Scripps's Murrelet Nest Monitoring at Anacapa Island, California in 2014: Continued Recovery 12 Years after Eradication of Black Rats

Darrell L. Whitworth[1], Harry R. Carter[1,3] and David M. Mazurkiewicz[2]

[1]California Institute of Environmental Studies
3408 Whaler Avenue, Davis, California 95616 USA

[2]Channel Islands National Park
1901 Spinnaker Drive, Ventura, California 93001 USA

[3]Contact Address: Carter Biological Consulting
1015 Hampshire Road, Victoria, British Columbia V8S4S8 Canada

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EXECUTIVE SUMMARY

- In 2014, the California Institute of Environmental Studies conducted Scripps's Murrelet (*Synthliboramphus scrippsi*) nest monitoring to measure hatching success and changes in the number of nests in standardized plots 12 years after the eradication of Black Rats (*Rattus rattus*) from Anacapa Island, California in 2001-2002. Nest monitoring in 2014 was funded by the American Trader Trustee Council, and conducted with assistance from Channel Islands National Park and the Montrose Settlements Trustee Council.

- Preliminary nest searches in 10 sea caves on West and Middle Anacapa islets began in 2000. Standardized nest monitoring was conducted in these caves from 2001 to 2010. In 2003 and 2005, we expanded nest monitoring to include 3 plots in accessible cliff, shoreline and offshore rock habitats ("non-cave plots") on all 3 Anacapa islets.

- In 2014, we monitored a total of 86 nest sites, including 56 in sea caves and 30 in the non-cave plots. A total of 25 new nests were discovered and 4 sites were lost since comprehensive monitoring was last conducted in 2010. New nests were found in 8 sea caves (n = 17) and the Rockfall Cove and Landing Cove plots (n = 8).

- Annual hatching success was 75% for all clutches (n = 65), 78% for single/1st clutches (n = 59) and 50% (n = 6) for "2nd clutches". Annual hatching success was 73% in sea caves (n = 45) and 80% in the non-cave plots (n = 20).

- Abandonment accounted for most (56%) clutch failures (n = 16), followed by egg depredation/scavenging (38%) and disturbance by other seabird species (6%).

- Murrelet clutches were initiated over 110 days between 17 February and 5 June, with peak egg-laying from late February to mid-March (mean = 18 March ± 23 d, n = 63). Timing of breeding in 2014 was earlier than in any year since monitoring began in 2000 (range of annual means = 1 April – 20 May).

- Evidence of avian predation on murrelets and other seabirds was found in 9 locations at Anacapa in 2014, including 9 Scripps's Murrelet carcasses at 7 locations, 2 Pigeon Guillemot (*Cepphus columba*) carcasses in 2 sea caves, and 1 Cassin's Auklet (*Ptychoramphus aleuticus*) carcass at Portuguese Cove.

- Overall hatching success post-eradication in 2003-2014 (82%; n = 304 clutches) was nearly 3 times that observed pre-eradication in 2001-2002 (30%; n = 20 clutches).

- The annual number of occupied nests increased nearly 6-fold from 11 in 2001 to 60 in 2014, while the number of clutches increased over 6-fold from 11 in 2001 to 67 in 2014.

- Slopes of the time series regression lines (2003-2014) for the log-transformed number of occupied murrelet nests indicated a per annum growth rate of 11.1% in sea caves and 18.6% in non-cave plots. The rate of increase in the number of occupied nests has remained stable in sea caves since 2010, but appears to have decreased in non-cave plots.

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INTRODUCTION

Scripps's Murrelet (*Synthliboramphus scrippsi*) nest monitoring at Anacapa Island (hereafter "Anacapa"), California before and after the eradication of Black Rats (*Rattus rattus*) has produced one of the most compelling case studies demonstrating the benefits of introduced predator eradication for insular breeding seabirds (Whitworth et al. 2005, 2013). With settlement funds from the 1990 *American Trader* oil spill, the American Trader Trustee Council (ATTC), in collaboration with Channel Islands National Park (CINP), developed a restoration plan (Anacapa Island Restoration Plan; AIRP) to enhance seabird breeding habitat on Anacapa by eradicating non-native Black Rats (ATTC 2001; Howald et al. 2005, 2009). A remnant Scripps's Murrelet population had been discovered at Anacapa in 1994-1997 (McChesney et al. 2000; H. Carter, unpubl. data) and was identified by the ATTC as the seabird species expected to benefit most from rat eradication at Anacapa. From the mid 19th century until 2002, rats apparently restricted nesting murrelets to sea caves and inaccessible coastal cliffs at Anacapa, although breeding was not recorded between 1929 and 1994 (McChesney et al. 2000). Thus, the eradication of rats was expected to prevent possible extirpation of the remnant murrelet colony, and permit population growth and eventual recovery of a much larger colony at Anacapa. While introduced mammals (mainly cats) have been eradicated from several murrelet breeding islands in Baja California and southern California over the past 30 years (Hunt et al. 1979, McChesney and Tershy 1998, Keitt 2005, Aguirre et al. 2008), little effort was made to document the expected benefits for murrelets or other seabirds (Lavers et al. 2010, Buxton et al. 2014). The AIRP provided a valuable opportunity to assess the degree and rate of post-eradication recovery for a seabird species that had been severely impacted by rats.

In 2000, preliminary surveys were conducted at Anacapa to confirm continued breeding by murrelets in sea caves and mark a sample of nests for future monitoring. In 2001-2002, a standardized nest monitoring program was initiated to determine annual hatching success and baseline numbers of murrelet nests in sea caves prior to eradication of rats in the autumn of 2002. From 2003 to 2010, nest monitoring measured increases in the number of murrelet nests and hatching success after eradication in both sea caves and non-cave plots. Highlights of the pre- and post-eradication monitoring included: (1) a nearly a 3-fold increase in murrelet hatching success after eradication; (2) a 14% per annum increase in the number of murrelet nests over all plots; and (3) colony expansion into previously vacant habitats on Anacapa (Whitworth et al. 2005, 2013). In 2011-2012, limited nest monitoring at Anacapa was funded by the Montrose Settlements Trustee Council (MSTC), but not all of the previously monitored habitats were visited each year (Harvey et al. 2013); thus the data was not considered comparable to the more extensive surveys conducted in 2001-2010.

In 2014, ATTC (with support from MSTC) financed a final year of extensive Scripps's Murrelet nest monitoring at Anacapa with the remaining *American Trader* settlement funds. After a 3-year hiatus, we resumed murrelet nest searches and monitoring in all plots monitored at Anacapa in 2001-2010. The primary goal in 2014 was to update the progress of murrelet colony restoration since 2010 by measuring hatching success and numbers of nests in all the previously monitored areas. Nest monitoring in 2014 was conducted in conjunction with nocturnal spotlight surveys (Whitworth and Carter 2014) as part of a complementary effort (funded by the National Fish and Wildlife Foundation; Pacific Seabird Program) to examine trends in colony size based on changes in the numbers of murrelets attending nocturnal at-sea congregations in near shore waters off breeding areas. In this report, we present only the results of 2014 nest monitoring with comparison to previous years. Comparisons of murrelet population trends between nest monitoring and spotlight surveys will be presented in a subsequent report (Whitworth and Carter, in prep.).

METHODS

Study Area

Anacapa Island is the easternmost and smallest of the northern 4 California Channel Islands and is located 15 km southwest of Ventura. It is comprised of 3 small islets (West, Middle, and East; Fig. 1) separated by narrow channels that are sometimes exposed at low tide. The island chain is approximately 8 km long and is surrounded by 17.5 km of rocky cliffs and steep slopes punctuated with over 100 sea caves (Bunnell 1993). West Anacapa is the largest (1.7 km^2) and highest (284 m) of the 3 islets, followed by Middle Anacapa (0.6 km^2, 99 m), and East Anacapa (0.5 km^2, 73 m). Anacapa Island is managed by CINP which maintains quarters for staff and facilities for campers on East Anacapa, but West and Middle Anacapa are uninhabited and access is restricted. Surrounding waters are managed by the Channel Islands National Marine Sanctuary (out to 9.7 km [6 miles] from shore), California Department of Fish and Wildlife (CDFW; out to 4.8 km [3 miles] from shore), and CINP (out to 1.6 km [1 mile] from shore).

Nest Monitoring

In March-July 2014, Scripps's Murrelet nest searches and monitoring were conducted in 10 sea caves monitored in 2000-10, and cliff, shoreline and offshore rock habitats ("non-cave plots") monitored in 2003-2010 (Landing Cove and Cat Rock) or 2005-2010 (Rockfall Cove)(Fig. 1). We also periodically checked 1 murrelet nest found at Portuguese Cove in 2014 (Fig. 1), but clutches in this site were not included in analyses. Due to limited funding in the first year of the study (2000), nest checks were conducted less frequently and not all caves were checked after April; thus, 2000 monitoring data were not directly comparable to 2001-10 and 2014 data.

All accessible potential nesting habitat in sea caves and non-cave plots was searched using hand-held flashlights during each visit. Sea caves and non-cave plots were checked every 10-15 days during the peak of the breeding season from 15 March to 6 June, and again later in the breeding season on 30 June. Monitored nest sites were identified as suitable crevices or sheltered sites, which contained evidence of past or present breeding in at least 1 breeding season during the years 1994-2014. Such evidence included an incubating or brooding adult (Fig. 2), whole unattended eggs (Fig. 3), hatched eggs (Fig. 4) or broken eggs (Fig. 5). During the first visit each year, caves were carefully inspected and any remaining eggshell fragments from the past breeding season were collected to avoid possible confusion with subsequent nesting efforts. We recorded contents for each tagged site (e.g., empty, 1 or 2 unattended eggs, incubating or brooding adult, abandoned eggs, broken or hatched eggshell fragments) and searched for new nests. Incubating adults were observed briefly with a small flashlight but were not handled or prodded to reduce the possibility of clutch abandonment due to researcher disturbance. Clutch size (1-2 eggs; Murray et al. 1983) could not be determined when only 1 egg was observed because murrelets are prone to abandonment when handled or prodded on nests and we did not consider hatched or broken eggshells to be reliable indicators of clutch size.

Hatching Success – As in 2000-2010, hatching success was determined as the percent of all clutches with known fates that successfully hatched at least 1 egg. Successful hatching was usually confirmed by observations of chicks or freshly hatched eggshells (identified by dried or bloody membranes which had separated from eggshells; Fig. 4) in or near the nest.

Failed clutches were classified as depredated, abandoned or disturbed by other seabird species. Depredated clutches were usually identified by the presence of broken eggshells in or near the site prior to potential hatching. Depredated eggshells usually had visible bite marks on the eggshell edges with little or no crushing (Fig. 5). However, it was not clear if depredated eggs were taken from active nests (with an incubating adult or when the egg was temporarily neglected) or scavenged after abandonment. Clutches were considered abandoned when whole unattended eggs were observed on at least 2 consecutive nest checks. Because egg neglect is known for Scripps's Murrelets, unattended eggs were not removed until after 2 or more nest checks to ensure that eggs were definitely abandoned. The few clutches with unknown nest fates were excluded from calculations of hatching success.

Occupancy – Annual site occupancy was calculated as the percentage of all monitored nest sites in which at least 1 clutch was detected in a specific year. Potential nest sites were not tagged until evidence of egg laying was observed, but because all habitats in sea caves and non-cave plots were thoroughly searched each year, untagged sites could reliably be considered unoccupied in the years prior to tagging. Site occupancy was determined for the current year and recalculated for all previous years after newly tagged nests were added to the sample of monitored sites. This technique increased comparability of occupancy rates among years. Using this method, calculated occupancy rates for past years decreased as the murrelet population grew and new monitored sites were added in following years, but occupancy rates for the most recent year most reliably reflected growth of the murrelet population. Occupancy rates treat each nest site independently, but did not account for the possibility of more than 1 clutch being laid in the same nest site by different pairs (*see below*). Estimates of nest occupancy in non-cave plots were calculated as for sea caves. However, systematic nest searches in non-cave plots began in different years (*see above*) and the total number of monitored sites used to calculate occupancy differed among years. Sites destroyed by rockfalls, erosion, or tidal surges were excluded from occupancy analyses in subsequent years (1 site in 2009, 2 sites in 2010 and 4 sites in 2014).

Sequential Clutches – In some years, particularly 2009, 2010, and 2014, a considerable number of nest sites had more than 1 clutch laid within a breeding season. In most cases, the latter clutch was laid after hatching or failure of the 1st clutch in the site ("sequential clutches"), although 1 instance of "simultaneous clutches" was documented in 2009. Without banded adults and with 10-14 day nest checks, we could not determine whether sequential clutches in the same site within a breeding season represented replacement clutches (i.e., a clutch laid by the same pair after failure to hatch eggs or raise chicks to independence), 2nd clutches (i.e., another clutch laid by the same pair after they successfully raised chicks to independence), or clutches laid by different pairs. Throughout the text, the latter of 2 sequential clutches is simply referred to as a 2nd clutch.

Timing of Breeding - A range of possible clutch initiation dates (i.e., laying date of the 1st egg of a clutch) was estimated for each clutch by subtracting an estimated period of time from the date of the most reliable evidence of laying or hatching of the 1st egg of the clutch. The number of days subtracted took into account: a) mean time between the laying of 2 eggs in a clutch is 8 days; b) mean time between clutch completion and start of incubation is 2 days; c) mean incubation period is 34 days; and d) mean time from hatching to nest departure is 2 days (Murray et al. 1983). By placing mean initiation dates in 10-day blocks each year, we partly accounted for error in the estimation of mean initiation date for each clutch. However, with nest checks every 10-15 days in 2005-2010 and 2014, slightly greater error was involved in this process than with weekly nest checks in 2001-2004.

Data Analysis

Annual hatching success was calculated for all clutches, as well as single/1st clutches and 2nd clutches separately. Second clutches were treated as independent (i.e., all clutches were pooled in samples) for most statistical comparisons. We used a Fisher Exact Test (FET) to examine differences in the relative frequencies of hatched and failed fates between: (1) single/1st vs. 2nd clutches in 2014; (2) sea caves vs. non-cave plots in 2014 and post-eradication; and (3) pre-eradication vs. post-eradication periods. We also tested for differences in frequencies of depredated/scavenged clutches and abandoned/disturbed clutches between: (1) sea caves vs. non-cave plots post-eradication; and (2) pre- vs. post-eradication periods.

Linear regression (Pearson r) was used to examine post-eradication trends (2003-2014) in the annual number of occupied nests and clutches (both acting as indexes of breeding population size) in the sea caves and non-cave plots. We also used Pearson r to perform time series regressions using log-transformed counts of the annual number of occupied nests to estimate population growth rates (Nur 1999, Eberhardt and Simmons 1992) in the sea caves and non-cave plots. Population growth rates were estimated based on the antilogs of the slope of the log-transformed times series regression line. We tested for homogeneity of the time series regression slopes between sea caves and non-cave plots using a Student's t-test. Time series regression used 2003, the first year rats were absent from the island, as the baseline year for sea caves, non-cave plots and combined plots. However, regression analysis of non-cave plot and combined plot data was complicated by the fact that monitoring in the non-cave plots did not begin until 2005 in Rockfall Cove. For these analyses, we assumed 2 nests found in Rockfall Cove were occupied in 2003-2004, as suggested by the rapid occupation of nest sites observed in other non-cave plots.

RESULTS

Nest Monitoring in 2014

Nesting Effort and Site Occupancy - In 2014, we monitored a total of 86 sites, including 56 in sea caves and 30 in the non-cave plots (Table 1). A total of 67 clutches (46 in sea caves and 21 in non-cave plots) were recorded in 60 nests (41 in sea caves and 19 in non-cave plots). Clutches were laid in 8 of 10 sea caves (all except Confusion Cave and Keyhole Cave) and in all 3 non-cave plots (Table 1). Occupancy of monitored sites was 70% over the entire island, with 73% in sea caves (Table 2) and 63% in non-cave plots (Table 3). Sequential clutches were recorded in 7 nests (Table 1), with 5 in sea caves and 2 in non-cave plots. We did not find any simultaneous clutches (i.e., 3 or more eggs found at the same time in a nest) in 2014. The above summary does not include sequential clutches laid in 1 nest in Portuguese Cove.

A total of 25 new nests were discovered and 4 sites were lost since 2010 (Appendix 1). Seventeen new nests were discovered in 8 sea caves, including 6 nests in Pinnacle Cave, 3 in Lonely at the Top Cave, 2 each in Lava Bench #1 and Refuge caves, and 1 each in Lava Bench #2, Moss, Aerie, and Respiring Chimney caves. One nest in Aerie Cave was lost under a large rockfall, but a new site was also established in this same rockfall. We discovered 8 new nests and lost 3 sites in non-cave plots; 6 nests were established in Rockfall Cove and 2 in Landing Cove. Two nests in Rockfall Cove and 1 in Landing Cove were lost due to erosion.

Hatching Success - Overall hatching success was 75% (n = 65 clutches with known fates; Table 1), with 73% in sea caves (n = 45 clutches; Table 2) and 80% in non-cave plots (n = 20 clutches; Table 3). Two clutches had unknown fates in 2014. There were no significant differences (FET; $p = 0.76$) in the relative frequencies of hatched and failed fates between sea caves and non-cave plots. Hatched eggshell fragments and/or membranes were found in or near the nest for all hatched clutches in 2014, although 11 clutches hatched only 1 egg of the 2 egg clutch, with single intact eggs remaining in these sites. Adults brooding chicks were observed in 5 nests in 2014. One dead chick and 1 unhatched egg were found near Pinnacle Cave nest #18 on 30 June.

Hatching success was 78% for single/1st clutches (n = 59) and 50% for 2nd clutches (n = 6). There were no differences (FET; $p = 0.15$) in the frequencies of hatched and failed fates between single/1st clutches and 2nd clutches. All 1st clutches hatched in 7 sites with sequential clutches.

Only 16 failed clutches (25%) were recorded at Anacapa in 2014, with 12 in the sea caves and 4 in non-cave plots (Table 1). Six clutches (38% of failed clutches) failed due to possible depredation or scavenging, including 1 nest in which clutch failure was associated with depredation of an incubating adult. Failed clutches with broken eggshells showing small tooth marks were assumed to have been depredated or scavenged by endemic deer mice (*Peromyscus maniculatus anacapae*).

Nine clutches (56%) were abandoned and 1 (6%) clutch was disturbed (probably by Pigeon Guillemots [*Cepphus columba*] which later nested in the site) in 2014.

Timing of Breeding - Murrelet clutches (all clutches combined) were initiated over 110 days between 17 February and 5 June, with an overall mean initiation date of 18 March (± 23 d, n = 63). Peak egg laying occurred from late February to mid-March, although smaller numbers of single/1st clutches and 2nd clutches were initiated through late April (Fig. 6). Over half (n = 33; 55%) of the 60 occupied nests in 2014 were already active (i.e., contained fresh eggs or incubating adults) when the first nest monitoring check was performed on 15-16 March, including 19 nests (32%) with incubating adults. Mean initiation date was 13 March (± 17 d, n = 56) for single/1st clutches and 30 April (± 17 d, n = 7) for 2nd clutches.

Cassin's Auklet – Cassin's Auklet (*Ptychoramphus aleuticus*) nests (Fig. 7) were found in 4 distinct areas (i.e., Rat Rock, Landing Cove, Portuguese Cove and Cat Rock) at Anacapa in 2014. We found a total of 8 "confirmed" nests (i.e., eggs, adults or chicks observed in the site) and 11 "inferred" nests (i.e., sites with fresh digging, guano and strong odor). Auklet nesting was already well progressed by the time of our first visit on 15-16 March when we found auklet chicks in 3 nests.

Most auklet nests were found at Rat Rock, including 6 "confirmed" nests and 3 "inferred" nests. In contrast, only 1 confirmed nest and 3 inferred nests were found at Landing Cove, and only 1 confirmed nest was found on Cat Rock. No confirmed nests were found during infrequent visits to Portuguese Cove, but 5 inferred nests were found on 15 March, and 20+ suitable sites, 1 auklet carcass, and 2 small piles of krill (presumably regurgitated by auklets) were found on 24 May. Despite 7 documented auklet nests at the Anacapa Lighthouse Wall in 2011 (Whitworth et al. 2015), no nests were found during the only visit to this area on 3 April 2014. Garbage Cove, another area where evidence of auklet nesting was found in 2011, was not visited in 2014.

<u>Pigeon Guillemot</u> – Pigeon Guillemot nests were found in 2 sea caves in 2014, including 4 nests in Keyhole Cave and 2 nests in Aerie Cave. Guillemot eggs were not observed until 12 May (although eggs were laid sometime after 24 April), with the first chicks observed on 24 May. Guillemots apparently disturbed 1 active murrelet nest in Aerie Cave (nest #2), where the disappearance of the murrelet eggs coincided with guillemot tracks observed at the crevice entrance on 17 April. Guillemots also appear to have permanently usurped a former murrelet nest in Keyhole Cave (nest #2) where murrelets were last documented in 2008.

<u>Avian Predation</u> – Evidence of avian predation on murrelets and other seabirds was found in 9 locations at Anacapa in 2014. Scripps's Murrelets were the most numerous and widespread victim (Fig. 8), with 9 carcasses in 7 locations including Portuguese and Cathedral coves (2 each), and Rockfall Cove, Lava Bench Cave #2, Moss Cave, Pinnacle Cave, and Lonely at the Top Cave (1 each). Two Pigeon Guillemot carcasses were found in Aerie Cave and 1 in Keyhole Cave, while 2 Western Gull (*Larus occidentalis*) carcasses were found in Rockfall Cove and 1 Cassin's Auklet carcass at Portuguese Cove.

Post-Eradication Hatching Success and Clutch Failure: Sea Caves vs. Non-Cave Plots

We detected no differences in the frequency of hatched vs. failed clutches between sea caves and non-cave plots post-eradication (FET; $p = 0.64$), with 83% hatching success in sea caves (n = 203; Table 2) and 80% in non-cave plots (n = 101; Table 3). Similarly, no differences (FET; $p = 1.00$) in the frequency of depredated/scavenged vs. abandoned/disturbed clutches were detected between sea caves and non-cave plots after eradication (Tables 2-3). Thus, we combined post-eradication samples from sea caves and non-cave plots for comparisons of hatching success and clutch failure between the pre- and post-eradication periods (*see below*).

Hatching Success and Clutch Failure: Pre-Eradication vs. Post Eradication

Excluding unknown clutch fates (*see Methods*), the relative frequency of hatched clutches was significantly higher (FET; $p < 0.0001$) post-eradication. Annual hatching success ranged from 22% to 36% prior to eradication, but increased to 75%-89% since eradication (Fig. 9). Overall, post-eradication hatching success (82%, n = 304 clutches) in sea caves and non-cave plots combined was nearly 3 times that observed pre-eradication in the sea caves (30%; n = 20 clutches) (Fig.10).

The relative frequencies of depredated/scavenged clutches and abandoned/disturbed fates differed significantly between the pre- and post-eradiation periods (FET; $p < 0.001$). Most post-eradication clutch failures (n = 55 clutches) were attributed to abandonment/disturbance (n = 37; 67% of all failed clutches), with smaller numbers of depredated/scavenged clutches (n = 18; 33%). In contrast, most pre-eradication clutch failures (n = 14) were attributed to depredation/scavenging (n = 12; 86%), with few (n = 2; 14%) abandoned/disturbed clutches.

Colony Growth Post-Eradication

The number of monitored sites (excluding 7 sites lost to erosion or other natural processes; Tables 2-3) at Anacapa has increased nearly 6-fold from 15 sites in 2001 to 86 sites in 2014 (Fig. 11). Assuming no nesting in non-cave plots pre-eradication, the annual number of occupied nests also increased nearly 6-fold from 11 nests in 2001 to 60 nests in 2014 (nest occupancy ranged from 11% in 2002 to 70% in 2014), while the total number of clutches increased over 6-fold from 11 clutches in 2001-2002 to 67 clutches in 2014 (Fig. 11). Since eradication, significant increases in the annual number of occupied nests and clutches were noted in sea caves (both $r^2 \geq 0.87$, both $p < 0.0003$) and non cave plots (both $r^2 \geq 0.81$, both $p < 0.001$)(Figs. 12-13).

Time series regression analysis demonstrated significant increases in the log-transformed number of occupied sites in sea caves ($r^2 = 0.87$, $p < 0.001$) and non-cave plots ($r^2 = 0.80$, $p < 0.002$)(Fig. 14). The slope of the regression line for the number of occupied sites was 0.105 (95% CI = 0.069 – 0.141) in sea caves and 0.171 (95% CI = 0.094 – 0.249) in non-cave plots, which indicated per annum growth of 11.1% in sea caves and 18.6% in non-cave plots. However, a test for homogeneity of the regression slopes detected a significant difference ($t_{14} = 2.82$, $p < 0.02$) between sea caves and non-cave plots. Thus, we did not combine samples from sea caves and non-cave plots to estimate overall per annum growth.

Significant increases in the number of clutches also occurred in sea caves ($r^2 = 0.86$, $p < 0.0005$) and non-cave plots ($r^2 = 0.78$, $p < 0.002$)(Fig. 15). The slope of the regression line for number of clutches in sea caves was 0.123 (95% CI = 0.078 – 0.168) and 0.189 (95% CI = 0.098 – 0.280) in non-cave plots, which indicated per annum growth of 13.1% in sea caves and 20.8% in non-cave plots. However, a test for homogeneity of the regression slopes detected a significant difference ($t_{14} = 2.51$, $p < 0.05$) between sea caves and non-cave plots.

Timing of Breeding

Annual mean clutch initiation ranged from 18 March (± 23 d) in 2014 to 20 May (± 29 d) in 2007 (Fig. 16; Table 4). The earliest clutch initiation occurred in 2014 (17 February), while the latest single/1st clutch initiation occurred in 2007 (8 July). The widest range of clutch initiation dates occurred in 2009 (132 days), while the narrowest range occurred in 2001 (36 days). Sequential clutches had little effect on mean clutch initiation except in 2009-2010 and 2014. Excluding 2nd clutches reduced the mean clutch initiation date by 11 days in both 2009 (28

March ± 21 d) and 2010 (21 March ± 22 d), and by 5 days (13 March ± 17 d) in 2014.

DISCUSSION

Scripps's Murrelet Recovery at Anacapa Island

Scripps's Murrelet nest monitoring in 2014 continued to provide solid evidence of improved breeding conditions on Anacapa Island (Whitworth et al. 2005, 2013) following the eradication of Black Rats in 2002 (Howald et al. 2005, 2009). Relatively high hatching success and increasing numbers of occupied nests and clutches in 2014 were generally consistent with the previous post-eradication years (2003-2010), although the mean clutch initiation date was 2 weeks earlier in 2014 than in any other year since 2000. While hatching success in 2014 (75%) was at the low end of the narrow range observed at Anacapa post-eradication (75%-89%; Fig. 9), it was much higher than observed in the 2 years prior to eradication (22%-36%). We also documented continued growth in the number of occupied nests in sea caves and, to a lesser extent, the non-cave plots since 2010 (Tables 2-3; Figs. 12, 14). However, several issues identified in 2014 may affect the rate and extent of colony recovery in the future, including: (1) apparent slowing of growth in the number of nests found in non-cave plots since 2010; (2) increased avian predation on murrelets; and (3) large numbers of 2-egg clutches which hatched only 1 egg.

Increases in the Number of Occupied Nests: Sea Caves and Non-Cave Plots

With 9 years of extensive nest monitoring data since the eradication of rats in fall 2002, we again measured the rate of increase in the annual number of occupied nests and clutches at Anacapa in 2014. Using the antilog of the slope of the regression line generated from the log-transformed data as an estimate of the rate of population change (Eberhardt and Simmons 1992), a significant positive trend was evident. Growth in the number of occupied nests was estimated at 11.1% in sea caves and 18.6% in non-cave plots, and growth in the number of clutches estimated at 13.1% in sea caves and 20.8% in non-cave plots. We currently consider changes in the number of occupied nests to be the most reliable index of murrelet population change from the nest monitoring data. However, estimates of population growth rates based on the number of occupied nests were somewhat conservative if any sequential clutches were laid by different pairs. If future studies verify significant use of the same nest site by different murrelet pairs within a breeding season, growth rates might be better represented by the overall number of clutches.

Significant differences in the slopes of the time series regression lines for annual number of occupied nests between sea caves and non-cave plots indicated per annum growth rates over the entire post-eradication period (2003 to 2014) were higher in non-cave plots. Higher initial growth in the non-cave plots was probably due to the lower baseline level of nesting (practically zero) and the large number of suitable but vacant crevice sites available in the non-cave plots in the early post-eradication period. However, by 2014 some slowing of growth in the non-cave plots had occurred that was not evident in the sea caves (Figs. 12-13). The slope of the times series regression had decreased markedly for non-cave plots in 2014 compared to 2010 (0.171 in

2014 vs. 0.243 in 2010), but changed little in sea caves compared to the 2010 estimate (0.105 in 2014 vs. 0.103 in 2010). Data from non-cave plots in 2011-2013 were lacking to assess whether the decreased rate of growth indicated a consistent trend since 2010 and, if so, which year the inflection point in the data may have occurred. As discussed in previous reports and publications (Whitworth et al. 2012, 2013), it was difficult to assess whether growth rates in the sea caves or non-cave plots were more representative of the entire island. Spotlight survey data quantifying the number of murrelets attending at-sea congregations in 2 standard transects off East Anacapa islet and a round-island transect circumnavigating all 3 islets (Whitworth and Carter 2014) should serve as an independent index of population size that will facilitate interpretation of the nest monitoring data (Whitworth and Carter, in prep.).

Sea Caves - Growth in the number of occupied nests in the sea caves could be expected to decrease over time because the number of suitable breeding crevices is more limited in these habitats (Whitworth et al. 2012). In fact, the overall growth rate in sea caves has remained relatively steady, although changes in the number of occupied nests have varied considerably among the individual caves, some of which may already be saturated. The observed increases in the number of occupied nests in sea caves have roughly corresponded with the apparent number of suitable but vacant nesting crevices that were available in each cave in 2003. Pinnacle Cave (the largest monitored sea cave) alone has accounted for 42% of the increase in the number of nests in sea caves since eradication, while 2 other large caves (Refuge and Lava Bench #1) have accounted for an additional 35% of the increase (Table 5). Sea caves with few vacant crevices in 2003 (Lava Bench #2, Moss and Confusion caves) have seen little or no growth in the number of occupied nests since eradication, and in one case (Keyhole Cave) the number of nests has actually decreased. Loss of Keyhole Cave as a murrelet breeding area (2 former murrelet nests have been disturbed or usurped since 2003) is likely permanent as long as Pigeon Guillemots continue to inhabit this cave (Appendix 1).

Post-eradication hatching success has been extremely high (90%; 64 hatched of 71 clutches) in 3 sea caves (i.e., Lava Bench #2, Respiring Chimney and Moss caves) where few suitable crevice sites were available for the philopatric offspring to establish new nests. Deployment of artificial nest sites to augment the sparse natural crevices in these caves would: (1) greatly enhance these apparently “high-quality” breeding habitats; (2) provide an opportunity to assess different nest box designs; and (3) perhaps permit studies of murrelet demographic parameters that are difficult to study in natural nest crevices.

Non-Cave Plots - Long-term changes in the number of occupied nests in non-cave plots from 2003 to 2014 also corresponded with the apparent number of suitable but vacant nesting crevices when monitoring began. Minimal growth (+1 nest) was observed on Cat Rock, where only a few suitable crevice sites had been identified in 2003, but larger increases were documented at Landing Cove (8 nests) and Rockfall Cove (6 nests) where many suitable crevice sites were available (Table 5). Despite the strong overall increase in the number of occupied nests in non-cave plots from 2003 to 2014, only a small proportion of the overall increase (1 nest) has occurred since 2010. In fact, a net increase of 3 occupied nests occurred in Rockfall Cove since 2010 (5 new nests established and 2 vacated), but a net decrease of 2 nests occurred in Landing Cove (2 new nests established and 4 vacated)(Appendix 1). Differences in the number of new nests found in each plot since 2010 may reflect the differing breeding habitats in Landing Cove and Rockfall Cove that likely affected our ability to locate nests. Most potential breeding crevices in Rockfall Cove are in shoreline rockfalls and scree that are easily accessible to researchers on foot. In contrast, Landing Cove has large patches of inaccessible sheer cliffs (where murrelets can nest undetected) interspersed with accessible slopes on which all the monitored nests are located.

Unfortunately, nest monitoring usually could not determine the cause(s) of nest site vacancy. A variety of factors that can cause murrelets to vacate a site for 1 or more years, include: (1) predation of 1 member of a breeding pair; (2) natural or anthropogenic disturbance at or near a nest resulting in movement to a new site; or (3) poor adult condition in a particular breeding season that results in a failure to lay eggs. Differences between plots in the breeding condition of adults is unlikely, but higher levels of disturbance or adult predation in Landing Cove are possible and may account for the higher overall proportion of vacant sites in this plot (44%) compared to Rockfall Cove (27%) and the rest of the island (27%). A more detailed analysis of patterns in the use of individual nest sites (in non-cave plots and sea caves) might be useful to detect correlations between failed clutches (indicating possible adult depredation or mortality during the breeding season) and nest site vacancies in subsequent years.

Avian Predation

Much more evidence of avian predation on murrelets and other seabirds was found at Anacapa in 2014 than in previous years. In most cases, we could not attribute predation to a particular avian predator. A variety of species are known or suspected predators of Scripps's Murrelet (Howell 1910, Dawson 1923, Oades 1974, Nelson and Hamer 1995). At Anacapa in recent years, we have observed Peregrine Falcons (*Falco peregrinus*; Sharpe 2015a), Bald Eagles (*Haliaeetus leucocephalus*; Sharpe 2015b), Western Gulls (Hunt et al. 1979, Carter et al. 1992), and Common Ravens (*Corus corax*; Collins and Jones 2015). Furthermore, Barn Owls (*Tyto alba*), perhaps the most serious predator of murrelets at nearby Santa Barbara Island (Murray et al. 1983, Drost and Lewis 1995), are classified as an uncommon regular breeder at Anacapa (Collins and Jones 2015). However, we have not observed Barn Owls at Anacapa and their recent abundance and distribution there is not well known.

Peregrine Falcons historically bred on all 8 Channel Islands (Willett 1912, Howell 1917), but populations had been extirpated by the mid-1950s due to organochlorine pollution (Kiff 1980, 2000). Following restrictions on the use of organochlorines in the U.S. in 1970, a series of successful re-introduction and relocation programs resulted in strong recovery of falcon populations in the 1980s and 1990s (Mesta 1999). Falcons now breed again on all 8 Channel Islands (Sharpe 2015a). Falcons were first observed breeding again at Anacapa in 1989 (Sharpe 2015a). By 2014, 3 pairs of falcons were confirmed breeding at Anacapa (1 on each islet), and 1 other breeding pair was suspected on West Anacapa (Sharpe 2015a). Falcons are voracious diurnal and crepuscular predators of seabirds (Howell 1910, Sharpe 2015a) and recovery of this species may have increased predation pressure on murrelets. Murrelet carcasses found in Rockfall Cove and at the mouth of Lava Bench Cave #2 likely were victims of the falcon pair which breeds on the cliffs between these areas (Sharpe 2015a) and were regularly observed during our monitoring visits.

It is not possible to quantify falcon predation of murrelets with nest monitoring data, but falcon predation may have accounted for a considerable proportion of the murrelet nests classified as abandoned or depredated/scavenged in 2000-2014. The increase in the number of falcon eyries at Anacapa since 1989 (1 new eyrie was added each year in 2003, 2007 and possibly 2014) was coincident with the murrelet population increase post-eradication, although the proportion of abandoned murrelet nests (a possible indicator of falcon predation on breeding murrelets) has remained relatively stable (6-18%) since 2001 (Tables 2-3).

Recent observations from the "Grace" oil drilling platform (1 of 4 platforms located within 20 km north of Anacapa) have indicated considerable falcon predation on murrelets away from colonies in the northern Channel Islands (Hamer et al. 2014). During the March and April 2013 survey periods, observers on Platform Grace documented frequent roosting by falcons (including individuals consuming murrelets), and found 17 murrelet carcasses deposited on the platform. Data from other nearby platforms is lacking, but the level of falcon predation observed on Platform Grace alone indicates a substantial threat. These oil platforms may increase the hunting efficiency of falcons by providing roosts close to the diurnal feeding areas used by murrelets, auklets and other seabird prey (Hamer et al. 2014).

Bald Eagles in the California Channel Islands suffered similar impacts from oraganochlorine pollution as Peregrine Falcons, but eagle populations are recovering more slowly; eagles were documented nesting on just 4 islands by 2013 (Sharpe 2015b). Shortly after eagles first resumed breeding in the California Channel Islands (Santa Cruz Island) in 2006 (Sharpe 2015b), 2 adult eagles were observed attempting to prey upon Western Gulls at Anacapa in 2008 (D. Whitworth and H. Carter, pers. obs.). However, the first eagle nest at Anacapa was not documented until 2011 at West Anacapa (Sharpe 2015b). Given the proximity of this eagle nest to Pigeon Guillemot breeding caves on the north side of Middle Anacapa, this pair may be responsible for the guillemot carcasses found at the entrance to Aerie and Keyhole caves in April and May 2014.

Direct evidence of recent Bald Eagle predation on murrelets is limited to a video observation of an adult eagle bringing a murrelet to a nest at Santa Catalina Island (Valoppi et al. 2000). However, much indirect evidence indicates that eagles preyed on murrelets in the past and likely do so presently: (1) murrelets were identified in the prey remains excavated from a historic eagle nest on San Miguel Island (Collins et al. 2005); (2) several alcids (including the similarly sized Cassin's Auklet) were detected as prey in stable isotope analysis of adult eagle and chick feathers collected in the northern Channel Islands (Newsome et al. 2013); and (3) a wide variety of seabirds, most notably Alcidae, Laridae, Phalacrocoracidae and Procellariidae, were detected in prey remains at modern Bald Eagle nests in the California Channel Islands (Newsome et al. 2013). In fact, alcids comprised about 20% of the individual prey remains identified in historic Bald Eagle nests on San Miguel and Santa Rosa islands, as well as 20% of the remains in modern eagle nests sampled on Santa Rosa, Santa Cruz and West Anacapa islands in 2010-2011, although murrelets were not specifically identified as prey species (Newsome et al. 2013). As Peregrine Falcon and Bald Eagle populations continue to recover in the California Channel Islands, more effort is needed to determine the likely increasing impacts of these and other avian predators on murrelets.

Since rat eradication, 5 depredated or scavenged murrelet clutches in sea caves were associated with depredated adults, presumably victims of Common Ravens, Western Gulls or Barn Owls, as evidenced by feather piles found near the depredated nest. It is extremely unlikely falcons or eagles would enter a cave while hunting. We suspect the murrelet carcass found in Lonely at the Top Cave in April 2014 was taken from a very shallow crevice nest (#8; Fig. 17) by either a gull or raven. This carcass did not display the typical pattern of falcon or owl depredation in which the sternum is picked clean; rather, the breast tissue appeared to have been irregularly torn from the sternum (Fig. 8) after the carcass had been battered against rocks. Western Gulls have been observed using this process to prey upon debilitated Cassin's Auklets at Santa Barbara Island in 1995 (D. Whitworth and H. Carter, pers. obs.). Furthermore, no eggshell fragments were found in or near the nest, suggesting removal and consumption of the eggs by a gull or raven.

We were not able to determine if raven, gull, and owl predation had increased to any great extent since 2000. The Western Gull population at Anacapa increased greatly between 1991 and 2007 (Capitolo et al. 2008) but gull nesting areas are disjunct from murrelet monitoring plots and increased predation may not have resulted. Common Ravens have increased at nearby Santa Cruz Island and increased raven predation has been noted at Ashy Storm-Petrel (*Oceanodroma homochroa*) restoration and monitoring locations (McIver et al. 2014; D. Mazurkiewicz, unpubl. data). However, Anacapa does not seem to have experienced a great increase in raven numbers since 2000 (D. Whitworth and H. Carter, pers. obs.). The current status of Barn Owls at Anacapa is not well known, but considering the heavy impact owls have on murrelets at Santa Barbara Island, periodic surveys are needed to determine their abundance and distribution.

Partial Clutch Hatch

In 2014, we documented 11 hatched clutches (22%; n = 49) in which only 1 of the 2 eggs hatched. We could not reliably determine clutch size in every nest to measure hatching success as the number of eggs hatched per egg laid (as measured at Santa Barbara Island; Murray et al. 1983, Schwemm and Martin 2005), but we did calculate a rough estimate of this alternate measure of hatching success for Anacapa in 2014 by assuming 2 eggs were laid in all nests with known clutch fates. Substantially lower hatching success (67%) was found compared to the standard measure (75% in 2014) used at Anacapa since 2000 (Whitworth et al. 2013), but it was still much higher than comparable measures reported for Santa Barbara Island from 1993 to 2002 (mean = 48%; Schwemm and Martin 2005). Given the very low number of "hatched" clutches with 1 unhatched egg at Anacapa from 2000 to 2010, the alternate estimate of hatching success did not differ greatly (or at all) from the standard measure during this period. We could not determine the cause(s) for the relatively high number of unhatched eggs in monitored nests in 2014. However, should large numbers of intact unhatched eggs be detected at Anacapa or Santa Barbara Island in the future, we would encourage collections to determine if failure to hatch was the result of continuing impacts from organochlorine pollution, egg infertility, or problems related to embryo development that warrant further study.

Cassin's Auklet Breeding at Anacapa

Cassin's Auklet nests found at Anacapa in 2014 provided additional evidence of recovery after rat eradication, beyond that documented from 2003 to 2012 (Whitworth et al. 2015). In previous years 42 nests (i.e., sites occupied in at least 1 breeding season) were documented in 6 different shoreline areas at Anacapa (Whitworth et al. 2015). However, auklet nest searches and monitoring were not a priority in 2014, and visits to previously documented nesting areas were infrequent, with the exception of Landing Cove and Cat Rock where small numbers of auklets nest in the murrelet plots. The shoreline at Portuguese Cove was visited several times through the breeding season to check 1 murrelet nest and an automated recording unit (ARU) that had been deployed to record Ashy Storm-Petrel vocalizations, but extensive searches of the main auklet nesting area on the fragile scree slopes at Portuguese Cove were conducted only in mid-March and late May. Extensive searches at Rat Rock occurred only in mid-March, early April and late April, while the Lighthouse Wall was checked in late March and early April. The Garbage Cove auklet nesting area was not checked in 2014.

Future Murrelet Monitoring at Anacapa

ATTC funds for Scripps's Murrelet nest monitoring at Anacapa were exhausted in 2014 and alternate funds to continue the monitoring program have not yet been identified. Continuation of Anacapa nest monitoring using a method comparable to 2001-2010 and 2014 efforts is critical for best documentation of the rate and pattern of recovery of this colony until it reaches a "recovered" condition. While this program has gathered 2 years of pre-eradication data (2001-2002) and 9 years of post-eradication data over 12 years (2003-2010 and 2014), the long-term value of rat eradication will not be determined without at least periodic monitoring for at least the next 2 decades. From scientific and management perspectives, high-quality annual data are needed to reliably measure the nature and rate of recovery of this colony after rat eradication, but periodic monitoring certainly would be better than a lack of monitoring for a general assessment of restoration progress in the future. Given the large financial investment in 2000-2014 to start this long-term monitoring program, if low-quality data or no data are gathered annually, a great opportunity to measure the detailed response of this state-threatened and federal candidate species to rat eradication will have been lost forever.

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Table 1. Number of monitored sites, clutches and clutch fates for Scripps's Murrelets at Anacapa Island in 2014.

Sea Cave/Plot	Monitored Sites	Occupied Sites	Clutches[a]	Clutch Fates			
				Hatched	Depredated	Abandoned/Disturbed	Unknown
Refuge	7	4	4	4	-	-	-
Lava Bench #1	6	6	7	6	-	1	-
Lava Bench #2	3	2	3	3	-	-	-
Respiring Chimney	4	4	5	4	-	-	1
Lonely at the Top	8	4	4	3	1	-	-
Confusion	-	-	-	-	-	-	-
Pinnacle	16	13	13	7	3	3	-
Moss	5	3	4	2	1	1	-
Aerie	5	5	6	4	-	2	-
Keyhole	2	-	-	-	-	-	-
Sea Cave Total	56	41	46	33	5	7	1
Cat Rock	3	2	2	2	-	-	-
Rockfall Cove	11	8	8	4	1	2	1
Landing Cove	16	9	11	10	-	1	-
Non-cave plots Total	30	19	21	16	1	3	1
Anacapa Total	**86**	**60**	**67**	**49**	**6**	**10**	**2**

[a]More than 1 clutch occurred in 7 sites (*see Methods*).

Table 2. Nest site use and clutch fates for Scripps's Murrelets in sea caves at Anacapa Island in 2000-2010 and 2014.

	Pre-Eradication				**Post-Eradication**									
	2000	2001	2002	**Total**	2003	2004	2005	2006	2007	2008	2009	2010	2014	**Total**
Tagged Sites	13	15	16	-	24	25	27	28	31	31	37	40	56	**-**
Potential Sites	59	59	59	-	59	59	59	59	59	59	59	57[a]	56[a]	**-**
Occupied Sites (Occupied/Potential)	9	11 19%	10 17%	**-**	15 25%	11 19%	17 29%	16 27%	18 31%	17 29%	24 41%	26 46%	41 73%	**-**
Clutches	9[d]	11[d]	11[b]	**22**	15[d]	11	19[b,c]	16[d]	18	19[b,c]	30[b,d]	34[b]	46[b,d]	**208[d]**
Hatched (Hatched/Clutches)	6	2 22%	4 36%	**6 30%**	12 86%	8 73%	16 84%	12 80%	16 89%	17 89%	27 96%	27 79%	33 73%	**168 83%**
Depredated (Depredated/Clutches)	1	6 67%	6 55%	**12 60%**	0	2 18%	0	0	0	0	0	4 12%	5 11%	**11 5%**
Abandoned/Disturbed (Abandoned/Clutches)	0	1 11%	1 9%	**2 10 %**	2 14%	1 9%	3 16%	3 20%	2 11%	2 11%	1 4%	3 9%	7 16%	**24 12%**
Unknown Fate	2	2	0	**2**	1	0	0	1	0	0	2	0	1	**5**

[a]Sites destroyed by storm surges (2010) or rockfalls (2014) were excluded from later occupancy analyses.
[b]More than 1 clutch was laid in 1 site in 2002, 2005 and 2008, 6 sites in 2009, 8 sites in 2010, and 5 sites in 2014 (see *Methods*).
[c]Eggs on cave floor (1 in 2005 and 1 in 2008) were considered to be clutches for calculations of hatching success but sites were not tagged and were excluded from occupancy analyses (see *Methods*).
[d]Clutches with unknown fates were excluded from calculations of hatching success.

Table 3. Nest site use and clutch fates for Scripps's Murrelets in non-cave plots at Anacapa Island in 2003-2010 and 2014.

	2003	2004	2005	2006	2007	2008	2009	2010	2014	**Total**
Tagged Sites	2	3	9	11	14	17	22	25	30	**-**
Potential Sites	34[a]	34[a]	34	34	34	34	33[b]	33	30[b]	**-**
Occupied Sites (Occupied/Potential)	2[c] 6%	1[c] 3%	8 24%	7 21%	9 26%	12 35%	16 48%	18 55%	19 63%	**-**
Clutches	2	1	8	7	11[d]	12[e]	20[d,e]	23[d,e]	21[d,e]	**105**
Hatched (Hatched/Clutches)	2 100%	1 100%	8 100%	6 86%	7 64%	8 73%	15 79%	18 82%	16 80%	**81 80%**
Depredated (Depredated/Clutches)	0	0	0	0	1 9%	1 9%	2 11%	2 9%	1 5%	**7 7%**
Abandoned/Disturbed (Abandoned/Clutches)	0	0	0	1 14%	3 27%	2 18%	2 11%	2 9%	3 15%	**13 13%**
Unknown Fate	0	0	0	0	0	1	1	1	1	**4**

[a] Includes nests in the Rockfall Cove plot where monitoring did not begin until 2005. See *Methods* and footnote c below for assumptions.
[b] Sites destroyed by a rock slide (2009) or erosion (2014) were excluded from later analyses.
[c] Assumes no nesting in the Rockfall Cove plot in 2003-2004.
[d] More than 1 clutch in 2 sites in 2007, 4 sites in 2009, 5 sites in 2010, and 2 sites in 2014 (see *Methods*).
[e] Clutches with unknown fates were excluded from calculations of hatching success.

Table 4. Timing of breeding for Scripps's Murrelets at Anacapa Island in 2000-10 and 2014.

Year	Mean Clutch Initiation Date (± sd)	Range of Dates	Range (d)	Clutches
2000	3 April ± 11 d	17 March - 24 April	38	9
2001	13 April ± 13 d	30 March - 5 May	36	11
2002[a]	10 April ± 16 d	7 March - 2 May	56	11
2003	11 April ± 12 d	27 March - 5 May	39	17
2004	2 May ± 21 d	6 April - 2 June	58	11
2005[a]	2 May ± 14 d	11 April - 2 June	52	26
2006	17 May ± 24 d	8 April – 20 June	73	22
2007[a]	20 May ± 29 d	18 March – 8 July	112	29
2008[a]	13 April ± 20 d	15 March - 29 May	75	30
2009[a]	8 April ± 32 d	18 February – 30 June	132	48
2010[a]	1 April ± 29 d	19 February – 10 June	111	57
2014[a]	18 March ± 23 d	17 February – 5 June	110	63

[a]Includes initiation dates for sequential and simultaneous clutches.

Table 5. Post-eradication changes from 2003 to 2014 in the number of occupied nests in each monitored sea cave and non-cave plot at Anacapa Island.

Sea Cave/ Non-Cave plot	Occupied Nests-2003	Occupied Nests-2014	Change 2003 to 2014
Refuge	0	4	+4
Lava Bench #1	1	6	+5
Lava Bench #2	1	2	+1
Respiring Chimney	2	4	+2
Lonely at the Top	2	4	+2
Confusion	0	0	-
Pinnacle	2	13	+11
Moss	4	3	-1
Aerie	2	5	+3
Keyhole	1	0	-1
Sea Cave Total	15	41	+26
Cat Rock	1	2	+1
Rockfall Cove	2	8	+6
Landing Cove	1	9	+8
Non-Cave Total	4	19	+15

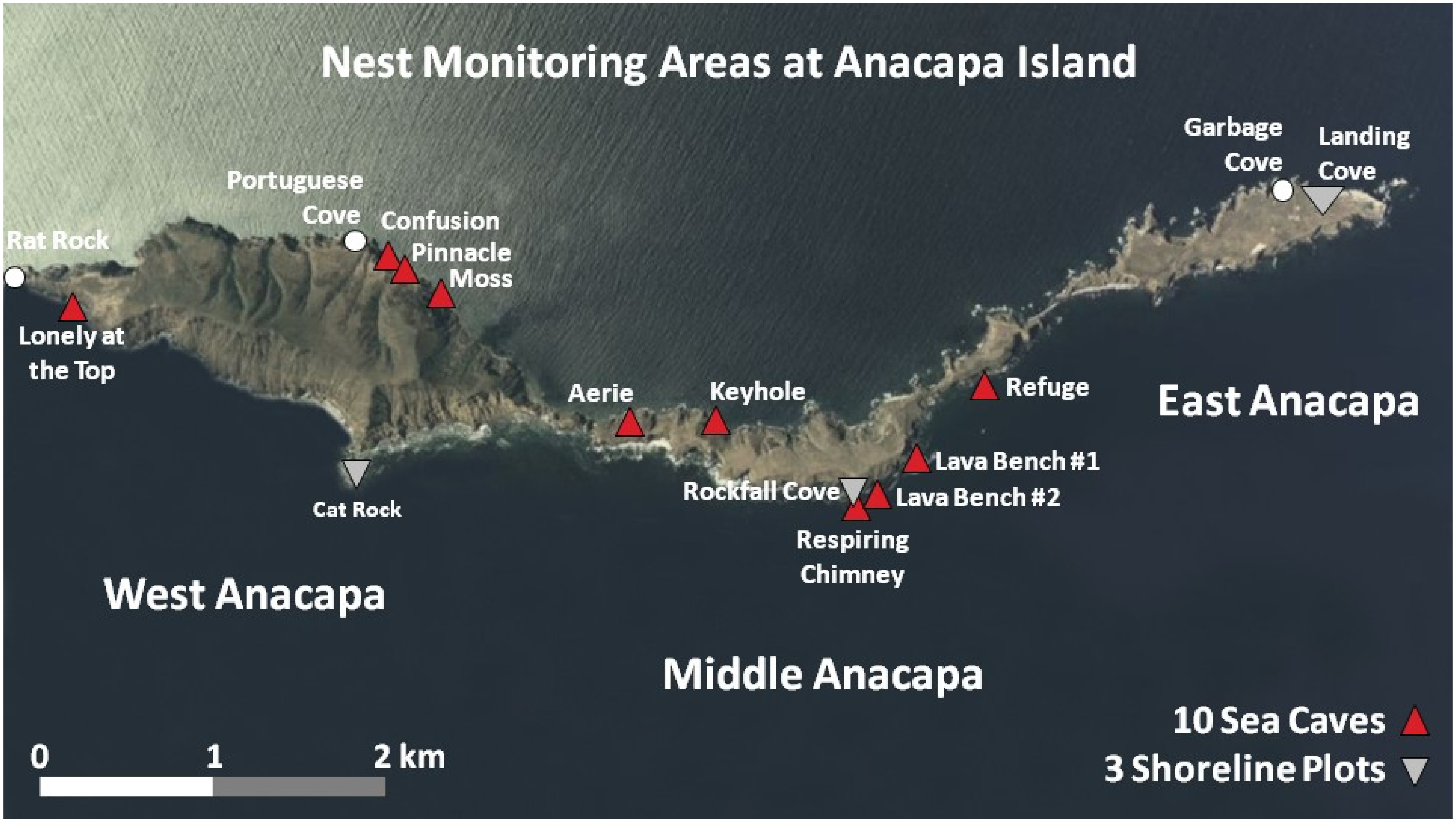

Figure 1. Satellite photograph of Anacapa Island, illustrating the 3 islets, sea caves (▲), non-cave plots (▼) and other areas (**O**) where Scripps's Murrelet nest searches and monitoring were conducted.

Figure 2. Adult Scripps's Murrelet brooding a chick in nest #9 at Landing Cove, Anacapa Island, 3 April 2014 (Photo by D.L. Whitworth).

Figure 3. Two-egg Scripps's Murrelet clutch in nest #17 at Pinnacle Cave, Anacapa Island, 17 April 2014 (Photo by D.L. Whitworth).

Figure 4. Hatched Scripps's Murrelet eggshells in nest #6 at Moss Cave, Anacapa Island, 12 May 2014 (Photo by D.L. Whitworth).

Figure 5. Depredated Scripps's Murrelet egg from nest #1 at Pinnacle Cave, Anacapa Island, 25 March 2014 (Photo by D.L. Whitworth).

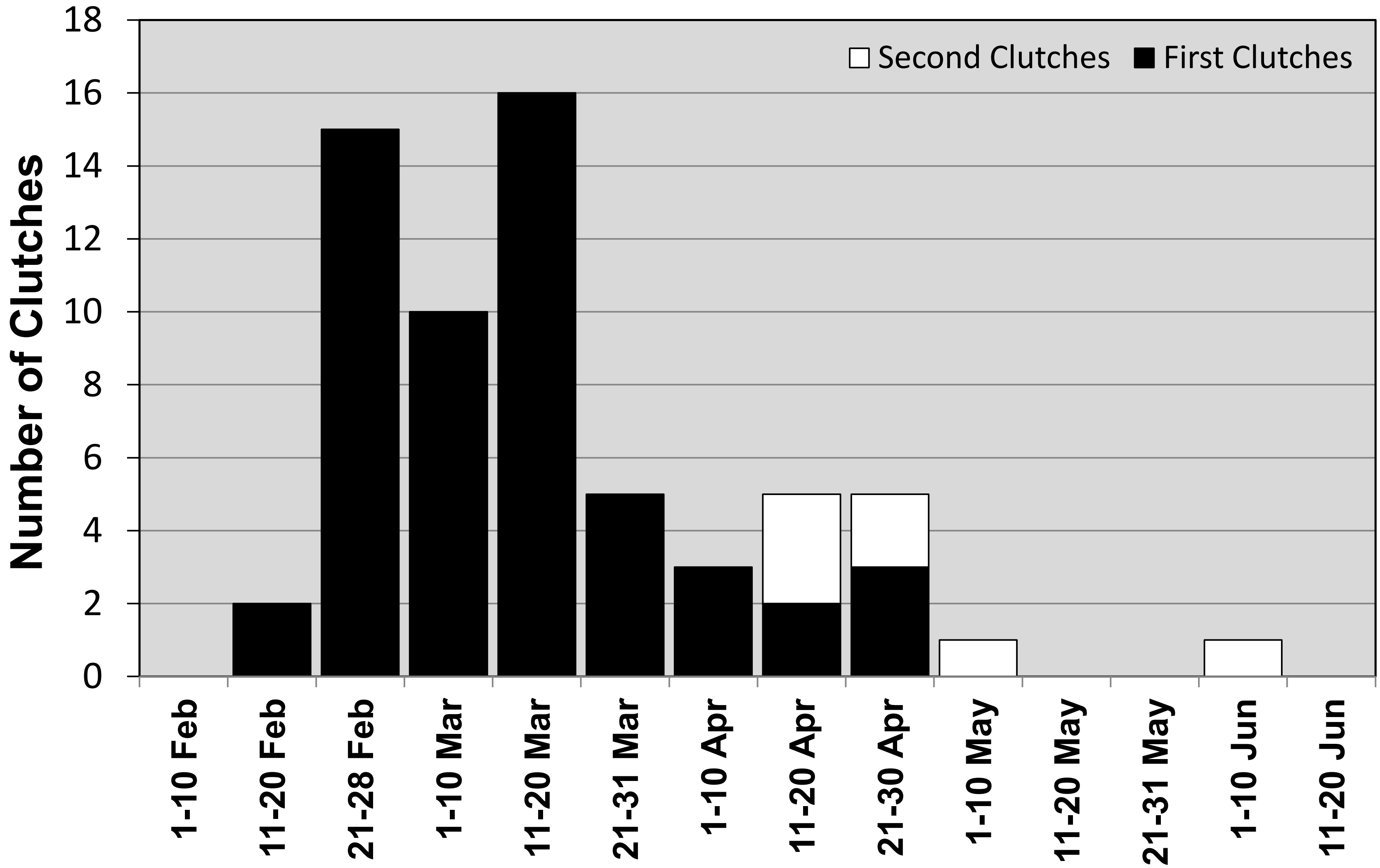

Figure 6. Initiation dates for Scripps's Murrelet clutches at Anacapa Island in 2014.

Figure 7. Incubating Cassin's Auklet in nest #2 at Rat Rock, Anacapa Island, 15 March 2014 (Photo by D.L. Whitworth).

Figure 8. Depredated adult Scripps's Murrelet from nest #8, Lonely at the Top Cave, Anacapa Island, 17 April 2014 (Photo by D.L. Whitworth).

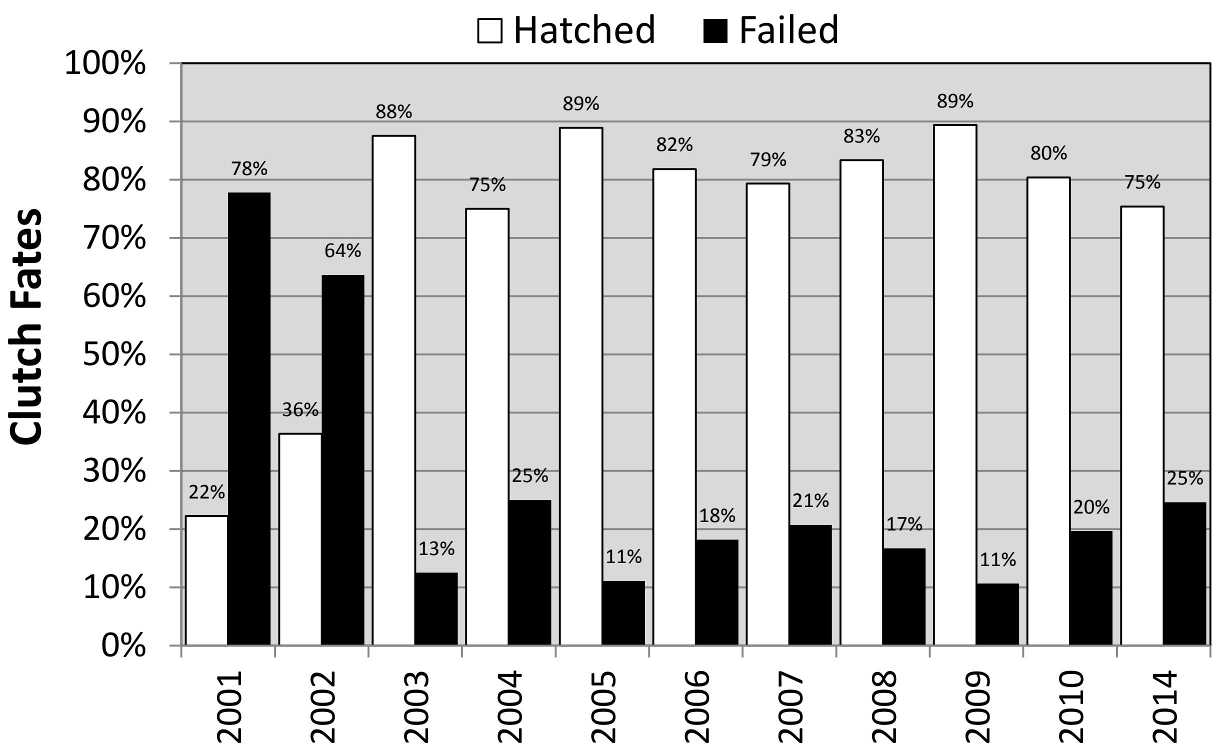

Figure 9. Annual hatching success for Scripps's Murrelets at Anacapa Island, 2001-2010 and 2014.

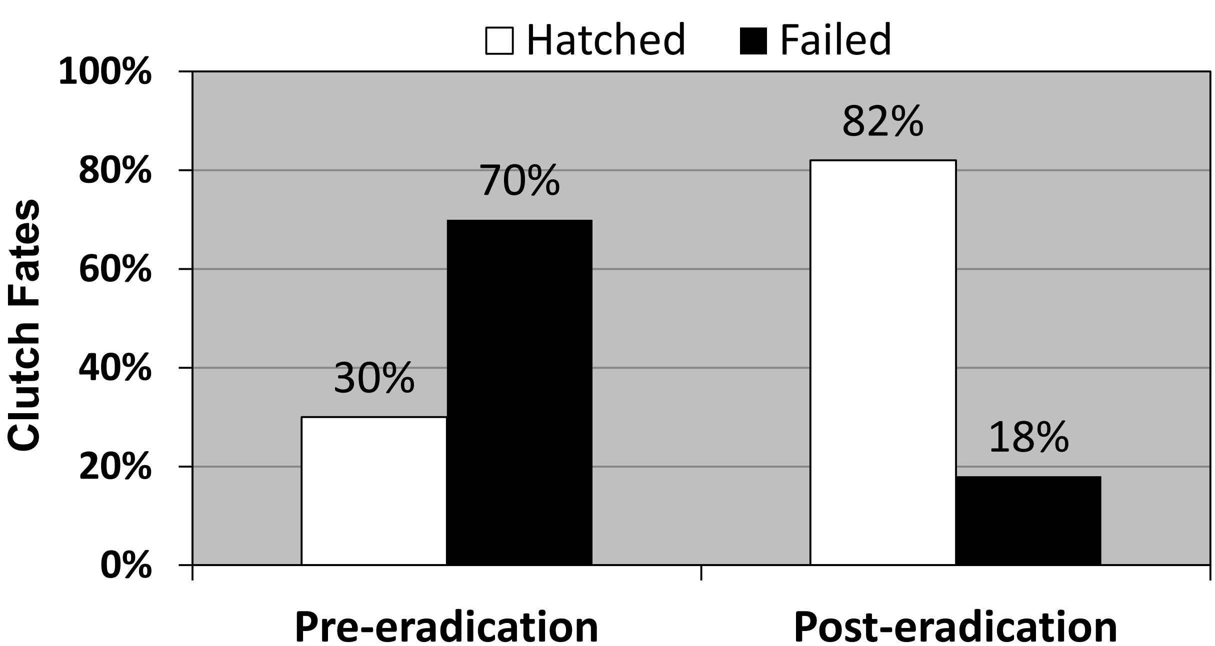

Figure 10. Comparison of Scripps's Murrelet clutch fates at Anacapa Island pre-eradication (2001-02) versus post-eradication (2003-10 and 2014).

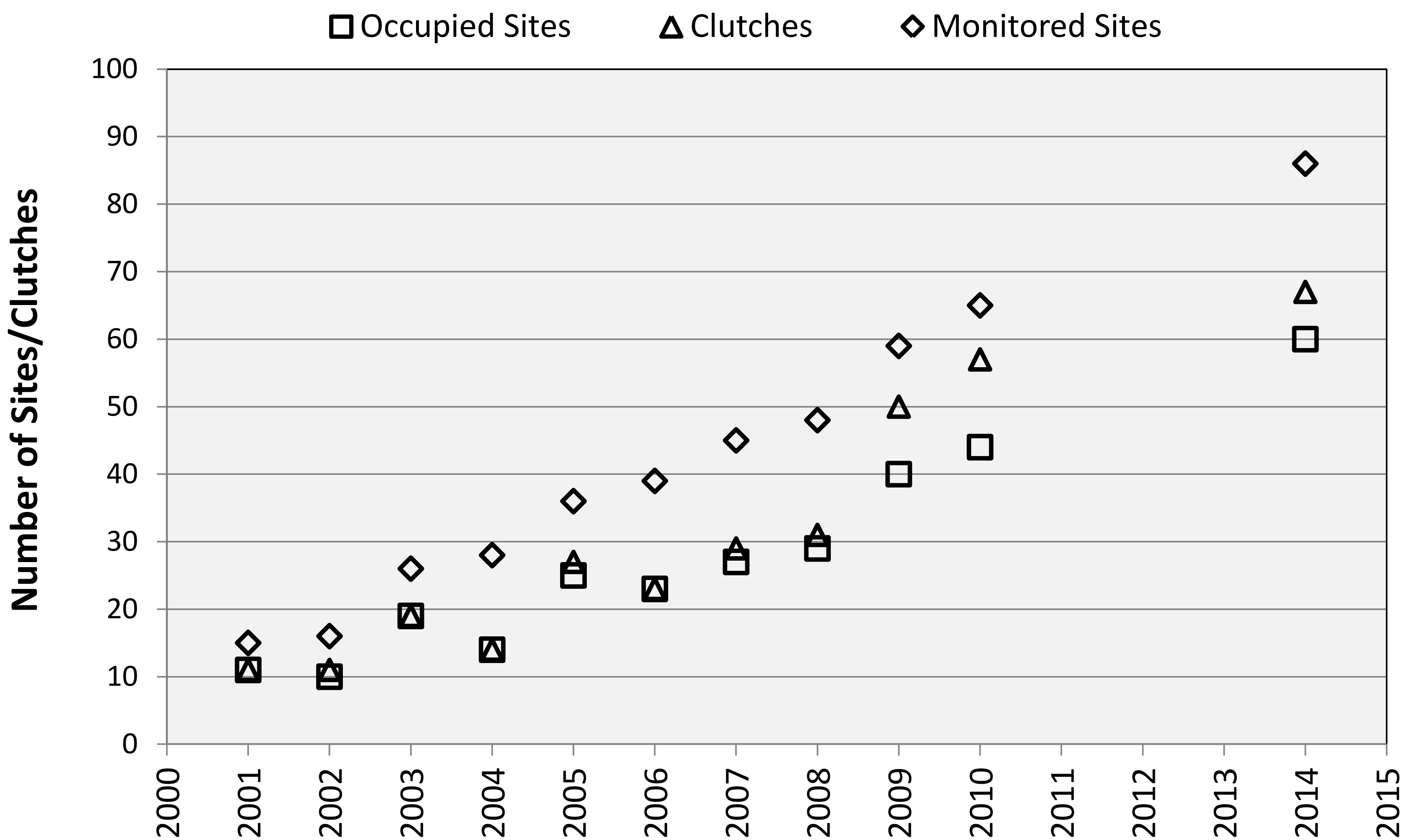

Figure 11. Number of monitored sites, occupied sites and clutches for Scripps's Murrelet at Anacapa Island, 2001-2010 and 2014.

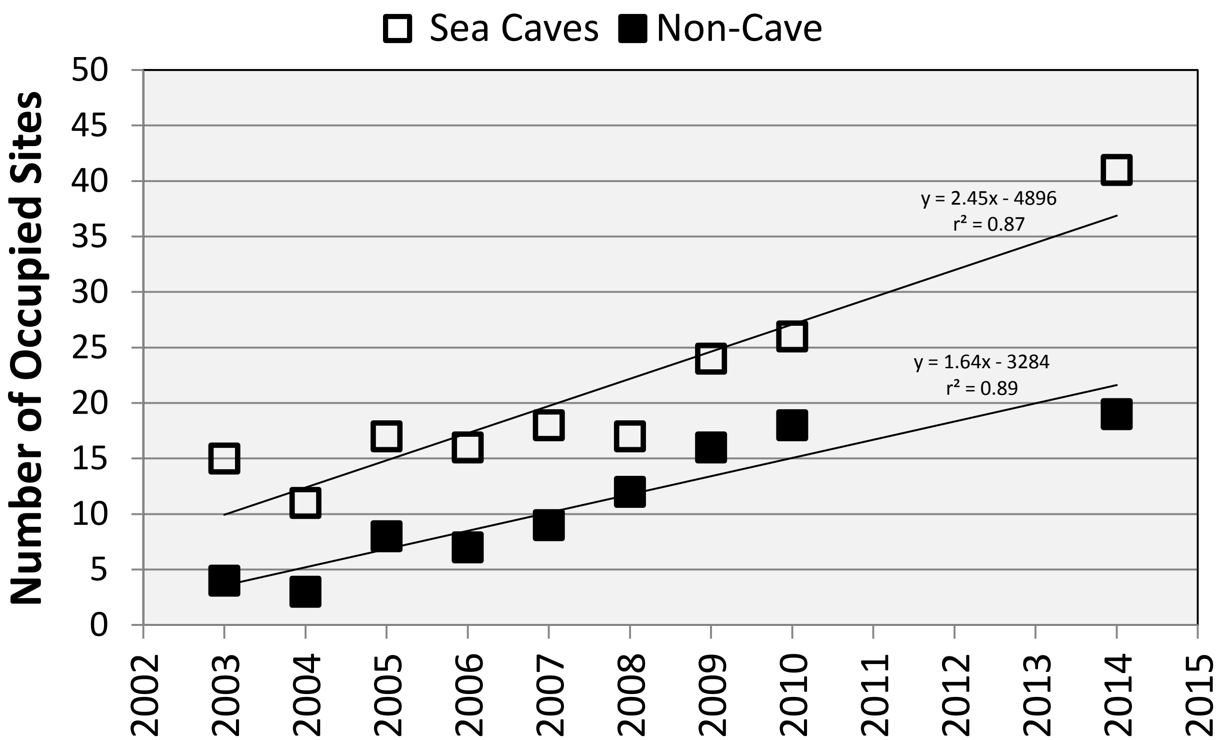

Figure 12. Number of occupied nests for Scripps's Murrelet in sea caves and non-cave plots at Anacapa Island, 2001-2010 and 2014.

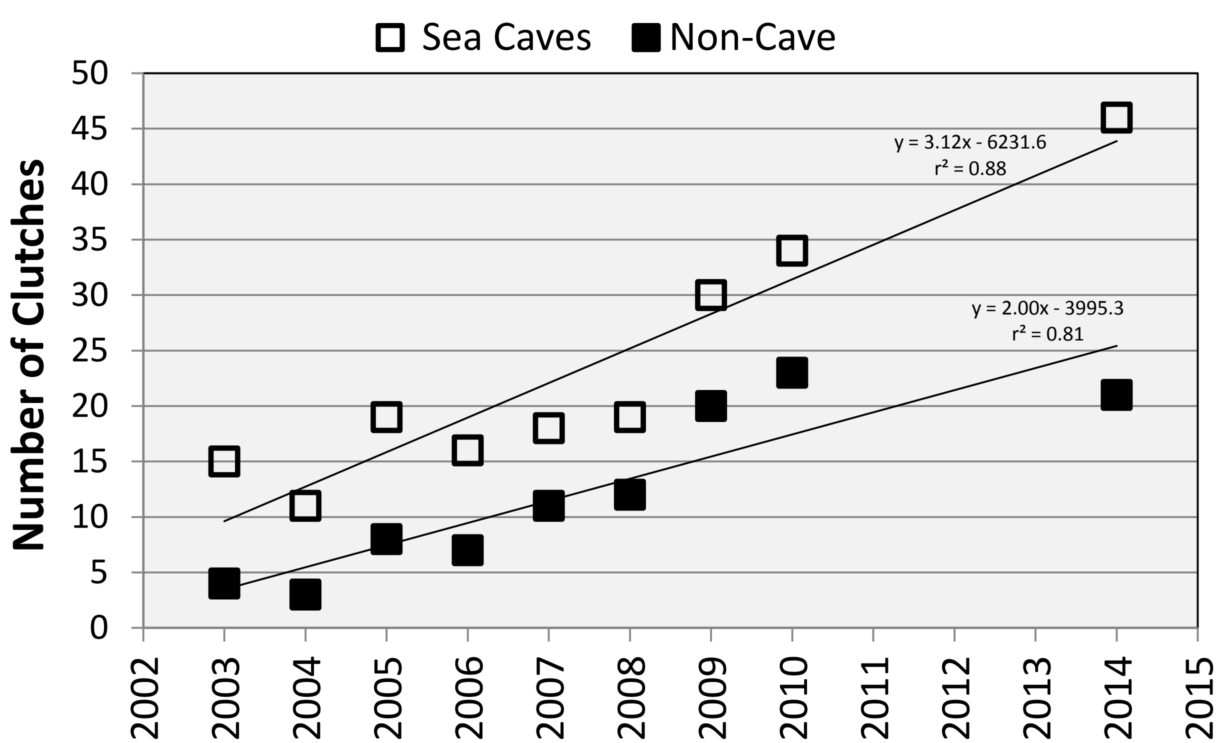

Figure 13. Number of clutches for Scripps's Murrelet in sea caves and non-cave plots at Anacapa Island, 2001-2010 and 2014.

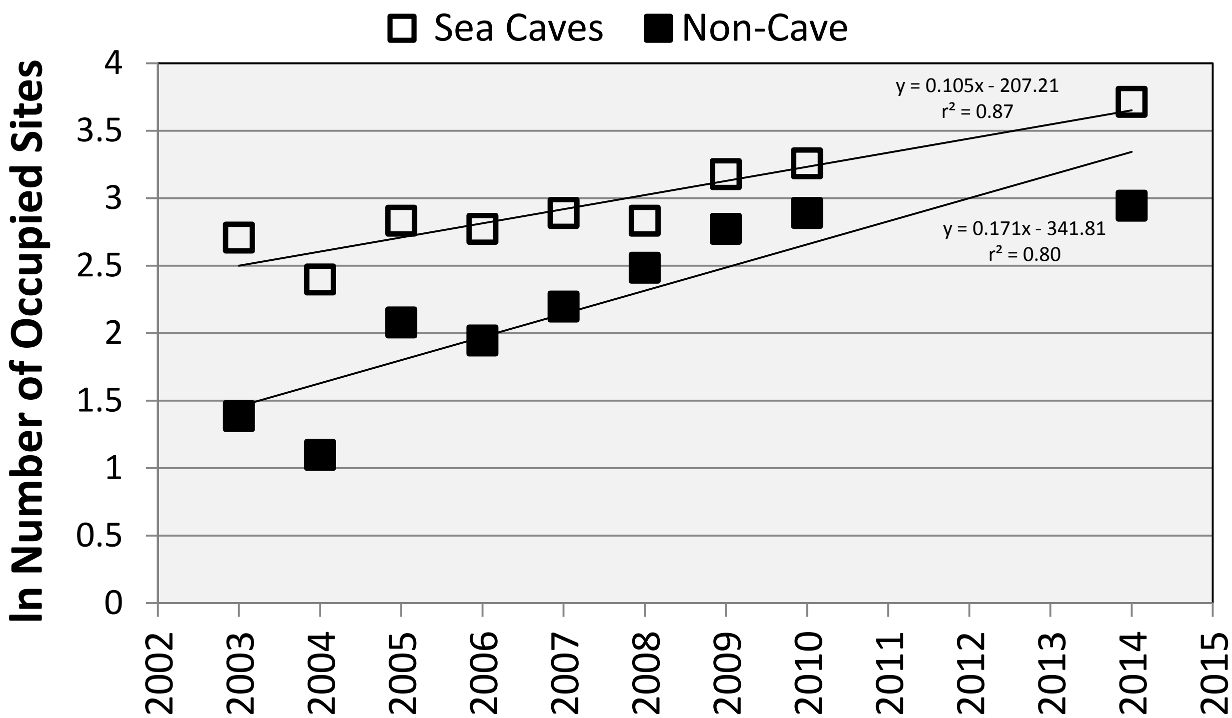

Figure 14. Log-transformed number of occupied nests for Scripps's Murrelet in sea caves and non-cave plots at Anacapa Island, 2001-2010 and 2014.

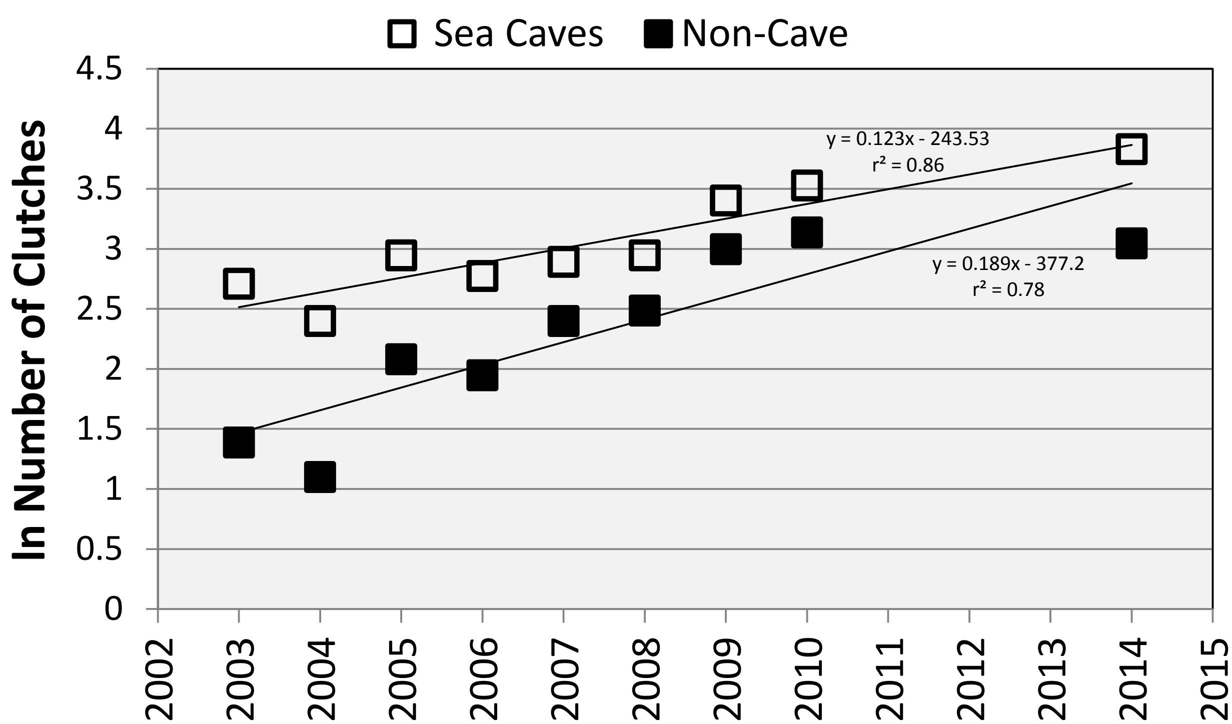

Figure 15. Log-transformed number of clutches for Scripps's Murrelet in sea caves and non-cave plots at Anacapa Island, 2001-2010 and 2014.

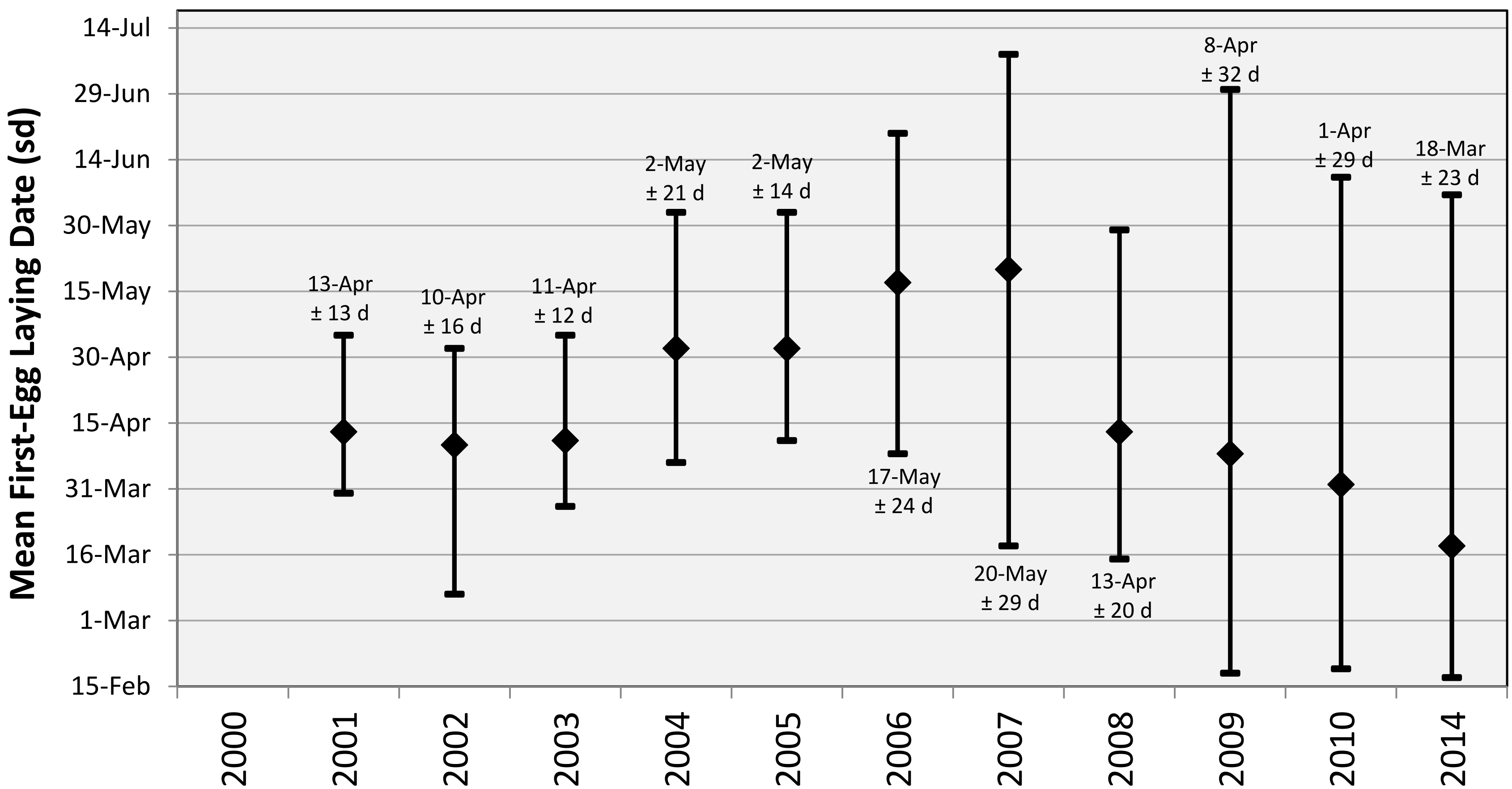

Figure 16. Annual timing of breeding (mean and range of clutch initiation dates) for Scripps's Murrelets in non-cave plots and sea caves at Anacapa Island in 2000-2010 and 2014.

Figure 17. Incubating adult Scripps's Murrelet in nest #8, Lonely at the Top Cave, Anacapa Island, 6 April 2014. The carcass of this murrelet or its mate was found in the cave on 17 April (see Figure 8)(Photo by D.L. Whitworth).

Appendix 1. Use and clutch fates of specific monitored Scripps's Murrelet nest sites in sea caves and non-cave plots at Anacapa Island in 2000-10 and 2014. Codes: hatched ●; abandoned 🔴; depredated or scavenged 🔵; usurped/natural disturbance 🟢; unknown ⚪; site destroyed x.

Cave/Plot	Nest	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2014
Refuge	1		🔵				●	●	●	●●	●	●	●
	2												
	3			🔴									
	4	🔵	🔵										
	5						●	●	●	●	●●	●	●
	6												●
	7												●
Lava Bench 1	1	⚪		🔵	●	●	●(🔴)	⚪			●	●	●
	2								●	●	●	●	●
	3								🔴		●	●	●
	4											●	●🔴
	5												●
	6												●
Lava Bench 2	1	●	🔵	🔵	●	🔵	●	●	●	●	●	●	●●
	2										●	●	
	3												●
Respiring Chimney	1	●	●	🔵●	●	●	●●	●	●	●	●🔴	●●	●⚪
	2		🔴	🔵	●		🔴						●
	3		🔵					●	●	●	●●	●	●
	4												●
Lonely at the Top	1				●	🔵							
	2				●	●	●	●	●	●	●●	●●	●
	3							●	●	(🔴)	●	🔵🔵	
	4										⚪		
	5											🔴	
	6												●
	7												●
	8												🔵
Pinnacle	1		●							●	●	●	🔵
	2				●	🔴	●	●	●				●
	3				●		🔴						
	4					●	●	🔴		●	●	●	●
	5								●	●			●
	6										●	●	●
	7										●	x	x
	8										●⚪	●	●
	9										●	x	x
	10											🔴●	
	11											🔵	
	12											●	🔵
	13												●
	14												🔴

Appendix 1 (continued). Codes: hatched ⚫; abandoned 🔴; depredated or scavenged 🔵; usurped/natural disturbance 🟢; unknown ⚪; site destroyed x.

Cave/Plot	Nest	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2014
Pinnacle	15												⚫
	16												🔴
	17												🔵
	18												🔴
Moss	1	⚫	⚪	⚫	⚫	⚫	⚫		⚫	⚫			
	2	⚫	🔵	⚫	🔴	⚫	⚫	⚫	⚫	⚫	⚫⚫	⚫🔴	🔵
	3	⚪	⚪	⚫	⚫	⚫	⚫	⚫	⚫	⚫	⚫	⚫	
	4				⚫		⚫	⚫	⚫	⚫	⚫	⚫⚫	⚫
	5												⚫🔴
Aerie	1	⚫	🔵	🔵									x
	2				⚪						⚫	⚫	🟢
	3				⚫	⚫	⚫		⚫	⚫	⚫	🔵⚫	⚫
	4						⚫	🔴					⚫
	5	⚫		🔵				🔴	⚫	⚫	⚫	⚫⚫	⚫🔴
	6												⚫
Keyhole	1				🟢								
	2						⚫	⚫	🟢	🟢			
Landing Cove	1	Not searched	Not searched	Not searched	⚫							⚫	
	2	Not searched	Not searched	Not searched		⚫	⚫	⚫	⚫🔴	⚫	⚫⚫	🔵⚫	⚫
	3	Not searched	Not searched	Not searched			⚫	⚫		⚫	⚫	🔵	⚫
	4	Not searched	Not searched	Not searched			⚫		🔵⚫	🔵		⚫	⚫
	5	Not searched	Not searched	Not searched			⚫			🔴	🔵	🔴	⚫
	6	Not searched	Not searched	Not searched			⚫	⚫	⚫				
	7	Not searched	Not searched	Not searched				⚫	⚫	🟢		⚫	
	8	Not searched	Not searched	Not searched				🔴					
	9	Not searched	Not searched	Not searched					🔴	⚫	🔵	⚫	⚫⚫
	10	Not searched	Not searched	Not searched						⚪	x	x	x
	11	Not searched	Not searched	Not searched						⚫	⚫⚫	⚫⚫	
	12	Not searched	Not searched	Not searched							🔴⚪	⚫	
	13	Not searched	Not searched	Not searched							🔴	⚫	⚫⚫
	14	Not searched	Not searched	Not searched							⚫		
	15	Not searched	Not searched	Not searched							⚫⚫	🔴	⚫
	16	Not searched	Not searched	Not searched							⚫		x
	17	Not searched	Not searched	Not searched									⚫
	18	Not searched	Not searched	Not searched									🔴
Cat Rock	1		Not searched	Not searched	⚫		⚫	⚫	⚫		⚫		⚫
	2		Not searched	Not searched							⚫	⚫	
	3		Not searched	Not searched								⚫⚫	⚫
Rockfall Cove	1	Not searched	Not searched	Not searched	Not searched	Not searched	⚫			⚫	⚫		x
	2	Not searched	Not searched	Not searched	Not searched	Not searched	⚫	⚫	⚫	⚫	⚫	⚪⚫	
	3	Not searched	Not searched	Not searched	Not searched	Not searched			🔴				⚫
	4	Not searched	Not searched	Not searched	Not searched	Not searched			⚫	⚫	⚫	⚫⚫	⚫
	5	Not searched	Not searched	Not searched	Not searched	Not searched				⚫	⚫	⚫	x

Appendix 1 (continued). Codes: hatched ●; abandoned 🔴; depredated or scavenged 🔵; usurped/natural disturbance 🟢; unknown ⚪; site destroyed x.

Cave/Plot	Nest	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2014
Rockfall Cove	6	Not searched										●	🔴
	7											●	
	8												🔵
	9												🔴
	10												⚪
	11												●
	12												●
	13												*
Portuguese Cove	1	Not searched											●●

(🔴) Abandoned egg on cave floor near site.
*Eggshell fragments from previous year found.