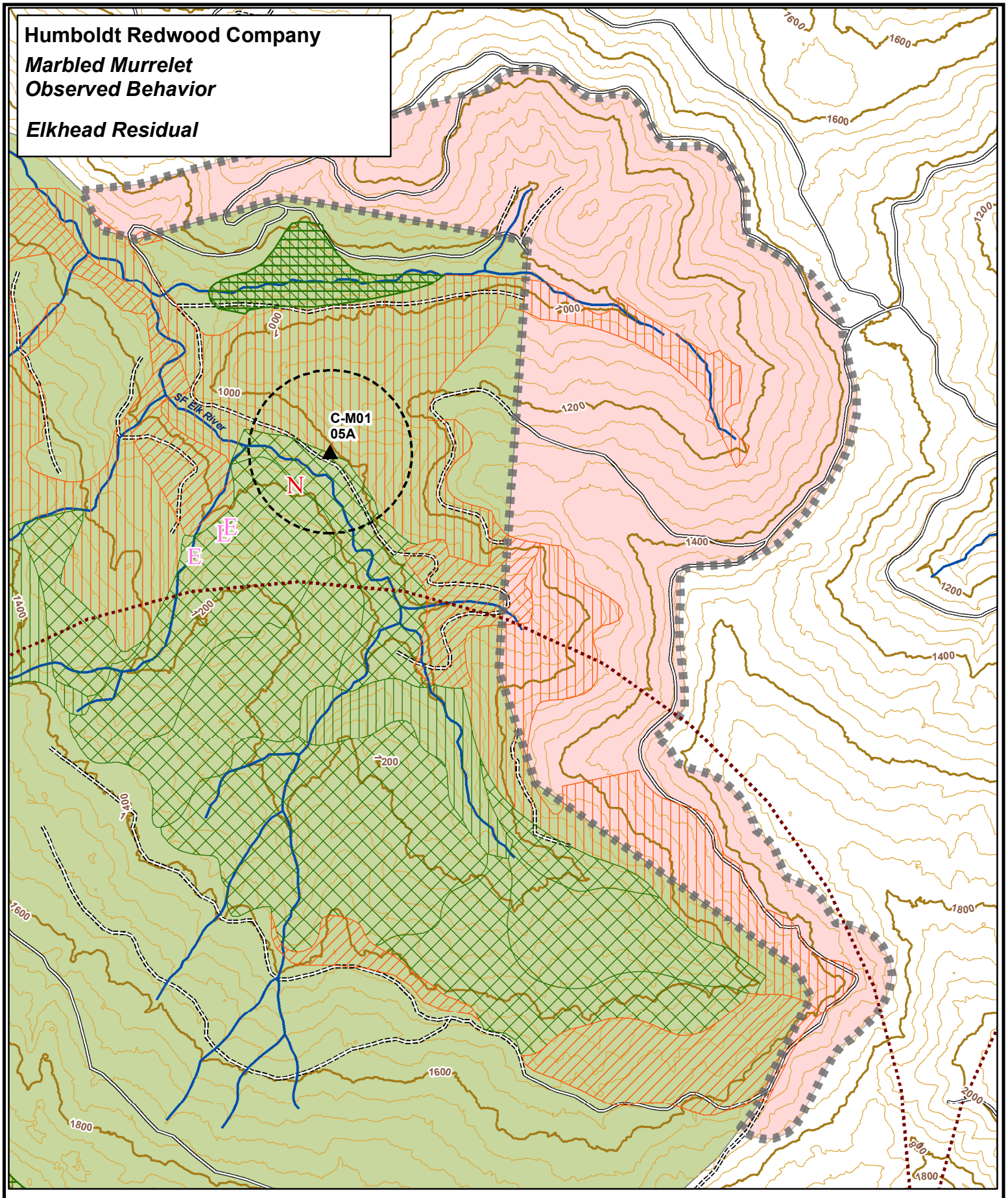
Habitat Types within MMCA, Parks and Reserves

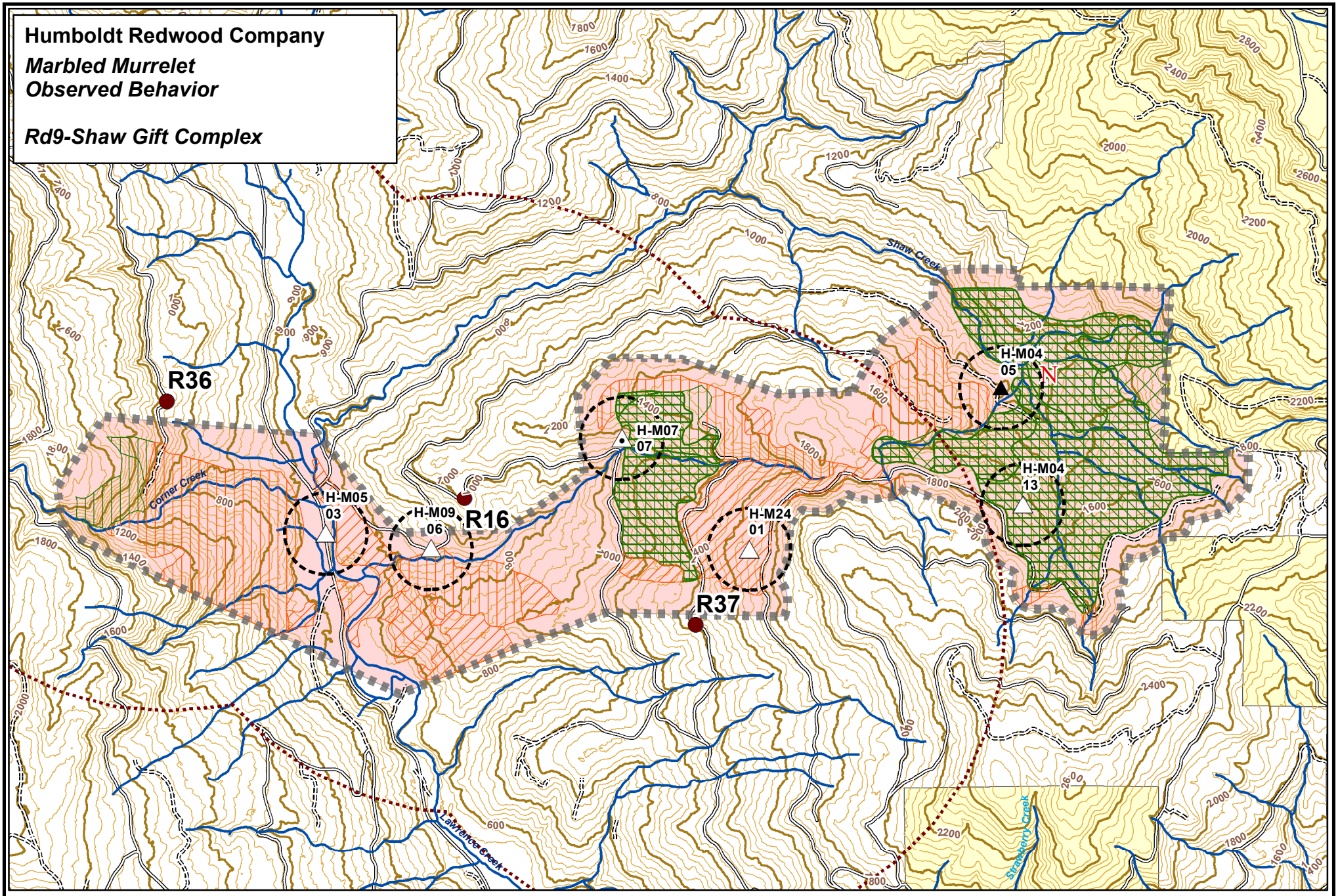
Canopy Closure

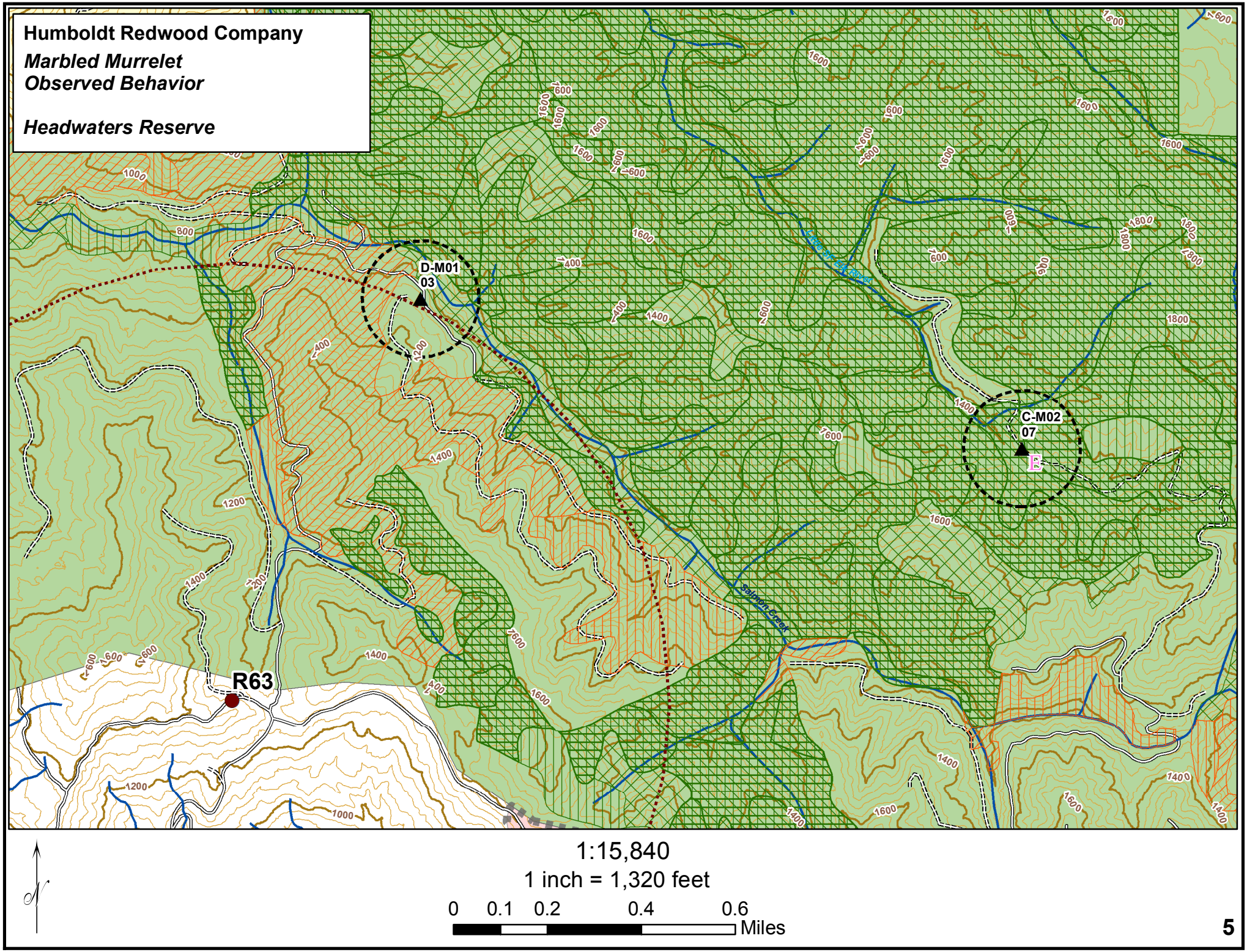
- Old Growth (75-100%)
- Old Growth (50-75%)
- Old Growth (25-50%)
- Residual Old Growth (75-100%)
- Residual Old Growth (50-75%)
- Residual Od Growth (25-50%)
- Residual Old Growth (5-25%)

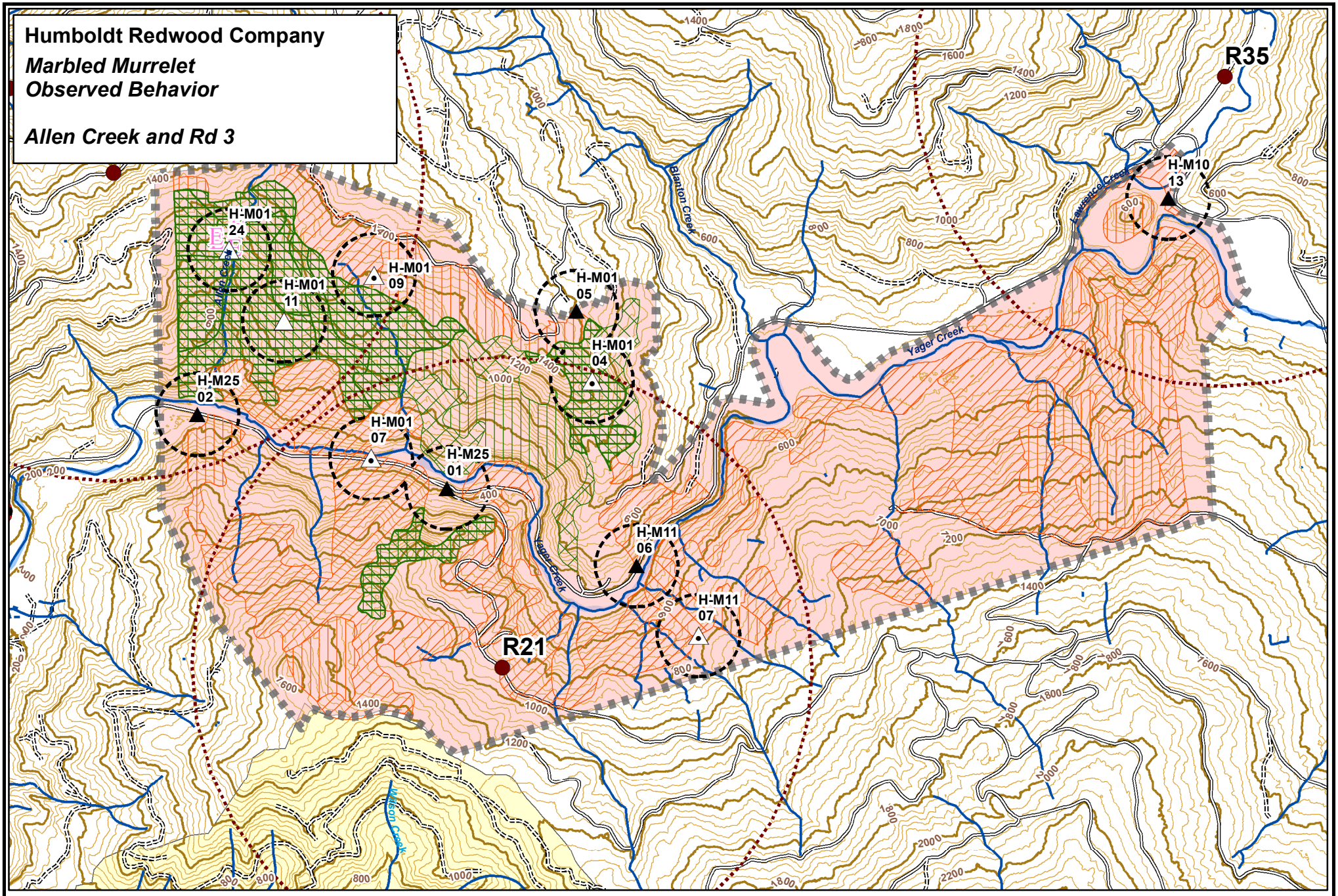

Humboldt Redwood Company
Marbled Murrelet
Observed Behavior
Bell Law-Booths Run
H-M12
03A
H-M12
04
H-M12
06
H-M13
06
H-M02
01
H-M23
01
H-M23
02
N
E
E
E
E
R60
Bell Creek
Lawrence Creek
Lawrence Creek
Booths Run
1800
1600
1400
2000
2200
1200
1:15,840
1 inch = 1,320 feet
0 0.1 0.2 0.4 0.6
Miles


Humboldt Redwood Company
Marbled Murrelet
Observed Behavior
Cooper Mill
H-M08
04B
H-M08
08
H-M08
13
R14
Cooper Mill Creek
Allen Creek
Stanos Creek
1:12,000
1 inch = 1,000 feet
0 0.075 0.15 0.3 0.45
Miles


Humboldt Redwood Company
Marbled Murrelet
Observed Behavior
Elkhead Residual
C-M01
05A
N
E
E
S. Fk. Elk River
1600
1200
1000
1400
1800
2000
1:12,000
1 inch = 1,000 feet
0 0.075 0.15 0.3 0.45
Miles


Humboldt Redwood Company
Marbled Murrelet
Observed Behavior
Rd9-Shaw Gift Complex
R36
R16
R37
H-M05
03
H-M09
06
H-M07
07
H-M04
05
H-M04
13
H-M24
01
Corner Creek
Shaw Creek
Lawrence Creek
Strawberry Creek
N
1:24,000
1 inch = 2,000 feet
0 0.15 0.3 0.6 0.9
Miles


Humboldt Redwood Company
Marbled Murrelet
Observed Behavior
Headwaters Reserve
D-M01
03
C-M02
07
R63
Lawrence Creek
Salmon Creek
1:15,840
1 inch = 1,320 feet
0 0.1 0.2 0.4 0.6
Miles


Humboldt Redwood Company
Marbled Murrelet
Observed Behavior
Allen Creek and Rd 3
R35
R21
H-M10 13
H-M01 24
H-M01 11
H-M01 09
H-M01 05
H-M01 04
H-M25 02
H-M01 07
H-M25 01
H-M11 06
H-M11 07
Blanton Creek
Lawrence Creek
Yager Creek
Allen Creek
1:24,000
1 inch = 2,000 feet
0 0.15 0.3 0.6 0.9
Miles

Humboldt Redwood Company

Marbled Murrelet Observed Behavior

Humboldt Redwoods SP